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Research Article

Development of Vegetative Propagation Strategies for *Balanites aegyptiaca* in the Sahel, Niger

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Forests have always been a source of wood, food, and medicine for the rural populations of the Sahel. Anthropogenic and animal pressures often lead to low tree recruitment rates and seedling survival. Under certain conditions, multipurpose species such as *Balanites aegyptiaca* have shown dramatic decreases in population numbers. The objective of the present study is to determine the natural colonisation behaviour of *B. aegyptiaca* and to develop vegetative propagation strategies. Surveys were carried out in the agroforest parklands of the Regional Centre for Agricultural Research of Maradi Research Station. An inventory was carried out in 1,500 m^2 plots to determine the species' regeneration methods. We then tested seed germination success, and suckering induction, air-layering, and stem cuttings were carried out to determine the techniques best suited for the propagation of *B. aegyptiaca*. It emerged from this study that in nature, *B. aegyptiaca* is propagated naturally by dispersion of seeds (81.2%), as well as by rejection of the strain (13.5%) and by suckering (5.2%). The germination test showed that heavy seeds (38.4%) germinated best because they have a higher nutrient reserve. With a success rate of 11.1%, distal suckers react better than proximal suckers (5.5%) because they quickly acquire relative independence from the mother plant. As for air-layering, stems with large diameters react better (53.3%) than those with small diameters (46.6%) because they have thicker bark and store a large amount of elaborate sap responsible for rhizogenesis. In the stem segment cutting test, cuttings of small diameter react better at 30.8% than those of large diameter (12.6%) because they have a higher number of meristematic tissues. The stem segment cuttings seem to be the best adaptable alternative to the natural propagation of *B. aegyptiaca* because it combines ease of use, low cost, and a significant success rate.

1. Introduction

Woody species are highly valued by Sahel populations in general and their rural communities in particular. In the woody stratum, this population finds fruits and more in general complementary food, medicine, energy (wood fuel), and materials essential to the manufacture of various objects for daily use, which play an important role in subsistence but can also provide for a substantial increase in the incomes of underprivileged households [1–3]. However, high demand often leads to overexploitation of multipurpose trees. As a consequence, we observe a decrease in natural regeneration and a reduction in the number and range of woody species [1, 4]. It therefore has become essential to set up strategies that reconcile (over)use and conservation of multipurpose perennial wood resources [5, 6].

Among the ecologically and economically important species in the region, we can mention *Balanites aegyptiaca* (L.) Del. (desert date palm; *Zygophyllaceae* family). The species is a medium tree (5–6 m of height) and widespread in the Sahelian to Sudano-Sahelian zones, from Senegal to Sudan, and from Egypt to Zambia, Saudi Arabia, and India. It occurs on a wide range of soils such as sandy, stony, and heavy soils and is an indicator of overgrazing [7–9].

B. aegyptiaca is highly exploited for its fruit. Fruit collection is a typical activity for women, especially in rural areas. Fruits are eaten raw but are also transformed into oil and soap by women's groups in certain areas of Niger and elsewhere in the species zone of occurrence.

Several studies have highlighted the presence of various nutrient content in *B. aegyptiaca* fruits, such as essential amino acids, saponins, flavonoids, alkaloids, and carbohydrates [10–13] [14]. The species also has numerous uses in traditional medicine. The parts such as fruits, leaves, and roots of the species are commonly used in the treatment of diabetes in various regions of the world [10, 15–17]. Recent studies have shown the effectiveness of *B. aegyptiaca* oil as a fuel and lubricant for high-speed engines [13, 14, 18]. The species (by-) products are frequently sold on local markets and contribute greatly to improving the populations' livelihoods, especially in rural areas [19–21]. The high demand for its products is reflected in ever-increasing overexploitation. Fruit collection of this species causes impoverishment of the soil seed bank. The absence of seeds compromises the regeneration of the species. As a consequence, current populations of the species in fallows and natural formations are dominated by adult individuals, with hardly any seedling recruitment [5, 22].

In this situation, there is an imperative need for developing sustainable propagation and management techniques making it possible to reconcile conservation and continued use. From this perspective, low-cost vegetative propagation, in particular the induction and use of suckers, cuttings, and (air-)layering, offers a set of techniques for cloning ecologically and economically advantageous phenotypes that can be easily adopted by local populations. We look at three vegetative propagation methods to assess which one offers much more possibility in the arid conditions of the Sahel for *B. aegyptiaca*. In Mauritania, the use of suckers has enabled people to build *B. aegyptiaca* hedgerows for the delimitation of their fields [6]. Vegetative propagation has been little studied for certain local fruit species with multiple uses such as *B. aegyptiaca*, *Diospyros mespiliformis*, *Sclerocarya birrea*, *Lannea microcarpa*, and *Tamarindus indica* [6, 23–25], although there has been some work done on *Pterocarpus erinaceus*, *P. africana*, *Faidherbia albida*, and *Acacia macrostachya* [23, 26].

The objective of the present study, therefore, is to develop propagation strategies for *B. aegyptiaca*. We carried out the research work at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Starting from the different propagation strategies naturally adopted by the species, we tested different vegetative propagation techniques to identify those that are low cost and can easily be transferred to local populations. We are trying to understand, among the less expensive techniques for the propagation of *B. aegyptiaca*, which one responds more under the conditions of domestication of farmers in Niger.

2. Materials and Methods

2.1. Study Site. The Maradi region is located in the southern centre of Niger between 13°00′ and 15°26′ north latitude and 6°16′ and 8°36′ west longitude (Figure 1). Maradi region has two distinct types of climate. The northern part of the region is characterised by a Sahelo-Saharan climate with annual precipitation between 200 and 300 mm. In the southern part of the region, the climate is a Sahelo-Sudanian type characterised by annual precipitation between 500 and 700 mm. CERRA covers an area of 270 ha, including 200 ha of duneland, 50 ha of valley land, 5 ha of forest, and 15 ha of infrastructure. Some of the experiments were conducted at the CERRA forest nursery in Maradi. Land use is guided by research activities; it should be noted that for good soil management, 50% of cultivable land is left fallow. The study was started in August 2018 during the rainy season. *B. aegyptiaca* is distributed to 23.73% of trees of the total vegetation of CERRA. Table 1 describes the dendrometric parameters of trees studied. The choice of trees was based on the distribution according to the age class and the toposequence (low bottom, slope, and plateau) of the CERRA.

2.2. Determination of Natural Regeneration Modes. Assessing *B. aegyptiaca* natural regeneration was conducted in the CERRA-Maradi agroforestry parkland following a systematic sampling of 10 plots of 1,500 m^2 (50 m × 30 m) in alternate arrangements. Each plot was subdivided into 60 quadrats of 5 m × 5 m. In each quadrat, we dug out the soil at the level of each young tree with main stem diameter of less than 2 cm to determine how it had started its life cycle (regeneration type: sucker, seedling, or stump rejection). Regeneration is considered by seed when the plant has roots not attached to any other of the same species. While suckers are identified when the plant is attached to the root of the parent plant and stump regeneration shows plants attached to stumps. The dominant height of all young individuals was measured using a 100 cm graduated ruler.

2.3. Seed Sowing in the Nursery. We first collected *B. aegyptiaca* seeds selecting 100 healthy ones randomly from 60 mother trees collected during November 2017. Seeds were characterised according to length and width, using an electronic calliper (precision, brand x model). Seeds were weighed separately using a Toprime Digital Gram Scale (500g-0.01g). Subsequently, weight was retained as a classification criterion for the seeds because it could be the most informative on the state of health and the possible germination power of the seed [27]. We used the mean (m) and standard deviation (SD) of the weight of the 100 seeds to classify each seed into light seed (LS), medium-weight seed (MS), and heavy seed (HS), similarly to [27]. All the seeds with a weight under m – SD are LSs. When the weight of the seeds included between m – SD and m + SD are MS. The seeds are heavy when the weight is up to m + SD. Then, the 100 seeds ended up into 28 light seeds, 41 medium-weight seeds, and 31 heavy seeds. Before sowing, the endocarp of each seed was slightly opened with a hammer to break physical dormancy and facilitate germination. Seeds were sown at one seed per pot filled with a substrate mixture of fine soil of the river (two-thirds) and manure (one-third). The substrate was put in a plastic nursery plot and watered daily every morning to maintain adequate soil humidity and

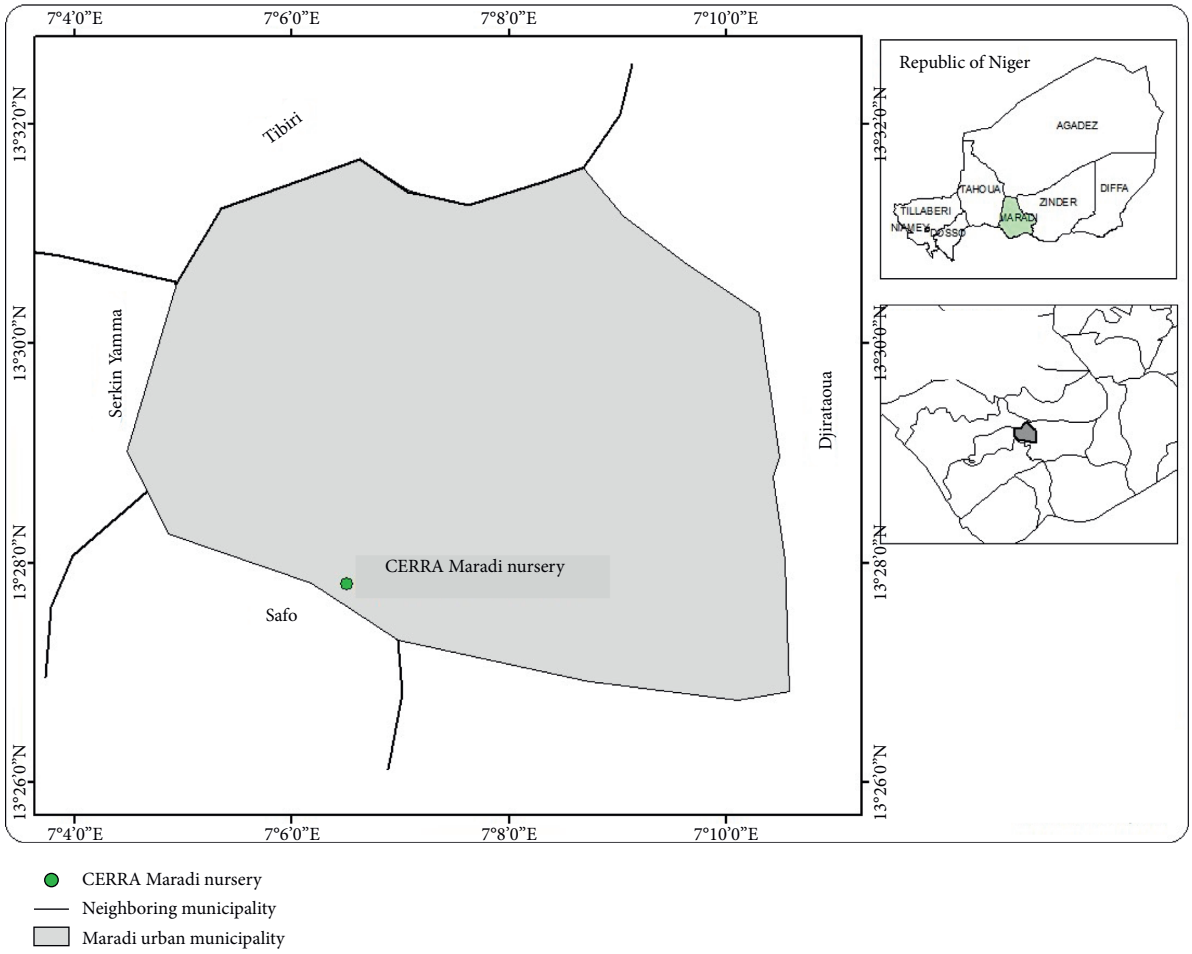

Figure 1: Location of the study zone.

Table 1: Dendrometric description of trees sampling of *Balanites aegyptiaca*.

Variables	DBH (cm)	Height (m)	CA (m^2)
Min.	18.15	4.5	15.90
Max.	66.88	13.5	1,017.36
Mean	34.21	8.42	72.73
SD	11.80	2.22	116.74
CV	0.35	0.26	1.61

DBH: diameter at breast height, CA: crown area, Min.: minimum, Max.: maximum, SD: standard deviation, and CV: coefficient of variation.

accelerate decomposition. Seedlings were made three days after. We recorded germination parameters daily (beginning time of emergence and duration of germination both in the day) and growth parameters of plants weekly (height and diameter of the collar both in cm) using a ruler and calliper, 0–150 mm (Calibre Digital Profesional, SKOLE).

2.4. Suckering Induction Test. The experimental set-up began with the identification of *B. aegyptiaca* trees in the CERRA-Maradi agroforestry parkland likely to support the operation. Trees showing no signs of disease and free of any obstacles were retained. Circular digging around suitable tree trunks was carried out to dig up the tracer and superficial roots likely to undergo root encirclement. The tracer and superficial roots were first stripped bare. We then made annular and transverse incisions to promote wound cambium formation and subsequent root and stem development. Before and after incision, the diameters and length of each root from the mother plant were measured with a calliper. The root was lightly covered with the substrate taken from around the plant, taking care that the injured part was not completely buried. This was made possible because the experiments occurred during the full rainy season where evapotranspiration is low, also the relative humidity is high, and water was added around the root in small quantities every 48 hours to prevent possible drought. In total, 18 roots were thus bruised on 18 different trees. Half of the treated roots (9) were close to the mother plant (<0.6 m), whereas the others (9) were more distant (>0.6 m). Suckering experiment plants were watered every 48 hours to prevent drought stress. We collected data on the time of the beginning at the end of suckering according to the number and the height of the suckers.

2.5. Air-Layering Test. Layering is a clonal technique allowing the production of the plant by surrounding the girdled branches of the tree while using a biochemical complex all around (substrate and water) allowing the

differentiation of cambial cells into roots. The tree shoot is then detached and planted outdoors to serve as an effective means of clonal propagation of the plant from which it came [28]. *B. aegyptiaca* trees were found exclusively in natural forest formations, agroforestry parklands, and farms [29]. Trees of this species were regularly subjected to pressure from animal grazing and regular cutting. It was very rare to find branches on the ground. Ground-layering seems unsuitable. Therefore, we tested the air-layering. We used an approach adapted from several authors to refine our protocol (e.g., [28, 30, 31]). Thus, air-layered candidate plants were identified in CERRA-Maradi research station. Branches that would be treated were identified and pruned using a pruner. Beforehand applying the air-layering, a mixture of fine soil of river (60%) and sawdust (40%) was prepared [32]. On each branch to be layered, two annular incisions spaced 5 cm high from each other were applied with thin blade knives without cutting into the wood (xylem). This was followed by a vertical incision of the bark from the first annular incision to the second. Abortion of the bark was thus removed, leaving the wood bare. The consequence was the breaking of the circulation of the sap from the upper part to the lower part of the incised. The diameter of the branch was measured using the calliper. The stripped part of the bark was wrapped with a transparent plastic sheet containing the mixture of soil and sawdust that would serve as a substrate for any root forming. Then, the two ends of the plastic were hermetically sealed off around the branch with the help of tape while taking care not to trap too much air. This support covered up to 10 cm on either side of the incised part to create a sufficiently spacious substrate to allow possible roots to grow normally. A total of 20 air layers were thus made distributed in 20 tees, 10 with branches with diameters between 1 and 3 cm (C1) and 10 with diameters between 3 and 5 cm (C2). The marcots put in place were generally located in the stems' proximal and middle positions because the distal part of the stems was generally smaller in diameter. Twenty millilitres of water was injected into the plastic cover each week using a syringe.

2.6. Cutting's Test. Two vegetative propagation trays were 160 cm long, 80 cm wide, and 20 cm high. To reduce the risk of drying of the cuttings and the attack of parasites, the containers were wrapped in a transparent plastic sheet [25]. The climatic data measured are related to the temperature and humidity of the air. The average daily internal and external temperatures during the experiment were $27.87 \pm 2.61^{\circ}$C and $30.53 \pm 4.45^{\circ}$C, respectively. The average daily internal relative humidity of the container was $54 \pm 7.11\%$. The trays were filled to three-fourths of their height (15 cm) with fine river sand. The sand was washed severally with tap water to limit the contamination of the cuttings. Young green twigs were taken from 20 *B. aegyptiaca* trees selected in the CERRA-Maradi agroforestry parklands. These branches were cut into 20 cm cuttings with 3–5 leaves. The middle diameter of each cutting was measured in the right middle, using the electronic calliper [33]. Cuttings were grouped into two categories: those with diameters between 1 and 3 cm (C1) and those with diameters between 3 and 5 cm (C2). At planting, cuttings were placed at the same depth of 5 cm to avoid any differentiating effect caused by the depth of slanted planting. Cuttings were placed in tubes with a spacing of 20 cm. In each bin, 28 cuttings were placed in a row with 14 cuttings per diameter class, for a total of 56 cuttings for the two tubs [5]. Watering was carried out at regular intervals of 48 hours. The tray was ventilated daily for 1-2 hours from the second week.

2.7. Data Processing

2.7.1. Specific (Relative) Frequency. The specific frequency makes it possible to appreciate the contribution of each species in the formation of the stand. It is calculated on the basis of the quantitative criterion by the following formula:

$$Fi\,(\%) = \frac{ni}{N} \times 100, \tag{1}$$

where n_i represents observed variables and N represents observable variables.

2.7.2. Density. Density is defined here as "the number of *B. aegyptiaca* individuals per unit area." The average density of woody trees is calculated with the aim of knowing the distribution of individuals according to the following formula:

$$D\left(\frac{ind}{ha}\right) = \frac{N\,total}{S}, \tag{2}$$

where $N\,total$ represents observed variables and S represents observation area.

2.7.3. Observation Rate. The observation rate expresses the relationship between a parameter (or a series of parameters) considered different by one or more factors and its total number. It can be considered in absolute value or in percentage.

$$Rate\,of\,X = \frac{ni}{N} \times 100, \tag{3}$$

where n_i represents observed variables and N represents observable variables.

The collected data were processed using an Excel and Minitab 14 spreadsheet. The germination parameters were calculated and summarized using principal component analysis (PCA).

3. Results

3.1. Demography of Natural Populations. A total of 259 individuals was inventoried across all 10 plots, with an average density of 172.6 ± 4 trees/ha. Young plants represented 37% and a regeneration rate of 27% (trees with a diameter of less than 2 cm). The species is propagated naturally by seed dispersion (81.2%), as well as by strain

rejection (13.5%) and suckering (5.2%). Among the young population, only 44% grow under the crowns of adults compared to 56% outside the crown (Figure 2(b)). Analysis of the distribution of the diameter classes of the juveniles showed a structure in the shape of the letter "J"; three individuals had a diameter less than or equal to 0.5 cm and represented 3.12%. Individuals with diameters between 0.6 and 1 cm totalled 7.2%, whereas those with diameters between 1.1 and 1.5 cm were well represented at 35%. Individuals with diameters between 1.6 and 2 cm were the most represented, comprising 54% of the total regeneration group (Figure 2(c)). The distribution of juveniles in height showed a bell distribution with a dominance of intermediate heights. Very small and tall juveniles were very little represented. Only 5.2% of individuals had heights between 101 and 150 cm (Figure 2(d)).

3.2. Seminal Multiplication and Growth Monitoring in the Nursery. The standby time was 15 days for heavy seeds (HS). The delay at the start of germination was only 9 days for medium-weight seeds (MS) and 19 days for light seeds (LS). The duration of germination observed was 4 days for HS and 15 and 3 days, respectively, for MS and LS. The average germination rate for the whole test was 29%. It was 38.4%, 29.7%, and 15.3%, respectively, for the HS, MS, and LS seeds (Figure 2(a)). This germination rate was identical to the emergence rate observed for the HS and LS classes. The average lifting rate (lifting capacity) over the whole test was 27%, dropping to 27.02% for MS. The rate of onset of heavy seed germination (HS) began on the 15th day at 7.69% and reached its peak on the 19th day. For MS, germination began on the 9th day at 1.35% and reached its maximum on the 24th day.

The average number of sheets formed per week in each class was counted to appreciate their different developments (Figure 3(b)). Leaf evolution was effective only for the PGM class on the 14th day with 0.31 leaves on average. On the 21st day, the average number of leaves reached 7, 7.6, and 1, respectively, for HS, MS, and LS. This average evolved gradually, but on the 42nd day, it reached11.6 sheets for LS (whereas it was 23.2 on the 35th day); for MS and LS, it was, respectively, 26.7 and 22.5 sheets.

The evolution of the height of the seedlings was on average 0.09 cm per week for the seedlings produced from MS seeds. On the 21st day, the average height of the plants was 4.39, 4.7, and 1.18 cm, respectively, for plants from HS, MS, and LS seeds. This height changed gradually, but on the 42nd day, it reached 14.7 cm for HS (whereas it was 14.87 cm on the 35th day). The evolution of height reached 17.71, 23.58, and 15.28 cm on average, respectively, for plants from HS, MS, and LS seeds (Figure 3(c)). Analysis of the growth of the aerial and underground parts of the seedlings from each type of seed revealed that the seedlings from MS seeds were very different from the other seedlings at the end of the 8th week (Figure 3(d)).

The principal components analysis allowed us to recapitulate the relations between the types of seeds and the parameters of germination and growth. The first two axes of the PCA reflect 100% of the total variance. Analysis of the factor plane showed that light seeds were characterised by a high latency time. The heavy seeds were distinguished by a relatively high emergence rate, whereas the medium-weight seeds were characterised by a long germination time, a high number of leaves, and a high growth rate of the above- and belowground parts (Figure 3(d)).

3.3. Suckering Induction. Analysis of the sucker induction results showed that 8.3% of the severed roots budded. Regarding the parts, 5.5% of the proximal roots emitted buds compared to 11.1% of the distal roots (Figure 4(a)). The latency time for the proximal part was 9 days, whereas it was 6 days for the distal part. In contrast, the duration of recovery was10 days for suckers from the distal part but only 5 days for suckers from the proximal part. As for the average height of the seedlings, those of the suckers of the distal part stood out considerably at 21.1 ± 2.6 cm compared to only 6.7 ± 3.1 cm for the seedlings. The latency time before the resumption of the buds was, respectively, 6 and 9 days for the distal and proximal buds. The recovery time was 10 days for the distal buds (from the 6th to the 16th day). For proximal suckers, cover time was only 5 days (from the 9th to the 14th day). Depending on whether the buds and suckers were carried by the distal or proximal parts of the severed roots, the behaviour of the latter differed. In the present experiment, 2 out of 8 possible roots emitted suckers, a proximal root, and a distal. The proximal root emitted 6 suckers compared to 7 suckers for the distal root. The evolution of the number of buds from the distal suckers started on the 6th day with 2 buds and reached its maximum on the 16th day with 9 buds. For proximal suckers, their evolution started on the 9th day with 3 buds and reached its peak on the 14th day with 6 buds (Figure 4(b)).

The average height of suckers at the distal part was 0.43 cm on the 7th day. On the 14th day, this average reached 2.14 cm for the same part, whereas it was 0.23 cm for the proximal part (Figures 4(c) and 4(d)). The average heights of suckers of these 2 levels gradually evolved to reach 15.01 and 2.97 cm, respectively, for the distal and proximal parts on the 42nd day. On the 77th day, the height of the stems reached 21.1 and 6.7 cm on average for the distal part (Figure 4(d)) and the proximal part, respectively.

3.4. Air-Layering. Among the 20 marcots produced, 15 were rooted (Figure 4(a)), that is, a rooting rate of 75%, and the other 5 layers (25%) were rotted (Figure 5(b)). Among the rooted layers, 46.6% came from small-diameter stems (C1) and 53.3% from large-diameter stems (C2). Regarding the relative position of the stems, 46.6% came from vertical stems and 53.3% from horizontal stems. Previously, 12 layers had a vertical position compared to 8 horizontals, that is, success rates of 58.3 and 100%, respectively. Regarding the interaction between the diameter of the stem and its position, the large-diameter stems produced roots with an average diameter of 3.9 cm (Table 2) compared to 2.6 cm for small-diameter stems. The vertically positioned stems

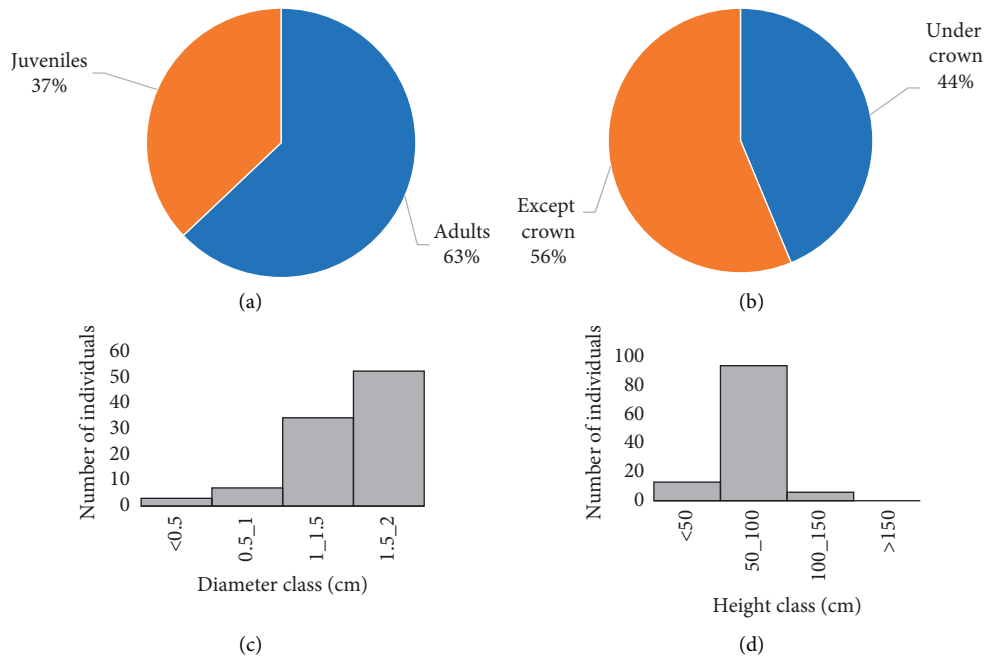

Figure 2: Structure of natural regeneration of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Distribution of the total number of adults and juveniles (a), exposure (b), diameter structure of the juveniles (c), and height (d).

produced roots of 3.4 cm compared to 3.3 cm for the horizontal stems. The marcots weaned in the field continued their normal development (Figure 5(c)).

3.5. Stem Cutting Segments. The recovery time (latency) was 3 days for small-diameter cuttings (C1 = 1–3 cm) and 9 days for large-diameter cuttings (C2 = 3–5 cm). The appearance of the first buds was recorded on the 3rd and 9th day, respectively, for small-diameter (C1) and large-diameter (C2) cuttings. The recovery period varied from 25 days for C1 cuttings to 22 days for C2 cuttings. The first bud for C1 appeared 3 days after the cuttings were planted, whereas the last bud was observed after 28 days, a difference of 25 days. For C2 cuttings, the first buds appeared after 9 days and the last one after 31 days, 22 days apart (Figure 6(a)).

The maximum budding rate was 30.8% for C1 cuttings compared to 12.62% for class C2. The C1 cutting nodes amounted to 107, of which 33 emitted buds with 103 knots, and 13 C2 cuttings were emitted. This difference was also noted in the evolution of these rates according to the 2 types of cuttings as a function of time. The budding rate began to change from the 3rd day with 1.8% for C1 cuttings and reached its peak at 28.9% at the end of the 28th day (Figure 6(a)). This rate dropped thereafter to stop on the 60th day, that is, the duration of 57 days. For class C2, budding started from the 9th day at a rate of 1.9%, whereas it had already reached 6.54% for C1 cuttings on the same day, reaching its peak on the 30th day, which corresponded to a rate of 11.6%. It dropped to zero by the end of the 63rd day, for a duration of 54 days (Figure 6(a)).

The maximum rate of cutting survival varied from 42.8% for C1 cuttings to 28.5% for C2 cuttings. Twelve C1 cuttings emitted buds compared to 8 C2 cuttings out of 28 of each type. This variation can also be seen in the speed of recovery, which reflects the daily variation in the rate of recovery in classes (Figure 6(b)). The recovery rate for C1 cuttings was 7.1% on the 3rd day, fluctuating until reaching its peak at 42.8% and stabilising on the 30th day. For C2 cuttings, this rate was 3.5% on the 9th day, reaching its peak to a value of 28.5% on the 33rd day and stabilising there.

3.6. Study of the Root Structure of Cuttings. After 70 days, we noted that for small-diameter cuttings (C1), some had developed only the aerial part without developing roots (B1C1, B6C1, B8C1, B12C1, and B17C1), whereas others had developed the aerial and underground parts (B2C1, B5C1, and B11C1) at the same time (Figure 7(a)). No cuttings of this class developed stem roots.

For large-diameter type (C2), cuttings B2C2 and B3C2 developed stems without developing roots. The B7C2, B13C2, and B14C2 cuttings developed both stems and roots. B5C2 and B25C2 stem cuttings developed fewer roots. The B7C2 cutting emitted a branch with an average height of 3.7 cm and a root of 1.7 cm. For the B13C2 cutting, the height of the medium-sized branch was 1.4 cm and the root 1.2 cm. The average stem of the B14C2 cutting was 4.2 cm with a root of 0.8 cm. Cuttings B5C2 and B25C2 without stem emission had, respectively, roots of 1.6 cm and 1.3 cm (Figure 7(b)).

4. Discussion

4.1. Ability of B. aegyptiaca to Regenerate Naturally. The regeneration density of the area is only 64 seedlings/ha with a regeneration rate of 36.7%. This rate of observed regeneration was obtained in the context of pressure exerted by

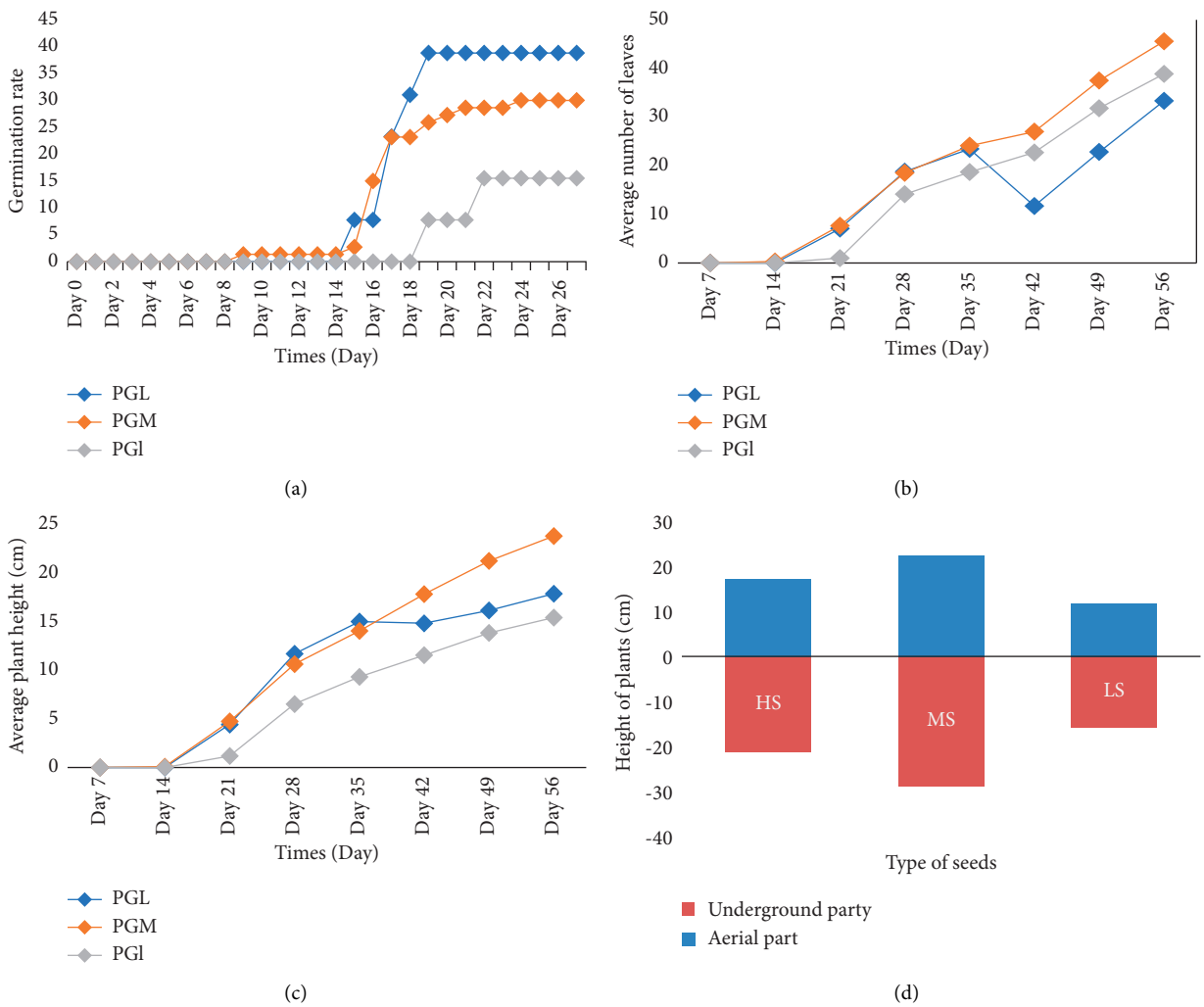

Figure 3: Parameters of growth monitoring of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Germination rate (a), evolution of the number of leaves (b), evolution of plant height (c), and final growth of above- and belowground parts of plants (d). PGL: heavy seed, PMG: medium-weight seed, and PGl: Light seeds. Day corresponds to the number of days after sowing the seeds.

humans and animals on young plants (such as fodder) and the collection of seeds of the species for processing and other uses. This result shows that *B. aegyptiaca*, despite these germination capacities, exhibits a low rate of renewal at this site. This regeneration rate is lower than that observed by Idrissa et al. [5] in similar areas in Niger with 47%. We can also note the low survival rate of seedlings caused by overgrazing, clearing, and bush fire in a metanalysis of *B. aegyptiaca* propagation in the Sahel [34, 35].

The naturally favoured mode of propagation by *B. aegyptiaca* is natural sowing (81.2%) during the rainy season (July to September), followed by strain rejection (13.5%) and suckering (5.2%). This demonstrates the ability of the species to spread sexually and asexually in the wild. Propagation by suckers and/or strain rejection is not common to all plants [34]. This shows the adaptive capacity of *B. aegyptiaca* to colonise even the most arid areas [36, 37]. These results easily reflect the choice of the species to propagate by seed. However, in the context of the study, strong competition is exercised around seeds for various uses, including human consumption by local populations and animal grazing. The challenge is so high that during the present study, we had evaluated 93.16% of the trees cut by the local populations for their various needs. Thus, it is necessary to think of the regeneration of the populations of the species, especially during the rainy season by the transplantation of the young shoots in the different parts of the center.

4.2. Seed Behaviour in Nursery. Sowing seeds in the nursery is the most commonly used means of propagating species because of the low cost of producing plants. Added to this is the easy accessibility to seeds and the production of a large number of plants in a short time in a small space. However, this mode of multiplication exposes the plant to parasitic attacks, rooting difficulties, and the risk of mixing with varieties or poor performance, causing the loss of the genetic purity of the desired

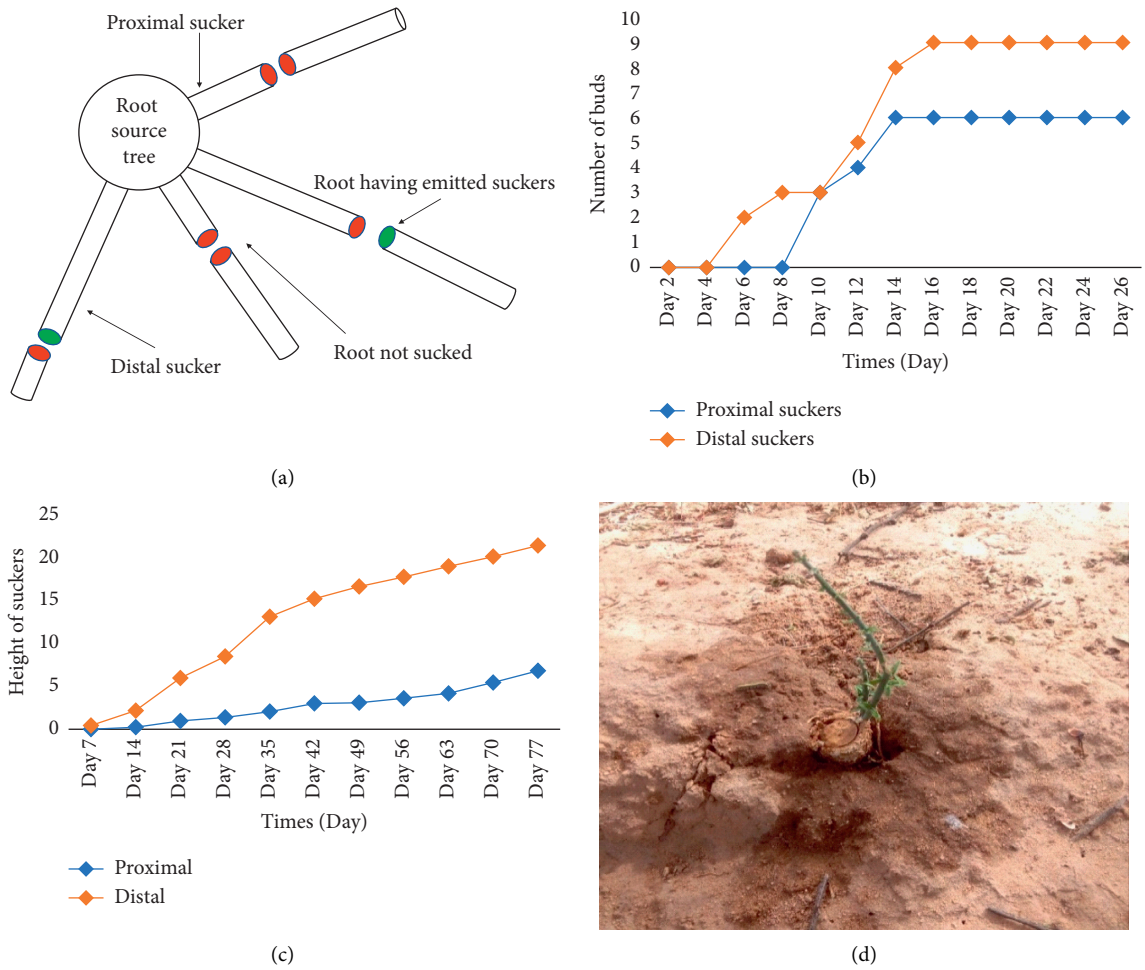

Figure 4: Parameters for monitoring suckers of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Illustration of suckers (a), growth of the number of buds (b), growth of the height of suckers (c), and photo of suckers (d).

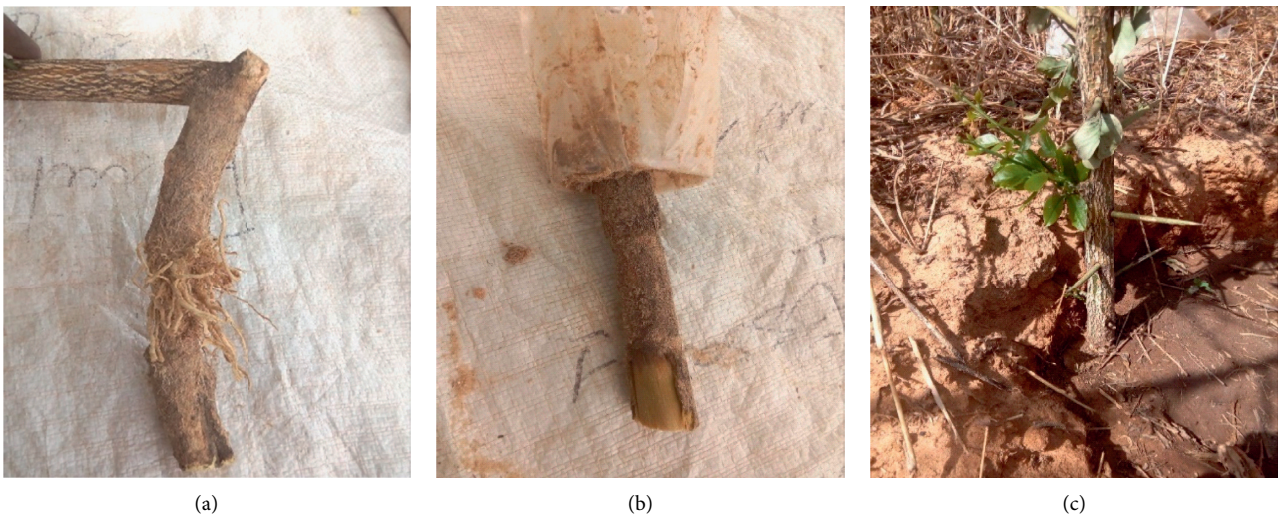

Figure 5: Parameters for air-layering of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. The marcots having developed the roots.

Table 2: Characteristics of the layers after skinning of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger.

Levels	Rod diameter (cm)	Rate (%)	Root trimmers (cm)	Root weights (g)
Status				
Rooted	3.3 ± 0.78	75	5.26 ± 1.99	6 ± 3.75
Rotten	3.3 ± 0.84	25	—	—
Interaction with stem diameter				
Rooted big diameter	3.97 ± 0.51	40	6.19 ± 2.30	7.3 ± 3.76
Large rotten diameter	4.2 ± 0.28	10	—	—
Rooted small diameter	2.67 ± 0.29	35	4.33 ± 1.43	4.7 ± 3.99
Rotten Small diameter	2.7 ± 0.2	15	—	—
Interaction with position				
Rooted vertical	3.41 ± 0.76	35	5.57 ± 1.88	5.75 ± 4.36
Rotten vertical	3.3 ± 0.84	25	—	—
Rooted horizontal	3.32 ± 0.85	40	4.64 ± 2.25	6.5 ± 3.53
Rotten horizontal	—	0	—	—

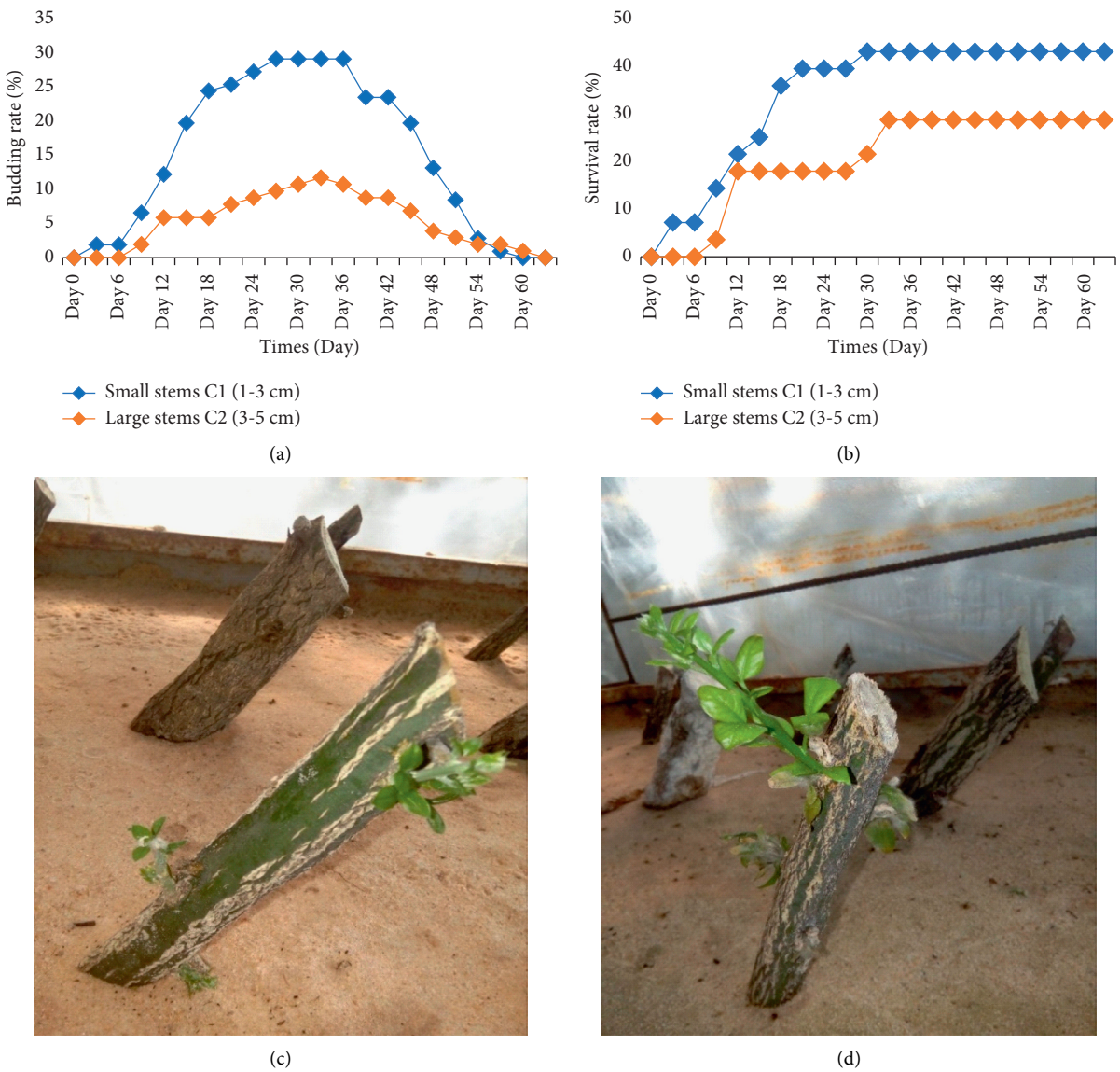

Figure 6: Parameters for stem cutting segments of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Variation in budding rate (a), variation in the recovery rate (b), budded (c), and resumed cuttings (d).

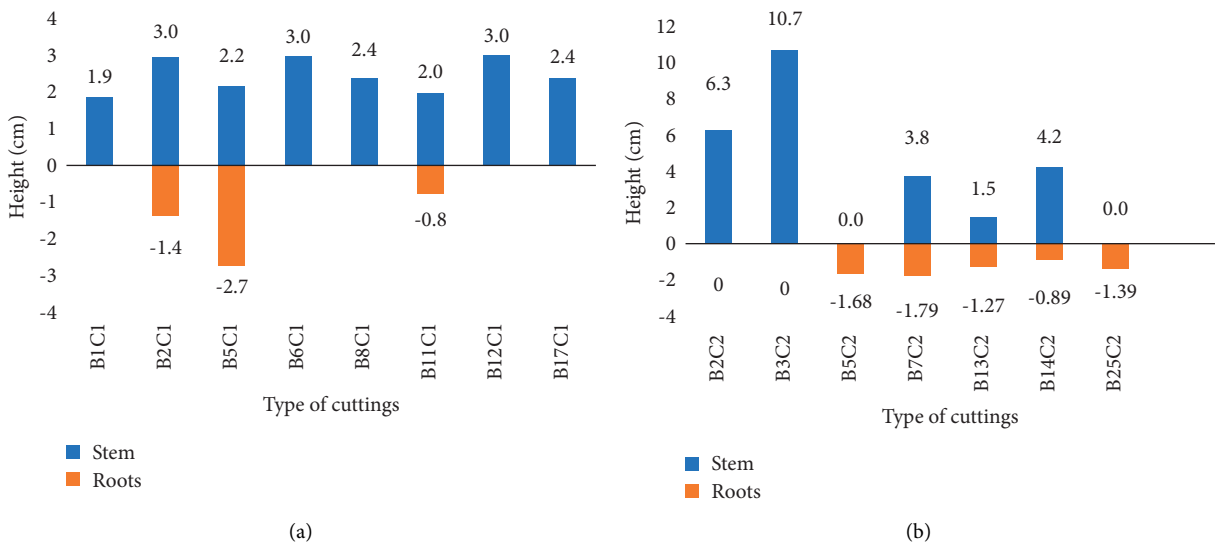

Figure 7: Distribution of roots within class cuttings of *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger. Small diameter (a) and large diameter (b). The symbol BiCi means the tree i and the root class i. During the experiment, both the cuttings were numbered. In the end, alone the cuttings making the root were presented in the figure.

trait. The rate of emergence observed during this experiment (29%) was clearly lower than that observed by Zida et al. ([16]; 71.1%) and Kamal et al. ([38]; 63.3%) for the same species. This could be explained by the differences in preprocessing, including hot water 70°C, sulfuric acid (H_2SO_4 at 98%), and mechanical scarification adopted by these authors. The study highlighted the influence of seed weight on the emergence rate and germination time. The rate increased with the weight of the seeds. Heavy seeds had a higher emergence rate and a longer germination time, whereas lower and shorter rates were observed in light seeds. Several authors have shown that the right choice of seeds guarantees better germination [2, 24, 35]. The seeds of medium weight were characterised by better performance in terms of growth (Figure 8). This could be due to the duration of seed germination. Indeed, medium-weight seeds germinated faster (9 days) than low-weight (19 days) and heavy-weight (15 days) seeds, which gives a slight early growth advantage for medium-weight seeds over others. The number of leaves and the length of the aerial and underground parts were higher at the plant level among the plants resulting from seeds of average weight at the end of the 56th day. These results differ from those observed by [24]. Seeds with a significant weight have more nutritive reserves and thus allow future seedlings to develop better [39]. The study also showed that germination of the cryptogenic type is one of the characteristics of *B. aegyptiaca*. Young plants showed significant development of the root system before the appearance of tigella. The portion of the rod located above the cotyledons lengthened faster than the hypocotylated part. The well-developed root system allows young plants to endure long dry seasons in the Sahelian zone and resists the teeth of herbivores [40, 41].

4.3. Suitability for Suckering. Suckering is a method that has many advantages in terms of vegetative propagation. Among these advantages, we can note low cost, the dispensation of regular watering, the rapidity of new plant growth, rapid sexual maturity, and conservation of the genetic purity of the multiplied species. The low suckering success rate (8.3%) observed during the present study could be explained by various factors. Indeed, Harivel et al. [23] claim that the genetic characteristics of the species influence the time taken to suckle. This observation is confirmed by the weakness of natural regeneration by suckering of the species under natural conditions in the same area. Studies carried out on *B. aegyptiaca* and *D. mespiliformis* have shown that young individuals suck more easily, whereas, in the context of this study, the majority of individuals whose roots were cut were adults. Many authors claim that a 70-day observation period is too short to allow a large number of roots to form suckers [34].

Nevertheless, a remarkable difference was observed between the distal and proximal suckers. The rate of proximal suckers was 5.5%, whereas it was 11.1% for distal suckers. This difference was accentuated in the latency time, which was 9 days for proximal suckers versus 6 days for distals. This could be explained by a physiological mechanism that causes the distal suckers to behave like cuttings because they have detached from the root system. They will mobilize their reserves for cell differentiation and the emission of a whole plant. It would seem that the need is higher in distal than proximal suckers [42]. This difference was observed by Quentin et al. [43] in the suckering of *Spathodea campunalata* (a medicinal species) and can be

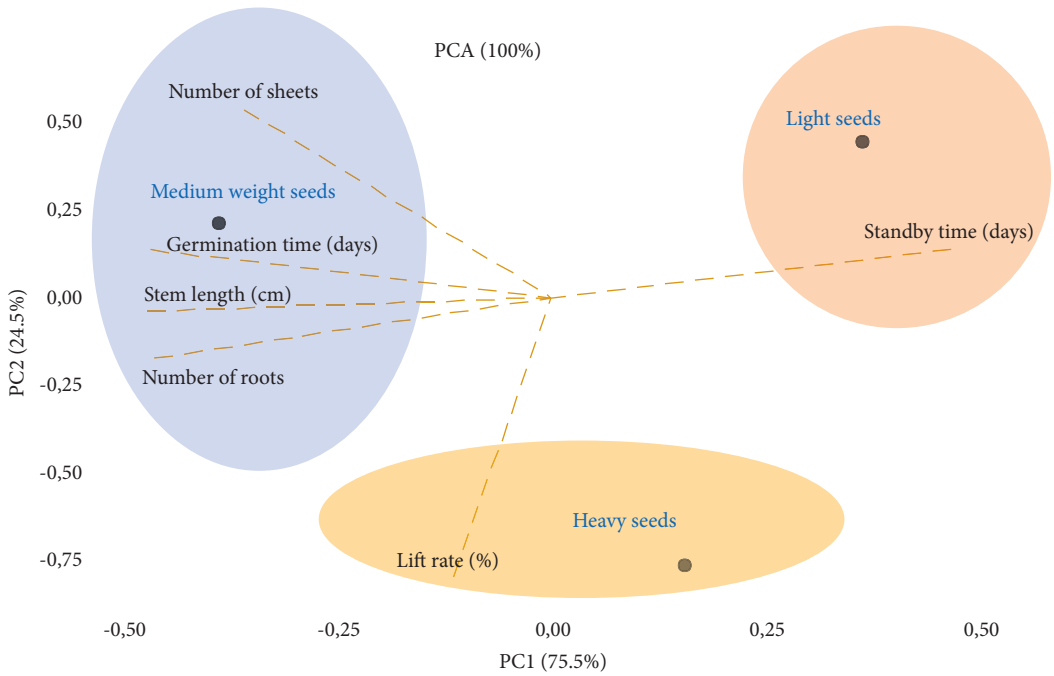

Figure 8: Summary of germination parameters for *Balanites aegyptiaca* at the Regional Centre for Agricultural Research (CERRA), Maradi, Niger.

explained by the relatively rapid independence that distal suckers acquire from the mother tree. Bellefontaine et al. [34] show that suckering occurs mainly but not exclusively when stress occurs, whether it is caused by age, fire, drought, cold, wind or cyclones, unexpected flooding, altitude, latitude whereas species is at the limit of its natural range, or introduction into a different climate. For this study, the most convincing factor is the stress caused to the roots of *B. aegyptiaca* trees because they have been cut. This could induce the plant to want to heal the injured place and emit a whole plant through cell differentiation.

4.4. Ability in Aerial Layering. Air-layering allows direct production of adult individuals capable of fruiting while avoiding fragility due to stress related to growth. It also offers the possibility of experimenting with new varieties without the risk of mixing with already tested species. Analysis of the success rate, that is to say, the rooting rate of the marcots, showed that the marcots of the stems with large diameters were more suitable for layering with a rate of 80%, whereas the marcots of the stems with small diameters exhibited a rate of 70%. Rabiou et al. [32] show that the rate of development and the success of layering depend on the age of the part of the layered branch.

The level located near the main stem is the oldest and has the highest average diameter and relatively thicker bark capable of storing a large amount of sap produced and supporting rhizogenesis. This was confirmed in this study; the marcots of stems of large-diameter emitted roots longer (6.2 cm) and heavier (7.3 g) than the stems of small diameter (4.3 cm and 4.7 g). Several authors who have worked on air-layering have shown the influence of the diameter of the stem and the success of layering [25, 32]. The high rooting rate obtained by this study (75%) is similar to that obtained by Zida et al. [25] on the basal (71.6%) and median (65%) parts of the same species in 98 days. The same authors obtained 40% for the marcots in the middle part of *S. birrea* but none at the level of the marcots in the basal part. These results are lower than those obtained by Thiagam et al. (2011; 96.6%) on *B. aegyptiaca*. Rabiou et al. [32] showed that *P. erinaceus* layers subjected to water stress have a lower success rate (21.5%) than those that were watered weekly (55.6%).

It is important to note that vertical stems produced the longest roots (5.5 cm) but lighter ones (5.7 g) than the horizontal stems (4.6 cm and 6.5 g). This difference could be explained by the relative superiority in diameter of the vertical rods (3.4 cm) compared to the horizontal rods (3.3 cm), thus supporting the above-mentioned results. Various factors can influence the success of layering, including, among others, the age of the carrier, individual, genetic characteristics, physiological activities, the phenological cycle, health status, and external factors such as humidity, temperature, and parasite attacks [23, 25, 34]. For this study, the most convincing factors would be: (i) the intrinsic value of the species (genetic) because the same study was carried out on *Ziziphus mauritiana* trees at the same period and on the same site with more successful results raised and (ii) the environment and the age of the trees because they did not react in the same way to layering (unpublished data).

4.5. Suitability for Cutting Stem Segments. Compared to seed propagation, the advantages of cuttings include low

cost, the possibility of experimenting with new varieties without the risk of genetic mixing, and the possibility of large-scale production of plants in a short time. The behaviour of the cuttings recorded in the context of this study showed a shorter latency time for cuttings of small diameter (3 days) than that of large-diameter cuttings (9 days). These results differ from those of Diatta et al. [44] on *Maerua crassifolia* with a uniform latency of 4 days. The budding rate was 30.8% for large-diameter cuttings, whereas it was 12.6% for small diameter cuttings. These rates are lower than those found by Zida et al. [25] on the same species and those of Diatta et al. [44] on *M. crassifolia*. Even they are not the same species, the results show a possibility of multiplying the two species by cuttings. However, despite the use of growth hormone such as indole 3-butyric acid, the rooting results of cuttings in *B. aegyptiaca* were not improved [45].

The resumption of cutting is due to a revival of activity at the level of one or more vegetative buds that will later give a branch [34]. Each bud has a vegetative point that is relatively vulnerable to shock or desiccation because it is composed of tissue with a meristematic character [23, 46], that is to say, undifferentiated cells capable of multiplying rapidly. These characteristics were particularly observed in small-diameter stems that had not yet finalised their development. This explains the higher rate of budding observed in these latter stems. In contrast, the length of the tigella and the number of leaves that appeared were significantly higher in large-diameter cuttings and lower in small-diameter cuttings. This could be explained by the relative importance of the reserve of sap contained in large-diameter cuttings.

4.6. Implications for Farmers Adoption. All the techniques tested have shown to varying degrees the conditions of application, namely the germplasm, the environmental conditions to be fulfilled, the methods of installation, the propagation, and the monitoring to be carried out to achieve convincing results. Due to the material, the time required for the follow-up, and the results obtained, some techniques are more demanding than others. To this end, for vegetative propagation, suckering and layering seem relatively more demanding than cuttings, which have given the most convincing results. For the latter, the least requirement seems to be the collection of cuttings, the purchase of pots, and the superficial watering of the cuttings. However, its use seems limited if a farmer has a large area to plant with the species. So the combination of the vegetative propagation and seed would be necessary to take advantage of the advantages of either method for the species.

5. Conclusion

B. aegyptiaca is a multipurpose species used by rural African populations for food, medicinal, cultural, and economic purposes. This species has a certain capacity to adapt to the vagaries of the climate of the Sahelo-Saharan zone, giving it a particular selective advantage. It naturally favours propagation by sowing (seed dispersal) but also exhibits strain rejection and suckering as propagation methods. The germination test showed that heavy seeds responded better to sowing in the nursery. The seeds of medium-weight are not only more abundant in nature but are also characterised by a shorter latency time and higher growth parameters. The suckering trial on *B. aegyptiaca* revealed that the distal roots were distinguished from the proximal roots by the high rooting rate and the performance of the growth parameters. In the air-layering test, the large-diameter stems had a slightly higher rooting rate than the small-diameter stems. The stem cutting showed that small-diameter cuttings succeeded in budding better than those of large diameter. The best performance in terms of growth was observed in large-diameter cuttings. However, the different techniques of vegetative multiplication of *B. aegyptiaca* can be used for the revegetation of arid ecosystems depending on the potential and opportunities of the environment [47–50].

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

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