

A study of *Entada abyssinica* Steud. : A new nodulating indigenous tree legume with promising agroforestry potentials on unfertile acid soils

Bakach Dikand KADIATA and Mupala MUYAYABANTU

Faculté des Sciences Agronomiques, Université de Kinshasa, B.P. 238 Kinshasa XI, Kinshasa, Democratic Republic of Congo.

Corresponding author email: bakach_kadiata@yahoo.com

Tel.: (+243) 998 92 32 90

Keywords: *Entada abyssinica*, growth, nitrogen, nodulation, oxisol, phosphorus

1 SUMMARY

In order to enlarge tree genotype base towards its integration into farming systems in the tropics, a study was conducted to assess seed germination, early growth and nodulation performance of a wild indigenous parkland tree, *Entada abyssinica*. The study was conducted over five months on an acid nitrogen-poor sandy soil. Phosphorus P and Nitrogen (N) were variably combined to determine their effect compared to no-fertilization on this tree legume performance in a trial comprising 12 treatments replicated four times in a completely randomized design. Seeds of the tree revealed no dormancy and their germination was highest under hot water scarification for 30 min. Tree height, base girth and dry biomass yield were found to be best under no fertilization (NoPo). This treatment did not significantly differ from the supply of 40 kg P ha⁻¹ that was the most performing in nodulation and the optimum P rate for this tree species. Without any rhizobium inoculation, *E. abyssinica* was found bearing nodules of indeterminate type, and of coralloid shape. Furthermore, its thriving in an unfertile soil with no supply of either P or N is a promising indication of its potential as N₂-fixing species for agroforestry in marginal soil areas and a potential alley cropping hedgerow species.

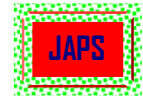
2 INTRODUCTION

Many woody plants, particularly nitrogen-fixing trees/shrubs are increasingly integrated into tropical farming systems to sustain food crop production (Kang *et al.*, 1984; Young, 1987), and to maintain productive and sustainable the ecosystems in which they could be involved (Ingram, 1990). One cropping system in which N₂-fixing trees (NFTs) have been successfully exploited during the last two decades, in humid and subhumid tropics, is the alley cropping (Kang *et al.*, 1990) despite its rather slow adoption.

The particular advantages of NFTs are their biological N₂-fixation, their ability to establish on nitrogen-deficient soils and the benefits of the fixed N₂ plus organic matter to succeeding or associated crops (Danso *et al.*, 1992). Thus

their use into cropping systems can reduce farmers' dependence on expensive chemical N fertilizers. Yet despite the success of integrating trees on farm, there have been very few indigenous species tested. Exotic ones have been the most studied among which *Leucaena leucocephala*, *Gliricidia sepium* and *Calliandra calothyrsus*. Introduced exotic species are usually very demanding for soil fertility status mainly at their earlier establishment. Most of them are sensitive to soil acidity (Haque and Jutzi, 1984; Hutton, 1984) and cannot find appropriate rhizobium strains (Kang *et al.*, 1990; Dommergues *et al.*, 1999) to nodulate efficiently and fix N₂.

In addition, the poor performance of species like *L. leucocephala* in some ecological zones due



to damage to stands by the psyllid, *Heteropsylla cubana* [Reynolds and Bimbuzi, 1993] has aroused the need for increasing tree diversity for alley cropping to match specific ecological conditions.

Searching for indigenous tropical tree species adapted to both soil and climate environment and that can thrive successfully on poor and acid soils and still keep high their N₂-fixing potential remains challenging (Kass, 1995; Dommergues *et al.*, 1999). Few tree species are well documented to the extent that the tree gene pool for agroforestry development in Africa remains still narrow (Kadiata, 1995). In particular, in Central Africa where tree biodiversity remains extremely rich, lack of appropriate tree species is due to little efforts invested in finding out indigenous species, some with multiple uses, to meet the challenge of agroforestry development. Vietmeyer (2008) stressed the existence of underexploited tropical plants with promising economic value. Yet, there is *Entada abyssinica* Steudel ex A. Rich, an understory forest species usually found in a savannah habitat and preferring sandy loam soils that is less documented for its attributes (Salim *et al.* 2002). Pantropical, *E. abyssinica* extends from Liberia to Mozambique and is present in central, eastern and southern tropical Africa (Rich, 1993; Salim *et al.*, 2002).

It is used by peasant farmers in Eastern Kasai Province Democratic Republic of Congo, as indicator of soil fertility such that usually, they spare it on the farm and subject it to regular lopping to reduce shade to food intercrops.

3 MATERIALS AND METHODS

3.1 Location: The study was conducted at the University of Kinshasa, on Mont Amba, southwestern Democratic Republic of Congo, located at 15°8' E, 4°19' S and 390 m altitude. It falls into Aw4 climate type according to Köppen classification. It is characterized by 4 months of dry season (from mid-May to August) and 8 months of rainy season, sometimes interrupted by a short dry period in January/ February. Daily temperature averages 24.5°C. The air relative humidity is maximal from August to October while annual rainfall is close to 1500 mm (Makoko *et al.*, 1991).

Moreover, yearly, in season, *Entada* bears a large quantity of edible caterpillars as food for humans. It also withstands seasonal bushfires. It is used as a fodder tree, as firewood and harbours many healing virtues. Salim *et al.* (2002) reports the treatment of miscarriage. A decoction of the bark is taken for coughs, chronic bronchial engorgement, rheumatic and abdominal pains. An infusion of crushed roots is also good for bronchial problems. A root or leaf decoction is used as a fever remedy; powdered or roasted pulverized seeds for sneezing; root bark as a massage for swelling; and the raw fruit induces vomiting as an antidote to snake venom. The seeds treat cataracts and diseases of the back of the eye (Salim *et al.*, 2002).

It was thus found relevant to investigate the possibility of domesticating this tree species of which there is still little information (Rich, 1993; Salim *et al.*, 2002). As commonly encountered, nitrogen and phosphorus are the most deficient and thus most demanded macronutrients by tree species for establishment on a new site in most tropical soils (Kang and Wilson, 1987; de Lucena *et al.*, 1993; Schachtman *et al.*, 1998; Kadiata and Lumpungu, 2003).

This study on *E. abyssinica* was thus undertaken to document its possibility of propagation through seeds, its nodulation if any, and its early growth and biomass yield dynamics on an oxisol, and to assess the influence of key macronutrients most demanded at the earlier stage of establishment.

Usually, the rainfall remains nil from June to September.

3.2 Soil characteristics and preparation: The study soil used (0-20 cm depth) was a sandy oxisol from Mont Amba, Kinshasa, characterized by a pH (H₂O) of 4.58, 0.651% organic carbon, 0.069% N; 1.121% organic matter; 9.44 C/N; 0.258 meq/100g Mg; 0.139 meq/100g Ca; 1.414 meq/100g potassium oxide K₂O and 25.55 mg.kg⁻¹ diphosphorus pentoxide P₂O₅. The site soil was air-dried, thoroughly mixed and then filled up to 10 kg

in each polyethylene container bearing perforations at the bottom.

3.3 Experimental design and plant management: The trial was conducted on *Entada abyssinica* Steud. ex A. Rich (syn. *Entadopsis abyssinica*

A. Rich, Gilbert & Boutique), of Mimosaceae subfamily (Rich, 1993), a parkland tree species found throughout the southern Congo. Seeds used were collected from a savannah around Kabinda, in the Eastern Kasai province.



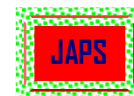
Figure 1: Specimen of 6-month old *Entada abyssinica* raised in potted soil.

Prior to trial, seeds were scarified by superficial scratching with blade, soaked in boiling water for 30 min, while others were kept untreated to assess a better method towards high and uniform germination. The seeds were then sown on a seedbed that received no fertilizer till one month growth, after which the best seedlings were transplanted individually into polyethylene bags being the experimental units. The soil was moistened to approximate field capacity before sowing. Seedlings were watered daily with 250 - 400 mL of tap water throughout the 5-month growth period.

A day after transplantation, plants were accordingly subjected to 12 treatments that included nitrogen (N) and phosphorus (P) combinations at various rates ranging from 0 to 80 kg ha⁻¹. Urea and triple super phosphate served as nutrient sources. The treatments were set in a completely randomized design with four replicates, and identified as control T0 (N₀P₀), T1 (N₃₀P₀), T2 (N₀P₄₀), T3 (N₃₀P₄₀), T4 (N₃₀P₈₀), T5 (N₆₀P₀), T6 (N₆₀P₄₀), T7 (N₆₀P₈₀), T8 (N₀P₈₀), T9 (N₈₀P₀), T10 (N₈₀P₈₀) and T11 (N₈₀P₄₀).

3.4 Data collection and analysis: Plant height and girth (as basal stem diameter) were measured

monthly as from two months of age. At 5 months after planting (MAP), plants were harvested by cutting the stem at the soil line and separating shoot into leaves and stems. Each container was then emptied of soil, and the excavated belowground biomass (roots and nodules) retrieved from the loose soil were washed free of soil over a sieve to maximize nodules recovery. Nodules were collected, counted and weighed after drying. Coarse plant parts such as stems and taproots were chopped into shorter pieces, where necessary. Then above- and belowground plant parts were separately oven-dried at 67 °C to constant weight for plant biomass yield determination. Nodulation index (NI) was calculated as the percentage of nodule dry weight over shoot dry biomass (Hughes and Herridge, 1989). All data were subjected to the analysis of variance using IRRISTAT software package version 92-1 while the Duncan multiple range test (DMRT) was used to separate treatment means at 5% probability level.



4. RESULTS

4.1 Seed germination: The rate of *E. abyssinica* seeds germination following three scarification methods is given in Table 1. Seeds that were soaked for 30 min in hot water gave the highest rate of

germination followed by physically scarified ones (73.9%). The untreated seeds comparatively yielded lesser seedlings but at a rate above 50%.

Table 1: Germination rate of *E. abyssinica* seeds in relation to the scarification methods

Treatment	Number of sown seeds	Number of seeds germinated	Germination rate (%)
None	46	28	60,8
Hot water	46	45	97,8
Physical	46	34	73,9

4.2 Plant height growth: The height of *E. abyssinica* over the study period is shown in Table 2. The unfertilized control treatment resulted in plants

being taller than others that benefited the supply of either N, or P or both nutrients.

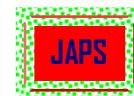
Table 2: Height growth (cm plant⁻¹) of *Entada abyssinica* over time as influenced by the different fertilizer treatments in an oxisol

Treatment	Height (cm plant ⁻¹) at			
	2 MAP	3 MAP	4 MAP	5 MAP
T0 (N ₀ P ₀)	12.7 b	15.2 cd	21.8 e	31.8 d
T1 (N ₃₀ P ₀)	11.7 ab	13.6 abc	15.8 bcd	21.8 bc
T2 (N ₀ P ₄₀)	12.5 b	17.3 d	26.0 f	27.8 d
T3 (N ₃₀ P ₄₀)	12.7 b	14.3 abc	15.9 cd	22.9 c
T4 (N ₃₀ P ₈₀)	12.5 b	14.5 bc	17.1 d	22.6 c
T5 (N ₆₀ P ₀)	12.4 b	13.6 abc	14.6 a-d	20.8 bc
T6 (N ₆₀ P ₄₀)	11.9 ab	13.1 abc	13.1 abc	15.3 a
T7 (N ₆₀ P ₈₀)	12.5 b	13.8 abc	17.0 d	22.3 c
T8 (N ₀ P ₈₀)	11.1 ab	11.9 a	12.8 ab	14.9 a
T9 (N ₈₀ P ₀)	11.9 ab	13.8 abc	15.1 a-d	18.8 abc
T10 (N ₈₀ P ₈₀)	12.8 b	13.8 abc	16.1 cd	17.4 ab
T11 (N ₈₀ P ₄₀)	9.5 a	12.1 ab	12.6 a	14.6 a
Mean	12.0	13.9	16.5	20.9
CV (%)	12.6	10.7	11.7	14.5

In column, means sharing a same letter do not significantly differ at 5% level by the Duncan Multiple Range Test

From 4 to 5 months of growth, control plants were significantly ($p=0.05$) taller than most fertilized ones except those under application of 40 kg P ha⁻¹ (T2). The worst growth in height was found with plants under treatments T11 (N₈₀P₄₀), T8 (N₀P₈₀) and T6 (N₆₀P₄₀) in this ascending order since they were significantly ($p=0.05$) shorter than the control throughout the growth period.

4.3 Plant girth: *E. abyssinica* stem growth at the base varied widely with applied fertilizer treatments (Table 3). At two MAP, before any treatment was applied, seedlings were of similar size (approximately 2 mm). As plants grew bigger with age, more significant differences arose among them, mostly from 4 to 5 MAP.

**Table 3:** Basal stem diameter growth (cm.plant⁻¹) of *E. abyssinica* over time as affected by the different fertilizer treatments in an oxisol

Treatment	Stem diameter (cm.plant ⁻¹)		
	3 MAP	4 MAP	5 MAP
T0 (N ₀ P ₀)	3.8 ab	5.4 de	8.9 f
T1 (N ₃₀ P ₀)	3.5 ab	4.6 bcd	6.5 e
T2 (N ₀ P ₄₀)	4.6 b	6.3 e	8.0 f
T3 (N ₃₀ P ₄₀)	4.5 b	5.0 cd	6.1 de
T4 (N ₃₀ P ₈₀)	3.5 ab	4.3 a-d	5.3 cde
T5 (N ₆₀ P ₀)	3.8 ab	3.9 abc	4.5 abc
T6 (N ₆₀ P ₄₀)	4.0 ab	4.1 abc	5.0 bcd
T7 (N ₆₀ P ₈₀)	4.0 ab	4.1 abc	5.0 bcd
T8 (N ₀ P ₈₀)	2.8 a	3.3 a	3.5 a
T9 (N ₈₀ P ₀)	3.5 ab	4.4 a-d	4.5 abc
T10 (N ₈₀ P ₈₀)	3.0 a	3.5 ab	3.8 ab
T11 (N ₈₀ P ₄₀)	3.1 a	3.6 ab	4.0 abc
Mean	3.7	4.4	5.4
CV (%)	21.4	16.8	16.4

In column, means sharing a same letter do not significantly differ at 5% level by the Duncan Multiple Range Test

Basal stem diameter of *E. abyssinica* revealed a similar trend under the different treatments as that observed for growth in height (Table 2). Indeed, the control plants (T₀) along with those fed with 40 kg P ha⁻¹ performed better than others, mainly at 4 and 5 months of age. Moreover, the increment rate from 3 to 5 MAP was double for T₀ and 1.7-fold for T₂. The lowest stem diameter means occurred

under treatments T₈ (N₀P₈₀) and T₁₀ (N₈₀P₈₀) which were significantly (p=0.05) lower than the control throughout the study period, except at 3 months. Most of other treatments remained intermediate in their ability to boost *E. abyssinica* basal stem girth (Table 3).

Table 4: Dry biomass yields of *E. abyssinica* at 5 MAP as affected by the different fertilizer treatments on an oxisol

Treatment	Dry biomass (g.plant ⁻¹)		
	Shoot	Root	Total
T0 (N ₀ P ₀)	8.7 g	17.0 f	25.7 f
T1 (N ₃₀ P ₀)	4.5 de	5.0 b	9.5 bc
T2 (N ₀ P ₄₀)	6.7 f	11.4 e	18.1 ef
T3 (N ₃₀ P ₄₀)	4.1 d	8.3 d	12.4 d
T4 (N ₃₀ P ₈₀)	3.8 d	7.1 c	10.9 c
T5 (N ₆₀ P ₀)	2.9 c	5.3 b	8.2 b
T6 (N ₆₀ P ₄₀)	1.5 ab	6.0 bc	7.5 b
T7 (N ₆₀ P ₈₀)	5.2 e	8.9 d	14.1 de
T8 (N ₀ P ₈₀)	1.5 ab	2.7 a	4.2 ab
T9 (N ₈₀ P ₀)	2.1 b	2.5 a	4.6 ab
T10 (N ₈₀ P ₈₀)	0.7 a	2.5 a	3.2 a
T11 (N ₈₀ P ₄₀)	1.1 a	2.5 a	3.6 a
Mean	3.6	6.6	10.2
CV (%)	15.0	11.0	13.0

In column, means sharing a same letter do not significantly differ at 5% level by the Duncan Multiple Range Test

4.3 Biomass yield: Dry biomass yield of *E. abyssinica* at 5 MAP on a sandy soil subjected to different fertilizers revealed very wide variation amongst the latter (Table 4).

Applied fertilizer treatments exhibited wider significant differences in influencing shoot, root or total dry matter production of the tree species. The unfertilized control significantly outperformed any fertilizing treatment for both shoot and root dry matter yields. Supply of 40 kg P ha⁻¹ (T2) resulted in total biomass yield similar to that of the control (T0) over the 5 months of growth. The other treatments produced less than half of the biomass

recorded for the control treatment. Treatments T10, T11, T8 and T9 produced significantly lower biomass in *E. abyssinica* than the control (Table 4). The highest rates of both N and/ or P (N₈₀P₀, N₈₀P₈₀, N₆₀P₈₀ and N₀P₈₀) induced mediocre response of the tree species tested.

In general for the 5 months growth period, *E. abyssinica* allocated more of its biomass to below ground parts than to shoot biomass (Table 4). It was observed that *E. abyssinica* displays a very striking root system that comprises two distinct root types (Figure 2).



Figure 2: Root system of a 6-month old *Entada abyssinica* raised on a sandy soil

There were tuberous roots originating from the stem base and growing deep in the soil and ordinary roots. Tuberous roots, usually prolonged by normal fibrous roots, looked like those of cassava or either common tuber crop, and they bore no nodules. The ordinary fibrous roots grew at the same insertion

point as the tuberous ones and much more after the tuber. Normal roots did all bear nodules.

4.4 Nodulation potential: At harvest done at 5 MAP, it was found that *E. abyssinica* was nodulating irrespective of the fertilization done. The nodules observed were of coralloid shape and of indeterminate type (Figure 3).



Figure 3: *Entada abyssinica* fibrous roots bearing collaroid nodules

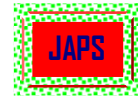
Table 5 shows the extent of nodulation in sandy soil of *E. abyssinica* under the influence of different N and P fertilization rates. Nodule numbers per plant of *E. abyssinica* ranged from 4 to 32 with an overall mean of 12 per plant irrespective of treatments

applied. The tree species bore more nodules when subjected to T7 and less under T8 (N₀P₈₀) (Table 5). T7 (N₆₀P₈₀) significantly ($p = 0.05$) outperformed in nodules number all other treatments applied to soil.

Table 5: Nodulation characteristics of *E. abyssinica* as influenced by the different fertilizer treatments at 5 MAP

Treatment	Nodulation characteristics ^a		
	Nodules no/plant	Nodule dry weight (mg/ plant)	Nodulation Index
T0 (N ₀ P ₀)	15.5 ab	212.9 b	2.46 a
T1 (N ₃₀ P ₀)	7.0 a	118.3 ab	2.66 a
T2 (N ₀ P ₄₀)	5.8 a	422.0 c	6.41 abc
T3 (N ₃₀ P ₄₀)	20.0 b	204.6 b	4.75 abc
T4 (N ₃₀ P ₈₀)	12.5 ab	333.7 c	9.08 c
T5 (N ₆₀ P ₀)	5.0 a	51.7 a	1.92 a
T6 (N ₆₀ P ₄₀)	9.3 ab	151.6 ab	9.42 c
T7 (N ₆₀ P ₈₀)	32.0 c	345.5 c	6.68 abc
T8 (N ₀ P ₈₀)	4.3 a	43.6 a	2.92 ab
T9 (N ₈₀ P ₀)	11.5 ab	110.3 ab	5.69 abc
T10 (N ₈₀ P ₈₀)	12.8 ab	49.1 a	7.46 bc
T11 (N ₈₀ P ₄₀)	6.8 a	59.7 a	5.73 abc
Mean	11.9	175.3	5.43
CV (%)	64.5	43.0	52.9

^a In column, means sharing a same letter do not significantly differ at 5% level by the Duncan Multiple Range Test



However, for nodule dry yield per plant, the highest mean was observed under T2 followed by T7 and T4, which were not significantly ($p=0.05$) different. As for nodulation index, the significantly high values over the control were recorded under the treatments T4 and T6 ($p= 0.01$) and under T7 and

5 DISCUSSION

In general, all treatments applied to soil did influence variably the growth, biomass production and nodulation of *E. abyssinica*. Owing to pre-treatment of seeds to boost germination, soaking in hot water for 30 min resulted in highest germination rate (97.8%) as compared to physical and no-scarification (Table 1). Given that unscarified seeds produced up to 60.8% of seedlings after germination, it was concluded that there is no dormancy with these seeds. This corroborates earlier observation by Salim *et al.* (2002) that pretreatment of the seed is sometimes necessary because of the hardness of the seed coat and seed germination remains very high: 70-100%. However, hot water scarification should be recommended. Hot water stimulated efficient seed imbibition as *E. abyssinica* seeds are small, shining and very thin. Thus, slow but high germination rates were due only to seed hard coat that disables easy imbibition as observed earlier for other species by Skerman (1982) and Salim *et al.* (2002). For seeds of similar shape such as those of *Senna siamea* and *L. leucocephala*, scarification with hot water has been practiced (Kadiata *et al.*, 1996). In agreement with Skerman (1982) that 10% seed germination only per year would be sufficient to ensure any species survival. *E. abyssinica* seeds offer an advantage towards a high scale propagation of this tree species when need arises. Furthermore, it was observed that *E. abyssinica* naturally bears a very high numbers of pods and thus large quantity of seeds at maturity and this could be the reason why it persists in harsh savannah environment, characterized by yearly devastating bushfires.

The growth pattern in height (Table 2) as well as in basal stem diameter (Table 3) of *E. abyssinica* observed under T2 (N_0P_{40}) at 3 and 4 MAP could be ascribed to P supply (Skerman, 1982; Dommergues *et al.*, 1999). This growth trend slowed down by the end (at 5th month) such that the control (T0) became more performing than other treatments, probably because of P that got insufficient to plants due eventually to its adsorption or exhaustion in the soil.

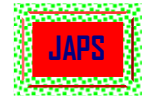
T10 ($p= 0.05$). In general, all the remaining six treatments involving N and P supply were not significantly different from the control (Table 5). Further, nodulation traits revealed a wide variation among and within treatments as high values of coefficients of variation (43 – 65%) occurred.

The superiority of the control over other fertilizer treatments with regards to both growth and biomass production suggests that *E. abyssinica* plants are able to thrive on poor soil, and maintaining high N_2 -fixing potential even in the absence of any fertilization. Thus, it is a low-demanding species for nutrients in contrast to *G. sepium* and *L. leucocephala* that require a good level of soil fertility for better start of growth (Dommergues *et al.*, 1999). Further, its nodulation without any rhizobium inoculation clearly indicates that it is not strain-specific and thus works with the “cowpea miscellany group” of rhizobia most common under the tropics.

The surprisingly special root structure of this species (Figure 3) marked by the existence of tubers could presumably explain why *E. abyssinica* withstands repeated bushfires in the savannah and still remains capable of sprouting yearly.

The results observed herein related to nodule dry weight that was nearly twice higher for T2 (N_0P_{40}) compared to the control T0 could be due to P application that might have stimulated the nod factors (McKay and Djordjevic, 1993). According to Dommergues *et al.* (1999), nodulation and N_2 fixation process do require more P than the plant growth, and often when a N_2 -fixing plant responds positively to P application in its nodulation, its growth likewise improves. This is consistent with Sanginga *et al.* (1991) report on *L. leucocephala* inoculated with a rhizobium strain and subjected to 20 to 80 mg P kg^{-1} soil application that exhibited an increase in the nodule mass and in the amount of N_2 fixed as well.

Nevertheless, in the present study it was noted that *Entada* nodule dry weight rather decreased with the increasing amount of P applied to soil. Sanginga *et al.* (1989) also observed that the growth of *Casuarina*, *Allocauarina torulosa* and *A. littoralis* was reduced when a higher P rate of 60 mg P kg^{-1} soil was applied. Further, it has been reported that in *G. sepium*, N_2 -fixation does not increase following the application of P above 40 kg P ha^{-1} (Sanginga *et al.*, 1995). Thus, this study results suggest that the



optimum P rate for *E. abyssinica* could be 40 kg P ha⁻¹.

High values observed of nodule numbers and nodulation index along with a rather low nodule dry weight did not give a clear picture of the nodulation status of the tree legume, likely due to a very high variation within treatments. In fact, this trend of nodulation parameters to exhibit very high variation (cv \geq 52 - 65%) has been common in relation with the life span of nodules in leguminous plants and so they do mask some differences among treatments (Kadiata *et al.*, 1996; Dommergues *et al.*, 1999). Lower shoot yields compared to roots to which the species allocated much more of its biomass (above

50%), explains the highest index values recorded in most cases.

Most tree variables decreased with increasing amounts of N applied to soil in form of urea. This suggests that for the growth period considered, *E. abyssinica* does not require a supply of available N. Instead, the excess of available N appears to hinder nodulation of this tree (Richards and Soper, 1979; Oghoghorie and Pate, 1996). The presence of nodules on the control treatment (T0) confirms that (1) the N₂-fixing tree found an indigenous strain of rhizobium capable of nodulating in such an acid soil (pH 4.58), and that (2) in N and P-poor soil, *Entada* could grow and sustain its growth for many months.

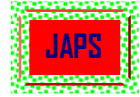
6 CONCLUSION

Entada abyssinica seeds showed no dormancy. However, soaking of seeds in hot water for 30 min improves germination to 97.8 % and should be recommended to practice. Unfertilized *E. abyssinica* had enhanced performance in biomass yield, growth dynamics as well as in nodulation although application of 40 kg P ha⁻¹ was outstanding for the latter. Thus, 40 kg P ha⁻¹ is the optimal rate to apply. The species exhibited its capacity to establish,

thrive and nodulate, and maintain high N₂ fixation on an unfertile sandy soil without any fertilization. This is unlike *L. leucocephala* or *G. sepium* among other exotic tree legumes so far tested in alley cropping. It is thus a promising, cheaper wild tree species for potential use in agroforestry particularly in most tropical savannah regions where soil deficiency in N and P prevail.

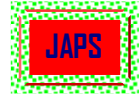
7 ACKNOWLEDGMENT

We gratefully acknowledge the assistance of Professor L. K. Kalanda, a botanist, in identifying the tree species, subject of the present study. Our deep thanks are extended to Prof. K. Nkongolo, Laurentian University, Canada, for his critical review of our earlier manuscript. The *Agence Universitaire Francophone* (AUF) granted a fellowship to the senior author for a short visit at the Faculty of Forestry and Geomatics, University of Laval, Canada, during which this paper was written.



8 REFERENCES

- Brewbaker JL, Van Den Belt R. and MacDicken K: 1982. Nitrogen fixing-tree resources: potentials and limitations. In: Graham PH. and Harris SC (Editors). Biological nitrogen fixation technology for tropical Agriculture. CIAT, Cali, Colombia, pp. 413-425.
- Danso SKA, Bowen GD. and Sangina N: 1992. Biological nitrogen fixation in trees in agro-ecosystems. *Plant Soil* 141: 177-196.
- De Lucena Costa N. and Valdinei Tadeu P: 1993. Phosphorus levels and sources affect growth, nodulation and chemical composition of pigeon pea. *Nitrogen Fixing Tree Res. Rep* 11: 68-69.
- Dommergues Y, Duhoux E. and Diem HG: 1999. Les arbres fixateurs d'azote. Caractéristiques fondamentales et rôle dans l'aménagement des écosystèmes méditerranéens et tropicaux, avec référence particulière aux zones subhumides et arides. CIRAD, Edition Espaces 34, FAO & RD.
- Haque I. and Jutzi S: 1984. Nitrogen fixation by forage legumes in sub-Saharan Africa: potentials and limitations. *ILCA Bulletin* 20: 2-13.
- Hughes RM. and Herridge DF: 1989. Effect of tillage on yield, nodulation, and nitrogen fixation of soybean in far north-coastal New South Wales. *Austr. J. Exp. Agric* 29: 671-677.
- Hutton EM: 1984. Breeding and selecting *Leucaena* for acid tropical soils. *Pesq. agropec. Brasil. (Brasília)* 19: 263-274.
- Ingram J: 1990. The role of trees in maintaining and improving soil productivity: a review of the literature. Technical paper no. 279. Commonwealth, Science Council, 39p.
- Kadiata BD and Lumpungu K: 2003. Differential phosphorus uptake and use efficiency among selected nitrogen-fixing tree legumes over time. *Journ. Plant Nutr.* 26(5): 1009-1022.
- Kadiata BD: 1995. Biological nitrogen fixation in some woody legumes with potential use in alley cropping. PhD Thesis, Rivers State University of Science and Technology, Port-Harcourt, Nigeria.
- Kadiata BD, Mulongoy K, Isirimah NO. and Amakiri MA: 1996. Screening woody and shrub legumes for growth, nodulation and nitrogen-fixation potential in two contrasting soils. *Agrof. Syst.* 33: 137-152.
- Kang BT. and Wilson CG: 1987. The development of Alley cropping as a promising agroforestry technology. In: *Agroforestry: a decade of development*. Steppler, HA, Nair, PKR (eds.), ICRAF, Nairobi, pp 227-243.
- Kang BT, Reynolds L. and Atta-Krah AN: 1990. Alley farming. *Adv. Agron.* 43: 315-359.
- Kang BT, Wilson GR. and Lawson TL: 1984. Alley cropping, a stable alternative to shifting cultivation. IITA Publication, 22p.
- Kass DL: 1995. Are nitrogen fixing trees a solution for acid soils? In: *Nitrogen-fixing trees for acids soils*. Evans DO. and Szott LT. (eds.). *Nitrogen Fixing Tree Res. Rep.* (special issue): 19-31.
- Makoko M., Ndembo L. and Nsimba M: 1991. Hydrodynamique des sols de Kinshasa, les sols du Mont-Amba: caractéristiques pédologiques, mécanique et stock d'eau. *Revue Congolaise des Sciences Nucléaires* 12 (1/2) : 72-82.
- McKay IA and Djordjevic MA: 1993. Production and excretion of nod metabolites are disrupted by the same environmental factors that reduce nodulation in the field. *Appl. Environ. Microbiol.* 59: 3385 - 3392.
- Oghoghorie CGO. and Pate JS: 1971. The nitrate stress syndrome of nodulated field pea (*Pisum arvense* L): techniques for measurement and evaluation in physiological terms. *Plant Soil spec. vol.:* 185-202.
- Reynolds L. and Bimbuji S: 1993. The leucaena psyllid in Coast province, Kenya. *Nitrogen Fixing Tree Res. Rep* 11: 103.
- Rich A: 1993. Guide des arbres et arbustes de la région de Kinshasa-Brazzaville. Pauwels L., Meuse Jard. Bot. National de Belgique, Bruxelles. Vol. 4, p. 168.
- Richards JE. and Soper RJ: 1979. Effect of N fertilizer on yield, protein content, and symbiotic N fixation in faba beans. *Agron. J.* 71: 807-811.
- Salim AS., Simons AJ., Oruwa C., Chege J., Owuor B. and Mutua A: 2002. Agroforestry Database: A tree species reference and selection guide. World Agroforestry Centre.



- Sanginga N., Bowen GD. and Danso SKA: 1991. Intra-specific variation in growth and P accumulation of *Leucaena leucophala*, and *Gliricidia sepium* as influenced by soil and phosphate status. *Plant Soil* 133: 201-208.
- Sanginga N., Danso SKA. and Bowen GD: 1989. Nodulation and growth response of *Allocasuarina* and *Casuarina* species to phosphorus fertilization. *Plant Soil* 118: 125-132.
- Sanginga N., Danso SKA, Zapata F. and Bowen GD: 1995. Phosphorus requirements and nitrogen accumulation by N₂-fixing and non- N₂- fixing leguminous trees growing in low P soils. *Biol. Fertil. Soils* 20: 205-211.
- Schachtman OP, Reid RJ. and Ayling SM: 1998. Phosphorus uptake by plants: from soil to cell. *Plant Physiol* 116: 447-453.
- Skerman PJ: 1982. Les légumineuses fourragères tropicales. FAO, Rome, Italy, pp. 535-543.
- Vietmeyer N: 2008. Underexploited tropical plants with promising economic value: the last 30 years. *Trees for Life Journal* 3: 1-13.
- Young A: 1987. The potential of agroforestry for soil conservation. Part II. Maintenance of fertility. ICRAF Working paper, 43p.