Factors of population dynamics of *Vitellaria Paradoxa* (Karite) in the commune of N'dali in Northeast Benin

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Abstract
The shea tree (*Vitellaria paradoxa*) is a woody plant species, very useful for the populations of the commune of N'Dali. However, this species suffers from degradation, which jeopardizes its sustainability. The objective of this study is to determine the factors of the population dynamics of *Vitellaria paradoxa* in the commune of N'Dali. To this end, 340 households in 18 villages were surveyed on their perception of *Vitellaria paradoxa* dynamics. In addition, 72 square plots (36 in shea parks and 36 in fields) were set up to collect dendrometric data on *Vitellaria paradoxa* as well as elements relating to the pressure on the species. These data were processed using descriptive statistics methods.
The density of woody plants is 25 feet per hectare in the fields and 141.66 feet per hectare in the open forests. The density of shea is 16 feet per hectare in the fields and 19 feet per hectare in the open forest. In general, the *Vitellaria paradoxa* population is in decline in the commune of N'Dali. The factors of its dynamics are: agriculture, wood exploitation, drought and winds. It is essential to train people in *Vitellaria paradoxa* based agroforestry.

Keywords: Vitellaria paradoxa, dynamics, agriculture, N'Dali commune, Benin

1. Introduction

In Benin, 162 species of forest plant resources are consumed by local people through their leaves, fruits, seeds, roots, tubers and flowers (J. T. C. Codjia *et al.*, 2003, p.324) [8]. Shea (*Vitellaria paradoxa*) is one such species whose nuts are used for various purposes. This dominant species in the Sudano Sahelian farming systems of Benin is preserved in the fields where it benefits from ploughing and protection against fire. The trees become more vigorous and productive than those in natural formations (E. G. Bonkoungou, 1987, p.12) [7]. In addition, shea parks are created in order to preserve shea trees from threats. However, the sustainability of the resources of the already ageing tree parks is being challenged by increasing demographic pressure and by agricultural and pastoral management methods (R. Peltier *et al.*, 2007, p.42) [18].
Despite the importance of shea locally, nationally and internationally (E. Torquebiau, 2007, p.58) [22], insufficient attention is paid to improving the traditional cropping system in which it is integrated and little concern is given to the main products of shea and néré parks in order to make them economically viable (G. Agbahungba and D. Depommier, 1989, p.44) [2]. The parks in which shea trees are found are deteriorating day by day under the combined influence of natural, technological and anthropogenic factors (P. C. Gnanglè, 2010, p.37) [12].
According to L. Oloukoï *et al.*, (2007, p.311) [15], vegetation formations are under permanent pressure from human activities and the probability that a unit of land use will be transformed into a field or fallow land is high and varies from 30% to 53% in central Benin. This dynamic is also observed in the commune of N'Dali, leading to the following question: What are the factors of *Vitellaria paradoxa* population dynamics? The objective of the present study is to determine the factors of *Vitellaria paradoxa* population dynamics. The hypothesis of this research is that agriculture is the determining factor in the population dynamics of *Vitellaria paradoxa*.

1.1 Study environment

The commune of N'Dali is located in the north of Benin in the department of Borgou, between 2° and 2° 40" East longitude; 9° and 10° North latitude. It is bordered to the north by the communes of Bembèrèkè and Sinendé, to the east by the communes of Nikki and Pèrèrè (PDC, 2017, p.12), to the south by the communes of Parakou and Tchaourou and to the west by the commune of Djougou. The commune comprises five (05) arrondissements: Bori, Gbégourou, Ouénou, Sirarou and N'Dali centre (figure 1).

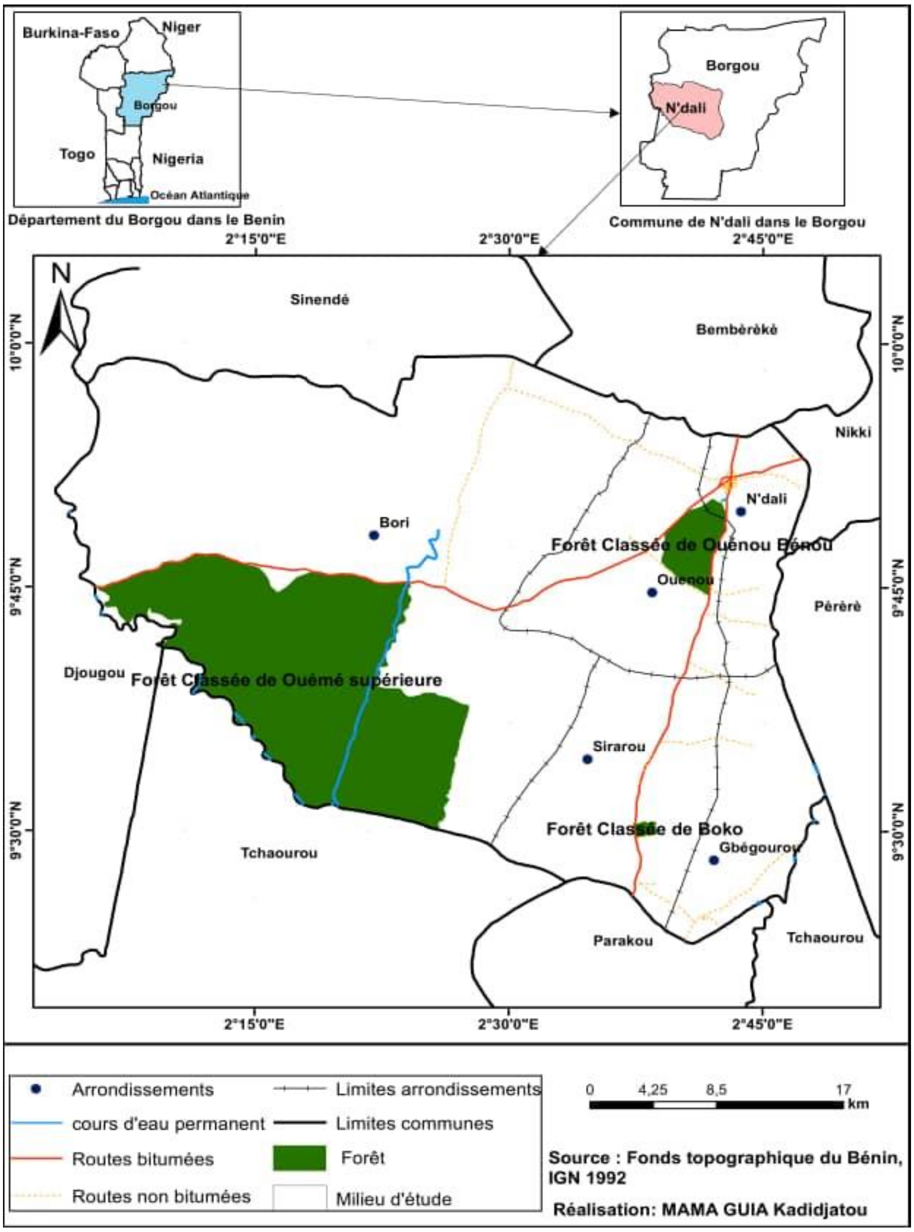

Fig 1: Geographical location of the commune of N'Dali

2. Material and methods

2.1. Data used

Several types of data were collected and analysed. These include: floristic and ecological data; dendrometry data and socio-economic data.

2.2. Data collection techniques and equipment

Two techniques were used to collect data on the dynamics of *Vitellaria paradoxa*. These were the inventory and surveys of the N'Dali populations.

2.2.1. Inventory in plant formations

In order to estimate the population dynamics of *Vitellaria paradoxa* in the shea fields and parks, inventories of adult *Vitellaria paradoxa* plants were carried out through forest surveys. Indeed, 72 square plots of 30 m x 30 m, 36 in the fields and 36 in the shea parks (clear forest) were installed. All individuals of species with a dbh ≥ 10 cm were inventoried. Individuals of *Vitellaria Paradoxa* with a dbh between 5 and 10 cm were counted. They represent regenerating plants.

The logger's cross method was used to estimate the height of shea trees. In addition, several pieces of equipment were used for data collection. These included a penta decameter for delimiting the plots; a fluorescent strip for marking the boundaries of the plots; a cutter for opening the layons and making the corner posts; a circumferential tape for measuring the circumference (dbh) of the trees; and a GPS (Global Positioning System) for geo-referencing the plots and the floristic inventory sheets. This inventory work was complemented by surveys.

2.2.2. Socio-economic surveys of the population

The probabilistic method was adopted due to the lack of a database. The units of observation are the agricultural households. The Schwartz (1995) formula is used for sampling $\mathbf{n = z^2 p \frac{1-p}{i^2}}$ **n** is the sample size, **z** is the confidence level according to the normal distribution (for a confidence level of 95%, **z** = 1.96), **p** is the estimated proportion of the target population; **i** is the margin of error tolerated (to know the real proportion to within 5%). A total of 340 households consisting of agricultural producers, shea nut collectors, traders, and shea nut processors were interviewed about their perception of the shea nut dynamic.

2.2.3. Data processing and analysis of results

To assess the population dynamics of *Vitellaria paradoxa*, the density of adult *Vitellaria paradoxa* trees was calculated per plot and extrapolated to the hectare. Dendrometric data were used to establish the diametric structure of the shea trees. The density of trees per hectare was chosen because it is more informative in terms of forest stand management (Glèlè Kakaï and Bonou, 2010, p.8) [11]. The calculation of the dendrometric parameters was done by plant formation (fields and shea parks). For each plant formation, the density N and the basal area g were calculated.

$\mathbf{N} = \frac{n*10000}{s}$ Where **n** is the number of inventoried trees and **S** is the area in m^2.

$g = \frac{10000\times\pi}{4\times s}\sum_{i=1}^{n} d_i^2$ (**g**, in m²/ha), **di** is the diameter at 1.30 m from the ground and **s** is the area of the plot in m^2. The species richness (**S**) is determined for each plot. The Shannon diversity index (**H** in bits) is obtained by the formula: $\mathbf{H} = -\sum_{i=1}^{n} pi\, log_2\, pi$ Where **pi** = the proportional abundance or percentage abundance of a species present *(***pi = ni/N***)*, **ni** = the number of individuals counted for a species; **N** = the total number of individuals of all species; and **S** = the total number or cardinal number of the list of species present. Extreme values range from 0.5 (very low diversity) to about 4.5 bits, or exceptionally more in the case of large sample sizes in complex communities. The Piélou Equitability Index (**EQ**) corresponds to the ratio between the diversity obtained and the maximum possible diversity (**Log_2S**). It is given by the relation: $\boldsymbol{EQ = \frac{H}{log_2 S}}$ Where Log_2S denotes the maximum diversity. This index varies between 0 and 1. If it tends towards E = 1, then the species present in the stand have identical abundances. If it tends towards E = 0, then there is an imbalance and one species dominate the whole stand.

In addition to these parameters, the three dominant species in each of the plant formations were determined by calculating the Importance Value Index (IVI) of the species. The Importance Value Index combines relative density, relative frequency and relative basal area. It is used to characterise plant stands and to identify dominant species. It is obtained by the formula: **IVI = relative density + relative frequency + relative dominance**; with *relative dominance = (total basal area of the species/Total basal area of all species) X 100*; *Relative density = (Number of individuals of the species per ha/Total number of individuals per ha) X 100*; *Relative frequency = (Frequency of a species/Summation of the frequencies of species) X 100*.

Also, the Excel 2013 software was used to establish the diameter and height structures of the *Vitellaria paradoxa* population. Individuals of all species surveyed are divided into diameter classes of 5 cm amplitude. The distribution of the diameter classes reflected the state of the population dynamics of *Vitellaria paradoxa* as a whole. The relationship between height and diameter of *Vitellaria paradoxa* trees was established. The il model used to describe the linear relationship between height and diameter is given by the straight-line equation: **Y=a+bX** where **Y** = the explained variable, **X** = the explanatory variable, **a** = is a constant; **b** = the leading coefficient of the explanatory variable

3. Results

3.1. Factors in the dynamics of *Vitellaria paradoxa*

Several factors contribute to the dynamics of the *Vitellaria paradoxa* population, including agriculture.

3.1.1. Agriculture, a factor in the regressive evolution of *Vitellaria paradoxa* and its companion species

The inventory carried out in the fields and in the open forests allowed us to count 69 individuals divided into 20 woody species. Table I shows the Importance Value Indices (IVI) of the species inventoried in the fields and in the open forests.

Table 1: Importance Value Indices (IVI %) of *Vitellaria paradoxa* and companion species

Fields					
Species	**Gi**	**Relative Dominance**	**Specific gravity**	**Relative Frequency**	**IVI (%)**
Azadirachta indica	0,34	1,50	5,56	7,14	14,2
Borassus Aethiopium	0,41	1,81	5,56	7,14	14,51
Parkia biglobosa	5,18	22,89	16,67	21,43	60,99
Piliostigma thonningui	0,13	0,59	5,56	7,14	13,28
Vitellaria paradoxa	16,55	73,21	66,67	57,14	197,02
Open forests					
Afzelia africana	3,95	18,06	15,69	9,68	43,43
Anogeissus leiocarpa	0,39	1,78	5,88	6,45	14,11
Crossopteryx febrifuga	0,59	2,72	1,96	3,23	7,91
Detarium microcarpum	0,92	4,21	1,96	3,23	9,39
Dispyros mespiliformis	0,77	3,5	1,96	3,23	8,68
Gardenia erubescens	0,08	0,36	1,96	3,23	5,55
Isoberlinia doka	3,03	13,86	15,69	12,9	42,45
Isoberlinia tomentosa	0,08	0,37	1,96	3,23	5,56
Khaya senegalensis	1,44	6,59	5,88	6,45	18,93
Lannea kerstingii	0,28	1,29	1,96	3,23	6,47
Parkia biglobosa	1,76	8,02	5,88	9,68	23,58

Piliostigma thonningui	1,09	4,97	7,84	6,45	19,26
Pterocarpus erinaceus	1,13	5,16	5,88	3,23	14,27
Sterculia setigera	0,32	1,46	1,96	3,23	6,64
Tamarindus indica	0,78	3,56	3,92	3,23	10,71
Terminalia avicennioides	1,52	6,94	3,92	3,23	14,09
Vitellaria paradoxa	3,48	15,91	13,73	12,9	42,53
Vitex doniana	0,27	1,24	1,96	3,23	6,43

Source **:** Analysis results, November 2021

The observation in table I shows that in the fields, four (4) species are companions of *Vitellaria paradoxa*. In contrast, in open forests, seventeen (17) species are companions. The low diversity of companion species of *Vitellaria paradoxa* in the fields is due to agriculture. In fact, farmers select in their fields the indigenous species with economic values and kill the others that they consider to be of little or no economic value. This is the case of *Parkia biglobosa*, which is kept in the fields because its nuts are used to make mustard. The same is true of *Borassus Aethiopium*, all of whose organs are used by the people.

3.1.2. Agriculture as a factor in the low density of companion species and the low diversity index in the field

Density, basal area, species richness and diversity indices (Shannon Diversity Index and Piélou Equitability) were presented in table II.

Table 2: Diversity parameters of woody species in different plant formations

Parameters	Plant Formations	
	Field	**Open forests (Shea Park)**
Density (trees/ha)	25	141, 66
Basal Area (m2/ha)	5,47 ± 1,07	2,83 ± 1,49
Specific wealth	5	18
Shannon Diversity Index	1,05 ± 0,46	3,34 ± 0,36
Piélou equitability Index	0,84 ± 0,31	0,91 ± 0,04

Source **:** Fieldwork, September 2021

The observation in table II shows that in the fields, the average density is 25 trees/ha. In open forests, it is 141.66 trees/ha, i.e. six (6) times the density observed in the fields. In terms of species richness, open forests are richer in woody species (18 species) than fields (5 species). The pressure of farmers on the farms is the reason for the low density and low species richness in the fields. Agriculture is therefore contributing to the regressive evolution of plant species. This regression does not spare *Vitellaria paradoxa*. On the other hand, basal area is higher in the fields (5.47 m^2/ha with a standard deviation of 1.07) than in the open forests (2.83 m^2/ha) with a standard deviation of 1.49. This is because on the farms, old *Vitellaria paradoxa* plants are preserved. These have a large diameter and their crown covers a large area. This explains the higher basal area in the fields. The highest values of the Shannon H diversity index and the Piélou Equitability index are obtained in open forests where many plant species are observed.

3.1.3. Agriculture as a factor in reducing the dendrometric parameters of *Vitellaria paradoxa* in fields and open forests

The dendrometric parameters considered are density, basal area, frequency of occurrence of the species, mean diameter and mean height (table III).

Table 3: Dendrometric parameters of *Vitellaria paradoxa* in the formations

Parameters	Vegetation formation	
	Field	**Open Woodland (Shea Park)**
Density (trees/ha)	16,66	19,44
Frequency of occurrence (%)	66,66	13,72
Average diameter	38,55 ± 10,19	22,62 ± 8,22
Average height	Field	Open Woodland (Shea Park)

Source**:** Fieldwork, September 2021

The density of *Vitellaria paradoxa* is higher in the forests (19.44 trees/ha) than in the fields (16.66 trees/ha). Indeed, even if they make a profit from shea, farmers regulate the number of trees on their plots by eliminating young shoots. In this way, they take measures to avoid disturbing the development of their crops (yam, millet, cotton, etc.) which need the sun. The frequency of occurrence of *Vitellaria paradoxa* is higher in the fields (66.66%) than in the open forests. This means that *Vitellaria paradoxa* is more abundant in the fields than in the open forest, as it is spared at the expense of other woody plant species.

The average diameter of *Vitellaria paradoxa* is higher in the fields (38.55 cm) than in the open forest (22.62 cm) with a standard deviation of 10.19 and 8.22 respectively. The mean height of *Vitellaria paradoxa* is 7.92 m in the field, which is higher than the mean height of *Vitellaria paradoxa* in open forest (7.12 m). The standard deviation of the mean height varies between 1.91 and 2.26 in the field and open forest respectively. Large diameter and tall species are most common in the fields. This is explained by the maintenance that farmers carry out on their farms. This observation was confirmed by the diameter structures of *Vitellaria paradoxa* in the fields.

3.1.4. Agriculture as a factor in the destruction of small diameters but in the growth of preserved large diameters of *Vitellaria paradoxa*

The diameter structure of *Vitellaria paradoxa* in the field and in open forest respectively showed a difference in the presence and absence of certain diameters in figures 2 and 3.

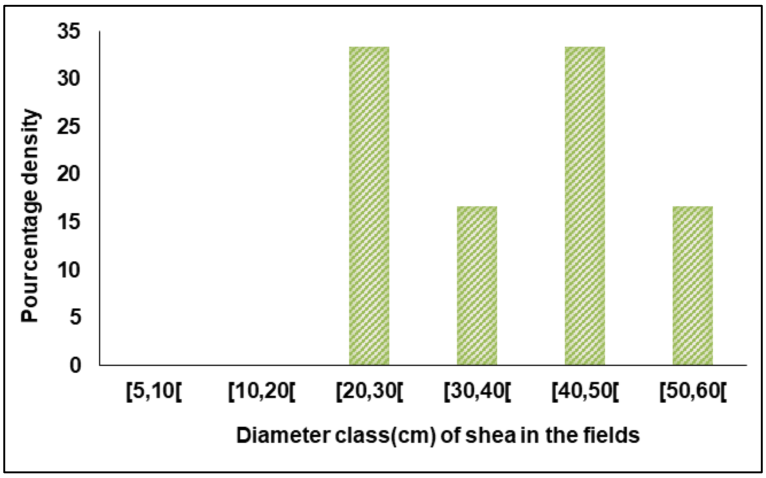

Fig 2: Diameter structure of *Vitellaria paradoxa* in the fields at N'Dali

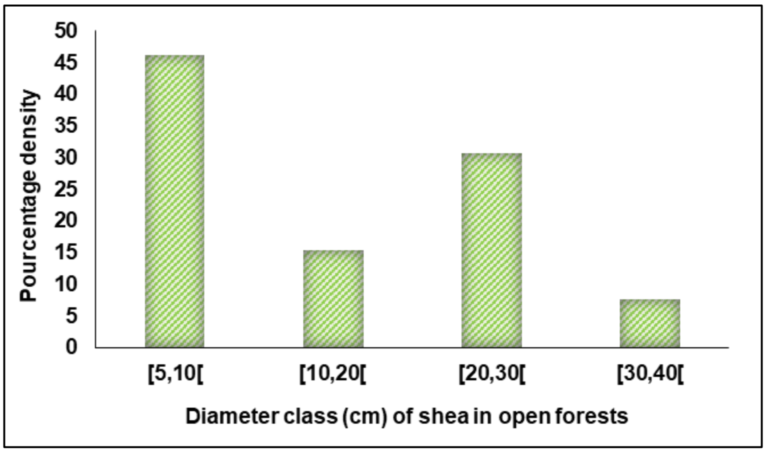

Fig 3: Diameter structure of *Vitellaria paradoxa* in open forest at N'Dali

***Source*:** Field survey results, October 2021

The distribution of *Vitellaria paradoxa* individuals reveals that the most represented diameter classes are [20,30] both in the fields and in the open forests. However, the [10,20[cm] diameter classes are absent in the fields, but present in the open forest. This shows that producers generally fell small-diameter trees ([10-20[cm) in order to keep large trees of productive age. In this way they avoid crowding the fields with small *Vitellaria paradoxa* trees. The diameter classes [5-10 [representing regenerating species are absent in the fields in contrast to the open forests. This can be explained by the fact that young shea shoots are destroyed in the fields during the preparation of the soil for the planting of crops. The open forests are therefore suitable environments for the preservation of young *Vitellaria paradoxa* individuals. Shea trees with diameters greater than 40 cm are absent in open forests, but present in the fields. Indeed, farmers maintain the preserved shea trees in their fields. This reinforces their growth, contrary to the shea trees located in the open forests, which are regularly exposed to vegetation fires.

3.1.5. Agriculture, a factor in the height growth of preserved large-diameter *Vitellaria paradoxa*, but eliminates small diameters

With regard to the height class, figures 4 and 5 show the height structures of *Vitellaria paradoxa* in fields and open forest respectively.

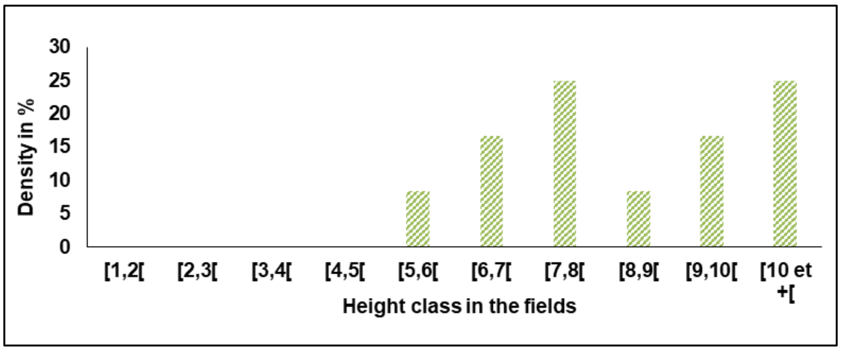

Fig 4: Height class of *Vitellaria paradoxa* in the fields at N'Dali

Fig 5: Height class of *Vitellaria paradoxa* in open forest at N'Dali

***Source*:** Field survey results, October 2021

From the analysis of figures 4 and 5, it appears that the small height class [4.5[cm is absent in the fields but present in the open forest. This is explained by the regular removal of regenerated trees and shrubs in the fields. Only large diameters at high heights are preserved in the fields. The distribution of *Vitellaria paradoxa* individuals in height classes shows an irregular pattern in the fields, with in terms of percentages in height classes [7,8[and [10 and +[. In the open forests, it shows a lefthanded asymmetry with the dominance of some individuals in height classes [5,6[. This means that in the open forests, young shea trees are abundant, unlike in the farms. In addition, the evolution in height of *Vitellaria paradoxa* depends on its.

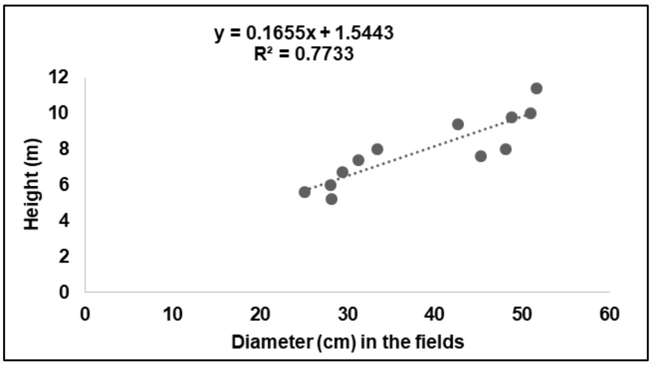

Fig 6: Relation Height-diameter of *Vitellaria paradoxa* in the fields

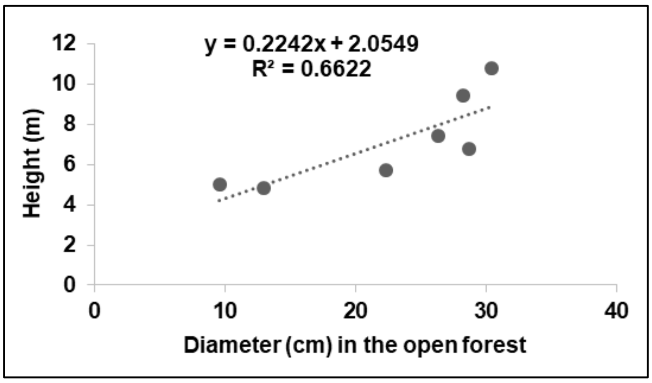

Fig 7: Relation Height-diameter of *Vitellaria paradoxa* in the open forest

Source: Field results, September 2021

The simple regression model expressing height and diameter is represented by the following two equations: Yf= 0.1655x+1.5443 (R^2= 0.7733) and Yo = 0.2242x + 2.0549 (R^2 = 0.6622)

With Y = total height and X = diameter at 1.30 m from the ground.

This relationship can therefore be written as: H = 0.1655D + 1.5443 with R^2 = 0.7733 in the fields and H = 0.2242D + 2.0549 with R^2 = 0.6622 in open forest.

In the fields, the constant 1.5443 and the coefficient of diameter (0.1655) are significant at the 5% level (F = 34.11; P = 0.000), and the same is true in open forest (F = 9.80; P = 0.026) with a constant of 2.0549 and a coefficient of diameter of 0.2242. From this analysis it can be deduced that for each additional centimetre of diameter, the height increases on average by 0.1655m in the fields and by 0.2242m in the forests. Therefore, considering the coefficient of determination, it can be deduced that 77.33% of the variation in height of *Vitellaria paradoxa* is explained by the variation in diameter in the fields. In open forests, 66.22% of the height variation is explained by diameter variation. It should be said that the height of trees depends on their diameter.

3.2. Other factors in the dynamics of *Vitellaria paradoxa*

These factors are natural and anthropogenic. The natural factor cited by 95% of the respondents is wind. Indeed, strong winds not only cause flowers to fall, but also uproot *Vitellaria paradoxa* trees (windthrow). Anthropogenic factors identified outside of agriculture are the felling of shea trees during honey harvesting by the traditional system, vegetation fires, pastoral exploitation, the felling of shea trees for charcoal and mortar production, and the demographic explosion.

4. Discussion

The shea tree is exposed to important pressures, leading in general to a regressive evolution of its population. The determining factor of this evolution in the commune of N'Dali is agriculture, which has generally reduced the diversity of species on the farms. The 20 species constituting the specific richness of open forests and fields in the commune of N'Dali are lower than those recorded by I. I. Toko (2008, p.187) [21] in the upper basin of the Ouémé River; M. Houinato *et al.* (2001, p. 895) [13], in the Monts Kouffè; M. S. Adame *et al.* (2020, p.274) [1], in the Forest Classified of Penessoulou (Commune of Bassila, North Benin). This low species richness in the commune of N'Dali is explained by the fact that the species richness in the fields is very low. The abundance of *Vitellaria paradoxa* and *Parkia biglobosa* in the fields shows that farmers keep these trees in the agricultural production areas because of their socio-economic importance. Similar results were obtained by G. Agbahungba *et al.*, 2001 [3], p.11 in Benin. Also, several other authors F. Folega *et al.*, 2011, K. Aleza *et al.*, 2015 [9, 4], have mentioned these two species as the most important ones in agroforestry systems in the Sudanian zones.

The distribution of species in diameter and height class is variable depending on the plant formation. There are younger *Vitellaria paradoxa* trees with a diameter of less than 30 cm in open forests than in the fields. The fields are therefore dominated by individuals with larger diameters (over 30 cm). These results are similar to those obtained by J. Arouko, (2011, p.25) [6] for the same species in the communes of Bantè, Bassila, Djougou and Ouaké. As for heights, similar results were found by M. L. A. Avana-Tientcheu *et al.* (2019 p.224), on other food species such as *Parkia biglobosa* contrary to those obtained by J. Arouko, (2011, p.26) [6] on the same species in the communes of Bantè, Bassila, Djougou and Ouaké.

Shea is exposed to many pressures, but agriculture is the most important. The results of R. K. F. M. Ali (2015, p.151) on the direct determinants of the degradation of sacred forest vegetation are agriculture, timber exploitation, subdivision, woody debarking and human settlement. These results are similar to those obtained in the present research. According to J. Odjoubéré (2014, p.137), the results of the inventory carried out in the protection series place agriculture at the top of the list of pressure factors.

Furthermore, P. M. Mapongmetsem *et al.* (2011, p.852) [16] and S. A. Kaboré *et al.* (2012, p.55) [14], explained that the reduced number of seedlings in agrosystems is strongly linked to field work. In addition, the use of ploughs is increasingly common, but often results in the uprooting of young shoots (H. J. M. Gijsbers *et al.*, 1994, p.10) [10]. According to H. Sanou *et al.* (2011, p.8) [20], regeneration is compromised, especially when cultivation is mechanised in agricultural areas. In the commune of N'Dali, the tractor and the plough are the most commonly used?

Conclusion

This study concluded that the dynamics of shea depends on types of plant formations (production systems) and that cropping systems and cropping techniques influence these dynamics. The study also provided information on the companion species of *Vitellaria paradoxa* in the plant formations (fields and open forests). The open forests are more diverse in woody species than the fields. Similarly, shea is more present in the fields than in the other species. Thus, shea is favoured in cultivable land. Shea faces natural pressures such as wind and drought. The only conservation strategy adopted by producers is assisted natural regeneration. There is still a lot of work to be done in terms of protection and conservation of the species. Programmes should be put in place to encourage farmers to plant shea or to maintain existing shea saplings.

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