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Full Length Research Paper

Growth of shea tree (*Vitellaria paradoxa* G F. Gaertn.) seedlings in semi-arid agroforestry systems of Burkina Faso under in situ climatic factors

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Abstract

Shea trees (*Vitellaria paradoxa*) are the most preferred tree species in agroforestry parklands and widely used in West Africa semi-arid areas. However, the number of shea trees in parklands declines where fruits are extensively harvested. This study aims to assess seasonal factors and land-use practices on the growth of young plants. The research questions were: (i) how do the recruitment, the mortality and the growth of juveniles occur during the year; and (ii) how does land-use affect the regeneration? The study was carried out at the South Sudanian climatic zone of Burkina Faso. Stratified and randomised sampling was used to set-up seventeen (17) plots in six (6) types of land-use. Monthly counting and growth measurement of the juveniles were performed on 4011 seedlings. The results show that during the dry season, the stems of 54 % to 84 % of the juveniles dried. Bush fires have negative impact on regeneration survival. Dry individuals regenerate during the wet season. The best average growth of juveniles recorded was 1.7 cm (p< 0.001) over ten months. It will be better to adopt assisted natural regeneration to rejuvenate shea trees in farmlands and to select tolerant individuals to the dryness climatic conditions for plantation.

Keywords: Plant growth, regeneration, shea tree, seedlings, semi-arid zone Burkina Faso.

INTRODUCTION

The juvenile phase of woody species is very important for the balance and the resilience of forest ecosystems. The different process of regeneration including germination, seedlings emergence and plant growth depend on many intrinsic and extrinsic factors (Stangeland et al., 2007; Vieira and Scariot, 2006). Abiotic and biotic factors can

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also shape tree growth (Avakoudjo et al. 2022). Natural regeneration is important for the sustainability of species including shea tree (*Vitellaria paradoxa* C.F. Gaertn., Sapotaceae), one of the major species in the agrarian landscape in West Africa dominated by agroforestry parklands (Serpentié et al. 1996). The sustainability of parklands is a major issue in a context where natural resources including woody formations are facing pressure particularly in the zones where trees represent important sources of food and income.

Shea tree, which dominates the parklands of West Africa have been studied extensively, including the experimentations of plant production in nursery and on field (Picasso, 1984; Zerbo, 1987; Yidana, 2004; Bayala et al*.,* 2009) as well as management tools such as crown pruning (Bayala et al., 2008). Despite its socio-economic importance and interests, and the good results obtained in nursery trials, shea tree remains a species not planted by farmers (Hall et al., 1996; Lafleur, 2008; Djossa, 2008). Lab-grown plants growth faster than those in field (Poorter et al., 2016).

Shea tree products have several uses: fruits are edible and the butter extracted from the kernel is used in food cooking, soap manufacturing, medicine, and provide an important income source for rural women. In the European and Asian countries, shea butter is highly valued in cosmetics, pharmacology and as a cocoa butter substitute (Hall et al., 1996; Ræbild et al., 2011).

Notwithstanding the importance of shea products, its populations in parklands decrease due to several constraints in maintaining and improving its densities. Unfortunately, they are lack of information on young plants behaviour in their natural area, the difficulties to plant shea trees because of the slow rate of growth in nursery and cultural barriers.

Management and use of resources in agroforestry systems are influenced by both land and tree tenure systems (Poudyal, 2009). Furthermore, customary tenure rules regarding trees like shea, through their influence on farmers' behaviour regarding the management of these trees on the parklands, are found to affect their population and stand characteristics (Poudyal, 2011). Therefore, it is necessary to consider farmers' practices like fallowing to understand the dynamics of natural regeneration of the species. Previous studies on shea parklands have focused on issues such as shea trees population structure in relation to land-use (Kelly et al., 2004; Kelly, 2005; Djossa et al., 2008; Diarrassouba et al., 2009), fruits production (Guira, 1997; Lamien et al., 2004) and parasitism (Boussim et al., 1993). However, very little is known about the natural regeneration, especially on the juveniles' development in relation to seasonal variations, which this study is attempting to understand.

We are especially interested in shea tree juveniles because of the association of this tree with the crops, particularly where there is a strong pressure on cultivable lands; and because of its biological particularities, for example, long cycle of development. This study aims to assess seasonal factors and land-use types on the growth of young plants. The objectives of the study were: (1) to study the height and diametric growth of shea tree juveniles in situ and (2) to assess the survival rate of shea tree juveniles after the dry season. The research questions were: (i) how do the recruitment, the mortality and the growth of shea tree juveniles occur during the year; and (ii) how does land-use affect shea tree regeneration?

MATERIALS AND METHODS

Study site

The study was carried out at Sobaka (11°43'-11°48' N and 1°38'-1°43' W) within the south sudanian phytogeographic sector of Burkina Faso (West Africa, Figure 1). The choice of the site is due to the presence of an important population of shea trees and the presence of farmlands and fallows with various and known ages. The densities of shea trees according to age and land use in the study site are 31 trees/ha in the young farmlands (2 years), 23 trees/ha in the old farmlands (more than 15 years), 23 trees/ha in the young fallows (2 years) and 85 trees/ha in the old fallows (more than 15 years) (Kaboré et al., 2012). The main plants grown in farmlands are millet, sorghum, beans and maize.

The study site is located 75 km South of Ouagadougou. Farming is the main activities of local population. With the population growth, pressure on land has increased significantly. The average annual rainfall during the last fifteen years at Sapouy (the nearest meteorological station located at 20 km from Sobaka) is 890 mm. In the study site**,** the rainfall is uni-modal with 5-6 dry months and big difference between average minimum temperature and average maximum temperatures. March, April and May are the hottest months with the temperature averaging 40°C. The relative moisture of the air is higher in August (85%) and lower in January (35%). The main soils type is sesquioxide of iron and manganese (Somé, 1996).

Experimental design

A stratified random design was adopted for shea tree population sampling. Prior the implementation of the experimental design, we conducted a survey on the study site to identify the types, the ages and the location of the different land-use types. This survey allows us to establish the plots in farmlands and fallows of different ages (young, intermediate aged and old). The choice of farmlands and fallows was justified by the fact that farmlands are the suitable biotopes were shea trees are biggest (Hall et al., 1996; Kelly et al., 2004) and produce the highest amount of fruits (Lamien et al., 2004) and fallows are known to be the suitable land-use type to rejuvenate shea trees population (Hall et al., 1996; Ouédraogo and Devineau, 1996).

The different treatments were: young farmlands cultivated for 2 years, intermediate aged farmlands cultivated for 6 years, old farmlands cultivated continuously for more than 15 years, young fallows i-e no cultivation for 2 years, intermediate aged fallows no cultivation for 6 years and old fallows more than 15 years without any cultivation. Each plot measured 2500 m^2 (50 * 50 m). For each treatment, three plot replications were setup except for the intermediate aged fallows where only two replications were possible because one of the three plots was re-used as farmland during the study. The total number of plots was seventeen (3x5 + 2).

For regeneration monitoring, each plot was subdivided into 16 subplots of 12.5 x 12.5 m (156.25 m^2). Six subplots in each plot were randomly selected and retained for a monthly measurement of seedling growth (Figure 2). The total number of subplots used for growth measurement was 18 for each type of land-use except intermediate aged fallows (12 subplots) giving a total of 102 (18x5 +12) subplots.

Data collection

Two modes of regeneration were considered following Ky-Dembele et al. (2007): seedlings from seeds, and shoots from the stumps. Heights of individuals less than 1 m, considered as juveniles, were measured. From December to September, all the juveniles in the full area of each plot were counted every month on the same date. Two adjacent sides of each of the 102 subplots retained for seedling growth study were used as orthonormal axis (of an orthonormal frame (X,Y)) to locate each seedling every month (Figure 2). The height and the collar diameter of each juvenile were recorded monthly. An inventory of all shea tree individuals (adults and juveniles) and all other woody species (adults and juveniles) were conducted on the plots.

Data analysis

The coordinates were just used monthly to locate the position of each seedling on the field and allow measuring the height and the diameter of the same individuals during the study. Data were analyzed using Xlstat 7.5.2 software. One ways analysis of variance (ANOVA) with land-use type as factor and two ways analysis of variance using age and land-use type as factors were conducted. Fischer LSD comparison test was used to look for significant difference in the number of seedlings between the different months. The mean variations in height of seedlings between two months were compared using Student t test. The number of seedlings was transformed into percentage. Seedlings numbers recorded in each plot in December (bigining of the study) is considered as the initial number (100%). The mean heights of the plants between December and September were compared using Student t test with α =5%.

Densities of adult shea trees and densities of other woody species were calculated. A Principal Component Analysis (PCA) was carried out using the densities of shea trees (adults and juveniles), those of other woody plants (adults and juveniles), the passage of fire, the land-use type, the land age and the rate of shea tree seedlings survival in April. The objective of PCA is to graphically highlight the essential information of a data table.

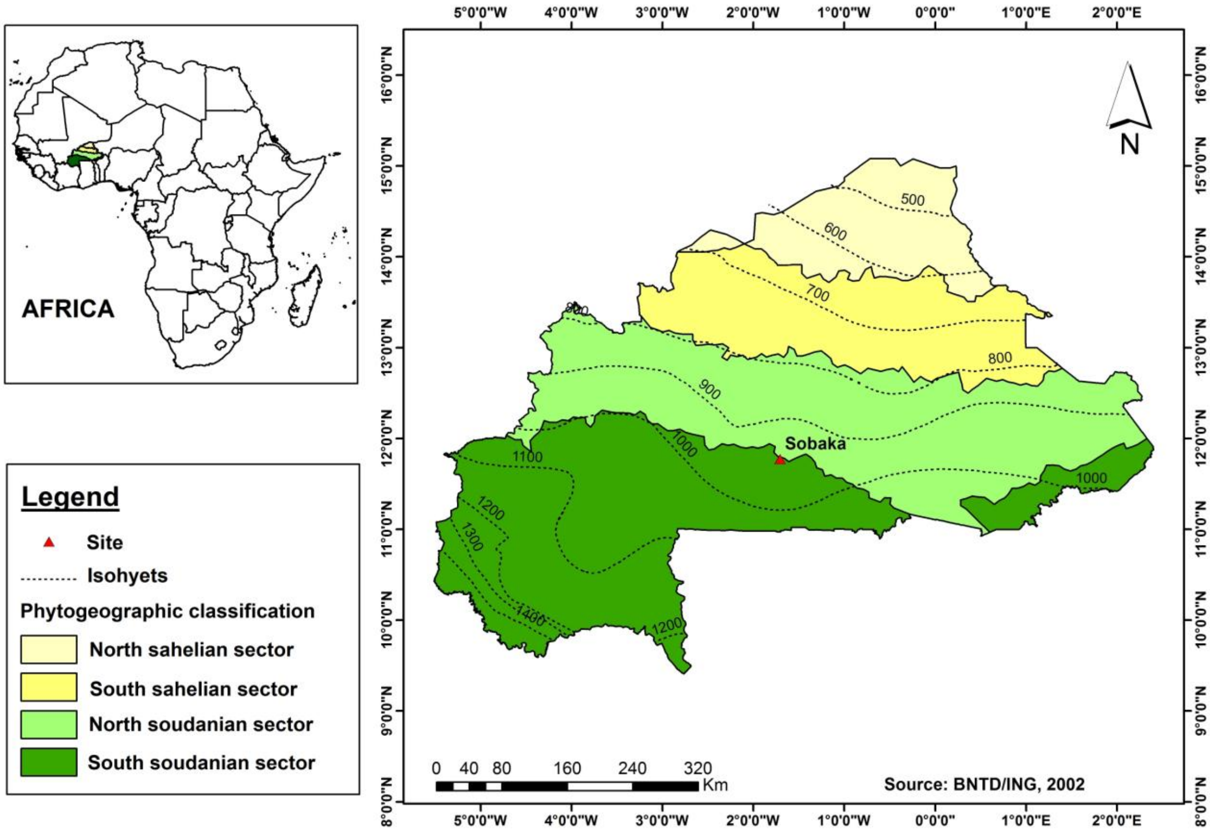
RESULTS

Dynamic of juveniles in farmlands

In the farmlands, 91% of the juveniles are seedlings and shoots represente 9%. From December to September, the number of living seedlings has varied in all treatments.

The intial densities of seedlings found in each type of land-use were: 136 stems/ha (272 seedlings in total) in the young farmlands, 270 stems/ha (539 seedlings in total) in the intermediate aged farmlands, 212 stems/ha (159 seedlings in total) in the old farmlands, 1 110 stems/ha (833 seedlings in total) in the young fallows, 1406 stems/ha (703 seedlings in total) in the intermediate aged fallows and 2007 stems/ha (1505 seedlings in total)

Figure 1. Study site location within the phytogeographic sectors and the isohyets of Burkina Faso.



in the old fallows.

Young farmlands – The figure 3 shows progressive decline in seedlings number. From 272 seedlings (136 stems/ha) in December, the total number of seedling observed in May was 49 (65 stems/ha) namely an average loss of 82% of the initial number of seedlings. Between December and May, the survival rate of alive stems of juveniles was only 18% in the young farmlands. From May, new growth of seedlings was observed. The increase of alive seedlings number has continued till July. It was followed by a new decline in seedlings numbers from July to August.

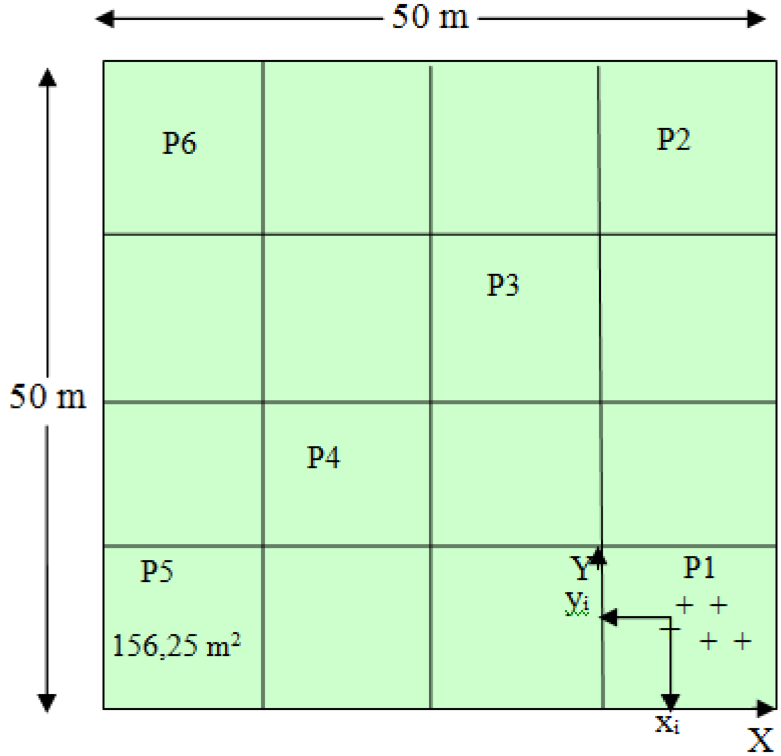
Intermediate aged farmlands – The drop of the number of seedlings was similar to that in the young farmlands (Figure 3). In the intermediate aged farmlands, the average decrease in the number of seedlings from December to May was 80 %. Only 20 % of the initial stems of seedlings remain alive at the end of the dry season, the others have dried. With the arrival of rainy season, the dried stems regenerate so that the initial number of seedlings was reached in June. The main causes of the decrease in seedling numbers in the intermediate farmlands were cutting of the seedling and uprooting stems during tillage after July.

Old farmlands – In the old farmlands, a significant decrease in the number of seedlings was observed early (February). Some dried seedlings regenerate after the first rains in May (Figure 3). However, only 34% of the initial seedlings were observed in September. Tillage practices explain the decrease of the number of seedlings after July.

Dynamic of juveniles in fallows

Young fallows- The figure 4 shows the variation of the number of seedlings in young fallows from December to March. Only 34% of seedlings have survived between these two dates. Seedlings have grown back in April in

Figure 2. Example of plot with the six subplots of 12.5 m^2 used to locate each seedling during the growth measurement. P: subplot; orthonormal frame (X,Y) used to locate the the seedling i (+si) with its coordinates xi and yi.



one plot where bush fire occurred at the end of December. This early bush fire did not increased seedlings mortality compared to the unburned plots. After May, seedlings regenerated in the plots allowing them to reach the number of June.

Intermediate aged fallows - Decreasing number of seedlings was observed till April (Figure 4). In one of the plot, a fire occurred on February that damaged 70% of the seedlings. Only 78% of damaged seedlings survived. Dried seedlings regenerated in May and the initial number of seedlings was reached between June and September.

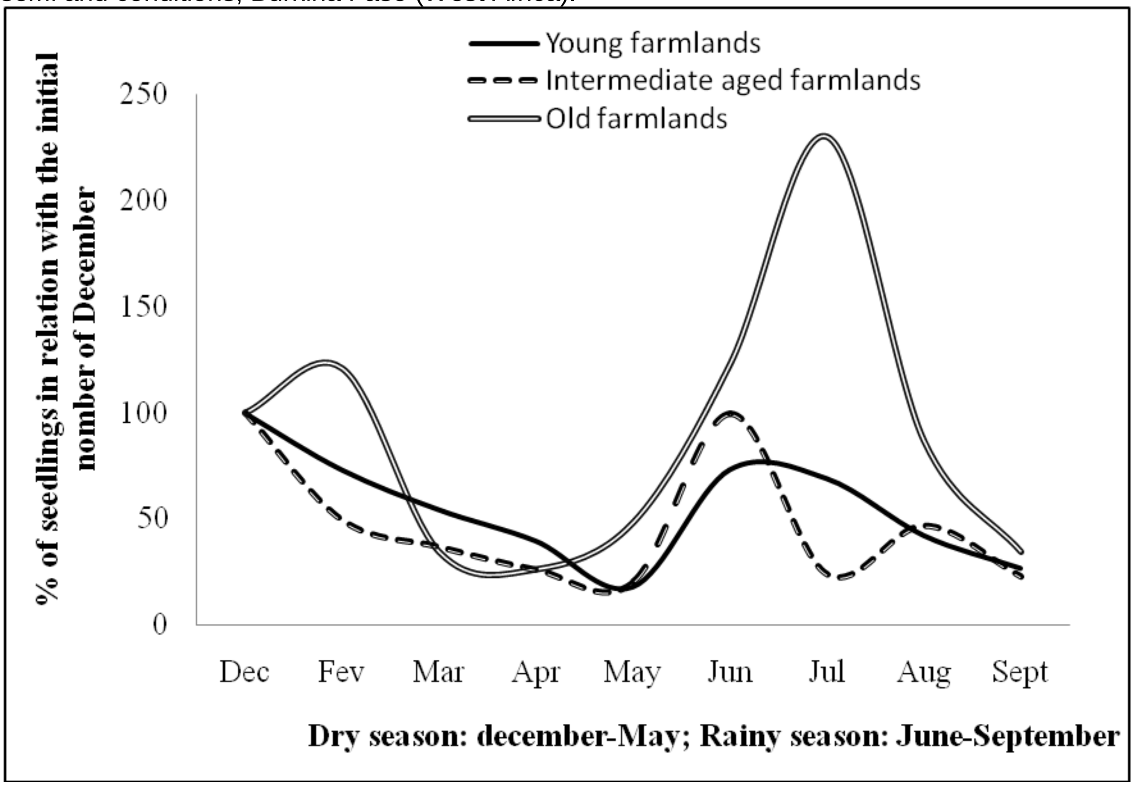
Old fallows – In the old fallows, 80 % of seedlings died between December and April (Figure 4). Fire occurred in two plots in January and February, damaging 70% and 96% of juveniles respectively. In May, 91% of juveniles had dried due to the hot and dry conditions. The baseline number of seedlings was reached between May and July except in one plot where seedlings began to regenerate in March. The number of seedlings remained stable till September.

Regarding the monthly dynamics of shea tree juveniles, there was no significant difference between the different land-uses for the period covering December to August. In September, highly significant difference ($p = 0.009$) appeared between the different plots. At this period, the number of juveniles was high in fallows while it was low in farmlands due to ploughing activities.

Recruitment and mortality of seedlings

During the data collection, no germination of shea tree seed was observed from December to September in the study plots of the different land-use types of Sobaka. Fire occurs usually in savannahs, fallows and farmlands during the dry season as a tool to prevent bush fire and

Figure 3. Changes of shea tree juveniles number in farmlands from December to September in semi arid conditions, Burkina Faso (West Africa).



to manage the land. Any mortality of the followed seedlings during the study was observed in early-burned (before January) and not-burned fallows as well as in some farmlands. In late-burned fallows (After the end of December), the real mortality rate was 23% and in the other farmlands it can reach 35 % (Table 1).

Growth of seedlings

Most of the young plants were continuously cut in farmlands so that they didn't growth in height between December and September. There was no significant change in the mean height of seedlings in young fallows. In the intermediate aged fallows and in the old fallows, significant increase of the mean height was observed between December and September. Plants have significantly grown in height of 1.6 cm ($p< 0.0001$) and 1.7 cm ($p < 0.001$) respectively in the intermediate aged fallows and in the old fallows during the ten month of study (Figure 5). No difference of the collar diameter was observed in any land-use type for any age during the study (One and two ways ANOVA; $p > 0.5$).

Results of the Principal Component Analysis

The PCA show that the percentage of shea tree seedlings alive in April do not depend neither on the age of plot, nor one the passage of fire, the adults of shea trees densities, the densities of shea trees juveniles, the densities of woody adults trees and the densities of juveniles of woody species (Table 2). The figure 6 shows the biplot of PCA with the above variables. Old fallows (OFW) are opposed to farmlands regarding these variables.

DISCUSSION

Shea tree juveniles are very sensitive to farmers' practices and were also found to be affected by abiotic factors. The stems dry out during the dry season

Figure 4. Changes of shea tree juveniles number in fallows from December to September in semi arid conditions, Burkina Faso (West Africa).

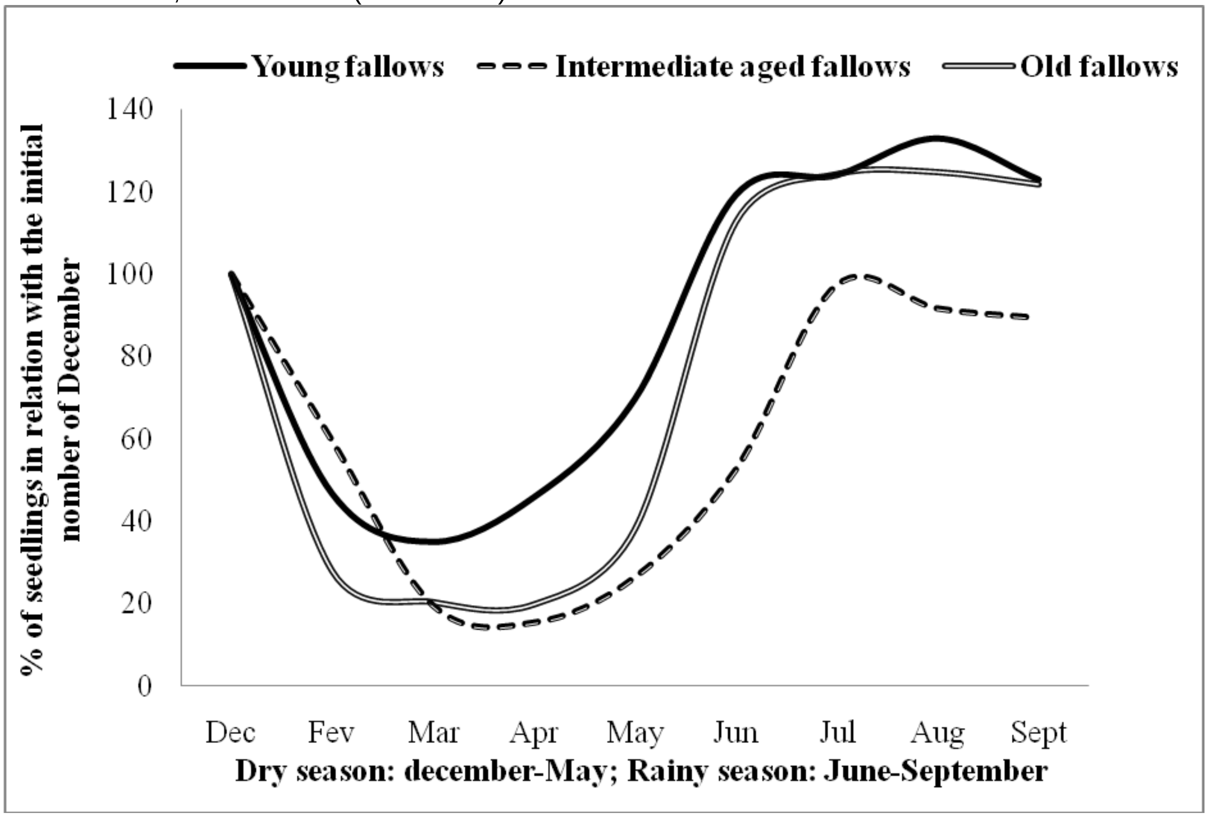


Table 1. Mortality rate (%) of *Vitellaria. paradoxa* seedlings between December and July in farmlands and fallows of different ages.

Types of lands	Young farmlands			Intermediate aged farmlands			Old farmlands		
Plot number	1	8	14	2	9	10	5	12	18
Mortality rate (%)	21	0	28	0	35	16	5	0	0
Types of lands	Young fallows			Intermediate aged fallows			Old fallows		
Plot number	7	15†	17	3†	4	6	13†	16†	7
Mortality rate (%)	0	0	0	23	0	0	0	0	0

†15: burned in mid December †16: burned at the beginning of February
†13: burned in mid January †3: burned at the end of February

especially from March to May. This is one of the characteristics of shea tree juveniles growth dynamic. This is a real constraint for the growth of shea tree seedlings, while authors have already mentioned slow seedlings growth even in controlled conditions (Picasso, 1984; Bayala et al*.,* 2009). The natural characteristics of shea tree juveniles (to dry out in the dry season) should be considered while planting or sowing this species.

Figure 5. Mean height variation of seedlings in three differents types of land-use from December to September. The same letter between the two months means that the seedlings mean height is not significant different (Student t test with α = 5%).

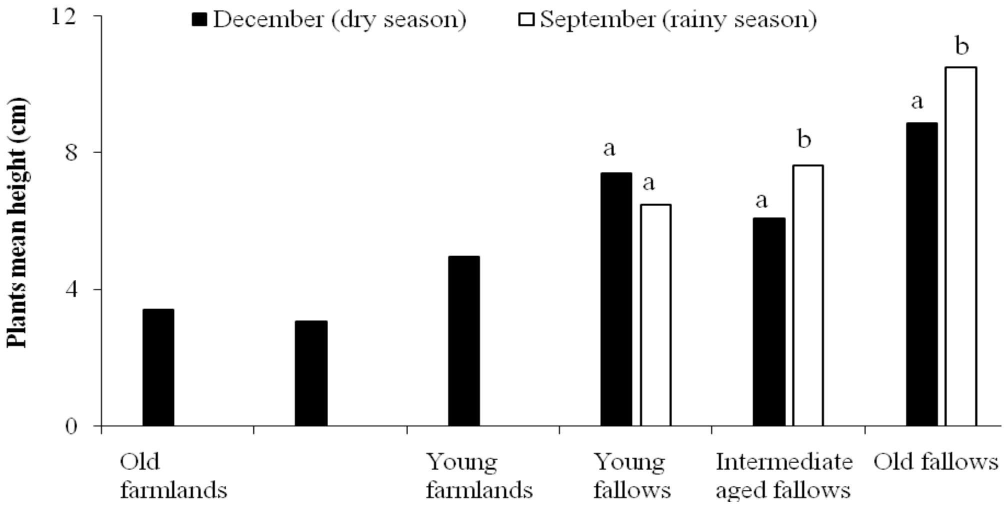


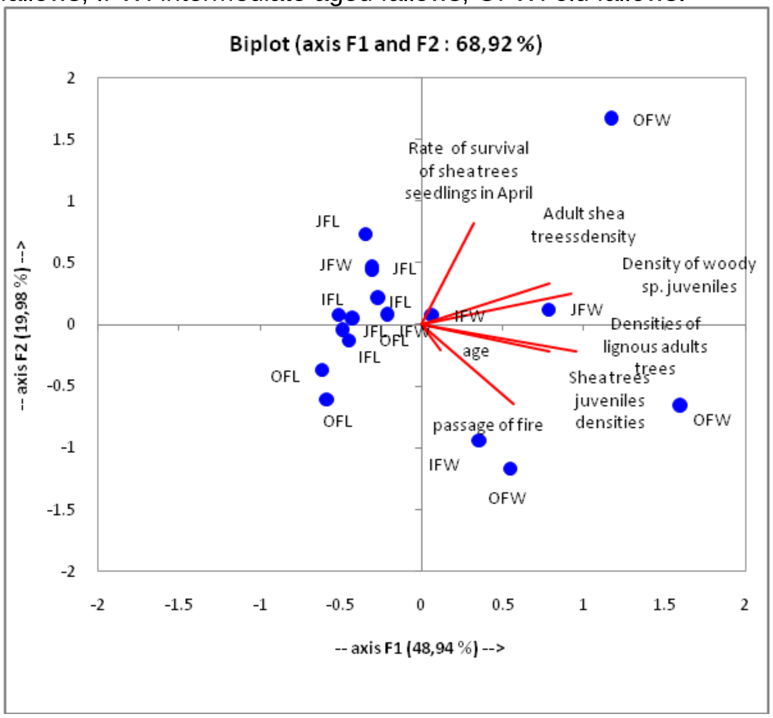
Table 2. Matrix of correlation on the rate of survival of *V. paradoxa* seedlings with some factors in situ.

	Age of plot	Passage of fire	Adults shea trees densities	Shea trees juveniles densities	Densities of woody adults trees	Densities of juveniles of woody species	Rate of shea tree seedlings survival in April
Age of plot	1	0,005	0,277	0,017	0,127	-0,033	-0,161
Passage of fire	0,005	1	0,138	0,445	0,685	0,342	-0,170
Adults shea trees densities	0,277	0,138	1	0,442	**0,630**	**0,802**	0,377
Shea trees juveniles densities	0,017	0,445	0,442	1	**0,757**	**0,609**	0,077
Densities of woody adults trees	0,127	**0,685**	**0,630**	**0,757**	1	**0,830**	0,152
Densities of juveniles of woody species	-0,033	0,342	**0,802**	**0,609**	**0,830**	1	0,435
Rate of shea tree seedlings survival in April	-0,161	-0,170	0,377	0,077	0,152	0,435	1

in bold, significant values with α=0,050.

The number of seedlings above the baseline (initial number in December) was observed for some plots during the wet season. Two main facts can explain this result. Firstly, when the juveniles were counted in December, some seedlings had already dried, therefore they would not have been included in the first count, but

Figure 6. Biplot of the PCA. JFL: young farmlands; IFL: intermediate aged farmlands; OFL: old farmlands; JFW: young fallows; IFW: intermediate aged fallows; OFW: old fallows.



only after they restart new growth during the wet season, leading to a higher number of juveniles than baseline. Secondly, some seeds from the year before may lie dormant in the plots and germinate late (May-June) thereby increasing the number of seedlings above the baseline. Indeed, Zerbo (1987) showed that the germination of shea tree seeds halts during the cold season (December, January) but restarts later when the conditions become favorable. Kelly (2005) has also reported that some seeds continued to germinate six month after being sowed.

In all the plots, a significant decrease in the number of seedlings, followed by an increase was observed. Several factors may explain this situation. For instance, when comparing unburned plots (n°7 and n°17) with the burned plot (n°15) in young fallows, we can assert that early fire stimulated seedlings regrowth. This is not the case for late fire as seen in intermediate aged fallows (plot n°3) where most of the damaged juveniles died definitively. Indeed, bush fires become harmful as the dry season progresses (Schmitz et al., 1996) and should be avoided as much as possible. May was the month which has received the first rains of the rainy season. That is why new growth of seedlings was observed. The decline in seedlings numbers from July to August was explained by the cutting and the uprooting seedling during tillage by farmers.

From February to June, land-use type seems not to impact shea tree juvenile dynamics. This may be explained by the fact that seedlings from seeds germination can withstand lack of water and high temperature during several months.

Our study confirms the slow growth of *V. paradoxa* juveniles already reported by others Picasso (1984) and Hall et al*.* (1996) but it is the first report of growth dynamic in situ. Between two cultivation cycles going from December to June, the seedlings of shea tree do not grow enough and thus farmers seem uninterested in saving them during cultivation. In contrast, juveniles of other parkland tree species, such as *Faidherbia albida* are reported to grow faster in the farmlands than those of shea trees (Ouédraogo, 1994). In situ seedlings have growth slower (Zerbo, 1987) compared to the transplanted ones when the conditions are controlled (Bayala et al., 2009). Recent study shown that cultivation techniques like fertilization and weed control don't have very impact on the growth of most trees planted in previous cropland (Ornelas et al., 2022).

The absence of a significant correlation between the survival rate of *V. paradoxa* seedlings found in April and the other variables seems to indicate that overall these seedlings do not benefit from any protection from adult shea trees and other woody species. The in situ climatic factors such as temperature and rainfall have major impact on the survival rate of seedlings than the biotic factor like the presence of woody species. As seedlings are a critical stage of woody species establishment, it would be better to into account the length of dry season and the temperature in arid species future distribution models. As suggested by San-Eufrasio et al. (2020) with *Quercus ilex* seedlings, future studies could explore the possibility to select tolerant individuals of *V. paradoxa* to the dryness climatic condition for plantation experiences.

CONCLUSION

The results of this study show that shea trees population is considerably unbalanced in farmlands compared to the fallows because of the difficulties the juveniles face in their growth. Fallows allow seedlings and saplings to establish. The dry season slows down plant growth because of it length and high temperature. In order to achieve shea tree domestication in the strict sense *V. paradoxa* biology and ecology must be mastered. Shea trees regeneration by seedlings presents many challenges including slow growth to which varietal research and vegetative multiplication could be proposed as alternatives. Many years ago, long fallow periods were common in Burkina Faso. This practice (old fallows, more than 15 years without any cultivation) can be proposed to rejuvenate *V. paradoxa* parklands only in a few areas with less pressure on the land. However, this solution is not realistic in many parts of the sudano-sahelian zone of Burkina Faso where there is considerable pressure on cultivable land. Nowadays, farmers do not save juveniles in the farmlands and the practice of fallow is significantly reduced or abandoned altogether. In the context of semi-arid area (900 mm; six dry months), shea trees regeneration must be assisted by regular watering if farmers decide to keep seedlings in their farmlands. Our results highlight the importance of further research on the ecology and the physiology of agroforestry species to better understand both the anthropogenic and the natural effects on their regeneration and growth. This work is important and timely because it have permit to know the recruitment, the growth and the mortality of juveniles which is the critical phase of plant establishment in different land use types. The study provides basis knowledge for the research of techniques for shea tree management in situ. These techniques include assisted natural regeneration which could be adopted to better manage shea trees in parklands.

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