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Vegetative Propagation by Suckering of a Multipurpose Plant: *Sclerocarya birrea* (A. Rich.) Hochst. Subsp. Birrea (Anacardiaceae Family) in the Sahelian Zone of Ouaddaï (Chad)

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Abstract

The present study was carried out in the Sahelian region of Ouaddaï in Chad on *Sclerocarya birrea*, a species of great socio-economic importance. The aim of this work was to contribute to its domestication. Socio-economic surveys were carried out among local farmers. The aim of these surveys was to identify local knowledge of vegetative propagation and, in conjunction with the people surveyed, to select morphotypes to be used as clone heads for suckering induction. Two suckering induction methods were used on these morphotypes and compared. These were: suckering induction by light wounding and suckering induction by complete root sectioning. The results of the survey showed that most respondents were aware of the degradation of the plant cover but had little perception of suckering (3.44%). Sucker induction trials were carried out on two morphotypes of *Sclerocarya birrea*. After 13 months of observation, the overall suckering success rate was 58.75%. This rate varied from 35.83% for induction by light wounding to 53.33% for induction by complete sectioning. Induction by complete sectioning was significantly more effective than induction by light wounding ($p < 0.05$). Whatever the mode of induction, light significantly influenced sucker emergence ($p < 0.05$). Suckers emerged exclusively distally (100%) for induction by complete sectioning. The method of inducing root suckering by wrapping roots in aluminum foil was not successful in this species, as no suckers were produced. On the other hand, rootlet formation was observed on the part connected to the mother plant in all the traumatized roots. We need to capitalize on this method to induce rhizogenesis in suckers that have already developed. These results demonstrate the urgent need to promote low-cost vegetative propagation techniques for the future domestication of this species.

Keywords

Vegetative Propagation, Suckering, Domestication, *S. birrea*, Sahelian Zone, Chad

1. Introduction

Sclerocarya birrea (A. Rich.) Hochst. (Anacardiaceae) or African plum is one of the woody species representatives of traditional land-use systems in the Sahelian zone of Ouaddaï in Chad [1]. It is called "Goundok" in Maba (local language) and commonly "Himmed" in local Arabic. It is a much sought-after species, contributing to a substantial increase in income and food security for disadvantaged households [2]. Unfortunately, it is one of the region's most overexploited species, used to satisfy the needs of local and regional markets for various products (fruit, almonds, mortars, tablets, utensils, etc.). To reverse the trend of ongoing resource degradation and declining local incomes, appropriate strategies need to be defined. These strategies must promote sustainable agriculture and indirectly contribute to maintaining biodiversity, while considering local economic difficulties [3]. In this context, the domestication of the best morphotypes of this species using simple and very economical vegetative propagation techniques remains a priority [4]. Nowadays, trees can be propagated at low cost by disadvantaged farmers far from urban nurseries [5] [6]. This is why it is so interesting to test suckering techniques on *Sclerocarya birrea* morphotypes, using simple methods that are familiar to the local populations themselves [7]. This situation could preserve the diversity of these species, and at the same time, enrich land use systems with better morphotypes selected by farmers [8]. This approach generates income for the local population, thus improving their living conditions while preserving biodiversity [9]. The aim of this study is to contribute to the domestication of *Sclerocarya birrea*.

2. Materials and Methods

2.1. Presentation of the Study Area

The work was carried out in the Sahelian Ouaddaï region of Chad. This region lies between 13˚39' north latitude and 21˚44' east longitude (**Figure 1**). It covers an area of 29,980 km^2 and has a population of 731,679. With isohyets ranging from 300 to 600 mm/year, the climate is warm tropical Sahelian. Temperatures are relatively mild in Ouaddaï, with an average of 28˚C. Vegetation is of the Sahelian-steppe type, with different plant formations depending on soil type, topography and depth of water table. Following the North/South gradient, vegetation evolves from North to South, from grassy steppes, low shrubs with thorns often very sparse to tree steppes and open or sparse to moderately dense forests in the South [10]. The deeply incised watercourses of the "ouadis" (temporary watercourses) are characterized by a loose shrub to tree cover, severely tested by the high intensity of water erosion due to runoff.

Acacia is the dominant genus. Skeletal soils on steep slopes or on granite or gneiss present a steppe with *Albizia amara*, *Acacia mellifera*, *Acacia laeta*…. The sandy areas, sometimes cultivated in the form of fallow land, are made up of *Boscia senegalensis*, *Guiera senegalensis*, *Acacia tortilis*, *Ziziphus mauritiana*…. [11]. The herbaceous stratum, composed mainly of annual species, includes: *Schoenefeldia gracilis*, *Cenchrus biflorus*, *Zornia glochidiata*, *Cassia obtusifolia*, *Aristida mutabilis*, and *Dactyloctenium aegyptium*. In the South, on clay soils, vegetation becomes more woody. The dense herbaceous layer is composed of grasses [11].

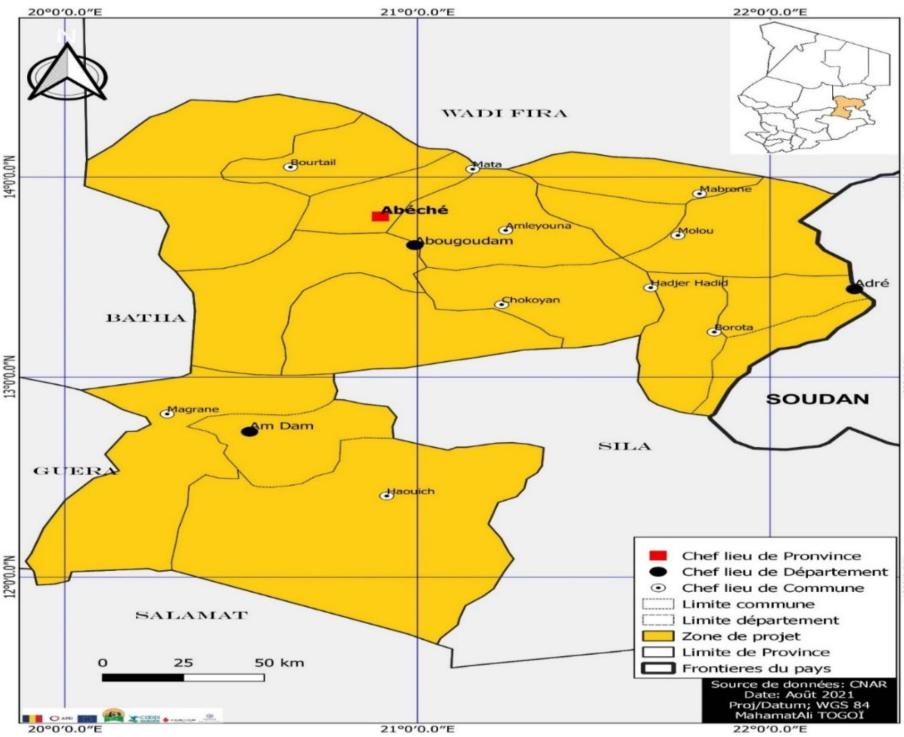


Figure 1. Map of Ouaddaï Province.

2.2. Methods

2.2.1. Household Socio-Economic Survey

The survey covered the villages of Khoummi (13˚83N and 20˚78E), Ogodondé (13˚85N and 20˚80E), Arkou (13˚86N and 20˚83E), Kiligan (13˚82N and 20˚95E) and Tondou (13˚81N and 20˚90E). The choice of these villages was guided by three types of factors: the condition of the stands and, above all, the degree of knowledge about vegetative propagation. The household socio-economic survey is an essential step in the domestication of this species. It should lead to the identification of the best *Sclerocarya birrea* individuals, with the participation of local populations. Specifically, the aim is to: 1) identify local knowledge concerning vegetative propagation, natural or induced regeneration, and biodiversity management and protection; 2) select the best *Sclerocarya birrea* morphotypes in the region, in consultation with farmers. The survey method used was semi-structured interviews. Data collected was based on a questionnaire drawn up in advance. The interviews involved 87 people, the majority of whom were indigenous. Interviews were conducted in local Arabic, either individually or in groups of 5 to 13 people. The interviews were followed by field trips with volunteer respondents to identify the morphotypes in question. Identifications were made on healthy plants, whether they still bear fruit or not, and spaced at least 80 meters apart. A morphotype of *Sclerocarya birrea* producing large, sweet fruits was selected. This selected morphotype was used as clone heads for suckering induction.

2.2.2. Suckering Induction

Suckering induction was carried out at the beginning of the rainy season (July) on morphotypes previously selected by farmers. Many of these plants were multi-stemmed and of different ages. Two induction methods were used and compared.

1) Induction by light wounding

On each mother tree, 2 to 8 roots were lightly wounded with a knife, *i.e.*, a total of 100 roots were involved. A piece 6 to 8 cm long was then taken from the upper half of each of these roots [12]. Four treatments were applied. Of the 100 injured roots, 40 were buried, 40 exposed to the open air and a further 20 rolled with aluminium foil (including 10 roots rolled simply and 10 others with the original soil). The procedures were as follows: 1) two roots were covered immediately with the original soil after treatment; 2) two others were also covered, but the induced part was exposed to the air over a length of 5 cm [13]; 3) two roots were rolled up with aluminium foil and buried; 4) the last two roots were covered with the original soil, then rolled up with aluminium foil and buried after treatment (**Figure 2**).

Figure 2. Wounded and exposed root (a); wounded root then wrapped in aluminium foil (b).

2) Induction by complete sectioning

Two to eight superficial lateral roots per mother tree were completely sectioned and a fragment approximately 6 to 8 cm long was removed [4]. One hundred roots per species were stressed. Four treatments were then applied to them: 1) Two sectioned roots were covered immediately by the original soil after treatment; 2) Two others were also covered but exposing the 2 ends (proximal and distal) to the open air over a length of 5cm [12] [13] Two roots are wrapped with aluminium foil and then buried; 4) the last two are covered with the original soil then wrapped with foil and then buried after treatment (**Figure 3**).

Figure 3. Sectioned root for wrapping with aluminium foil (a); exposed sectioned root (b); sectioned root covered with original soil and wrapped with aluminium foil (c).

The experimental set-up is a split-plot with three replicates. The main treatment was induction (complete sectioning-light wounding), while the secondary treatment was exposure (roots exposed to open air-roots covered with original soil). Data was collected on the number of roots that had produced at least one sucker. The position of emergence of the induced sucker was noted according to whether it was proximal (close to the point of attachment to the mother tree) or distal (separated from the mother tree). The height of suckers emitted was measured, and the number of leafy axes and leaves per sucker emitted was counted. The number of suckers having initiated their own root system was also noted.

2.3. Data Processing

Analysis of the suckering induction data focused on variance. The Duncan Multiple Range Test was used to separate significant meanings. The software used was Statgraphics Plus version 5.0. A simple ANOVA was applied between parameter means. The Small Significant Difference (SSD) method at the 5% level was used to discriminate between means.

3. Results

3.1. Status of Wood Resources and Natural Regeneration Methods

Most farmers surveyed reported a decline in plant cover in recent decades. According to them, woody species such as *Ziziphus spina christi*, *Bauhinia rufescens*, *Acacia laeta*, *Balanites aegyptiaca*, *Faidherbia albida* and *Acacia mellifera* are in steep decline, and others such as *Sclerocarya birrea*, *Ziziphus maritiana*, *Tamarindus indica*, *Anogeissus leocarpa*, *Grewia bicolor*, *Hyphaene thebaica*, *Diospiros mespiliformis* and *Combretum glutinosum* are becoming increasingly rare in the zone's agrarian landscape. However, their opinions are divided on the causes of tree cover degradation. More than half of those surveyed (58.62%) attributed the degradation of woody species to human pressure. Others (31.03%) cited drought as the primary factor. For some respondents (14.94%), lack of planting, regeneration and disinterest are also threats to the survival of woody species. Seed multiplication in *Sclerocarya birrea* is known to most respondents. However, vegetative propagation was rarely mentioned (18.63% ± 12.52%) by respondents. The highest frequency of responses for vegetative propagation was found for reiteration (68.89%). Suckering seems to be little known to the respondents, since only 3.44% of them mentioned it.

3.2. Farmer's Morphotype

The people surveyed have a good knowledge of how to classify the woody plants whose products they use, whether they are trees saved from the savannah, fields or fallow land. There are five main selection criteria, dominated by food (73.56%) (**Figure 4**).

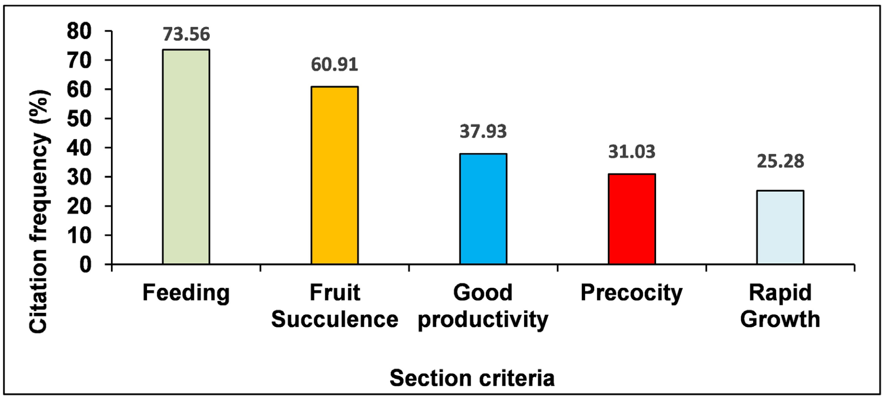


Figure 4. Farmers' ecotype selection criteria.

3.3. Induction of Suckering

3.3.1. Success Rate of Suckering Induction

1) Effect of induction

Sucker induction was carried out on 74 adults *Sclerocarya birrea* trees at least 80 m apart. The trees responded positively to the trauma applied to their roots. Ninety-four suckers were counted on the traumatized roots (**Figure 5**). The overall success rate of induction suckering was 58.75%. This rate varied significantly from 35.83% for induction suckering by light wounding to 53.33% for suckering by complete root sectioning ($p < 0.001$).

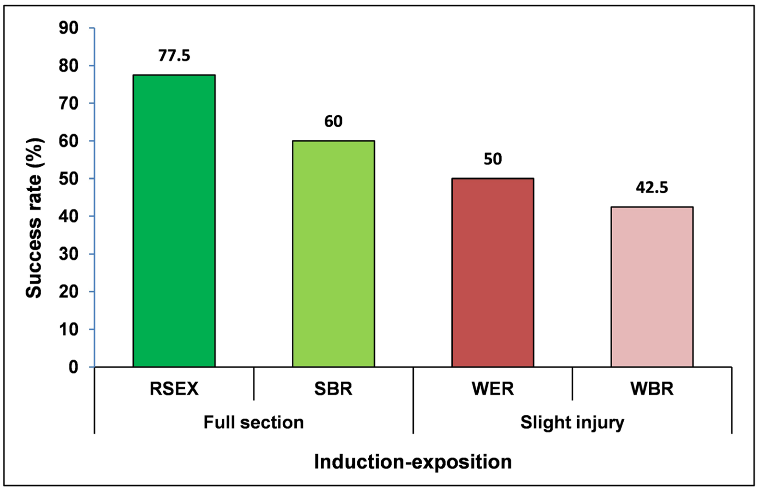
Figure 5. Suckers from complete section (a) and from light wounding in *Sclerocarya birrea* (b).

2) Effect of exposure

The total number of soil-covered roots having produced at least one sucker varied from 65% (52 roots) to 52.5% (42 roots) for roots exposed to the open air. Analysis of variance shows that there is a significant difference for the type of exposure (0.01 < 0.05).

3) Effect of induction mode-exposure type interaction

Sectioned roots exposed to the open air had a success rate of 59.16%, compared with 30.83% for lightly wounded roots covered with the original soil. Overall, fully sectioned roots had a higher success rate of suckering induction than exposed or covered roots (**Figure 6**). The interaction between induction mode and type of exposure was significant (0.000 < 0.001).



RSEX = Roots Severed and Exposed; SBR = Severed and Buried Roots; WER = Wounded and Exposed Roots; WBR = Wounded and Buried Roots.

Figure 6. Variation in sucker success rate by species, induction method and exposure type.

3.3.2. Induced Sucker Emergence Rate

1) Effect of induction

The emergence rate of suckers from fully severed roots was 56.48%, while suckers emerging from slightly injured roots had an emergence rate of 43.12% (0.01 < 0.05). Vigorous suckers appear on fully severed roots exposed to the open air (Figure 7).

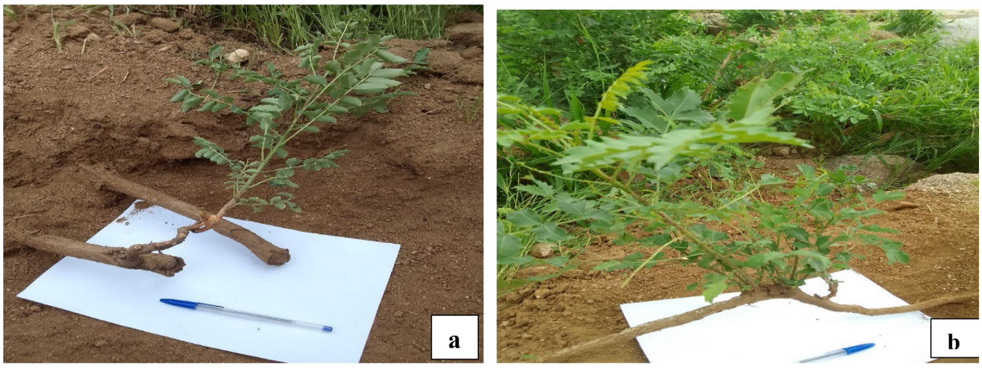


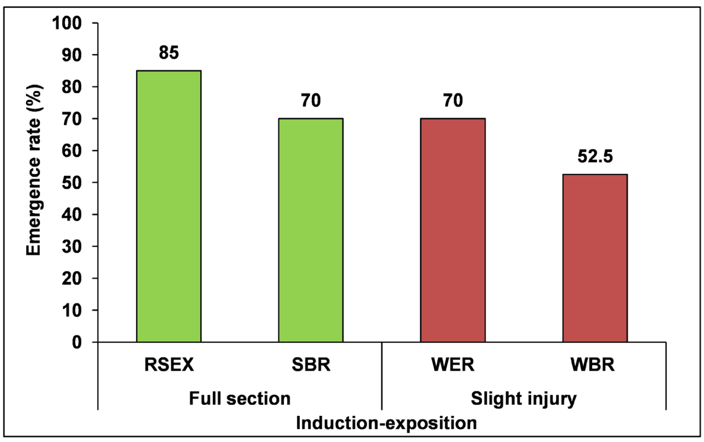
Figure 7. Suckers from a completely severed root (a) and suckers from a wounded root in *S. birrea* (b).

2) Effect of exposure

The overall number of suckers from light-exposed roots was 60% or 75%, while that from covered roots was 49% or 61.25% ($p < 0.05$). These results show that, whatever the mode of suckering induction, the number of suckers resulting from the exposure of traumatized roots to light is greater than that of covered roots.

3) Effect of the induction mode-exposure type interaction

Sectioned roots exposed to the open air had the highest sucker emergence rate at 85%, compared with 52.5% for injured roots covered with soil (Figure 8). Analysis of variance does not show a significant difference for this interaction (0.94 > 0.05).



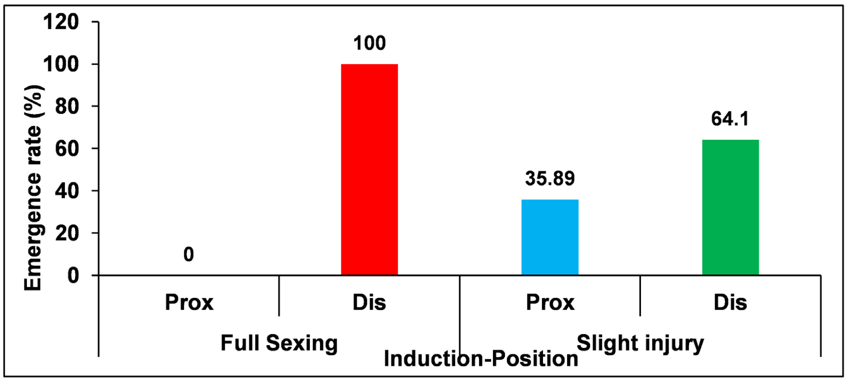
RSEX = Roots Severed and Exposed; SBR = Severed and Buried Roots; WER = Wounded and Exposed Roots; WBR = Wounded and Buried Roots.

Figure 8. Variation in sucker emergence rate according to induction mode and exposure type.

3.3.3. Polarity of Induced Suckers

1) Effect of induction

The position of suckers induced on stressed roots varies according to the mode of induction. Complete sectioning induces only distal suckers (100%) in this species, whereas light wounding produces 35.89% proximal and 64.1% distal suckers. Overall, induction produces a greater proportion of suckers distally (82.05%) than proximally (17.94%). Roots that had been completely severed had a greater number of suckers than roots that had been slightly injured (Figure 9). This variation in sucker emergence position is confirmed by analysis of variance, which reveals a significant difference for this parameter (0.02 < 0.05).



FS = Full section; SI = Slight Injury; Prox = Proximal; Dis = Distal.

Figure 9. Variation in sucker localisation as a function of induction mode.

2) Effect of exposure type

Exposure type had a positive influence on sucker position. *S. birrea* emitted exclusively distal suckers (100%), whatever the type of root exposure. Analysis of variance revealed a significant difference in sucker polarity ($p < 0.001$).

3.3.4. Growth Parameters of Induced Suckers

Sucker height ranged from 22.55 ± 5.37 cm for suckers from wounded and covered roots to 29.95 ± 9 cm for completely severed roots. The diameter at ground level of the suckers ranged from 0.61 ± 0.14 cm for wounded and covered roots to 0.7 ± 0.12 cm for wounded and exposed roots (Table 1). The number of leafy axes per sucker varies according to induction mode and type of exposure. This variability is 2.7 ± 2.88 leafed axes for wounded and covered roots and 5.35 ± 3.49 leafed axes for sectioned and exposed roots. However, disparities in height, sucker diameter and number of leafy axes per sucker were not confirmed by analysis of variance ($p > 0.05$).

3.4. Impact of Aluminium Foil on Suckering

3.4.1. Effect of Induction

Trials to induce suckering by complete sectioning and wounding were inconclusive in this species. No suckers were observed in roots that had been traumatized and covered with the original soil, then rolled up with aluminium foil and buried. However, analysis of variance revealed no significant difference between suckering induction methods ($p > 0.05$).

Table 1. Characteristics of induced suckers.

	80 severed roots		80 wounded roots		
	Exhibitions	Covered	Exhibitions	Covered	Average
Number of roots that have suckered	31 ± 0.89	24 ± 0.76	21 ± 0.88	18 ± 0.74	**23.25**
Numbers of suckers	34 ± 0.92	28 ± 1.14	26 ± 1.03	21 ± 0.94	**27.75**
Average number of leafed axes	5.35 ± 3.49	4.25 ± 3.64	3.75 ± 3.36	2.7 ± 2.88	**4.01**
Average axis height (cm)	27.77 ± 8.64	23.95 ± 6.43	29.95 ± 9	22.55 ± 5.37	**26.05**
Average number of leaves per axis	16.1 ± 2.05	13.55 ± 2.09	15.21 ± 3.41	12.83 ± 2.73	**10.65**
Average diameter of axes (cm)	0.7 ± 0.12	0.68 ± 0.11	0.65 ± 0.12	0.61 ± 0.14	**0.67**

3.4.2. Rooting of Roots

Rolling up roots traumatized by aluminium foil promotes rootlet development exclusively on the proximal (100%) side of the root section or wound (Figure 10).

Figure 10. Rooted wounded root (a) and rooted severed root (b).

4. Discussion

4.1. Socio-Economic Survey

In this study, farmers cited factors such as population growth, falling rainfall, bushfire and overexploitation to justify the decline in woody resources. To explain the degradation of vegetation cover, some spoke of the reduction in the number of trees in traditional land-use systems. Indeed, the size and density of woody species are criteria often used to assess the health of land-use systems [14]. A list of regressing and rarefied woody species was drawn up by the farmers. Among the woody species cited, some, such as *Diospyros mespiliformis* and *Anogeissus leocarpa*, are recognized by several authors as characteristic of frequently flooded environments [15]. The change in rainfall regime would therefore be at the root of this rarefaction. Similar findings have been reported in studies carried out in the Sahelian zone of Burkina Faso and Senegal [16]. The rarefaction of *Sclerocarya birrea* populations in land-use systems could have enormous consequences for populations because of their dependence on the exploitation of this species' products.

4.2. Farmer Morphotype

For farmers, trees in the agrarian landscape are sources of food, for which they need to produce lots of succulent fruit and be fast-growing. According to [9], local knowledge is a source of inspiration in identifying good seed sources. It can also help to identify the morphological characteristics required for domestication. Based on these criteria, farmers have selected an interesting morphotype of *Sclerocarya birrea*. For this species, only female plants are mainly sought for agroforestry parks [17]. Similar work in Burkina Faso has identified six woody species suitable for suckering, based on five peasant identification criteria [18]. Farmers' choice of this morphotype is based on knowledge that has been passed down for several generations and can therefore help in setting up a domestication program for this species based on traditional knowledge.

4.3. Farmers' Perceptions of Vegetative Propagation

The results of this survey show that most farmers are aware of the reproduction methods for these species, *i.e.*, planting from seed, reiteration and suckering. However, the practice of producing seedlings of these species from seed in nurseries is still unknown in the area. Similar results were obtained by [19] on *Detarium microcarpum* in Mali. Our own field observations have shown that field and fallow trees are not planted but only spared and more or less maintained. Similar observations were made by [20] in Burkina Faso. Natural suckering in *Sclerocarya birrea* seems to be little known to the people interviewed, since only 3.44% ± 0.71% of them mentioned it. However, several research studies have highlighted the ability of *Sclerocarya birrea* to reproduce by reiteration and suckering [21] [22]. According to [19], farmers use suckering to propagate certain woody species such as *Faidherbia albida* in Burkina Faso. The transfer of knowledge and skills in vegetative propagation of this multi-purpose tree should be considered to densify land use systems in this region.

4.4. Suckering Induction

The species responds favourably to the two modes of artificial suckering induction tested (induction by complete root sectioning and by light wounding) to varying degrees. According to [23], suckering aptitude varies according to species. The number of suckers obtained from these two different techniques proves that trauma is often a determining factor in vegetative propagation by suckering for the survival of endangered species [23]. The overall success rate for the induction trial was 44.79%. These modest results reflect the simplicity of the artificial suckering induction technique. All that needed is to stress the superficial roots of suckering species, usually at the end of the dry season [24]. According to [25], the induction of suckering can complement sexual regeneration. This is because reproduction by seed alone is generally not enough to maintain a sufficient density of woody plants [23]. Indeed, in the Sahel, seedlings from natural seedlings die in very large numbers due to the long dry season or bush fires and/or overgrazing [26].

4.5. Effect of Light

The result shows that the emergence rate of suckers from roots exposed to the open air is higher (56.35%) than that of suckers from covered roots (43.63%). According to [27], the shade produced by the mother tree's crown may condition sucker emergence. The absence of light appears to be a limiting factor in their development. The influence of light is decisive for the suckering of this species, since sucker production is all the greater the more traumatized roots are exposed to light. According to many authors [28] [29], light has a positive influence on the appearance of suckers. However, isolation is a stimulating factor, but not sufficient to induce suckering [13]. This is because we need to be able to separate the effect of light from that of dry air [6]. The effect of light can only be better demonstrated under controlled conditions (using propagators) with root segment cuttings.

4.6. Sucker Emergence Position

Suckers emerge in two places: either on the segment of the root disconnected from the tree (distal part) or on the root still connected to the tree (proximal part). Overall, most suckers emerged distally rather than proximally (58.17% distal suckers and 41.82% proximal suckers), with 100% distal emergence in the case of complete sectioning in this species. Similar results obtained in Cameroon showed that induced suckers are predominantly located at the distal pole for *Ximena americana* [30]. Similarly, the study carried out in Uganda [31] showed exclusively distal suckering in *Spathodea campanula*, with suckers located on root segments disconnected from the mother tree, and the opposite for *Melia azedarach* (suckers emitted exclusively on the proximal pole). Moreover, the exclusively distal suckering (100%) observed in *S. birrea* for complete sectioning is contrary to the results obtained by [6], who reported exclusively proximal suckering in the same species in northern Cameroon.

4.7. Characteristics of Induced Suckers

The present results show that sucker growth varies according to species, mode of induction and type of exposure. Suckers from roots that have been completely severed and exposed to light show better development than those from roots that have been wounded and covered with the original soil. According to [32], trauma affects the hormonal balance of the root system, which can increase the number and growth of suckers. However, severe root trauma reduces the success rate of root suckering, leading to degeneration by reducing hormonal stimulation, such as cytokinin production and limiting the suckers' access to the nutrients (carbohydrates, water, nutrients, etc.) required for their development [32]. In some cases, severe trauma exposes roots to parasitic attack [31].

4.8. Effect of Aluminium Foil on Suckering

Induction of suckering by light wounding and complete sectioning with aluminium foil wrapping was carried out on a limited number of roots (40 roots). The success rate for this new trial was very inconclusive, with major differences depending on the induction method used (induction by rolling up roots stressed by aluminium foil and then buried). Indeed, after thirteen months of observation, no suckers were observed in the traumatized roots, which were covered with the original soil, then rolled up with aluminium foil and buried. However, the natural suckering ability of *Sclerocarya birrea* is demonstrated by the previous work of several authors [4] [6] [25]. Results were nil for this first series of suckering induction trials using aluminium foil, presumably due to the high temperature caused by the absence of air and light. According to [12], a layer of air of a few centimetres should be left between the root and the paper to avoid high temperatures, which would hinder sucker emergence. However, new rootlets were formed on the part of the root still connected to the mother tree, without suckers emerging. These results are similar to those reported by [23] on *Spathodea campanulata* in Uganda and by [32] on *Vitex doniana* in the high Guinean savannahs of Adamaoua in Cameroon. Further observations and experimentations will be needed to improve this induction method. The suckering technique is simple, inexpensive and easily assimilated. It could undoubtedly alleviate the shortage of seedlings, especially for farmers in this region, lacking nurseries, to increase the density of agroforestry systems.

5. Conclusion

The study showed that local populations have very good knowledge of how to identify the morphotypes of this species, whose products they use and are aware of the negative evolution of the plant cover. However, they have little knowledge of vegetative propagation. Faced with the threats of forest degradation and climate change, people want to see an improvement. The induction of suckering by complete sectioning of the mother root best meets the objectives of this study. Suckers from severed roots are more numerous than those from slightly injured roots. Overall, the number of distal suckers produced is greater than that of proximal suckers. *Sclerocarya birrea* mainly produces suckers on the distal side, although only distal suckers are produced after complete sectioning. This simple, inexpensive and easily assimilated technique could undoubtedly alleviate the shortage of seedlings, especially for farmers in this region lacking nurseries, to densify agroforestry systems. The results of this study, although still insufficient, could provide basic information for a silvicultural strategy and make it possible to envisage the integration of this species into land-use systems. The results obtained with the induction of suckering by complete sectioning of the mother root are promising and open up interesting prospects for the multiplication and domestication of *Sclerocarya birrea* in the region. Its adoption by farmers could help set up a vast domestication program based on local knowledge. The foil-wrapping strategy deserves to be capitalized on to induce rhizogenesis in suckers that have already developed.

Conflicts of Interest

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

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