Gezira J. of agric. sci. 18(1): 1-19 (2020)

Regeneration of *Heglig* [*Balanites aegyptiaca* (Del)] west of the Blue Nile river within the short grass Savanna zone in the Sudan

Hasabelrasoul F. Mustafa[1] and Mohamed A. Abaker[2]

[1]Faculty of Forest Sciences and Technology, University of Gezira, Wad Medani, Sudan.
[2]Forests National Corporation, Wad Medani, Sudan.

ABSTRACT

Balanites aegyptiaca is a promising widely distributed tree of high value in terms of economic, social, and environmental issues, but it is neglected and not given full attention concerning its conservation. The objective of this study was to assess the regeneration of *B. aegyptiaca* west of the Blue Nile river within *Acacia-Balanites* vegetation zone in Sudan. A field experiment was carried out during the rainy season in 2015 in *Nawara* natural forest on its germination where viable fruits with intact or removed pericarp and mesocarp were buried at 0-cm and 5-cm depth in plots each surrounded by a metallic ring. Germinated fruits were counted weekly. An experiment on the effect of salinity on germination was performed, using both NaCl and CaCl to fix different levels of salinity in the clay soil. Number of germinated fruits was recorded weekly. Survey of the regeneration in the field was carried out in spot samples laid immediately after the rainy season at distinguished locations; abandoned agricultural farms, vicinity of the villages, crusted sites (*Karab*), valley meander and valley banks. In each location, three spot samples, 50 m in diameter each, were demarcated. All the *B. aegyptiaca* plants within the samples were calculated and their shoot height and diameter at ground level were measured. The soil moisture content in the five sites was measured in April, the driest month. The results revealed that fruits of *B. aegyptiaca* sown after the removal of both the pericarp and mesocarp or left them intact germinated readily when placed on the soil surface (91%) or buried to 5-cm depth (88%). Salinity significantly decreased the germination as it dropped from 83% on average at EC 0.8dSm^{-1} (control) to 36% at EC12 dSm^{-1}. *B. aegyptiaca* regenerated continuously on all the sites except on the valley bank and meander, where newly recruited natural regeneration was lacking. The study recommended more concern and attention to conserve *B. aegyptiaca* through improving management and extension programs and reserving lands as forests where the tree exists.

INTRODUCTION

Balanites aegyptiaca is a valuable economic, social, and environmental species; source of fodder and foliage in the dry season, medicinal and nutritional non-wood products, wood and timber. It is indigenous to all dry lands south of the *Sahara*, extends southward to Malawi (Hall, 1992; NRC, 2008).

In the Sudan, it grows in association with *Acacia seyal* on cracking clay soil in short grasses Savannah and along the valleys in Kordofan and Darfur regions (El Amin, 1990). It was observed in relatively fertile, loamy or clay soil of low salinity, but in the northern *Sahel*, was widely present on lighter and drained soil (Hall 1992; Hardwick, 2004).

There are various socioeconomic activities being practiced in the clay soil plain of the Sudan where the species is widely grown. Shifting cultivation is mainly practiced by villagers living permanently around the natural forests, where these farmers tend to clear an area of about two hectares for cultivating their crops. The farmer could pursue successive cultivation at the same area and this could have destructive impact on the soil and the appropriate environment for tree species to grow (Badi *et al*., 1989).

The clay plain of Sudan provides natural pasture for most of the animal population in Sudan. Camels and goats within this population depend largely on *B. aegyptiaca* during the dry season. *B. aegyptiaca* is being grazed intensively in its natural habitats at the regeneration stage (El Siddig, 2007). Natural regeneration was found to be four times more under rotational grazing as opposed to conventional grazing (Fischer, 2009). Over grazing is more intensive and obvious in the surroundings of the villages where tree vegetation is reduced to stunted stumps or absolute bare area (Badi *et al*., 1989). Some *Acacia* and *B. aegyptiaca* disappeared under the pressure of over grazing (El Siddig, 2007). More to cultivation and grazing practices, the species is subject to continuous felling to meet peoples demand for fuel wood, building and fencing poles and timber for furniture, but the most serious felling is due to crop cultivation.

B. aegyptiaca is not given full attention concerning its conservation, although it is protected by law. Hall (1992) and NRC (2008) stated that the current conservation status of the tree could change if human and animal pressure increased sharply. Several studies concerning the species were made on the chemical composition, fodder value, pharmaceutical ingredients and morphological variation (Elfeel, 2009; Elsafori, 2009) but little was done on its natural regeneration. By all those threats, unless management measures are taken, the tree may disappear from large areas which would lead to environmental and social impacts. Hence, launching of conservation programs is of utmost necessity and its success would be underlined unless provision of the relevant and valid technical information on regeneration is made available. Therefore, the objective of this study was to assess the natural regeneration of the species on the western bank of the Blue Nile river within *Acacia-Balanites* vegetation zone.

MATERIALS AND METHODS

Area of the study

The study was conducted during 2015 along the Blue Nile western bank between latitude 11.49° - 13.33° N and longitude 33.37° - 34.42° E, south of Sennar Dam to *Khor Addisa*. The climate is characterized by a short rainy season during June to October with an average annual rainfall of about 500 mm, high temperature during the dry period (44^{0}C in May), relative humidity with a maximum of 75% in the rainy season and minimum of 25% in dry season and potential evapotranspiration of 2000 mm (Elagib and Mansell, 2000).

The soil was classified into four distinguished types; the *Jerf* soil fringes the river meander, clay soil next to *Jerf* in depression known locally as *Mayá* which floods annually during the rainy season and used to manage *Acacia nilotica* forests, the *Karab* soil stretches out of the *Mayá* slope to the flat plain with crusted surface and concentration of iron oxides and cracking clay soil extends far away from the river banks on the flat plain where staple crops are grown under rainfed agriculture.

Germination of *Balanites aegyptiaca*

Fresh fruits of *B. aegyptiaca* were collected in April, 2015 from the area of the study and then subjected to viability test. The fruits were sown in June, 2015 when rains commence, in *Nawara* Reserved Forest in the area of study; annual rainfall was around 500 mm. The experiment was laid out in a split-plot design. The main plot was the presence or absence of the fruit epicarp and mesocarp while the subplot was sowing at 0-cm or 5- cm depths. Sowing was done in plots of 25 cm in radius, surrounded with a metallic ring and contained 50 fruits. Germination was recorded through June to November.

Another experiment was conducted to find out the effect of salinity on germination at different levels of salinity, measured as EC in clay soil. In addition to the control (0.8 dSm^{-1}), five levels of salinity were fixed at 4 dSm^{-1}, 6 dSm^{-1}, 8 dSm^{-1}, 10 dSm^{-1} and 12 dSm^{-1} using both NaCl and CaCl salts to fix them. The amounts of NaCl and CaCl salt required to prepare one liter of each of the different planned levels of salinity are shown in Table 1. The salts were then added separately to the exact quantity of distilled water and magnetically stirred till all granules were completely dissolved. Then, viable fruits of *B. aegyptiaca* after removing their epicarp and mesocarp were sown in Petri dishes of 15 cm in diameter and filled with one kilogram of clay soil having a field capacity of 420 ml/kg. About 18 dishes were laid out in a glasshouse and arranged in three blocks. Each dish contained 25 fruits. The weight of each Petri dish was measured and recorded. Salt solutions were applied once. Irrigation was applied every 48 hours using distilled water for five weeks. The amount of water applied to each dish was equal to the difference in weight of the filled dish at application of irrigation water (wet weight) and before application (dry weight). Germination was recorded for five weeks. Data were subjected to analysis of variance and the Duncan's Multiple Range Test was used for means separation at 5% level of significance.

Table 1. Amounts of NaCl and CaCl required for making one liter solution to adjust different levels of salinity (EC) in clay soil.

EC (dSm^{-1})	NaCl (g/l)	CaCl (g/l)
0.8	0.00	0.00
4	1.66	2.13
6	4.97	3.20
8	6.62	4.26
10	8.28	5.33
12	9.94	6.39

Survey of *Balaintes aegyptiaca* natural regeneration

The range of the species distribution within the study area was divided into three subzones; the northern, central and southern. Spot samples were laid out in the field at selected sites in each subzone immediately after the rainy season. Those were; cleared forest site which was stocked with natural *A. seyal* and *B. aegyptiaca*, abandoned agricultural farms where traditional agriculture was practiced, vicinity of the villages where there was heavy grazing and browsing, crusted sites (*Karab*) between the Blue Nile and the flat plain, valley meander where water run-off was powerful and valley banks where galley erosion occurred. In each location and in each site, three spot samples, 50 m in diameter each, were laid. The boundaries of the samples were marked using colored flags to avoid missing or measuring trees outside them. All *B. aegyptiaca* plants within the samples were recorded and their shoot height and diameter at ground level were measured. The soil moisture content in the five sites in each subzone was measured in April, the driest month.

RESULTS AND DISCUSSION

Effect of fruit status and sowing depth on fruit germination in the field

There were no significant differences between the means of germination percentage due to sowing depth or status of fruits, on average it was 90%, but it was observed that germination was delayed for two weeks when the fruits were sown at 5cm depth (Table 2). This result was unexpected because the soil moisture available at 5cm depth could be more conserved for a long time to induce germination compared to the conditions of the soil on surface.

The other conception is that the thin epicarp and fleshy mesocarp didn’t withstand the natural conditions on the surface and decomposed in due time to rectify any effect that cause delaying of germination. It’s possible that the time taken to remove the effect to delay germination is not long, within days the epicarp could be fractured and mesocarp liquidated by sunlight or by high temperature, and the woody endocarp decomposed by the natural biotic factors.

Del Tredici (1978) obtained high germination percentage when fruits of *Pontetieria cordata* and *Comptonia peregrina* are sown without removing their epicarp and mesocarp. However, the result seems to be controversial according to previous reports. Watt and Whalley (1982) found that the soil depth had no effect on seed germination but it did on emergence. Asgharipour (2011) found that germination decreased linearly with increasing depth of sowing. The result was also backed by the finding provided by Dalling (1995) who investigated tropical soil seed banks and reported that dense regeneration was obtained from soil seed bank at 1-cm depth and most of the seedlings emerged within six weeks.

Table 2. Germination (%) of the fruits of *Balanites aegyptiaca* in the field under the conditions of the clay plain of central Sudan.

Sowing depth (cm)	Fruit status		Mean (SE ± 2.8)
	Removed epicarp and mesocarp	Intact epicarp and mesocarp	
0	92	91	92
5	90	85	88
Mean (SE± 2.7)	91	88	90

CV = 3.6%

Results reported by Woods and Elliott (2004) were contradictory to these results. They reported that deeper soil layers had higher soil moister than shallow layers and hence more conducive for germination. Moreover, they reported that fruits laid on the surface of the soil could suffer drying by both sun and wind. Indeed, seeds buried deeply in the soil are expected to have a low germination percentage because the seedlings are unable to make their way to the soil surface. Generally seed size and type of soil determine the optimum depth of planting.

Effect of soil salinity on fruit germination

Table 3 shows the effect of salinity on germination. Increase in salinity significantly decreased the germination at both CaCl and NaCl concentrations. The results are in line with those of Omami (2005), Abdelmajid (2006) and Abari (2011).

Comparable results of reduction in germination of seeds by increasing salinity levels had been described by Hall (1992). Daffalla (2011) reported that germination percentage of *Acacia senegal* was reduced with the increase of salt concentration to 10 dSm^{-1}.

Table 3. Germination percentage of *Balanites aegyptiaca* fruits sown at different NaCl and CaCl concentrations

EC (dSm^{-1})	Germination (%)	
	NaCl	CaCl
0.8 (control)	84 a	82 a
4.0	74 b	72 b
6.0	58 c	72 b
8.0	50 d	64 c
10.0	40 e	45 d
12.0	32 f	41 d
SE	0.9	1.3
CV%	8.2	14.1

Means in columns followed by different letters are significantly different according to DMRT at 5% level of significance.

Agboola (1998) reported similar results and found low germination percentage (3-10%) in *Ceiba pentandra* and *Terminalia superbs* seeds, due to high salt content. The reduction in the germination percentage might be attributed to the ability of the salts to absorb the water surrounding the fruits, osmotic retention of water or toxicity to the embryo.

It was observed that germination was delayed for two weeks. Rapid fruits germination is particularly important in dry climatic conditions, where salinity is aggravated by scarce and erratic rainfall. Fast seed germination could efficiently make use of the short duration of moisture to establish seedlings before adverse climatic conditions prevail.

Natural regeneration of *Balanites aegyptiaca*

The survey of the natural regeneration carried out in the study zone revealed the occurrence of *B. aegyptiaca* trees at various sizes and ages, in all the sampled locations (Fig. 1). That occurrence of trees was continuous in all locations except on valley banks and meander. In the vicinity of the villages, the diameter at ground level ranged between 7.0 and 82 cm and shoot height ranged between 1.0 and 14 m. Occurrence was dense within the diameter range of 40 to 60 cm (Fig. 1). As far as the number of *B. aegyptiaca* plants was concerned, it was found to be 90 per ha (Fig. 2). The occurrence of *B. aegyptiaca* within the vicinity of the village at all growth stages could prove two assumptions; there are some traditional and religious beliefs which prevent its cutting, and the species is very adapted to grazing and trampling even at the early juvenile stage.

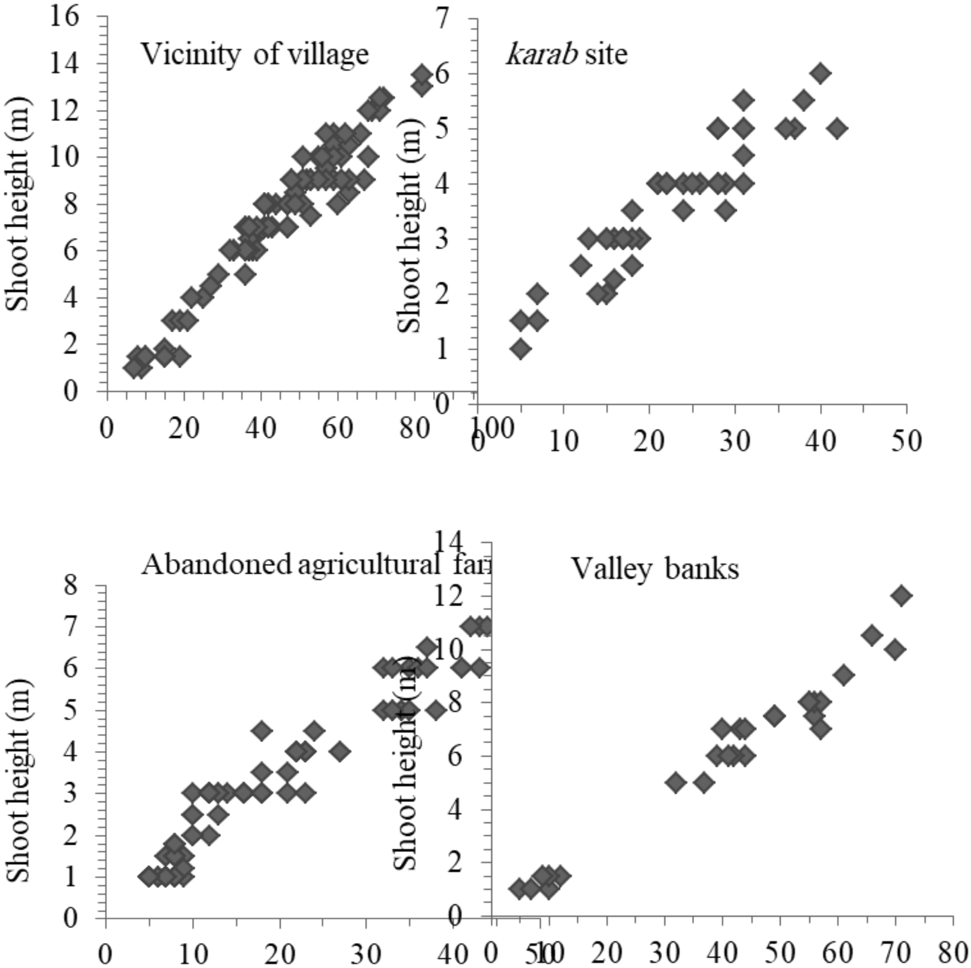
The growth of *B. aegyptiaca* on abandoned agricultural farm ranged between 5.0 and 49 cm in diameter at ground level and shoot height between 1.0 and 8.0 m at stocking density of 399 plants per ha (Figs.1 and 2). Most of the trees were young at this site. The results indicated that natural regeneration of *B. aegyptiaca* is possible on cultivated land when abandoned. These results are in line with those of El Amin (1990) and Goransson and Widgren (1996). The abandoned lands surveyed in this study were previously dominated by *B. aegyptiaca* and *A. seyal* species before cultivation. This may be the reason behind the good regeneration of *B. aegyptiaca* found on this land; the tending operations improved the moisture conditions and physical properties of the top soil, which enhanced the regeneration after ceasing crop cultivation.

In cleared natural forest site, the stem diameter of *B. aegyptiaca* at ground level ranged from 5.0 to 56 cm and shoot height ranged between 1.0 and 11 m at stocking density of 202 plants per ha (Figs.1 and 2). The studies on natural distribution of *B. aegyptiaca* showed that natural regeneration was successful in association with *A. seyal* on cracking clay soils (EL Amin, 1990; Hall, 1992; McLaren and McDonald, 2003). The growing conditions of the two species are almost the same.

Natural regeneration of *B. aegyptiaca* was not dense as on abandoned agricultural land because the natural forests in the Sudan clay plain swept by fires every year during the dry season which reduce the number of generated seedlings and damage the source of the soil seed bank.

The diameter of *B. aegyptiaca* at ground level on *Karab* site ranged between 5.0 and 42 cm and the height ranged 0.2 and 6.0 m at stocking density of 127 plants per ha (Figs. 1and 2). *Karab* soils are known of their low soil moisture content which affects natural regeneration success and also the development of seedlings, but despite of that, there was considerable regeneration of *B. aegyptiaca* on *Karab. B. aegyptiaca*, the desert date, is considered a drought resistant species which grows under hard conditions and annual rainfall as low as 250 mm. Its tap root goes deeply and this could help the species to survive dry conditions and at harsh sites such as *Karab*. The woody endocarp of fruits could help the seeds to tolerate the *Karab* dry conditions and stay viable for a long time in the top soil waiting for suitable germination and growth conditions. Buck *et al*. (1999) stated that some plants have evolved specialized rooting systems, while others have unique leaf characteristics to allow them to withstand prolonged periods of drought. The natural regeneration obtained on *Karab* site could also be referred to the fact that it contained low salt. Hall (1992) and EL Amin (1990) mentioned that *B. aegyptiaca* was found in association with *Acacia nubica*, the species that dominates the *Karab* sites and of low water requirement.

Natural regeneration of *B. aegyptiaca* was also found on the banks of the valley with discontinuous distribution regarding the growth stages (Fig. 1). It was of less stocking density, 57 plants per hectare, compared to abandoned agricultural farm, natural forest or village vicinity sites (Fig. 2). The diameter at ground level ranged between 5.0 and 71 cm and tree height between 0.2 and 6.2 m. Heavy felling, over-grazing and browsing were observed at this site. The tree was subjected to felling probably for timber and building poles due to the good quality. This may explain the few number of trees found along the valley banks. Besides, the valley banks are good sites for growing some crops during the


Vicinity of village
Shoot height (m)
karab site
Shoot height (m)
Abandoned agricultural
Shoot height (m)
Valley banks
Shoot height (m)

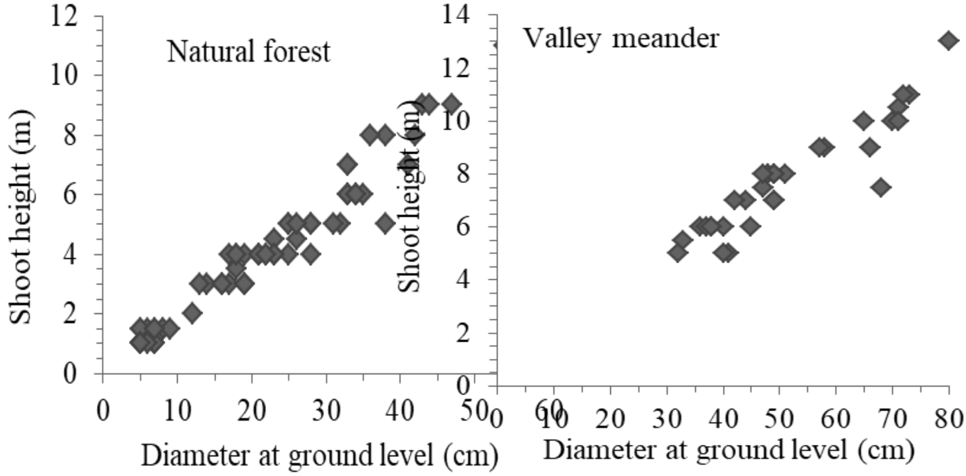


Fig. 1. Relationship between diameter at ground level and shoot height of *Balanites aegyptiaca* in different sites on the western bank of the Blue Nile.

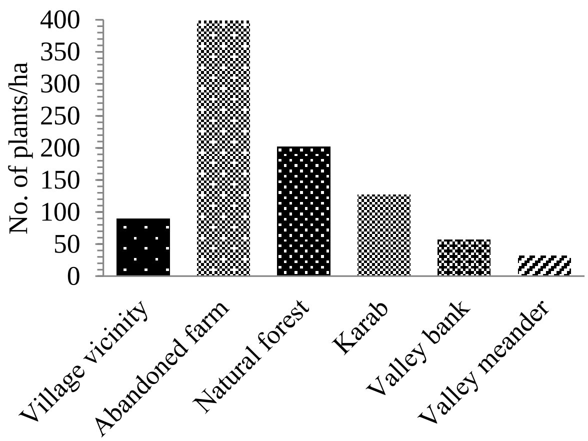


Fig. 2. Stocking density of natural *Balanites aegyptiaca* in different sites on the western bank of the Blue Nile.

winter season due to the high fertility and moisture contents of the soil which encourages people to clear the area for cultivation. Moreover, the site was suitable for grazing the remains of vegetables and other crops. Hence the species suffered from heavy grazing, lopping and removing of saplings and young trees for fencing and firewood. It could be the need for shade during summer or while people were collecting their crops that forced them to leave some *B. aegyptiaca* trees. The gap in the diameter distribution (Fig. 1) might be properly attributed to the assumption that farmers cut the trees of medium size as they were more preferable for building poles and fencing of their farms. In general, valley banks were suitable sites for growing *B. aegyptiaca* but the clearance taking place for winter cropping would limit the success of natural regeneration and the development of trees at the site.

B. aegyptiaca was also regenerated in the valley meander (Fig. 1) but all of the recorded plants were trees and new regeneration was completely lacking. The figure also indicated that natural regeneration was not continuous and the diameter at ground level ranged between 32 and 83 cm while the shortest shoot height recorded was 5 m and the highest was 13 m. Also the population was not dense as on the other sites; number of trees was 34 per ha (Fig. 2). It is possible that the reason behind lacking of new regeneration was the lack of stock fruits; being removed and washed away by running water to far distances, or being rotted, even if some fruits succeed to germinate, they would not have the chance to survive because the flood submerged these seedlings to death since valleys uphold water on them for months. The occurrence of mature trees found in this site could be due to the chances given to the recently produced seeds to germinate and survive in some rainy seasons with low rainfall that didn’t cause flood. *B. aegyptiaca* is known to produce fruits every year.

The soil of the abandoned agricultural farms and natural forest are of high clay content (60%), swells when wet and shrinks when dry forming a network of cracks. This explains why its moisture content was very low in dry season compared to that of valley banks and meander where clay contents are low due to water washing (Table 4). When looking at figures 1 and 2, these results could be linked with the status of clay contents in the soil; high regeneration density of *B. aegyptiaca* on sites with high clay contents, and sizable growth on the sites with high sand contents. This could be explained in view of the environmental requirements of *B. aegyptiaca* which prefers clay soil despite of its dry-up character. Then development to sizable growth was mainly because of high moisture contents preserved by the soil of low clay contents of valley banks and meander.

Table 4. Soil moisture content measured during April (dry month) at northern (A), central (B) and southern (C) parts of the zone of the study from *Sinja* town in the north to *Addisa* village in the south on the western bank of the Blue Nile.

Location	Soil moisture content (%)		
	A	B	C
Karab	3.6	4.8	5.0
Natural forest	6.7	4.8	4.5
Abandoned agricultural farm	3.8	6.1	7.7
Vicinity of villages	6.4	6.6	8.5
Valley banks	8.3	9.8	27.2
Valley meander	10.3	13.7	37.2

In conclusion, the fruit of *B. aegyptiaca* germinated readily at high capacity (90%) whether epicarp and mesocarp were removed or not, even when laid on the ground. Germination decreased when the salinity increased. There was continuous regeneration of *B. aegyptiaca* on flat clay sites; abandoned agricultural farm, cleared forest site and village vicinity. Along the valley banks and in the meander, the generation was not continuous but it was sizable in growth compared to that on flat clay sites. *B. aegyptiaca* was generated even on the crusted site (*Karab*). It is recommended to pay more attention to conserve *B. aegyptiaca* tree. This requires formulation of management plan, reserving lands as forests where the tree exists, introduction of the tree in production to encourage investment in its products and introduce it into agroforestry programs.

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