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Assessment of *Tamarindus indica* L. stands in the forest areas of Kuinima and Dindéresso in Western Burkina Faso

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ABSTRACT

Tamarindus indica L. is a multi-purpose wild fruit tree that is highly exploited in Burkina Faso, and its habitats are being degraded. This study aimsed to determine the demographic and health characteristics of *Tamarindus indica* conserved in different habitats in western Burkina Faso. So three types of land management were identified: agroforestry parklands (PA), parts of forests subjected to wildfire (FAF) and parts of forests that have not been subjected to wildfire (FSF). Some 146 square plots measuring 2,500 m^2 each were set up, including 65 in PA, 46 in FAF and 37 in FSF. An exhaustive inventory of trees was carried out and the dendrometric parameters recorded. The health of each individual was assessed. The results reveal a species richness of 82 species composed of 65 genera and 33 families. The highest density values were found in the FAF (55.33±4.27 N/ha); mean diameter in the PA (30.22±16.46 cm); mean number of *T. indica* regenerations (PA=1.73±0.67 seedlings/ha; FAF=3.30±1.02 seedlings/ha; FSF=7.14±1.14 seedlings/ha). These values varied significantly ($p<0.05$) with the land management method. Tamarind has low regeneration and it regenerates more by seedling (77.44%) than by shoot (22.56%). It is cut down and burnt, and the tree infestation rate is higher in agroforestry parklands (11.84%). It would therefore be essential to determine the conditions for conserving its seeds and encourage the practice of assisted regeneration to safeguard the species.

Keywords: *Tamarindus indica*, agroforestry park, classified forest, sustainable management, Burkina Faso

INTRODUCTION

In Sahelian countries, the rational use of plant resources is a major socio-economic and ecological challenge (Diatta et al., 2016; Ouédraogo, 2021). Climatic variations and rapid population growth are forcing the uncontrolled exploitation of forest resources, leading to rapid changes of the vegetation (Ndiaye et al., 2013; Elhadji Seybou, 2017). Anthropogenic pressures combined with natural factors appear to be the main causes of biodiversity loss in tropical forest ecosystems

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(Traoré et al., 2022). The dynamics of the plant species take into account the space, the way the environment is managed and the relationships that exist between it and other species in the environment (Ouoba et al., 2018; Samarou et al., 2022). The study of the structure of a plant species therefore serves as a basis for its silviculture, guides the forest economy and makes it possible to assess the state of degradation of its habitat. All this is done in a view of drawing up and implementing management plans or development programs for sustainable management, promoting Non-Timber Forest Products (NTFPs) and enhancing the value of useful species in the quest for food and nutritional security, and the fight against poverty in rural areas (Belem, 20009). In Burkina Faso, strong human pressure is locally affecting the structure, population density and regeneration potential of plant species (Traoré et al., 2020). Among these species is *T. indica*, a wild fruit tree with multiple uses that is highly prized by people in Africa. The main objective of this study was therefore to determine the demographic and health characteristics of *Tamarindus indica* stands in different habitats in Western Burkina Faso.

MATERIALS AND METHODS

Study site

The selected sites were the classified forests of Kuinima (FCK), Dindéresso (FCD), and agroforestry parklands. Both forests are located on the outskirts of Bobo-Dioulasso. The Kuinima classified forest is located to the south-west of the city, with geographical coordinates of 11°03' and 11°7' north latitude and 04°19' and 04°36' west longitude. The classified forest of Dindéresso lies to the north-west of the town, at longitude 4°18' to 4°26' west and latitude 11°11' to 11°18' north (Figure 1). These different sites belong to the Southern Sudanian phytogeographical sector (Fontes and Guinko, 1995). The vegetation in these forests comprises artificial plant formations planted with exotic species, and natural plant formations represented by gallery forests, wooded and grassy savannahs. The agroforestry parklands bordering these forests, consisting of cultivated and fallow fields, are characterized by useful woody species. The climate is characterized by a dry season (November - April) and a rainy season (May - October). Rainfall varies between 900 and 1200 mm/year, with an average of 1042.84±181.35 mm over the last thirty years (Traoré et al., 2022). Temperatures vary between 16°C and 40°C (Cissé et al., 2023). Most of the soils in the Houet province are leached tropical ferruginous soils (Noufé et al., 2023).

Sampling

To better assess the state of *T. indica* stands in its habitats, three (03) main types of land management were identified: agroforestry parklands (PA), parts of forests subject to wildfire (FAF) and parts of forests that have not been subject to wildfire (FSF). The sampling was oriented. Plots were installed based on the presence of *T. indica* in each land management mode (Bognounou, 2009; Ouédraogo, 2021). A total of 148 inventory plots were set up, including 65 in PA, 46 in FAF, and 37 in FSF. The plots were square, measuring 50 m x 50 m, or 2,500 m^2 each.

Ligneous species stand inventories and structures

The work first consisted of inventories of *T. indica* and other ligneous species in the various formations. In the plots installed, the dendrometric parameters measured were the base circumferences at 20 cm and 130 cm above the ground; the total height of all *T. indica* individuals and those of other woody species were estimated using the method of Arbonnier (2000). The circumference of each individual at 130 cm above the ground was measured using a tape measure, and the total height was measured using a 6 m long graduated pole; beyond this value, the rest of the height was estimated by visual observation. In addition, unidentified samples were taken with secateurs and transported in plastic bags. Species identification was based on Arbonnier (2000). The nomenclature was updated according to the International Plant Nomenclature Index. A list of the species inventoried was drawn up and their taxonomy was compiled to assess the floristic composition. Floristic diversity was measured based on species richness (Rs) and the Shannon diversity (H') and Pielou equitability (Eq) indices. These indices take into account the species richness and the total number of individuals present in each land-use system.

Assessment of *T. indica* regeneration

To assess regeneration, the number of plants with a diameter of less than 5 cm at 130 cm above the ground was counted in five 5 m x 5 m plots placed at the four corners and in the center of the main plot. For *T. indica*, the number of seedlings was counted in the same main plots. The type of regeneration was identified according to whether it was a shoot, a seedling, or a sucker. The average number and rate of regeneration will allow a better understanding of the contribution of *T. indica* to the renewal potential and the dynamics of *T. indica* stands under each management method.

Assessment of the health status of *T. indica*

The health of *T. indica* plants was assessed by visual observation during the inventory work, taking into account the three land management methods. Information was collected on individuals attacked by insects and all forms of parasites present on the tree; wood cuttings and samples taken from parts of the tree (branches, trunk, etc.); the presence of fire marks attested that the plant has been subjected to bush or vegetation fires. Individuals who have not been subjected to any form of visible pressure here said to be healthy. For each plant, the dominant pressure was identified, and for each plot under each land management system, the numbers of healthy, attacked, cut, and burned individuals were determined, and their proportions were calculated about the total numbers on the plots under the three management systems.

Data processing

The data collected was used to calculate the dendrometric characterization variables, the diversity of woody species inventoried, and an assessment of their state of health.

- The Shannon diversity index (H') and Pielou equitability index (Eq) were determined using the following formulae:

➢ *Shannon index (H'):*

$\boldsymbol{H' = -\sum_{i=1}^{n} \frac{n}{N} \log_2(\frac{n}{N})}$ where *log*$_2$ is the natural logarithm, *n* = total number of woody individuals; *N* = total number of individuals of species *i* (Samarou et al., 2022);

➢ *Pielou regularity index (Eq):*

$\boldsymbol{Eq = \frac{H'}{\log_2(Rs)}}$ where *log*$_2$ *(Rs)*: expresses Shannon's maximum diversity, *H'max*; *Rs* = total number of species (Samarou et al., 2022).

- The *T. indica* stand was characterized by calculating the density, average diameter and basal area of individuals at 20 cm and 130 cm from the ground.

➢ $\boldsymbol{Density = \frac{N}{S}}$ where *N* is the total number of woody individuals, *S* = area sampled in hectares;

➢ $\boldsymbol{D = \frac{C}{\pi}}$ where D is the Diameter; C = Circumference at 130 cm from the ground;

➢ $\boldsymbol{G = \frac{C^2}{4\pi}}$ where G = basal area; C = circumference at 130 cm from the ground.

The regeneration rate (Tr) of *T. indica*: this makes it possible to judge its regeneration capacity according to the de Rothe (1964) scale used by Yaméogo et al. (2020):

Regeneration rate (Tr: $\boldsymbol{Tr = \frac{Total\ number\ T.indica\ regenerations}{effectif\ total\ of\ T.\ indica}\ x\ 100}$

- if Tr <100%: low regeneration;
- if 100%≤Tr≤1000%: good regeneration;
- if Tr >1000%: very good regeneration.

To assess the health status of *T. indica* in the plots surveyed, the proportions of healthy, attacked, cut and dead plants were calculated:

$$N = \frac{Total\ number\ of\ healty\ or\ attacked\ or\ cut\ plants}{Total\ number\ of\ T.\ indica\ plants}\ x\ 100$$

A single-factor analysis of variance (ANOVA) was performed using IBM SPSS Statistics software (version 2022) to assess the influence of land management methods on the various parameters calculated (density, diversity indices, mean diameter, basal area, mean height, mean number of regenerations, regeneration rate). The means of the parameters were compared using the *Tukey* test with a threshold of 5%. Minitab 14 software was used to fit the various histograms constructed to the theoretical Weibull distribution. This distribution is based on the probability density function of the three-parameter Weibull distribution.

The function f is represented as follows:

$$\mathbf{f(x)} = \frac{c}{b} + \frac{(x-a)^{C-1}}{b} \quad e^{x}\left[-\left(\frac{x-a}{b}\right)^{c}\right]$$

where **x** is the diameter or height of the trees, **a** is the position parameter, **b** is the scale or size parameter, and **c** is the shape parameter linked to the structure observed and interpreted according to Garba et al. (2020), Samarou et al. (2022), Cissé et al. (2023). The Weibull parameter c is interpreted according to the Table 1.

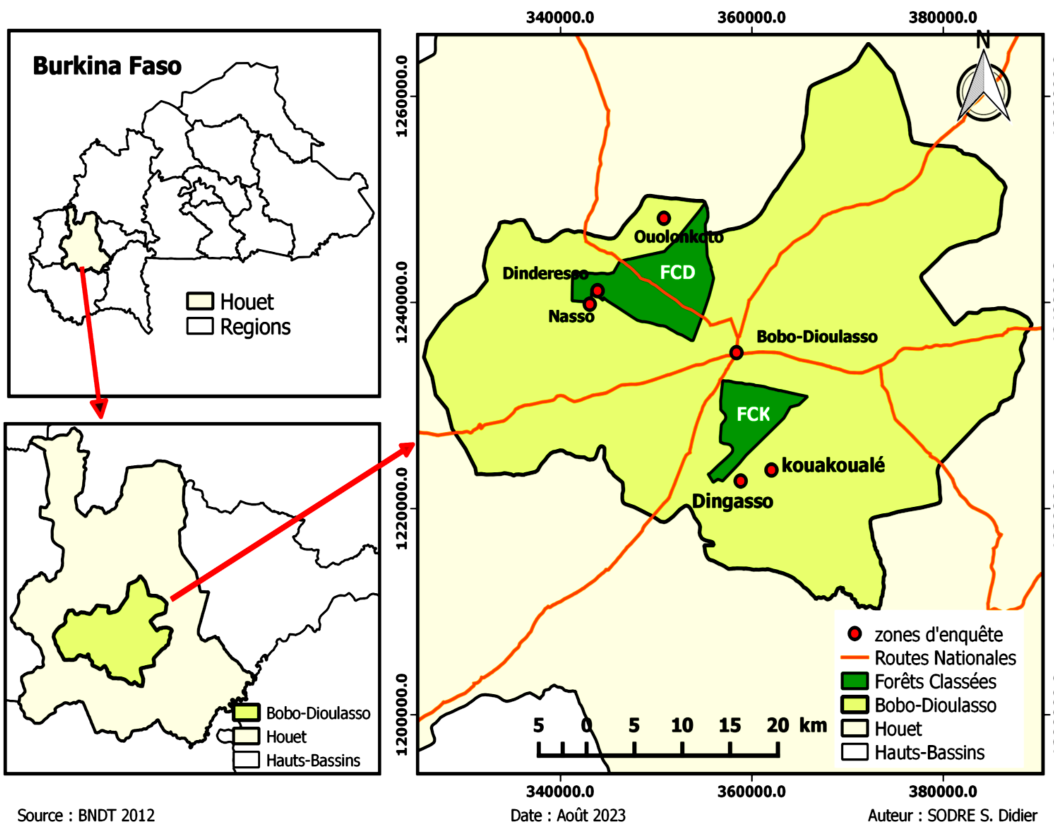


Figure 1: Location of study sites.

Table 1: Interpretation of the Weibull parameter c.

Value	Interpretation
c < 1	J-shape distribution
c =1	Exponentially decreasing distribution
1 < c < 3,6	Positive asymmetric or right asymmetric distribution
c = 3,6	Symmetrical distribution
c > 3,6	Negative asymmetric or left asymmetric distribution Also characteristic of degraded populations with very low regeneration potential

RESULTS

Floristic composition, richness and diversity of *T. indica* stands

Floristic composition and species richness

By floristic inventories in *T. indica* stands 82 species were identified and classified in 65 genera and 33 families (Figure 2). Four families were most more represented, with at least eight (08) species. These were Combretaceae (10 species), Anacardiaceae (9 species), Leguminosae-Caesalpinoideae (9 species) and Leguminosae-Mimosoideae (8 species). The Asclepiadaceae, Balanitaceae, Boraginaceae, Capparaceae, Celastraceae, Chrysobalanaceae, Ebenaceae, Loganiaceae, Moringaceae, Ochnaceae, Polygalaceae, Rhamnaceae, Polygalaceae, Sapotaceae, Sterculiaceae, Tilliaceae, Ulmaceae were the least represented families with one species each.

Floristic diversity according to land management method

Parts of the forest not subjected to fire contained the highest number of species (7 species/survey), followed by those subjects to vegetation fires (5 species/survey) (Table 2). The lowest number of species was observed in agroforestry parklands (4 species/survey). Shannon diversity index varied from 1.29 bit to 2.18 bit. It was high in the parts of the forest that had not been subjected to wildfire (2.18 bits), confirming the superiority of the average species richness in this land management method compared with the other two systems. The Pielou equitability index was higher in all three land management modes (ranging from 0.71 to 0.87), reflecting the high equipartition of the vegetation diversity in each of the land management modes.

Demographic and dendrometric characteristics of *T. indica* populations

Demographic and dendrometric parameters varied significantly with the land management method, as illustrated by the analyses of variance. (Table 2). The average population density of *T. indica* varied between 10 and 55 plants/ha. The highest numbers of individuals per hectare were found in the parts of the forest subjected to wildfire (55.33±4.27 N/ha) and those that had not been subjected to wildfire (41.62±4.70 N/ha); agroforestry parklands had the lowest value in terms of stocking density (10.19±1.62 N/ha). In terms of mean diameter, basal area and mean height, the agroforestry parklands contained *T. indica* trees with a large diameter (30.22±16.46 cm), with a basal area (0.96±0.06 m^2/ha) and height (7.93±2.79 cm) higher than in the parts of the forest subjected to wildfire and those not subjected to wildfire.

Structural characteristics of *T. indica* (Tamarind)

Distribution of T. indica individuals by diameter class

In general, the shape parameter c showed values between 1 < c < 3.6 of the *T. indica* adult populations in the three land management modes (Figure 3). This shows a straight asymmetric distribution characteristic of a predominance of young or small-diameter *T. indica* individuals. Diameter classes greater than 65 more very small or non-existent in the different management modes.

Distribution of T. indica individuals by height class

Examination of Figure 4 reveals a significant distribution of *T. indica* individuals in the height class between 2 and 6 m in the forests (87%) and 4 to 12 in the agroforestry parklands (98.04%), confirmed by the Weibull probability shape coefficient of between 1 and 3.6. This means that the majority of *T. indica* individuals in the parklands and forests are shrubs. There was also a significant presence of *T. indica* trees in the parklands, marking the tree stratum.

Potential and mode of regeneration of *T. indica*

T. indica has a very low regeneration potential (Table 3). It is very low in agroforestry parklands (2 seedlings/ha) and parts of forests subject to wildfire (3 seedlings/ha) compared with parts of forests that have not been subject to wildfire (7 seedlings/ha). This was confirmed by the regeneration rate, which was very low for all the different land management methods. *T. indica* regenerates mainly by two routes in the three land management modes. These are regeneration by seedling and regeneration by shoot. Regeneration by seedling is the most common method, accounting for 77.44%.

Assessment of the health status of *T. indica* populations

The results recorded in Table 4 summarize the health spectrum of *Tamarindus indica* under the land management methods. Assessment of the health status of the *T. indica* population as a whole revealed 38.71% healthy individuals, 49.41% cut plants, 11.49% attacked plants and 0.39% dead plants. In the agroforestry parklands, the proportions were slightly higher than in the forest areas.

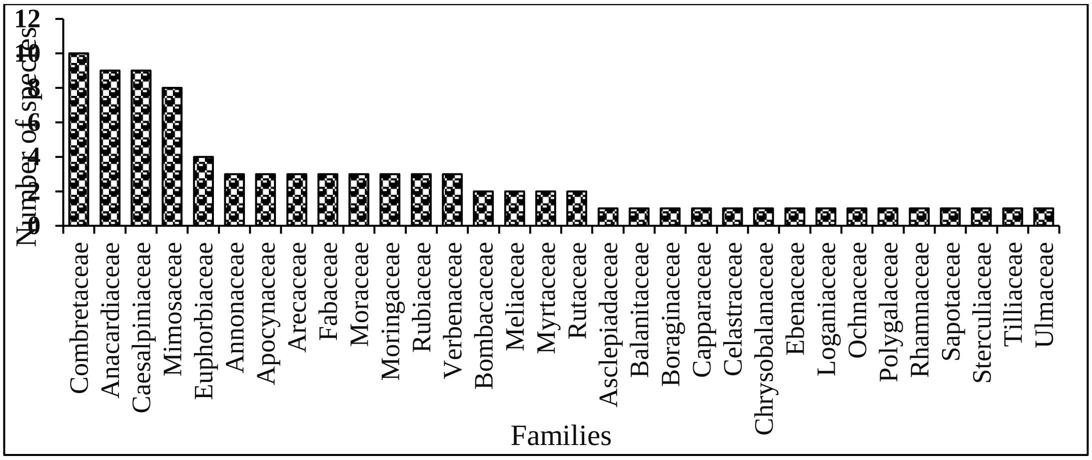


Figure 2: Spectrum of families of species inventoried.

Table 2: Variation in species richness and diversity according to land management method

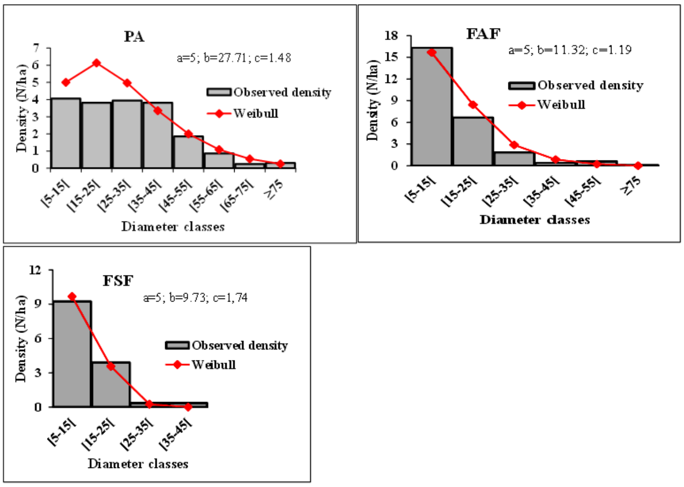
Parameters	PA	FAF	FSF
Average species richness	3,92±1,40[a]	5,41±3,02[b]	7,43±3,05[c]
Shannon index	1,29±0,08[a]	1,53±0,11[a]	2,18±0,09[b]
Piélou equitability index	0,80±0,02[a]	0,71±0,02[b]	0,87±0,02[a]

PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire. Averages followed by the letters indicated on the same line for each parameter are not significantly different according *(P>0,05)* to Tukey

Table 3: Variation in structural parameters according to land management method.

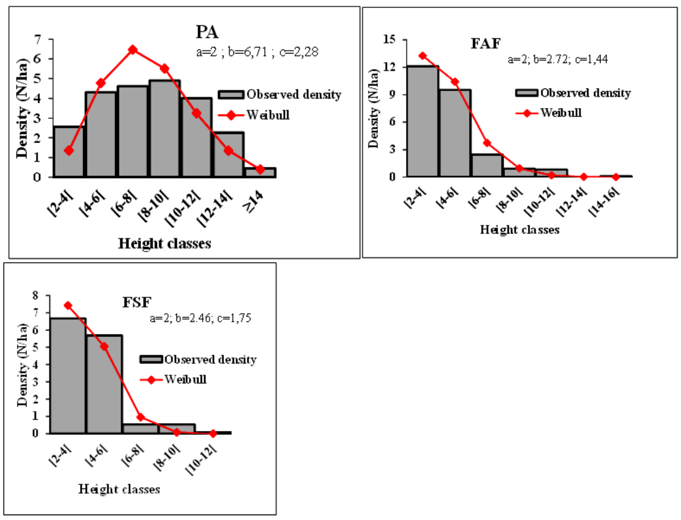
Parameters	PA	FAF	FSF
Average density (N/ha)	10,19±1,62^{a}	55,33±4,27^{b}	41,62±4,70^{c}
Average diameter (cm)	30,22±16,46^{a}	15,63±10,16^{b}	13,66±5,14^{b}
Average height (m)	7,93±2,79^{a}	4.44±1.9 4^{b}	4,08±1,36^{b}
Basal area ($m^{2\cdot}$/ha)	0,96±0,06^{a}	0,42±0,08^{b}	0,28±0,11^{b}
Average number of regenerations (seedlings/ha)	1,73±0,67^{a}	3,30±1,02^{a}	7,14±1,14^{b}
Regeneration rate (%)	21,72	14,86	44,16

PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire



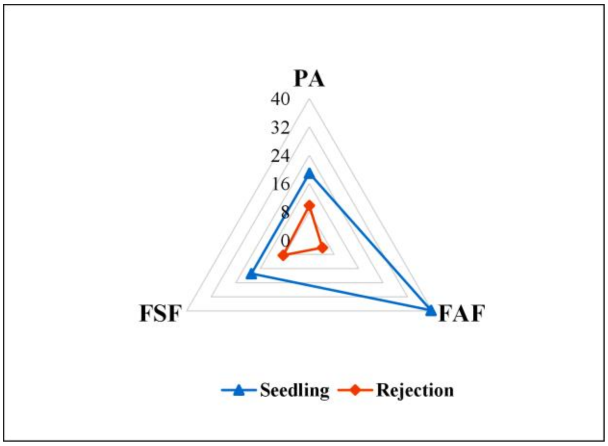
PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire

Figure 3: Horizontal structure of T. indica adult populations according to land management method.



PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire

Figure 4: Vertical structure of adult T. indica populations according to land management method.



PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire

Figure 5: Regeneration mode of *T. indica* according to land management method.

Table 4: Variation in the infestation rate of *T. indica* populations as a function of land management method.

Land management	Health status of *T. indica* populations			
	Healthy	Attacked	Cut	Deaths
Agroforestry parklands	42,76 %	11,84 %	45,07 %	0,33 %
Forest areas subject to wildfire	49,721 %	1,12 %	48,60 %	0,56 %
Parts of forests not affected by wildfire	30,80 %	3,13 %	65,63 %	0,45 %

PA=Agroforestry parklands; FAF=Part of forests subject to wildfire; FSF= Parts of forests unaffected by wildfire

DISCUSSION

Composition, richness and floristic diversity of woody stands of *T. indica*

The *T. indica* stands on the study is rich with 82 species, with a dominance of the Combretaceae family (10 species), Anacardiaceae (9 species), Caesalpinoideae (9 species) and Mimosoideae (8 species). This floristic richness differed according to land management methods; it was higher in the parts of the forest that had not been subjected to wildfire and lower in the agroforestry parklands, regarding the value of the Shannon diversity index. These results corroborate with those of Ndiaye et al. (2013), who also highlighted the impact of farming, livestock rearing and drastic climatic conditions on the modification of floristic composition, diversity and structure. The practice of farming in association with animals consists of deliberately sparing trees according to their importance by species in a well-defined area for the good development of crops. Added to this are vegetation fires, often late in the season, which decimate individuals of different species, particularly young seedlings. It should also be emphasized that agroforestry parklands bordering classified forests and created by farmers to introduce useful species that are inaccessible in these forests would not be able to contain more dense individuals than those in the forests. Thus, the land management method appears to be a factor that strongly influences the diversity and distribution of species in Sudanian plant formations. However, the results reveal a more balanced and homogeneous distribution of species for each of the three land management methods, as shown by the values of Pielou's equitability index. This also reflects the relatively low level of competition between species in the communities under the different modes.

Demographic and dendrometric characteristics of *T. indica*

The study of the various demographic and dendrometric parameters explains the conditions and state of *Tamarindus indica* stands under the three land management methods in western Burkina Faso. The distribution of densities according to land management mode is not uniform; they show significant variations (F=47.33; p<0.001). The average population density of *T. indica* in the different plant formations sampled varied from 10 to 55 plants/ha. Parts of forests subject to wildfire (55.33±4.27 N/ha) contained more *T. indica* individuals, followed by those that had not been subject to wildfire (41.62±4.70 N/ha) compared with agroforestry parklands where the density of plants was relatively low (10.19±1.62 N/ha). As reported by Bourou et al. (2011) and Bondé (2019), these results show that *T. indica* abounds favorably in the Sudanian zone. However, these densities are very different from those reported by Bondé (2019), who found less than 2 individuals per hectare regardless of land use. Moreover, they are comparable to those in ecological zones in Niger and Senegal and *T. indica* agroforestry parklands in Togo (Bourou, 2012; Garba et al., 2020; Samarou et al., 2022). Compared to some agroforestry species with high socio-economic importance, these densities are close to those of *Vitellaria paradoxa* C.F.Gaertn in agroforestry parklands (Bondé, 2019; Yaméogo et al., 2020) and *Parkia biglobosa* (Jacq.) G. Don in savannahs (Cissé et al., 2023).

Structural characteristics of adult populations of T. indica

The study of the structure of a plant species serves as a basis for its silviculture, guides forest economics and makes it possible to assess the state of degradation of its habitat. For *T. indica*, the agroforestry parklands contain large-diameter individuals with larger land areas and greater heights than the parts of forests subject to wildfire and those that have not been subject to wildfire. These differences could be explained by the fact that trees in agroforestry parklands benefit from fertilizer inputs to the soil and cultivation practices, unlike those in forests which, in addition to drastic climatic conditions, have to contend with wildfire, cutting and overgrazing. The diameter and height structure of *T. indica* in the three land management modes shows a positive asymmetric distribution of the species, characteristic of a predominance of young or small-diameter and low-height individuals, confirmed by the Weibull probability "c" shape coefficient between 1 and 3.6 (Garba et al., 2020; Samarou et al., 2022; Cissé et al., 2023). These structures indicate instability in *T. indica* stands.

Regeneration potential and mode of *T. indica*

The renewal capacity of populations of a woody plant species is an indicator of its state of health, its development and its state of reproduction in plant formations. Thus, the diameter and height structures of *T. indica* reveal that the species in these habitats have difficulty regenerating, as shown by the very low average number and rate of regeneration. These results could be explained by the lack of seed banks in the soil and their reduced viability. The tamarind is a wild tree whose fruit is much sought after and used in households as a dish, for the production of drinking juice and also in traditional medicine (Fandohan et al., 2011; Ganamé, 2014; Bondé et al., 2018; Garba et al., 2019). In addition to this, there are premature harvests, attacks on the fruit by insects and rodents, ageing populations of the species and the non-productivity of certain individuals, making seeds unavailable. It should be noted that *T. indica* regenerates more by sowing and by rejection. In addition to the drastic climatic conditions, the clearing of fields for the establishment of crops, vegetation fires and uncontrolled grazing are all factors that contribute to the reduction in the density of young plants of the species, and also of other species (Yaméogo et al., 2020). These results corroborate those of Garba et al. (2020) and

Samarou et al. (2022) in the Sudanian ecological zone.

Tamarindus indica health status

The tamarind tree is not spared from parasites and insect pests. The results of the health status assessment show that agroforestry parklands have the highest number of infested (8.59%), cut (18.23%) and dead (0.26%) individuals compared to forests. These results corroborate those of Ahamidé et al. (2017) and Yaméogo et al. (2020) who showed that the impact of Loranthaceae is more severe in fields than in protected areas. In fact, in the fields, fertilizer inputs to the soil and cultivation practices such as ploughing and weeding contribute considerably to the development of tamarind plants, increasing their flowering and fruiting, which are favorable conditions for the establishment, development and reproduction of Loranthaceae. This infestation of the tamarind tree could be encouraged by the openings or damage caused by cutting the tree. Compared with shea, the infestation rate of tamarind in plant formations is very low (Ahamidé et al., 2017). Furthermore, the high proportion of felling in agroforestry parklands is due to clearing and cultivation practices, in particular pruning and topping, to allows crops development for good yields (Yaméogo et al., 2020). On the other hand, in protected areas, notably the classified forests of Dindéresso and Kuinima, the technical environmental services have developed and implemented management systems involving local populations through cooperative societies and permanent agents such as ecoguards to monitor and protect these ecosystems (Traoré et al., 2022; Noufé et al., 2023).

Conclusion

This study has highlighted the influence of land management methods on the dynamics of *Tamarindus indica* in the South Sudanian zone of Burkina Faso. The results indicate an unstable demographic trend in the adult and juvenile populations. There are many factors causing the disturbances to the structure of *Tamarindus indica*. Bush fires, overgrazing, intensive organ harvesting and parasitic attacks are real threats to the development of the species' populations. This study revealed a floristic procession of 82 species divided into 65 genera and 33 families evolving with *Tamarindus indica*. The species is in difficulties of regeneration. This is due to the lack and short viability of seeds, as well as anthropogenic and climatic pressures. The work carried out revealed the impact of land management methods on the structure of the adult population of *Tamarindus indica*. It has also given us an insight into regeneration, which is characterized by low natural recruitment. All these results point the way towards sustainable management of *T. indica*.

COMPETING INTERESTS

The authors state that they have no competing interests to declare.

AUTHORS' CONTRIBUTIONS

IK is the principal investigator, responsible for the collection, analysis, and processing of the data, as well as the writing of the article. JY, AT, and MH, as supervisors of IK, contributed to the revision of the manuscript and approved its final version. IS granted permission for the use of field equipment available in the laboratory.

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