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Evaluation of Different Fertilizer Application Levels on Early Growth of Baobab Seedlings in Malawi

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Abstract

Although there has been remarkable research on domestication of baobab (*Adansonia digitata*), its early growth using fertilizer at different application levels is still not well known. This study aimed at investigating an ideal NPK fertilizer application level on early growth of *A. digitata*. The study was conducted in the forest nursery from 23 November 2020 to 24 May 2021. *A. digitata* seeds collected from Namalaka in Mangochi were directly sown in polythene tubes of a 15 × 24 cm size. Four treatments of different compound D NPK fertiliser levels (0, 20, 40 and 60 g plant^{-1}) consisting of 10 tubes per treatment were arranged in a completely randomized design (CRD) with 4 replicates each. Results showed significant differences among treatments for the various growth parameters with 20 g plant^{-1} giving the highest number of leaves, root collar diameter, plant height, tuber length, tuber diameter, tuber weight, leaf diameter and length for all treatments. The study concluded that the best baobab growth response is achieved using an NPK level of 20 g plant^{-1} in the nursery environment. Notwithstanding, a study on fertilizer application levels involving different seed sources should be conducted in reference to this study for more comprehensive fertilizer application effect on baobab seedlings.

Subject Areas

Plant Science

Keywords

Adansonia digitata, NPK Fertilizer, Dormancy, Growth Parameters, Salt Index, Seed Provenance

1. Introduction

Adansonia digitata, also known as baobab, is one of the most important fruit trees in Africa. It belongs to the Malvaceae family and Bombacoideae sub-family. The genus *Adansonia* has eight species growing in the tropics [1]. Baobab species occur in most of the Sub-Saharan countries, spanning eastwards from Senegal to Sudan and Ethiopia and southwards to South Africa. In Malawi, the baobab tree is mostly found in southern region, but it also occurs in the northern and central regions, particularly along the Lake Malawi shore [2]. Generally, *A. digitata* grows well in dry woodlands [3] receiving an average precipitation of ≤800 mm yr^{-1} [4].

Baobab forms an integral part of the dietary condiments, traditional medicines and cultural commodities of rural communities in Africa [5]. Every part of a baobab tree (bark, leaves, fruits/seeds, stem and roots) is useful either as a source of food, or traditional medicine. In South Africa, estimates showed that indigenous fruit products (including those of baobab) contributed about 6.5% of the total household income among rural communities over the past decades [6] [7]. *Adansonia digitata* is considered as the fruit tree with the highest annual income which can reach up to US$ 1 billion for producers per year in southern African countries [8].

Environmentally, baobab trees play a significant role in sequestration of huge quantities of carbon (CO_2) from the atmosphere [9]. It is estimated that 1-$tonha^{-1}$ of CO_2 is sequestered annually [10]. Thus, an increase in the number of stems of baobab trees in the African landscapes has potential to mitigate the effects of greenhouse gases (GHGs), particularly atmospheric CO_2. Further, the species is highly resistant to forest fires which are common in savanna biomes [11]. Fire resistance is, therefore, an important property that makes *A. digitata* become well adapted to such fire prone environments.

Despite high socio-economic and environmental reverence and valorization of *A. digitata* among users, the tree is pressured to extinction due to increased demand for its goods and services [12]. During the past decade, remarkable research efforts have been directed towards propagation and domestication of *Adansonia digitata* [13]-[17] to prevent its extinction. Notwithstanding, there exists research gaps on design of nutritional regimes in nursery management of baobab tree seedlings.

Many studies [18]-[20] acknowledge that the application of fertilizers helps to facilitate soil nutrient availability and access to the developing root systems of young plants. It is also a known fact that some fertilizer elements become immobile under certain soil conditions making those elements that are naturally present to be unavailable to plant root systems in what is referred to as Liebig's law of the minimum [21]. For instance, nitrogen (N) and phosphorus (P) are such important macronutrients that in many cases limit the growth of plants [22], particularly, under acidic environments. Often, seedlings exhibit a P deficiency in their early developmental stages because it is less mobile than N in the soil. Further, soil microbes also make stiff competition with plants rendering P immobile hence deficient [23]. Thus, fertilization regimes must be applied to improve forest tree nursery productivity through the production of high quality stocks suitable for afforestation and reforestation programmes [24]-[26] indicate that optimal fertilizer application regimes tend to reduce plant stresses stemming from soil water and nutrient shortages. Strong and well developed seedling root systems are ideal for high penetration through dense subsoil layers and assimilation efficiencies from the belowground (water, oxygen and nutrients) resources [27].

However, excess dosages of fertilizer application could lead to high buildup of soluble salt concentrations in the soil where in extreme cases, contaminating ground water [28] [29] warns that N and K fertilizers may present higher salt index (SI) values with greater potential to cause osmotic stresses to plant roots. This is mainly due to the application of large quantities of fertilizers that take place each year and low rainfall that is characteristically common in the sub-tropics [30]. When soluble salt concentrations increase in the soils, there is likelihood of increased plant root injuries arising from high toxicity levels originating from free salts such as ammonia (NH_3) [31]. Free NH_3 environments tend to build up when the soils are moderately alkaline [29].

On the other hand, [32] reports that NPK granular compound D (NPK 8:18:15) fertilizers are more suitable with compound S (6:18:6) as an alternative for early growth of tree seedlings the in nursery. Accordingly, NPK fertilizers provide the required essential elements that are critical for early plant growth and development [33].

Although positive results on the effect of fertilizers are evident on the growth of baobab seedlings [34], the amount of fertilizer needed for their optimum growth, in terms of height, collar diameter, leaf size and tuber size, remains unspecified. Blanket practices on application of fertilizer levels can have lethal outcomes on domestication and utilisation initiatives of baobab trees among farmers. Therefore, this study sought to: (1) evaluate the effect of different levels of NPK fertiliser application on soil pH and nutrient content, and (2) determine the effect of different levels of NPK fertiliser application on early growth of baobab seedlings.

2. Materials and Methods

2.1. Study Area

The study was carried out at Department of Forestry and Environmental Management Nursery of Mzuzu University from 23rd November 2020 to 23rd April 2021. The nursery lies within silvicultural zone M [32] between 11˚25'19.2" S and 33˚59'34.8" E, at an altitude of 1270 m above sea level. Mzuzu University has a mean annual temperature range of 13.5˚C to 24˚C and mean annual rainfall range between 1150 mm and 1487 mm [35]. In **Figure 1** shows map of Malawi depicting location of Mzuzu city (where the experiments were carried out) and

Dedza and Mangochi districts where seeds for this study were sourced (see Figure 1).

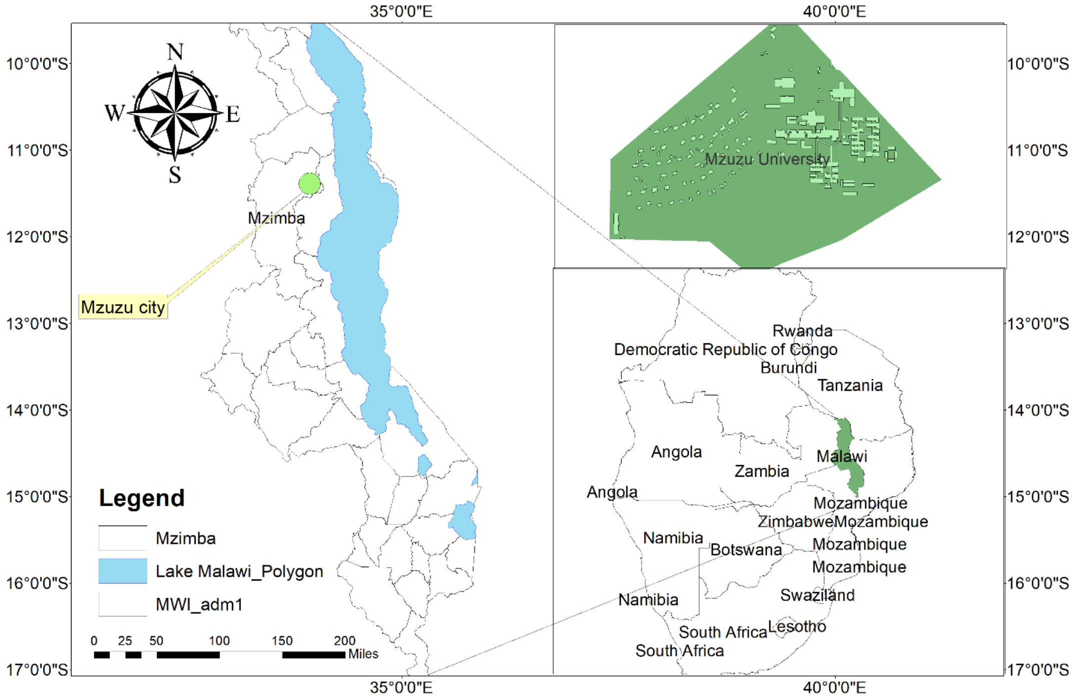

Figure 1. Map of the study area.

2.2. Seed Pretreatment

The pretreatment of seed followed a methodology adapted from [36]. In order to soften the seed coat, seeds were first soaked in very hot water (100˚C) for 30 minutes, followed by wrapping them in a wet cloth for 4 days. Thereafter, the seeds were split using a knife to expose the endosperm. The seeds were then subjected to a floatation test in cold water and sinkers were wrapped again with a wet cloth for 24 hours before sowing. This procedure was done to break the dormancy and facilitate the germination.

2.3. Experimental Design

The experiment was laid in a completely randomized design (CRD) with 10 tubes per treatment and replicated 4 times. Seeds were sown in polythene tubes of 15 × 24 cm sizes on 23 November, 2020, and the polythene was filled with a mix of soil and sand. The compound D NPK (8; 18; 15 + 5S + 0.1B) fertilizer was used for this study due its availability and scarcity of straight fertilizers on the local market. The following fertilizer application levels: 0, 20, 40 and 60 g plant^{-1} as adapted from [37] (Table 1) were applied three months after sowing the seeds [38]. The fertilizer quantities were weighed using a digital SS Adam CQT 5000 weighing balance calibrated to the nearest 0.1 g (Figure 2). Water was applied to the plants when necessary to keep the medium moist.

Table 1. Treatment and description of fertiliser application per plant.

Treatments	Description of hydro conditioning
L1 (0 g)-Control	Fertilizer level 1 (0 g)
L2 (20 g)	Fertilizer level 2 (20 g)
L3 (40 g)	Fertilizer level 3 (40 g)
L4 (60 g)	Fertilizer level 4 (60 g)

Figure 2. Fertilizer measurements

2.4. Data Collection

Soil samples were obtained at a depth of 0 - 20 cm from the media surface of the tube and taken to a Soil Science Laboratory at Lunyangwa Agricultural Research Station in Mzuzu, Malawi for analyses on soil pH, extractable N (%), P (μg g^{-1}) K (cmol kg^{-1}) and organic matter (%). Quantitative data on seedling growth parameters of plant height, root collar diameter, number of leaves, tuber diameter, weight and length were collected. Plant height was measured in centimetres (cm) using a metric transparent ruler and root collar diameter in millimetres (mm) using a digital Vernier Caliper. Counts were made on the number of leaves. The measurements were extended to tuber length in centimetres using a ruler, tuber diameter in millimeters using a digital Vernier Caliper and tuber weight in grams (g) using a digital balance following the methodology used by [39]. Width of the largest leaf and length of the longest leaf in centimetres were also measured using a ruler. The experiment was closed two (2) months after the application of fertilizers.

2.5. Data Analysis

All data were analyzed using R i386 Version 4.0.3 software. Data were subjected to normality and homogeneity of variances using Shapiro-Wilk's and Levine's tests, respectively. This was done to safeguard against violation of parametric test statistics. A one-way Analysis of Variance (ANOVA) was performed to compare significantly different treatment means at 5% level of significance. Statistically (significantly) different treatment means were separated using Tukey's multiple comparison test.

3. Results

3.1. Analysis of Soil pH and Nutrient Content

The results in Table 2 show that the soil pH was not statistically different among the different levels of fertilizer application in baobab seedlings. In contrast, organic matter (OM) was highly significantly different among the different fertilizer application levels. The highest level of fertilizer application (60 g) showed the highest amount of OM of 1.65 ± 0.2% whilst the lowest amount of 1.07 ± 0.02% was observed with the control. The multiple comparison of means analysis indicated that all treatments were statistically different except the levels 20 g and 40 g. All the plants under the application of 60 g/plant died after the fertilizer application

Further results showed that there was a high statistical significant difference in nitrogen (N) among the levels of fertilizer application with the control having the lowest rate (5%) while treatment 60 g had most of 8% of N percentage. The multiple comparison of means analysis indicated that all treatments are statistically different except the levels 20 g and 40 g. Similarly, phosphorus (P) was significantly different among the treatments whereby the two levels 40 g and 60 g had the highest quantity of P and the control had the lowest (The multiple comparison of means (Tukey contrast) analysis indicated that some treatments are statistically different 2). The multiple comparison of means analysis showed that treatments levels 0 g and 20 g were statistically indifferent and 40 g and 60 g were also different from each other.

The quantity of potassium (K) was statistically different among levels of fertilizer application where the control had the lowest quantity of potassium (0.59 ± 0.06 cmol kg^{-1}) as depicted in Table 2. The multiple comparison of means analysis showed that all the fertilizer levels 20 g, 40 g, and 60 g are not different from one another but are different from 0 g.

Table 2. Soil chemical analysis of the treatments used to raise baobab seedlings in the pots at the nursery.

Treatments	pH (Mean ± SD)	OM (%) (Mean ± SD)	N (%) (Mean ± SD)	P (ugg^{-1}) (Mean ± SD)	K ($cmol_c kg^{-1}$) (Mean ± SD)
0 g	5.29 ± 0.38**a**	1.07 ± 0.02**a**	0.05 ± 00**a**	16 ± 1.42**a**	0.59 ± 0.06**a**
20 g	5.03 ± 0.23**a**	1.37 ± 0.06**b**	0.07 ± 00**b**	19 ± 1.42**a**	0.85 ± 0.05**b**
40 g	6.11 ± 0.82**a**	1.39 ± 0.00**b**	0.07 ± 00**b**	26 ± 1.42**b**	0.88 ± 0.04**b**
60 g	5.51 ± 0.05**a**	1.65 ± 0.20**c**	0.08 ± 00**c**	27 ± 1.42**b**	0.94 ± 0.04**b**
p-value	0.265	<0.001	<0.001	<0.001	0.01

SD denotes a standard deviation. Means in the same column followed by different letters are statistically different according to Tukey'SD ($p < 0.05$).

3.2. Seedling Growth Parameters of Baobab

Number of leaves

A significant difference in number of leaves across the treatments was observed. Treatment L2 (20 g) had the highest number of leaves (17.55 ± 9.28) whilst the lowest number of leaves were found in treatment L1 (0 g) with 10.55 ± 2.54 leaves. A multiple comparison test indicated significant differences cross all treatments (Table 3).

Plant height

Significant differences in plant heights across all treatments were observed. Treatment L2 (20 g) had the tallest seedlings with a mean height of 22.5 ± 8.19 cm while L1 (0 g) had the shortest mean height of 16.94 ± 3.4 cm. Statistically significant differences among treatment means were detected in a multiple comparison test as shown in Table 3.

Root collar diameter

The root collar diameter among treatments was found to be statistically indifferent. The collar diameters ranged from 8.63 ± 1.44 mm in the treatment L1 (0 g) to 10.5 ± 2.29 mm in L2 (20 g) (Table 3).

Tuber length

The length of the tuber was found to be highly statistically different among the treatments. The treatment L2 (20 g) had the longest tuber (17.53 ± 3.39 cm) while the shortest tubers of 12.68 ± 3.11 cm were observed in treatment L3 (40 g). The mean separation test indicated that all treatments were statistically different (Table 3).

Tuber diameter

Tuber diameter was significantly different among the treatments where L2 (20 g) had the biggest tuber diameter of 30.22 ± 6.41 mm and treatment L1 (0 g) had the smallest tuber diameter of 22.77 ± 5.98 mm. The multiple comparison of means (Tukey contrast) indicated that all treatments were statistically different (Table 3).

Tuber weight

There was statistical significant difference in tuber weight among different levels of fertilizer application. The level L2 (20 g) had the heaviest tubers with a mean weight of 88.5 ± 25.56 g while the control L1 (0 g) had the smallest tuber weight of 65.35 ± 26.4 g. The multiple comparison of means (Tukey contrast) indicated that all treatments were statistically different (Table 3).

Leaf width

There were statistically significant differences in leaf width among the levels of fertilizer application with the treatment L2 (20 g) having the widest leaf (4.57 ± 1.02 cm). The control L1 (0 g) had the smallest leaf width of 3.36 ± 0.93 cm. The multiple comparison of means (Tukey contrast) indicated that all treatments were statistically different (Table 3).

Leaf length

There were significant differences in the leaf length among the different levels of fertilizer application. The second level L2 (20 g) yielded the longest leaf with a mean value of 11.97 ± 3.13 cm. The shortest leaf values were observed in treatment L1 (0 g) with a corresponding mean value of 9.24 ± 2.21 cm. The multiple comparison of means (Tukey contrast) revealed that all treatments were statistically different (Table 3).

Table 3. Growth parameters (Mean ± SD) (number of leaves, plant height, root collar diameter, tuber length, tuner diameter, tuber weight, width of leaf and length of leaf) from different levels of fertiliser application.

Treatment	Number of leaves	Plant height (cm)	Root collar diameter (mm)	Tuber length (cm)	Tuber diameter (mm)	Tuber weight (g)	Width of leaf (cm)	Length of leaf (cm)
L1 (0 g)	10.55 ± 2.54^{a}	16.94 ± 3.40^{a}	8.63 ± 1.44	15.23 ± 3.36^{ab}	22.77 ± 5.98^{a}	65.35 ± 26.4^{a}	3.36 ± 0.93^{a}	9.24 ± 2.21^{a}
L2 (20 g)	17.55 ± 9.28^{b}	22.5 ± 8.19^{b}	10.55 ± 2.29	17.53 ± 3.39^{b}	30.22 ± 6.41^{b}	88.5 ± 25.55^{b}	4.57 ± 1.02^{b}	11.97 ± 3.13^{b}
L3 (40 g)	14.82 ± 8.04^{ab}	17.46 ± 13.54^{a}	10.06 ± 3.82	12.68 ± 3.11^{a}	27.37 ± 8.46^{ab}	70.44 ± 33.35^{ab}	4.34 ± 1.27^{b}	10.36 ± 3.52^{ab}
p-value	0.02	0.04	0.06	<0.001	0.01	0.03	0.01	0.02

SD dontes a standard deviation. Means in the same column with different superscripts are statistically significant at $P < 0.05$ according to Tukey'SD.

4. Discussion

4.1. Soil pH and Nutrient Content

Arise in quantities of compound D (NPK) fertiliser application in baobab seedlings showed direct proportionality to the amount of soil organic matter (SOM), nitrogen (N), phosphorus (P) and potassium (K) content in the soil except for soil pH (Table 2). Although N has the potential to increase soil pH [40], its effect is largely dependent on the type of nitrogen fertilisers used. For instance, ammonium (NH^{4+}) based fertilizers tend to acidify the agricultural soils more than nitrate fertilizers [41]. This is because ammonium fertilizers easily releasehuge quantities of hydrogen ions (H^+) into the soil during the process of nitrification thereby decreasing the soil acidity. On the other hand, Pfertilizers have lesser effect on soil pH than N fertilizers. However, soil acidity decreases significantly when phosphoric acid is used as a fertilizer [42]. Again, potassium fertilizers have little or no effect at all on soil pH. Thus, it is not surprising to observe that the soil pH was rather insensitivity to the application effect of different levels of the compound D (NPK) fertilizer. Perhaps, the quantities of NPK fertilizer applied had not yet reached the threshold limit point where significant soil pH values could have been detected. Similar results were reported by [43] and [44]. However, with excessive or repeated application of NH^{4+} based fertilizers, there is high probability that the soil pH could fall [45], leading to soil toxicity and unavailability of P to plant root systems. While soil pH influences the solubility of metals, soil nutrients and carbon, it also determines the bioactivity of soil microbes [46].

The study further revealed that organic matter (OM) content was directly proportional to the amount of fertilizers applied into the soil. The mean percentage content of soil OM was the least in a control, where no fertilizer was added. With no fertilizer in the control, there could have been low bioactivity and root biomass growth due to limited soil nutrients. According to [44], the application of inorganic NPK fertilizers helped to improve soil chemical properties which are pivotal to increased growth and yield of plant biomass. It can, thus, be submitted that high levels of fertilizer application lead to increase below-ground plant biomass and associated bioactivity which in turn increases soil OM.

Variations on soil N, P and K concentrations in relation to the amount of compound D (NPK) fertilizer applied were also observed in the study. Sixty g per plant registered the highest soil concentrations of N, P and K. While mean concentrations of P and K in the soil showed a true proportionality to fertilizer application levels, N displayed a staggered proportionality in its treatment levels. At application doses 20 and 40 g plant^{-1}, the N soil concentration (0.07%) was indifferent to that of L1 and L2 treatment levels. At a dose of 40 g plant^{-1}, ox osmosis might have had already set into initiate dilution of the residual soil N concentration to about that of a 20 g plant^{-1} dose. However, there is need to further investigate whether indeed no effect exists on soil N concentration due to the application of different amounts of NPK fertilizers with particular reference to L1 and L2.

4.2. Fertilizer Effect of Baobab Growth

Fertilizers are applied to the nursery to accelerate the growth of plants. Its effect varies considerably depending on the species being fertilized [32]. The use of NPK (compound D) fertilizer with different levels of application significantly affected the early growth of the baobab seedlings in the nursery. The growth response in plant height, number of leaves, leaf length and width, tuber length, diameter and weight were statistically different across the treatments except root collar diameter. This could be related to the 40 g plant^{-1} having a higher suppression on the fixation of N in the roots which decelerates the growth. An appropriate quantity (optimum dose per plant) of NPK fertilizer application boosted up the growth of baobab seedlings which eventually increased all the growth parameters in treatment L2 as compared to L3 and the control.

Plant height response to the NPK application levels could be attributed to the high nitrogen availability which enhanced more leaf area growth which led to higher photosynthetic capacity thereby inducing overall seedling growth [47]. These results are in agreement with the findings of [48] and [49] who indicated that, the application of NPK significantly enhanced the growth parameters such as number of leaves, leaf length, leaf width, plant height and root collar diameter 4 to 6 weeks after application of the fertilizer.

A fertilizer application dose of 60g led to the mortality of all the seedlings in the experiment. This fertilizer application dose of 60 g seemed to have been too much for all the seedlings. An overdose of the fertilizer may have induced hypertonic conditions in the soil adjacent to the seedlings leading to plasmolysis. Similar findings on overdosing of fertilizers have been reported by [28] [50]. Therefore, appropriate doses of fertilizers must be applied in order to gain meaningful growth responses of tree seedlings in the nursery.

5. Conclusions and Recommendations

Fertilizer application at different levels has a great effect on early growth of baobab seedlings at the nursery stage. The findings further revealed that 20 g plant^{-1} of compound D NPK fertilizer gives the best growth response. Sixtyg per plant compound D NPK fertilizer application was found to be too much per plant. It led to death of all the seedlings treated with a 60 g plant^{-1} dose. Therefore, this study recommends the use of 20 g plant^{-1} of compound D NPK as the optimal level of fertilizer application when seeds are sown in a polythene tube width of 15 cm. This study is limited by the fact one seed source was used for the experiment.

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Declaration

I, Ngagne Ndong, declare that this thesis is a result of my own original effort and work which has never been submitted to any other institution for similar purpose. Where other people's work has been used, acknowledgements have been made.

Conflicts of Interest

The authors declare no conflicts of interest.

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