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The effect of soil moisture conservation technique on the resilience of parkia biglobosa: Survival and growth of seedlings in field plantation in southern Mali

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Abstract

Parkia biglobosa faces several constraints like ageing population, mortality and poor natural regeneration. To contribute to the domestication of the species and improve its resilience to drought, a study was conducted in southern Mali. Studied factors were the Provenance (North Sudanian "NS", South Sudanian "SS", North Guinean "NG) and Soil Moisture Conservation Technique "SMCT" (Half-moons made with Rubble Stones "H-M R", Half-moons made with Ground "H-M G" and the Control). The average survival rate was 50% and the highest mean survival rate (78%) was observed at Diou 24 months after planting. For provenance, survival rate varied from 47% (NS and SS) to 58 % (NG) at Somasso, 18% (NG) to 28% (NS) at Zanzoni and 73% (NG) to 83% (NS) at Diou. For SMCT, survival rate ranged from 48% (H-M G and Control) to 56% (H-M R) at Somasso, 17% (Control) to 28% (H-M G) at Zanzoni and 76% (H-M G) to 82% (H-M R) at Diou. The mean height was 37 cm, 24 months planting. The highest mean height (42 cm) was observed at Somasso. A significant interaction Provenance*SMCT was observed at Zanzoni. The highest mean height (72 cm) was observed in the combination (SS*H-M G). The result of the study revealed that the use of SMCT particularly half-moon made with rubble stones could improve the resilience of P. biglobosa and renew the agroforestry parklands. This allows maintaining the biodiversity of parklands in the sudanian and sudano-guinean zones.

Keywords: Domestication; Half-moon; Parkia biglobosa; Provenance; Parkland; Revegetation

1 Introduction

The domestication and cultivation of species is a very convenient option to relieve the pressure on valuable and threatened wild populations and species, contributing both to conservation and overall socioeconomic developmental objectives [1]. The domestication of wild edible fruit species has more than production benefits; it has also social and ecological benefits [2]. This statement was confirmed by Teklehaimanot [3], reporting that the increased planting and management of the indigenous and wild edible fruit trees also help to restore degraded ecosystems and conserve their declining diversity.

Parkia biglobosa (Néré), a wild edible fruit tree species faces multiple constraints (mortality, aging populations, poor regeneration, declining production, etc.). Due to these constraints, the domestication and cultivation of this agroforestry parkland tree species would be only and ultimate way to ensure its sustainability [4, 5, 6, 7, 8]. According to authors ([9, 10], several species would be further endangered and threatened with extinction if they would be left on their own without measures for conservation, cultivation, and promotion. In the Sahel region, farmer-managed natural regeneration (FMNR) can be combined with planting [11]. For planting, seedling production and propagation methods

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to shorten the juvenile phase and improve the quality of the products have been developed in a domestication effort [12, 13].

The mortality of *P. biglobosa* due to the drought was considered as a natural phenomenon by farmers, who are nevertheless observers and experimenters in terms of anticipating climate change [14]. Even if farmers are aware of certain actions to combat the main causes of mortality of *P. biglobosa*, it is unpleasant to note that nothing is being done in this direction despite the range of possibilities for adaptation to climate change, that farmers are developing. Hence, the use of Soil Moisture Conservation Technique like half-moons could reduce post-planting mortality of *P. biglobosa* caused by drought and increase the resilience of this species. In allowing better survival of the seedlings, they will contribute to the safeguarding of the park's biodiversity, regenerating the aging park and ensuring the sustainability of the resource.

In the Sahelian and northern Sudanian zones of Burkina, water and soil conservation measures such as filter dikes, stone barriers, half-moons and partitioned furrows have had a positive impact on the reconstitution of woody vegetation [15]. In Niger, in the Arewa Valley, a combination of mechanical and biological devices was used to promote infiltration, allow groundwater recharge and exploit new biological resources in a rational manner [16]. The mechanical devices consisted of half-moons, forest trenches and benches, low walls, dikes and dry stone sills. The biological devices consisted of reforestation, assisted natural regeneration and seeding of grasses.

The objective of the study was to contribute increasing the production and the productivity of *P. biglobosa* parklands by renewing populations through techniques favoring the resilience of the species to the drought. More specifically, the study aimed to assess the impact of Soil Moisture Conservation Technique (half-moons) on the survival and growth of *P. biglobosa* seedlings in field plantation.

2 Material and methods

2.1 Study sites

The study was conducted in three agro-climatic zones (the North Sudanian NS, the South Sudanian SS, and the North Guinean NG). These zones were selected based on climatic and environmental conditions as well as management practices (land use and tree management systems). In the NS zone, the mean annual rainfall varies from 500 to 800 mm. It is a zone of slightly undulated plains, lowlands and depressions with heavy soils quite wet, and actively cultivated. It also contains extensive, fine-textured plains. The natural vegetation is constantly being degraded, and the existing woody species are those spared by man. In the SS zone, the mean annual rainfall varies from 800 to 1100 mm. Soils are deep alluvial, often the most fertile in the country, used for continuous cultivation and short fallow systems. The soils on rocky foundations are shallow or moderately deep. There are open or moderately dense woody stands on shallow soils. In the NG zone, the rainfall is over 1100 mm per year. The valleys in this area are cultivated in a continuous regime. Fallow system is longer and the density of woody species is higher. It is an excellent zone of timber exploitation.

In each zone, one site was selected based on the availability of *P. biglobosa* populations, the accessibility in all seasons, and the willingness of farmers to collaborate in research activities. Selected sites were Somasso (district of Bla) in the NS zone, Zanzoni (district of Koutiala) in the SS zone and Diou (district of Kadiolo) in the NG zone. Figure 1 shows the localization of the three zones within southern Mali and the localization of the study sites within zones.

The site of Somasso (51°31'N, 36°27'W) in the NS zone, has a little uneven relief composed of cultivable plains. The climate is north sudanian, characterized by two seasons (the long dry season from October to May and the short rainy season from June to September). Agriculture is the main activity and the cultivated areas are large, dominated by cereal crops. Cotton and groundnuts are the cash crops. Vegetation is shrubby savannah with some big trees spared in the fields such as *Parkia biglobosa*, *Vitellaria paradoxa*, *Faidherbia albida* [17]. The site of Zanzoni (36°52'N, 32°05'W) in the SS zone, has little hilly relief composed of plains favourable for off-season crops. The climate is south sudanian, with also two seasons with length similar to those of the site of Somasso. Agriculture concerns cereals production and cash crops such as cotton and peanuts. Vegetal resources are similar to those of the site of Somasso but, some protected forests and sacred woods are present [17]. The site of Diou (35°46'N, 58°33'W) in the NG zone, has a slightly uneven relief. The climate is north guinean, with a dry season from November to May and a rainy season from May to October. Agriculture is the main activity and cereal production is mainly composed of Maize, while Cotton is grown as a cash crop. There are important natural stands of forest resources, artificial plantations of exotic species and sacred woods [18].

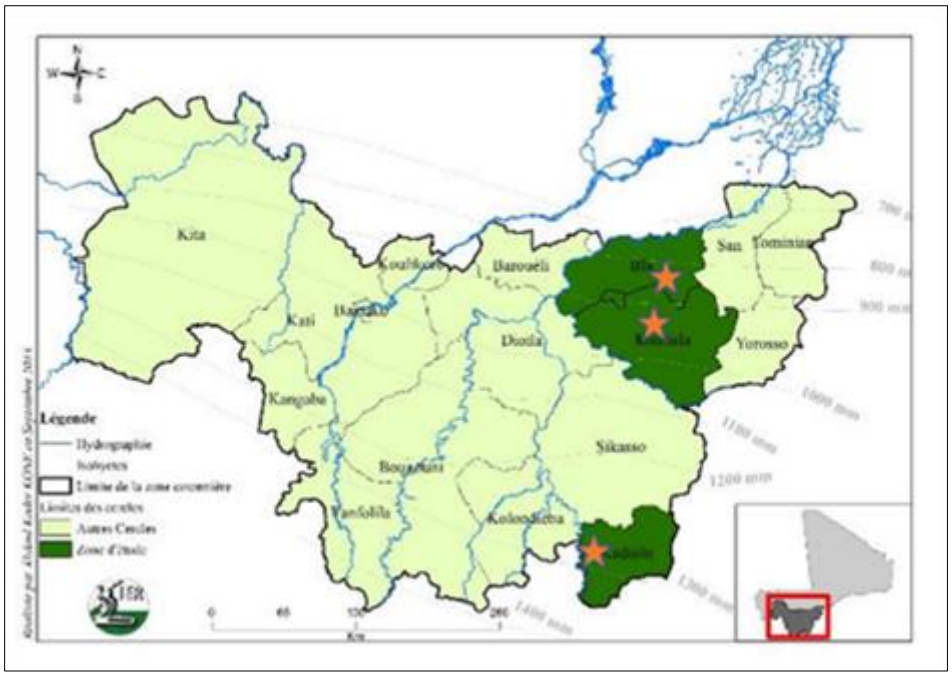


Figure 1 Localisation of study zones (green areas) within southern Mali and study sites★

2.2 Vegetal material

The vegetal was *P. biglobosa* seedlings produced from seeds of three provenances. The seedlings were produced by private nurserymen. Polyethylene pots (15 x 20 cm), provided by the project, were used for production. Seeds were sown in the nursery from June 2019 to July 2020.

P. biglobosa is a forest tree species of the family of Leguminosae/ Fabaceae [19], common in agroforestry parklands in the Sudanian zone. [20] reported that its conservation and domestication for the diversification of agricultural production depend on its ability to adapt to climate change. [21] reported that, a sound conservation strategy for *P. biglobosa* and the promotion of its sustainable management should be based on scientific information about threats as well as ecological and genetic processes affecting this species.

Populations of this species are highly threatened in large parts of its range due to over-exploitation and environmental degradation [21]. Nowadays, the density of *P. biglobosa* trees is very low in farmed fields as well as in the fallows. The low density could be explained by several causes like natural mortality, density reduction by farmers in the field to reduce competition with associated crops (mainly cash crops like cotton which was in expansion in the whole Southern Mali) and the weak natural regeneration in the fallow.

2.3 Design of the experiment

The design was a factorial experiment with two factors (Provenance with three levels: North Sudanian “NS”, South Sudanian “SS”, North Guinean “NGN) and Soil Moisture Conservation Technique (SMCT) with three levels also: Half-moons made with Rubble Stones “H-M R”, Half-moons made with Ground “H-M G” and the Control i.e. any management). The experiment was conducted in three sites (Somasso, Zanzoni, Diou) and in each site there were three replicates (parcels of volunteer farmers). The experimental unit was a line of ten seedlings of each treatment (3 Provenances x 3 Soil Moisture Conservation Technique = 9 treatments). The spacing was 6 x 6 m (6 meters between seedlings in the line and 6 meter between lines).

To allow farmers understanding the design, treatments were grouped by provenance giving for each repetition threes plots (one plot by provenance). Each plot was made of three lines (one line by management technique). Each line has ten seedlings of the same provenance. The provenances were randomly allocated to plots and management techniques were randomly allocated to lines. Figure 2 shows the layout of the experiment which was the same for all repetitions within each site.

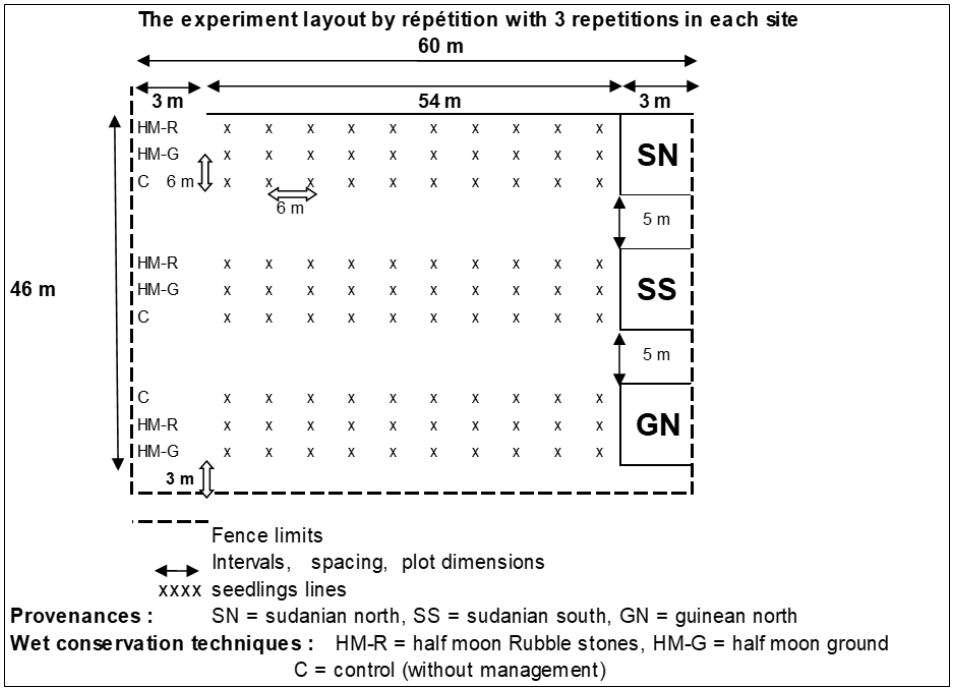


Figure 2 Design of the experiment (illustration of one replicate)

2.4 Description of the device for soil moisture conservation

In order to conserve soil moisture around the seedlings, half-moons were confectioned. The half-moon is a semicircular trough, opened with a pickaxe. They were made of two types of material (rubble stones and ground). Dimension of half-moons and the distances between seedling and half-moons vary according to agro climatic zones. In the sudanian zones, half-moons were 30 cm high, 20 cm wide with 100 cm of diameter and 40 cm of radius (distance between seedling and the device). In the sudano-guinean zone, half-moons were 50 cm high, 20 cm wide with 60 cm of diameter and 50 cm of radius. They were placed downstream from the plant depending on the direction of the slope.

These half-moons allow for the collection of runoff water and are thus well adapted to semi-arid and arid areas an improvement of the soil's water reserves as well as an increase in the depth of wetting from 20 to 40 cm. Hence they could be two treatments compared to a control treatment without any device.

2.5 Preparation of the plots before planting

The preparation of the plots consisted in materializing the planting place, digging holes of 30 m x 30 m, filling in the holes and making the soil moisture conservation structures (half-moons made of rubble stones and ground). The types of half-moon were illustrated by figure 3

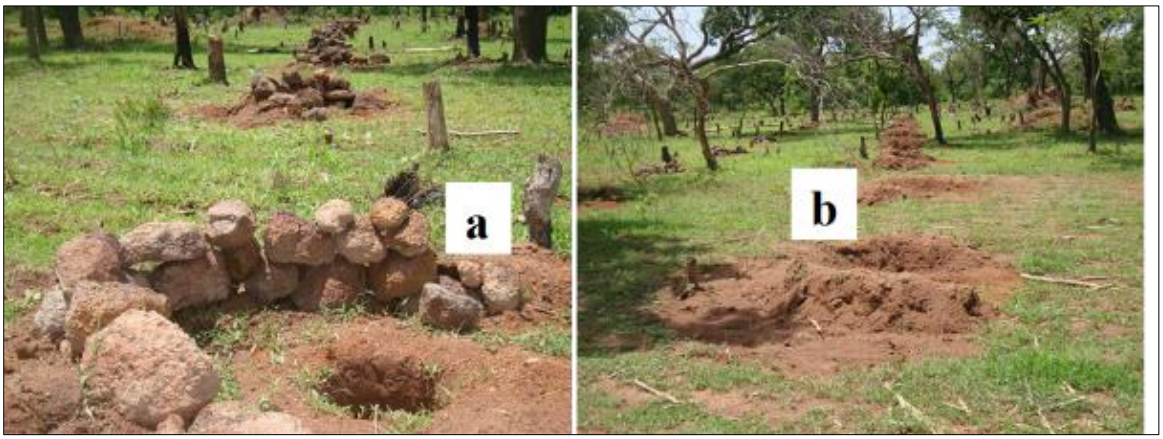


Figure 3 Soil Moisture Conservation Technique, 3a Half-moon with rubber stones (H-M-R), 3b Half-moon with ground (H-M-G), 3c Control

2.6 Data collection and analysis

Data collection included all plants in each treatment. It concerned the recovery rate, the growth in height and the survival rate of seedlings. Observations and measurements were made twice a year, at the end of the dry season in May and at the end of the rainy season in November.

Data were processed with SYSTAT9 FOR WINDOWS software. Descriptive statistics were computed. Analysis of variance was used to determine the effect of studied factors at 5% significance level. For factors whose effects were significant, Bonferonni's method was used to distinguish the levels of the factor that were significantly different.

3 Results

3.1 Survival of seedlings

Table 1 Survival rate (%) of P. biglobosa seedlings according to site, provenance and Soil Moisture Conservation Technique 24 map

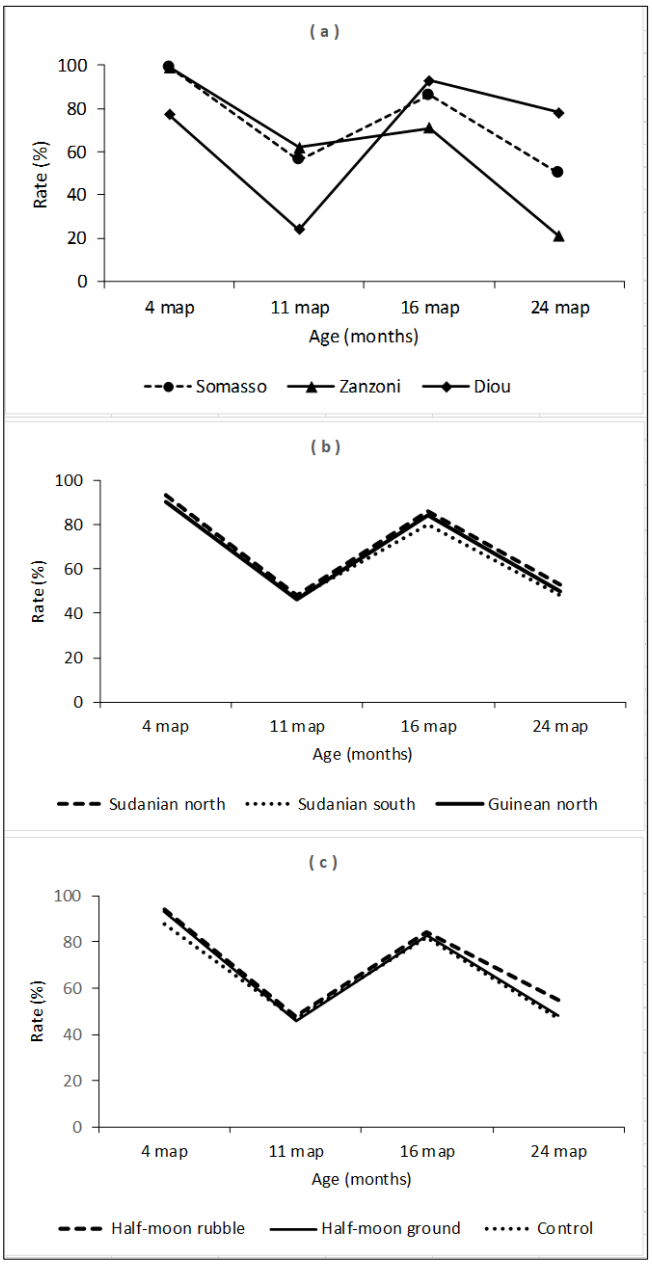
	Survival rate (%)
Site	
Somasso	50b
Zanzoni	21c
Diou	78a
	p < 0,001 VHS
Provenance	
NS	53
SS	48
NG	50
	p = 0,405 NS
SMCT	
H-M R	55
H-M G	48
Control	47
	p = 0,300 NS

Legend : NS = north sudanian, SS = south sudanian, NG = north guinean; SMCT = soil moisture conservation technique; H-M R= half-moon rubble stone, H-M G = half-moon ground. Bonferroni's test was used to compare the means at 5% level. Means with the same letter were not significantly different, VHS = very highly significant, NS = non-significant.

Twenty-four (24) months after planting (map), the average survival rate of the seedlings was 50%. At this age, the overall analysis of variance on survival showed that the interactions between the factors (site*provenance, site*SMCT, provenance*SMCT) were not significant. The site effect was very highly significant and the site of Diou had the highest average survival rate (78%), significantly different from the other two sites (Zanzoni and Somasso). However, the effect of SMCT was not significant, nor was the provenance effect. The average survival rates by factor are shown in Table 1.

The analysis by site showed that in all sites, the interaction provenance*SMCT was not significant. In all sites, the effects of provenance and SMCT was not significant. The mean survival rates by provenance and SMCT for each site were shown in Table 2.

Figure 4 shows the evolution of survival rate of seedlings according to study factors.



map = months after planting

Figure 4 Evolution of survival rate according to sites, provenances and soil moisture conservation technique

Table 2 Mean survival rate (%) of *P. biglobosa* seedlings according provenance and Soil Moisture Conservation Technique at each site 24 map

Site	Provenance/SMCT	Mean survival rate (%)
Somasso	Provenance NS	47
	SS	47
	NG	**58**
		p = 0,596 NS
	SMCT H-M R	**56**
	H-M G	48
	Control	48
		p = 0,739 NS
Zanzoni	Provenance NS	**28**
	SS	19
	NG	18
		p = 0,484 NS
	SMCT H-M R	**28**
	H-M G	20
	Control	17
		p = 0,454 NS
Diou	Provenance NS	**83**
	SS	78
	NG	73
		p = 0,135 NS
	SMCT H-M R	**82**
	H-M G	76
	Control	77
		p = 0,723 NS

Legend : NS = north sudanian, SS = south sudanian, NG = north guinean; SMCT = soil moisture conservation technique; H-M R= half-moon rubble stone, H-M G = half-moon ground. Bonferroni's test was used to compare the means at 5% level. Means with the same letter were not significantly different, NS = non-significant

For the provenances, the survival rate varied from 47% (NS and SS) to 58% (NG) at Somasso, from 18% (NG) to 28% (NS) at Zanzoni and from 73% (NG) to 83% (NS) at Diou. For the SMCT, it ranged from 48% (H-M G and Control) to 56% (H-M R) at Somasso, from 17% (Control) to 28% (H-M G) at Zanzoni and from 76% (H-M G) to 82% (H-M R) at Diou (Table 2). Although the difference between provenances was not significant, the NS provenance tended to perform best. Like the provenances, the effect of SMCT was not significant, but H-M R improved the survival of *P. biglobosa* seedlings in all the three planting sites.

3.2 Growth of seedlings

At 24 months, the mean height of the seedlings was 37 cm. The overall analysis of variance on the height showed that the interactions between the factors (site*provenance, site*SMCT, provenance*SMCT) were not significant. The site effect was very highly significant and the site of Somasso had the highest mean height (42 cm), significantly different from that of the site of Diou (34 cm). However, the effect of SMCT was not significant, nor was the provenance effect. Table 3 showed the average height according to factors.

Table 3 Mean height of *P. biglobosa* seedlings according to site, provenance and soil moisture conservation technique 24 map

	Mean height (cm)
Site	
Somasso	42[a]
Zanzoni	38[ba]
Diou	34[b]
	p < 0,001 VHS
Provenance	
SN	37
SS	36
GN	37
	p = 0,789 NS
SMCT	
HM-R	36
HM-G	37
Control	38
	p = 0,692 NS

Legend: NS = north sudanian, SS = south sudanian, NG = north guinean; SMCT = soil moisture conservation technique; H-M R= half-moon rubble stone, H-M G = half-moon ground. Bonferroni's test was used to compare the means at 5% level. Means with the same letter were not significantly different, VHS = very highly significant, NS = non-significant

At Zanzoni, the interaction Provenance*SMCT was significant. The average height of seedlings by SMCT according to provenance was shown in Table 4.

Table 4 Mean height (cm) by SMCT according to provenance at Zanzoni 24 map

Soil Moisture Conservation Technique (SMCT)			
Provenances	**H-M R**	**H-M G**	**Control**
NS	52	36	28
SS	32	**72**	39
NG	50	28	49

Legend: NS = north sudanian, SS = south sudanian, NG = north guinean; H-M R= half-moon rubble stone, H-M G = half-moon ground.

The highest average height (72 cm) was observed in the combination South Sudanian * half-moons made with ground (SS*H-M G). The average heights by provenance and by SMCT for Somasso and Diou were shown in Tables 5 and 6, respectively.

Table 5 Mean height (cm) by provenance and by SMCT at Somasso 24 map

	Mean height (cm)
Provenances	
NS	39
SS	40
NG	45
	p = 0,355 NS
Soil Moisture Conservation Technique	
HM-R	40
HM-G	41
Control	44
	p = 0,629 NS

Legend : NS = north sudanian, SS = south sudanian, NG = north guinean; H-M R= half-moon rubble stone, H-M G = half-moon ground

Table 6 Mean height (cm) by provenance and by SMCT at Diou 24 map

Facteurs	**Mean height (cm)**
Provenances	
NS	37
SS	33
NG	33
	p = 0,034 NS
Soil Moisture Conservation Technique	
HM-R	34
HM-G	35
Control	35
	p = 0,897 NS

Legend: NS = north sudanian, SS = south sudanian, NG = north guinean; H-M R= half-moon rubble stone, H-M G = half-moon ground

4 Discussion

Twenty-four (24) months after planting *P. biglobosa* seedligns in different agro-climatic zones of Mali using three provenances and Soil Moisture Conservation Technique (SMCT), the site of planting influenced significantly the survival and the growth of seedlings. The highest survival rate (78%) was observed at Diou in the north Guinean zone. The average survival rate (50%) was relatively low in comparison to those observed by authors in previous studies. The highest mean height (42 cm) was observed at Somasso in the north sudanian zone. The average height (37 cm) was also low in comparison to previous studies. In Ivory Coast, Louppe [22] reported a survival of 85% at 31 to 67 months and an average height of 63 cm, 117 cm and 286 cm at 19, 31 and 67 months respectively. In Mali, [23] reported an average height of 26 cm and 36 cm respectively for holes of 30 x 30 x 30 cm and 50 x 50 x 50 cm at 18 months after planting and an average survival rate of 77%, 7 years after planting.

Regarding site effect on survival and growth of *P. biglobosa* seedlings and saplings, our results were in accordance with several findings. In Ivory Coast, Adji et al. [24] observed a significant difference between two sites with respect to height and collar diameter growth of *P.biglobosa* seedlings in the nursery. At 4 months, the wettest site (Daloa) recorded the

highest average height (16.21 cm) compared to the driest site (Korogho) which recorded an average height of 6.79 cm. In Senegal, Diatta [25] observed a significant variation among provenances in survival, height, and diameter and stated that differences could be partly explained by the climate at their site of origin. According to this author, in general, provenances from dry sites survived better at both sites. This author observed also interactions between genotype and environment and stated that provenances from dry sites on average performed relatively poorer in height and diameter at the wettest site (Bambey) compared to the drier site (Dahra), while the opposite was the case for provenances from wetter sites. Adji et al. [26] also observed a difference between three seedling production sites with respect to several growth parameters, including the height of three months aged *P. biglobosa* seedlings, which varied from 19.51±0.74 cm (Korhogo's nursery) to 26.35±0.85 cm (Montpellier's greenhouse).

We also observed a significant drop in survival rate (from 83% before the dry season to 50% after the dry season) suggesting the susceptibility of the species to drought and confirming previous findings. For instance, Florent et al. [27] reported that irrigation during the dry season markedly increased the survival of *P. biglobosa* saplings, for which the mortality rate at 11 map was ten times higher in non-watered plots. They conclude that their "results found that *P. biglobosa* was the most susceptible to drought stress, as evidenced by the increased mortality in non-irrigated plants compared to their irrigated counterparts. Hence, extending the habitat range of this species to marginal croplands may be possible through supplemental irrigation". Several other authors [22, 23, 28, 29] reported *P. biglobosa* susceptibility to drought stress as well as the variability of its growth which has been observed in field plantation as well as in the nursery.

At the nursery production stage, Mukhtar et al. [30] reported an average height of seedlings that varied from 0.80 cm to 5 cm and a collar diameter that varied from 0.49 mm to 3.78 mm, at 12 weeks after germination, depending on the type of organic manure added to the substrate. In an experimentation of seed dormancy breaking technique and different types of substrates, Oyebamiji [31] reported a mean height of *P. biglobosa* seedlings that varied from 22 cm to 29 cm at 12 weeks after sowing. Similarly, Mohamed et al. [32] observed a mean seedling height in 42 days that ranged from 0 to 16.75 cm in the first season and 0 to 16.25 cm in the second season based on five methods of pretreatment of *P. biglobosa* seeds.

In field plantation, Florent et al. [27] reported a survival rate of 67%, 15 months after planting which would be the lowest rate. The other three species: *L. leucocephala*, *M. oleifera* and *A. occidentale* have 98%, 94% and 87% as survival rates respectively. Yaméogo [29] observed that out of 14 local species tested, only *P. biglobosa* had a 0% survival rate, 5 years after transplantation. At this age, the best survival rates were observed in *Sclerocarya birrea* (24.11 ± 0.42%) and *Combretum nigricans* (19.25 ± 0.39%). Regarding height growth, Florent et al. [27] observed an average height of 80 cm and an average collar diameter of 2.32 cm which were the lowest averages and significantly different from the other three species. It is important noticing that the average height obtained by Florent et al. [27] was significantly higher than the one we observed for this species at almost the same age (16 months) which was 32 cm. However, the survival rate we observed at this age (83%) was higher than that observed by Florent et al. [27], which was the lowest survival rate (67%) in their study.

Several other studies addressing the survival and growth revealed high susceptibility of *P. bigobosa* seedlings to drought stress. Bouda et al. [28] reported that in the nursery, at 18 months after water stress, the survival rate of seven *P. biglobosa* provenances was 0% for severe water stress (50% reduction in watering amount), 0% to 11% for medium water stress (75% reduction in watering amount), and 36% to 87% for the no-water-stress treatment (100% of the expected water amount). They observed a significant interaction between provenances and water regime (stress type) and concluded that provenances responded differently to stress. This conclusion was not in agreement with our results because we observed no significant difference between the three provenances for both survival and height growth at 24 map and the interaction between provenance and site was not significant.

Regarding SMCT, survival rates ranged from 48% (H-M G and Control) to 56% (H-M R) at Somasso, from 17% (Control) to 28% (H-M R) at Zanzoni, and from 76% (H-M G) to 82% (H-M R) at Diou. The difference between half-moons and between them and the control was not significant, but at all sites, H-M R showed the highest survival rate. Hence this type improves the survival of *Parkia biglobosa* seedlings in all experimental sites.

This result confirmed the findings of many authors regarding the effect of half-moons on survival and growth of tree species seedlings. Bira et al. [33] found that moisture conservation structures were significant in tree survival rate, plant height, and root collar diameter of five tree species (*M. oleifera*, *M. azedarach*, *G. robusta*, *L. leucocephala* and *S. sesban*. Philippe et al. [34] reported that survival and growth of seedlings of three trees species (*A. nilotica*, *A. tortilis* and *J. curcas*) were significantly higher using the half-moon technique compared to zaï and standard plantation. Kagamèbga et al. [35] reported that Half-moon treatment yielded a significantly higher growth both in height and diameter and

survival rate of *J. curcas* seedlings and conclude that "the Half-moon technique was found to be the most effective and that is recommended to be used for improving the revegetation of *J. curcas* in the future". The half-moons give the best results for the density and floristic composition of woody plants [15]. According to the same author, the half-moons, like the stone barriers, the filtering dikes and the subsoilings, promote the appearance and development of perennial and forage vegetation of *A. nilotica*, *A. tortilis*, *B. aegyptiaca*, *L. hastata* and *Z. mauritiana*

5 Conclusion

At this stage (24 map), the results of this study are interesting and strenghetned previous stdy funding regarding the importance of SMCT in the survival of tree species. Based on the findings, we recommend the use of SMCT particularly half-moon made with rubbles to improve the resilience of *P. biglobosa* and for the revegetation of agroforestry parklands of this important and multipurpose tree species. This allows maintaining the biodiversity of parklands in the sudanian and sudano-guinean zones.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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