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How Diverse is Tree Planting in the Central Plateau of Burkina Faso? Comparing Small-Scale Restoration with Other Planting Initiatives

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Abstract: In the Sahelian region, different approaches are being used to halt environmental degradation and restore tree cover, with varying degrees of success. Initiatives vary according to projects' objectives, type of land to restore, and technical practices used (natural regeneration, farmer-managed assisted regeneration, enrichment planting, etc.). This study investigates tree planting choices and selection of tree seed sources in some villages of the Central region of Burkina Faso. The study targeted 96 farmers and compared planting practices adopted by farmers involved in small-scale forest restoration using fences, with those not involved in this initiative. The objective was to understand what portfolio of tree species were planted, what factors influenced tree species selection, what tree seed sources were used, what collection practices were generally adopted, and whether there were significant differences between types of farmers. The results showed that the use of fencing to promote forest restoration support the planting of a more diverse portfolio of tree species than other small scale efforts and includes a greater representation of indigenous trees. Fenced plots have therefore a conservation value in landscapes where the diversity of tree species is progressively declining. In addition to the use of fences, some other key factors affect tree planting, mainly land tenure, availability of diverse tree seed sources, and availability of land. Farmers tend to collect directly most of the planting material they need, but in the majority of cases they do not follow recommended best practices. In light of the ambitious forest restoration targets of Burkina Faso and the need to provide diverse options to rural communities to enhance their resilience vis-à-vis increasing environmental challenges, strengthening the capacity of farmers in tree planting and establishing a robust tree seed systems are crucial targets.

Keywords: Tree species diversity; forest landscape restoration; tree seeds; fencing; exclosure; NTFPs

1. Introduction

In the face of worldwide increasing deforestation and forest degradation, global initiatives have been launched to support large-scale forest restoration. The Bonn Challenge, set by the UN Convention on Biological Diversity (2011–2020), identified the bold goal of restoring at least 150 million hectares of the world's degraded ecosystems by 2020. This initiative was later extended by the New York Declaration (2014) to a target of 350 million hectares by 2030, and regional implementation platforms, such the AFR100 for Africa.

Forests cover approximately 5.3 million ha in Burkina Faso and represent circa (ca.) 20% of the country's land area, to which ca. 4.8 million hectares (ha) of other woodlands can be added [1]. Between 1990 and 2015, Burkina Faso lost 21.8% of its forest cover and the remaining area has been subjected to fragmentation [2]. In sub-Saharan Africa, rapid population growth and poverty constitute the main drivers of change in land use [3,4]. Under severe pressures due to overexploitation and climate change, woodlands and tree savannas are degrading into wastelands [5]. Northern Burkina Faso is part of the Sahel Belt, which is losing forest annually to desertification. Climate change will pose increasing challenges affecting temperature and rainfall regime, threatening the long-term adaptation of tree species.

Forests and woodlands have important biological and socio-economic roles, especially in arid lands [6]. Dry forests in Burkina Faso provide approximately 25% of the household incomes in rural areas and most households rely on fuelwood as a source of energy [7–9]. Dry forests also provide important environmental services and goods such as fruits, fodder, honey, and medicines [10]. Moreover, they serve as a buffer during drought-related crises and offer food and fodder for communities [11].

Forest management and restoration are often seen by the stakeholders as an opportunity to protect ecosystems while raising social benefits (e.g., plantations of fruit trees to increase food security and nutrition quality). The Burkinabè government, local authorities, local communities and non-governmental organizations (NGOs) are investing resources in forest restoration to contain desertification in the Sahel and improve the sustainable use of natural resources. Burkina Faso is one of the countries involved in the Great Green Wall (GGW) initiative, promoting soil and forest restoration. In a recent assessment bythe GGW office, approximately 5 million hectares of land could be targeted by restoration initiatives. The country is also participating in REDD+ -related initiatives, still in an early phase of implementation.

The large extension of degraded lands requires implementing cost-efficient methods for forest restoration tailored to the characteristics of the types of land targeted (e.g., forest land; protective land and natural buffers; agricultural land) [12]. Furthermore, restoration of vast areas of wastelands requires addressing and overcoming risks of failure associated with political and socio-economic aspects (e.g., land tenure and property rights, conflicts among different groups) and technical aspects (such as the quality and the composition of the materials planted, and the processes needed to restore a self-sustaining ecosystem) [13,14].

In the Sahelian region, a range of forest restoration projects have been set in place at different scales, promoted by various initiatives, from locally driven small projects supported by NGOs and associations, to larger regional programmes promoted by international organizations. They have involved smallholder farmers, community organizations and land owners with larger properties. Different approaches have been used, according to projects' objectives and type of land to restore, ranging from communal forest management, improvement of pastures, sustainable exploitation of forest resources through the adoption of improved ovens (which limit the consumption of fuelwood), to extensive tree planting and the adoption of traditional soil management practices [15]. Farmer-managed assisted regeneration, where trees are pruned, coppiced, and protected by farmers, has been successfully implemented on a large scale in Niger and other Sahelian countries [16]. In Burkina Faso, the association tiipaalga, involved in this study, has promoted a household-based approach based on the establishment of enclosures around targeted areas to trigger tree regeneration processes. Similar measures have been adopted to safeguard tree plantations [17]. Different strategies and approaches are currently being used to halt environmental degradation and restore a tree cover, with varying degrees of success.

One factor that increases the success of forest restoration efforts is involving local people in their design, implementation and monitoring. But reports from different geographic contexts indicate that this is not done systematically despite it being critical to the efforts' success [18,19]. Including the differentiated needs of different groups within the community (e.g. women, disadvantaged groups, migrants, including both pastoralists and agriculturalists) not only boosts chances of success, but also leads to more equitable outcomes regarding who benefits from the restored lands [20]. Participation of farmers in tree planting initiatives and natural resource management has been identified as a pillar in the national reforestation policy of Burkina Faso and is part of the strategy of numerous NGOs. The plantations of trees in the fields of the farmers and the management of species-rich parklands can contribute greatly to the conservation of forest genetic resources, by connecting fragments of remaining woodlands and reducing the pressure of local populations on forest resources [21].

Evidence from a global review of forest and woodland restoration efforts indicates that the success of the huge global investment in forest restoration is threatened by a tendency to neglect tree intraspecific and interspecific diversity [22]. Restoration usually does not use a wide mix of tree species, and even more rarely a wide range of varieties of the same tree species [23,24]. This reduces the chances of long-term viability of the restored ecosystems. However, despite the general poor adoption of best practices, the growing global interest to support reforestation and forest restoration is accompanied by interest in using native plant material and in selecting appropriate genetic planting stocks [3,25–27]. Using locally adapted native tree species reduces the need for inputs such as water or fertilizers. This allows people to choose tree species culturally suited to specific contexts, land-uses, and market niches. Selecting and using good quality sources of forest reproductive material ensures better and more consistent quality of products.

One of the reasons why tree diversity is neglected in ecosystem restoration is that good quality planting material is not available to the farmers and nursery owners who need it [28], or it is not available in sufficient quantities. In addition, in Burkina Faso, many multipurpose indigenous tree species have not been sufficiently characterized to enable a proper selection and supply of planting material, despite their significant contributions to food security, nutrition, medicine, wood and a number of processed products for income generation.

In order to understand the potential future trajectories of forested landscapes in Burkina Faso, under the impulse provided by different factors (e.g.,. funding opportunities, general awareness of rural communities, role of local institutions) we examined and compared tree planting activities in selected villages of the Central region of Burkina Faso. This study focused on the following questions:

- What are the main processes through which the forest cover is maintained or restored in the landscape?
- What is the portfolio of tree species planted?
- In case of active planting by farmers, what factors most influence tree species selection?
- In case of tree planting, what are the main seed sources used and the collection practices adopted?

2. Materials and Methods

2.1. Study Sites and Sampling

The survey was conducted in 31 villages spread across the Kadiogo, Oubrintenga, Kourwéogo, and Boulkiemdé provinces, located in the Centre, Centre-West and Plateau Central regions of Burkina Faso (between 12°11′ and 12°48′N, 2°6′ and 0°54′W; Figure 1) with an average population density of 681, 86 and 58 inhabitants/km^2 [29] respectively. In all study sites, Mossi were the main ethnic group, followed by Fulani, Bissa, and Samo.

The study sites are characterized by flat terrains with few rocky hills ranging from 310 to 340 m above sea level. All selected villages were located in the North Sudanian climatic region, with an annual rainfall between 600 and 800 mm, concentrated mainly from May to October. The prevalent mix of land uses includes traditional agroforestry systems (parklands), other woodlands and pastures. The main cultivated crops are cereals (millet, sorghum, maize) and cash crops (e.g., sesame, peanut). Extensive animal husbandry is largely practiced, primarily by the semi-nomadic Fulani.

Figure 1. Map of the study sites.

Out of the 31 villages selected, 20 were targeted by activities of the association tiipaalga (headquartered in Ouagadougou), focused on sustainable use of natural resources. The activities implemented by tiipaalga included the promotion of improved ovens, distribution of microcredits for the development of value chains around non-timber forest products and capacity building of farmers in sustainable agricultural practices. The remaining 11 villages were selected based on two main criteria: a presence of farmers actively involved in tree planting and a low degree of externally driven interventions targeting sustainable forest management. By sampling these three groups of farmers, we covered a diversified set of contexts in which tree planting take place (e.g., with and without support of projects' interventions to establish fences, with and without exposure to best practices promoted by NGOs, etc.) and could examine the potential different modalities through which tree planting takes place (e.g., different choices of tree species and seed sources, different constraining factors).

A total of 96 farmers were interviewed across the 31 selected villages during two periods in the field, in April–June 2017 and in February–April 2018. In both cases, interviews were conducted mainly during the dry seasons to benefit from a greater availability of farmers. The low proportion of women interviewed is because local customary practices tend to exclude women from tree planting. Farmers fell into three main groups, based on the following characteristics:

1. Group 1: farmers partnering with the association tiipaalga in the establishment of small fenced plots = 48 farmers (43 male individuals, 4 female groups).
2. Group 2: farmers in the same villages as those above, but not involved directly in activities promoted by tiipaalga and without fences = 24 farmers (all male individuals).
3. Group 3: farmers in villages other than those above, not exposed to the activities promoted by tiipaalga and not reached by externally driven interventions promoting sustainable forest management, selected based on the indication of local forest officers = 24 farmers (23 male individuals, 1 female individual).

2.2. Data Collection

After establishing a contact with traditional local authorities, focus group discussions (FGDs) were organized in a representative sample of five villages to obtain preliminary information on the topics of investigation and to refine the questionnaires for individual interviews. Participants to the FGDs were selected based on their involvement in tree planting or knowledge of tree nursery practices. When possible, old villagers were involved in FGDs to better assess changes over time in the forest cover surrounding the selected villages. The FGDs were structured around questions on land tenure, access to forest resources, tree planting and management, and the perception on the conservation status of important tree species. Between 4 and 17 peoples participated to each of the FGDs.

In each village, a focal point helped in the organization of the survey. The focal point helped targeting farmers with fenced plots, in villages where tiipaalga was active, and farmers with the ideal profile and experience in other villages. In addition, at the end of each individual interview, the selected farmer was asked to put the research team in contact with other farmers known for being active in tree planting. The relatively low number of farmers interviewed per village is due to the limited extent of tree planting in the regions examined, so the sample is representative of the dynamics researched.

The individual questionnaire was focused on the following aspects: a description of on-farm productive activities, land tenure and land use, tree planting practices, preferred species, seed sources, constraints faced by farmers in tree planting, and social networking activities in relations to some specific on-farm activities. Both FGDs and individual interviews were conducted in the native language of the respondents (mooré) by the first author with help of a translator who assisted in field work, previously trained on the content of the survey. When interviewing representatives of women's groups, one woman always accompanied the interviewer to facilitate more open communication. Individual interviews and FGDs were all tape recorded after obtaining consent.

2.3. Data Analysis

The diversity of tree species planted in farmers' fenced plots and fields was defined by four variables: number of species, number of trees per hectare, proportions of exotic species, and proportions of exotic tree individuals. In addition, a total of 19 categorical variables (see Table 1), which constituted the structure of individual questionnaires, were used to define attributes of the respondents. Finally, the different types of seed sources used by farmers were characterized based on the provider, the entity responsible for collection, the type of land where seed collection takes place, and the type of access to the seed source.

Data were analyzed in R program version 3.5.1 [30]. The Wilcoxon-Man-Whitney test was used to compare mean values of the four variables related to tree planting, given that not all variables had a normal distribution, and the Chi-Squared test was used to compare the frequency of the different tree species planted. To explore patterns of planted tree diversity in farmers' fenced plots and fields, we used a Multiple Correspondence Analysis (MCA). The analyses enabled to reveal similarities in the diversity and type of tree species planted in farmers' fenced plots and fields and were performed using the FactomineR and Factoextra packages [31]. For the MCA analysis, the four variables used to characterize tree planting choices were utilized to define the Euclidean space and the 19 categorical variables were set as passive.

To reveal what factors seemed to have most influence on the patterns observed in planted tree diversity in farmers' fenced plots and fields, we used a Random Forest analysis, performed using the Party package [32]. Four models were developed, one for each of the variables describing tree planting practices. The models predicted the likelihood of observing certain planting practices being set in place by a farmer (as defined by each of the dependent variables) by looking at the set of critical attributes considered potentially influential in determining farmers' choices regarding tree planting (19 explanatory variables; Table 1). The out of bag score (OOB) indicated the predicting power of the model (the lower the value, the better the model). We generated a permutation score to assess correlations between variables, considering relevant all factors scoring above 0, the higher the permutation score, the higher the weight in the model [33]. Barplots were generated using ggplot2 packages [34]. Information of the main tree seed sources used by each farmer and by type of species planted was collected, analyzed, and frequencies were presented.

Table 1. List of the 19 variables structuring individual questionnaires, considered to have an influence in determining farmers' choices regarding management of natural resources, including tree planting. The variables were used for constructing the four models in the Random Forest analysis.

Variable	Abbreviations	Descriptions
Size of the household	Household	Number of people living in the household
Land size	Surface	Surface of land owned, including fallow
Secondary activity	Secondary_activity	Activities supplying important income in addition to crop cultivation and husbandry (e.g., tree planting, establishment of commercial nurseries and off farm jobs).
Indigenous knowledge	IK	Farmers' knowledge was tested by posing questions about tree species uses, tree species used in the past and disappearing from the landscape. The total number of species emerging from this exercise was used as a proxy for defining individuals' knowledge on tree species.
Education	Education	Level of education of the farmer. Religious education has been considered as primary education.
Constraints in seed supply	Seed_supply	Number of different type of constraints reported by the farmer interviewed in getting an adequate (meeting demand) supply of seed
Constraints due to seed price	Seed_price	High seed and seedlings price reported as a limiting factor in accessing forest reproductive material by the farmer.
Constraints in availability of seed of some tree species	Seed_avaibility_sp	Lack of availability of seed and seedlings of some desired tree species.
Other types of constraints concerning access to tree seed sources	Seed_other	Limitations faced by farmers in accessing tree seed, other than seed price or seed availability for certain tree species
Remoteness of the village	Remoteness	Distance between the town hall of the municipality and the first paved road.
Municipality of intervention of tiipaalga	Municipality	Presence or not of farmers assisted by tiipaalga in setting up fenced plots and other agroecological practices in the same municipality of the interviewed farmer.
Fences	Fences	Direct support received from tiipaalga by the farmer interviewed for fencing his plot.
Termites	Termites	Issues due to termites affecting planted trees reported by the farmer interviewed.
Wildfire	Wildfire	Issues due to wildfire reported by the farmer interviewed.
Tree planters' groups or associations	Tree_planter_grp	Affiliation to an informal group or an official association of tree planters jointly involved in tree planting efforts (nurseries, tree plantations, etc).
Autoproduction of seedlings	Autoproduction	Own production of seedlings by the farmer interviewed.
Presence of private commercial nurseries	Privates_nurseries	Presence of at least one private nursery, most commonly run by one individuals, producing seedlings for his own use but also for selling within the same municipality of the interviewed farmer.
Capacity	Capacity	Whether or not the farmer interviewed had training in seed harvesting and/or in establishing a nursery.
Contact with organizations/institutions	Contacts	Whether or not the farmer interviewed had contact with institutions supporting farmers in tree planting.

3. Results

3.1. Diversity of Tree Species Planted in Farmers' Plots

On average, the farmers interviewed owned 11.8 hectares of land, mainly acquired through heritage (in ca. 93% of cases). All women's group gained access to land through informal renting agreements. All farmers interviewed belonged to the Mossi ethnic group, except for one Fulani farmer. Around 54% of the farmers interviewed had not received formal education.

A total of 65 tree species were collectively planted by all farmers interviewed. Of these tree species, 55 were found across farmers in Group 1, 35 across farmers in Group 2, and 27 across farmers in Group 3.

Farmers in Group 1 have planted more species than farmers in Group 3 (Table 2, Table S1 in Supplementary Materials), while differences between Group 2 and 1 and Group 2 and 3 were not significant. The density in trees planted was not significantly different across the three groups. Within groups variation in the number of trees planted/ha was pronounced, especially in Group 2. Farmers in Groups 1 planted fewer exotic tree species than farmers in Group 3, or in Group 2 and 3 combined, while no significant difference in the proportion of exotic tree species between Group 1 and Group 2 was observed. Furthermore, farmers in Group 1 planted fewer individuals of exotic tree species than Group 2 and 3 examined alone or combined.

Table 2. Mean and standard deviations of the four variables used to assess tree plantation practices of the three groups of farmers. For the three groups, couples of values marked with the same letter and an asterisk are significantly different from each other, (Wilcoxon Mann Whitney test; p value < 0.05). Values with the same letter and no asterisk are significantly different with p value < 0.1 (this second cut-off value was used to detect patterns, despite the small size of the sample). Group 1 = farmers with fences; Group 2 = farmers without fences, in the same villages as Group 1; Group 3 = farmers without fences, in different villages from Group 1 and 2. Group 2 + 3 = it includes all farmers without fences, as opposed to farmers with fences in Group 1.

Categories of Farmers	Total Number of Tree Species Planted	Number of Trees Planted/ha	Exotic Tree Species Planted (%)	Number of Exotic Trees Planted (%)
All farmers (n = 96)	6.41 ± 3.75	267.12± 735.84	56.60 ± 25.50	55.30 ± 39.61
Farmers in Group 1 (n = 48)	7.18 ± 4.34 (a,b)	213.36 ± 283.13	50.28 ± 24.15 (c,d*,e*)	36.68 ± 35.81 (f*,g*,h*)
Farmers in Group 2 (n = 24)	5.96 ± 3.56	424.76 ± 1353.29	63.40 ± 27.84 (c)	64.26 ± 30.90 (f*)
Farmers in Group 3 (n = 24)	5.33 ± 2.10 (a)	217.04 ± 454.61	62.40 ± 23.47 (d*)	83.56 ± 26.46 (g*)
Farmers without fences (Group 2 + 3) (n = 48)	5.95 ± 3.62 (b)	316.17 ± 994.21	61.68 ± 25.06 (e*)	72.44 ± 34.78 (h*)

The two tree species most commonly planted by all farmers were exotics: *Mangifera indica* L. and *Eucalyptus camaldulensis* Dehnh. (Figure 2). *Azadirachta indica* A. Juss. was much more favored by farmers of Group 3 than by those in the other groups.

Out of the 15 most planted tree species, seven were indigenous, with the first indigenous tree species, *Acacia senegal* L., found in third position in the overall ranking. It was planted more densely in fenced plots to create a natural barrier all around the plot and progressively replace the artificial fence when damaged (Figure 2). The second and third most planted indigenous trees were *Parkia biglobosa* Jacq. and *Adansonia digitata* L., the first planted by significantly more farmers of Group 1 than by other groups. Indigenous tree species were more frequent in fenced plots (e.g.: *Parkia biglobosa* Jacq. and *Adansonia digitata* L.) than in plots without fences.

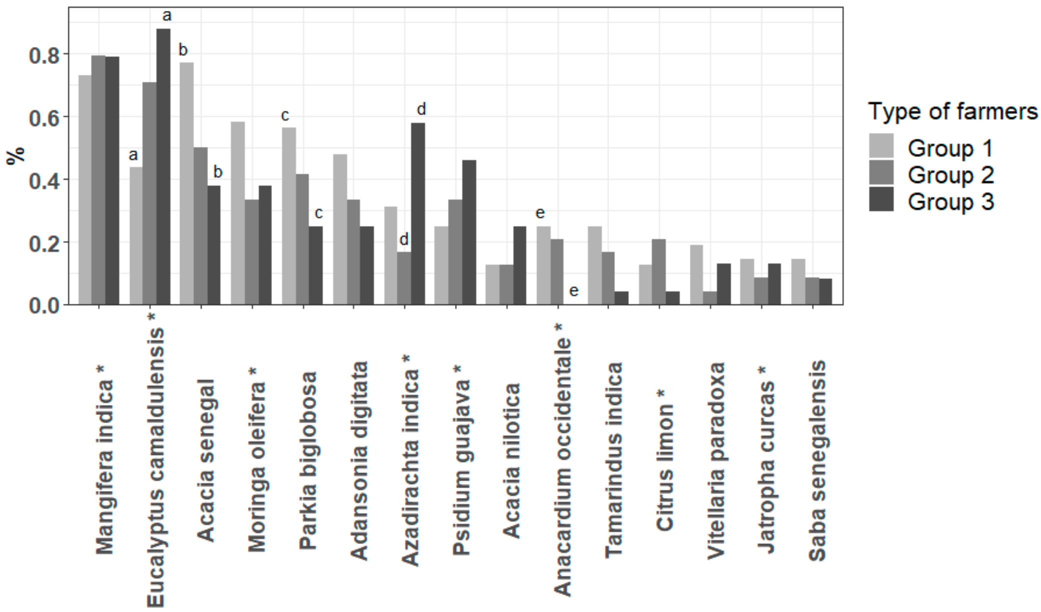

Figure 2. The 15 most frequently planted tree species and the percentage of farmers planting them in each of the three main farmers groups identified: farmers with fences (Group 1), farmers without fences in the municipality of action of tiipaalga (Group 2), and farmers without fences in a different municipality from those where tiipaalga is active (Group 3). Tree species with an asterisk are exotics. Values associated to bars with the same small letter are significantly different from each other (Chi-Square test, p value < 0.05).

Of the 15 most commonly planted tree species, 10 supply edible products, two are used for construction, and three are planted for fencing. In total, 10 species had a considerable market demand and were a significant source of income for the household. Looking at the overall total number of tree individuals planted by all farmers, 49.8% had a commercial use, 37.3% were used for fencing, 4.5% had nutritional value, and 4.2% medicinal value (Figure 3).

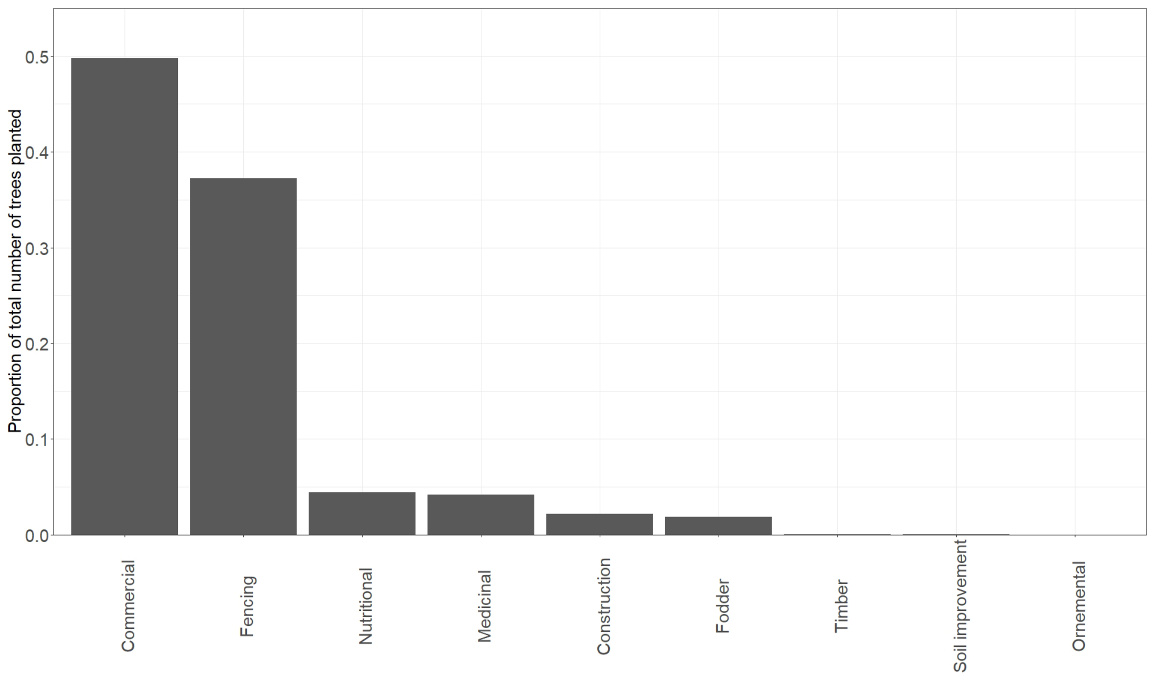

Figure 3. Proportion of trees planted according to the primary use of the species, as defined by farmers, with integration of information derived from scientific literature. The sum of all categories gives 100%.

3.2. Factors Influencing the Diversity of Tree Species Planted by Farmers

Each point in the MCA bi-plot (Figure 4) corresponds to a farmer (an individual in case of male farmers, a group of individuals in case of female farmers, except one case). The position of each farmer/farmers' group on the biplot was defined by the four variables describing the tree planting practices adopted by each: number of tree species planted, density of trees planted, proportion of exotic tree species planted, percentage of individuals of exotic tree species planted. The first two dimensions of the MCA explained 45.2% of the variance and three main groups of observations emerged. Points positioned on the left-hand side of the bi-dimensional space represent farmers who planted a low number of trees in their plots, mainly of exotic species; points clustered on the right side, lower quadrant, represent farmers who planted many tree species, mainly indigenous; points clustered on the right-hand side, upper quadrant, represent farmers who planted many tree individuals/ha, mixing native and indigenous trees in similar proportions.

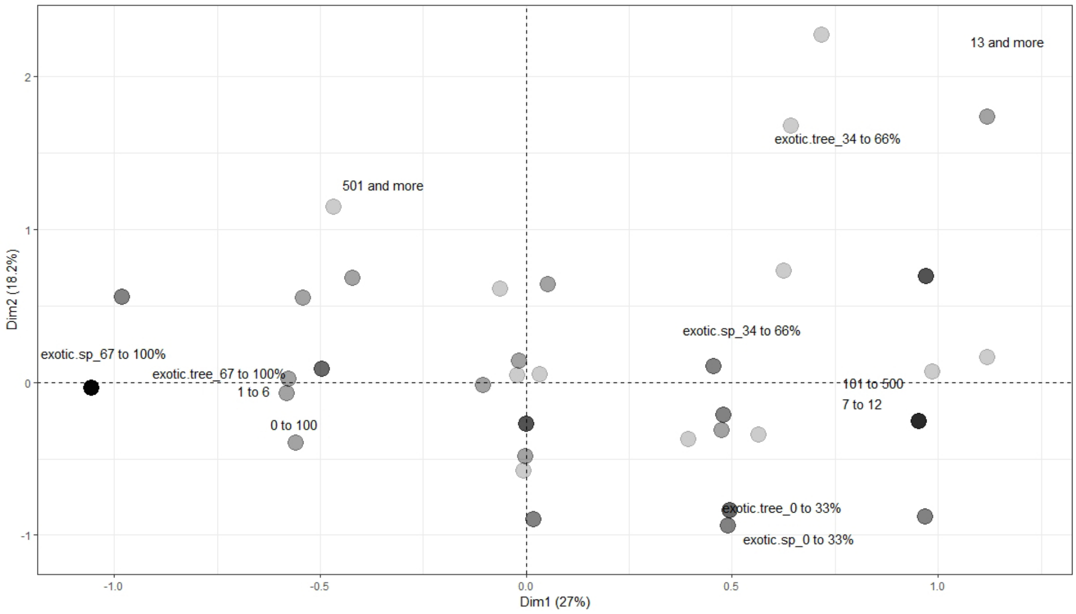

Figure 4. Multiple Correspondence Analysis (MCA): each point corresponds to a farmer interviewed and its position relates to tree planting choices of each farmer interviewed. Darker points correspond to overlapping observations.

The variable that most contributed to axis 1 in the MCA was the percentage of exotic tree species planted (declining from left to right and corresponding to a relative increase in indigenous tree species among those planted). The variable that most contributed to axis 2 was the percentage of exotic individual trees planted (declining from the upper part to the lower part of the graph, coupled by a relative increase in the number of individuals of indigenous tree species planted versus exotics) (Table 3).

Table 3. Contribution of the four variables used to characterize farmers' tree planting practices to axis 1 and 2 of the Multiple Correspondence Analysis. Figures in bold have the highest values.

Variable	Axis 1	Axis 2
Number of tree species planted	24.53	24.31
Number of individual trees planted/ha	21.21	12.33
Percentage of exotic tree species planted	**29.17**	22.56
Percentage of exotic individual trees planted	25.09	**40.80**

By fitting the random forest without explanatory variables, the predictions will be wrong in 66.67% of the cases, so OOB scores for the four models indicate that the predicting power of the model increases significantly using the explanatory variables identified. The model with the best predictive power was the one predicting the percentage of exotic tree individuals planted (Table 4). The variable that most influences this aspect was the fencing of the planting site. The second most accurate model was the one explaining the diversity of tree species planted. In this case, the most critical variables affecting the choice of how many tree species to plant were the constraints found in accessing diverse seeds. According to the other two models, which have lower predictive power, fencing was the most important variable affecting the percentage of exotic tree species planted, while the density of tree planting was affected mainly by the size of the land available to the household. Capacity was a significant variable in three out of four models.

Table 4. Permutation score of all the most relevant independent variables in the four random forest models developed, one for each of the four dependent variables. The out of bag score (OBB) indicates the proportion of wrong predictions obtained using each model from 5000 runs of the model.

Independent Variable	Permutation Score
Number of tree species planted	
OOB: 40.62%	
Constraints in seed supply	3.30 $^{-2}$
Tree planters' groups or associations	2.96 $^{-3}$
Termites	9.89 $^{-4}$
Presence of private commercial nurseries	1.77 $^{-4}$
Secondary activity	1.37 $^{-4}$
Density of tree planting	
OOB: 51.04%	
Size of the household	1.53 $^{-2}$
Constraints in seed supply	1.08 $^{-2}$
Capacity	1.04 $^{-2}$
Secondary activity	6.40 $^{-4}$
Land size	1.94 $^{-4}$
Percentage of exotic tree species planted	
OOB: 47.91%	
Fences	4.58 $^{-2}$
Autoproduction of seedlings	2.99 $^{-2}$
Capacity	1.27 $^{-2}$
Contact with organisation	7.49 $^{-4}$
Presence of private commercial nurseries	5.03 $^{-4}$
Constraints in seed supply	1.31 $^{-4}$
Percentage of exotic tree individuals planted	
OOB: 35.42%	
Fences	1.08 $^{-1}$
Municipality of intervention of tiipaalga	1.69 $^{-2}$
Remoteness of the village	1.09 $^{-3}$
Indigenous knowledge	4.80 $^{-4}$
Capacity	1.89 $^{-4}$
Land size	3.43 $^{-5}$

3.3. Tree Seed Sources Used by Farmers

Our study revealed that the farmers interviewed obtain seed from diverse sources (see Table 5). Most of the tree seed used (47.1%) derived from direct collection by farmers from plantations, fields, woodlands, and fenced plots. About 31.2% of the seed used came from sources in which seed collection was carried out by trained staff (NGOs, National Tree Seeds Center—CNSF), forest department), thus potentially of higher quality. Finally, around 21.7% of the seed used came from informal sources, which included small private nurseries, seeds brought from Ivory Coast by migrant workers, the local market, and large seed companies (whose seed supply is also largely not registered).

Table 5. Categories of tree seed sources used by farmers for tree planting. Seed sources are presented based on the expected level of compliance with best practices in seed collection. (*) Although trees found across farmers' fields have a specific owner, seed collection happens almost freely; it is sufficient to ask permission to collect seed from trees on land belonging to others and this is rarely refused. (**) More than one seed source could be indicated by each farmer, so the total is more than 100%. Figures in bold have the highest values and are above 50%.

Type of Seed Sources	Responsibility for Seed Collection	Type of Access	Description	Farmers Using Each Source (%) (**)
Fields	Farmer	Open (*)	Seed collected by a farmer on his farmland	**58.33**
Plantations	Farmer	Own source	Commercial plantations of tree species	33.29
Woodlands	Farmer	Open	Fallow and forest land with significant forest cover	31.25
Fenced plots	Farmer	Own source	Plots fenced with the support of tiipaalga	10.42
NGOs	Officially trained staff	Own source	Donation by NGOs and associations (in our samples of farmers an important provider is the association tiipaalga)	42.71
Forest department	Officially trained staff	Purchase	Donation of local forestry officers	25.00
CNSF	Officially trained staff	Purchase	National Tree Seed Center of Burkina Faso	7.29
Local nurseries	Staff without official training in most instances	Purchase	Private nurseries found within a range of 20 km from the planting site	**57.29**
Nurseries in Ouagadougou (capital city)	Unclear whether collection has been carried out by trained or untrained staff	Purchase	Nurseries in the main city, Ouagadougou, with greater availability of a diversity of tree species and cultivars compared to local nurseries	33.33
Market	Unclear whether collection has been carried out by trained or untrained staff	Purchase	Sellers on the market of the municipality	23.96
Other	Unclear whether collection has been carried out by trained or untrained staff	/	Seeds coming from private companies, seed bought abroad or supplied by relatives returned from Ivory Coast	1.25

Fields and private nurseries were the seeds sources used by the largest proportions of farmers (Table 5). The markets, forest department, and woodlands were also sources used by an important proportion of the farmers. Woodlands were the most diverse source in terms of number of tree species from which seed is collected (16 tree species are exclusively collected from woodlands, including 10 medicinal tree species; Figure 5a). On the other hand, seed of only a few species was collected in tree plantations. However, plantations represent the sources where the largest quantities of seeds were sourced (Figure 5b). Private nurseries and NGOs constituted additional significant sources in terms of size of the seed supply. The NGOs, fenced plots, woodlands, CNSF and other seeds sources provided most of the seed of indigenous species, while the market, plantations, and forest department were sources that primarily provided seed of exotic species (Figure 5c).

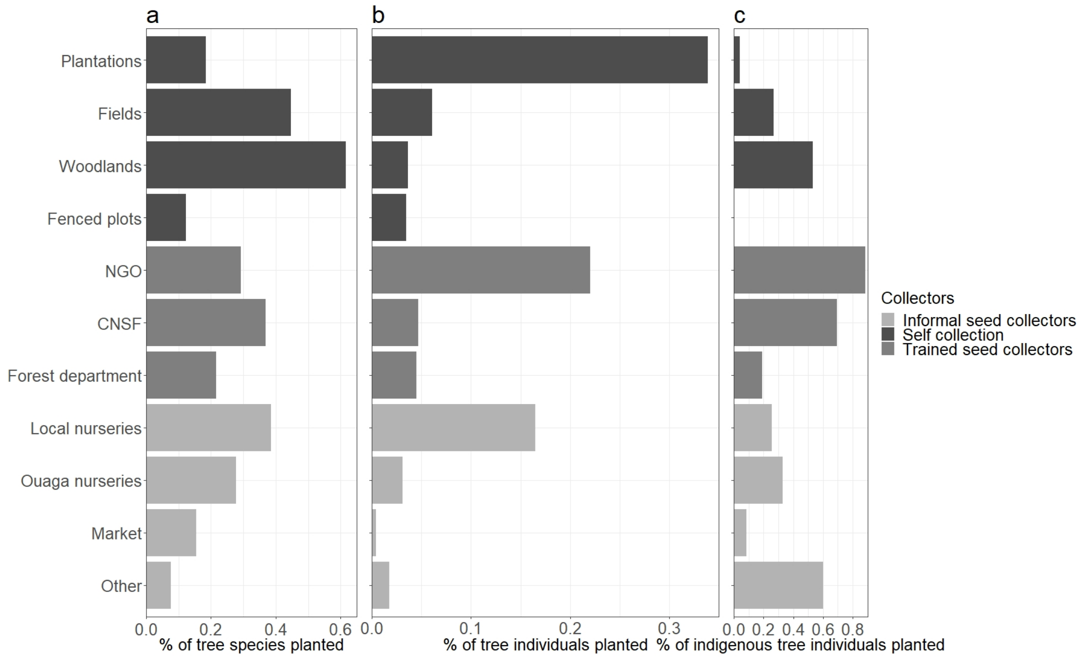

Figure 5. Barplots representing (**a**) percentage of the overall 64 tree species planted by type of source, some species being present in several categories (the sum is more than 100%), (**b**) percentage of tree individuals planted by type of seed source (the sum of all seed sources equals 100%), (**c**) percentage of indigenous tree individuals by type of seed source (the sum is more than 100%), Three categories of seed sources (characterized by different colors) are identified based on the expected level of training of seed collectors.

In total, 52% of the farmers are harvesting their own seeds and producing their own seedlings. For each species, different seed sources are privileged (Figure 5c, Figure 6). Most of the seeds of *Adansonia digitata* are sourced in the fields or woodlands, while most of the seeds of *Mangifera indica* are supplied by informal sources and seeds of *Moringa oleifera* are supplied mainly by NGOs and the forest department.

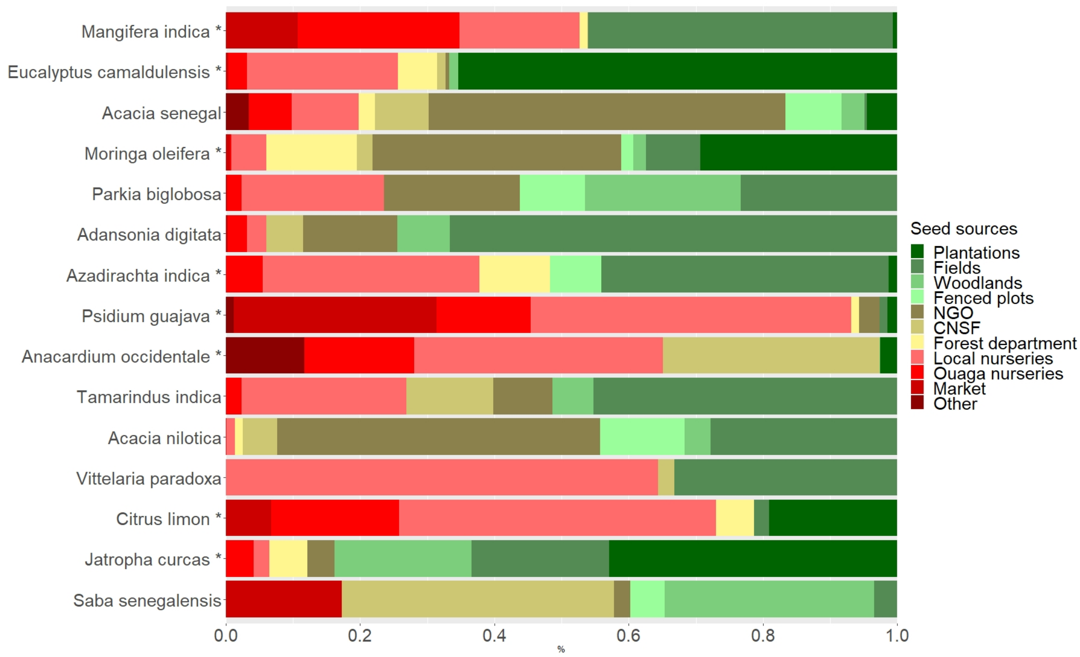

Figure 6. Barplots representing the proportions of the seeds coming from the different types of sources for the 15 most frequently planted species.

Information was collected on the criteria used by farmers in identifying tree seed sources from which to collect seed. It emerged that farmers base their selection of mother trees on seven main traits (Table 6). They primarily screen characteristics of individual mother trees (mainly health conditions of a tree, followed by fruit taste and productivity). A minority of farmers stated that they take into account characteristics of a tree population, not just of a single individual, when looking for mother trees (Table 6).

Table 6. Criteria for choosing mother trees based on the number of citations of each criteria by farmers directly involved in seed collection, in each of the three different farmers' groups. More than one criteria could be mentioned, so the total in each column is more than 100%. Others = ripeness of the fruits, shape of the fruits, similarity of soils conditions with planting sites. Group 1 = farmers with fences; Group 2 = farmers without fences, in the same villages as Group 1; Group 3 = farmers without fences, in different villages from Group 1 and 2.

Criteria	All Farmers (%)	Group 1 (%)	Group 2 (%)	Group 3 (%)
Good health of the mother tree	84	84	100	71
Taste of the fruits of the mother tree	62	64	64	57
Productivity of the mother tree	64	64	82	50
Non-isolated mother tree	12	16	9	7
Minimum number of trees available to collect seed from	12	20	9	0
Trees located at a minimum distance from each other	6	12	0	0
Phenotype of the mother tree	10	4	27	7
Phenology of the mother tree	4	8	0	0
Others	16	16	9	21

About 69% of the farmers interviewed reported constraints in accessing seeds in adequate amounts (see Table S2). The most cited limitations were excessive seed price and the limited availability of seed of desired species (Table 7).

Table 7. Different issues affecting tree seed supply and frequency of citation of each issue by the different farmers directly involved in seed collection, in each of the three farmers' groups interviewed. More than one criteria could be mentioned, so the total in each column is more than 100%. Group 1 = farmers with fences; Group 2 = farmers without fences, in the same villages as Group 1; Group 3 = farmers without fences, in different villages from Group 1 and 2.

Factors	Total (%)	Group 1 (%)	Group 2 (%)	Group 3 (%)
High price of tree seed	53	42	80	50
Limited availability of seed of desired tree species	45	55	47	28
Lack of capacity building in tree seed management	12	12	7	17
Degradation of tree populations where tree seed is sourced	11	15	7	6
Limited overall quantity of tree seed available	9	9	20	0
Quality of seedlings	8	3	13	11
Transport of tree seed	6	0	0	22
Limited diversity of fruit tree species available	3	3	0	6
Constraints in accessing planting materials in nurseries	2	3	0	0

4. Discussion

4.1. Diversity of Tree Species Planted in Farmers' Plots

Across the sites examined in this study, farmers engaged in tree planting represented a minority. They were planting a wide diversity of trees, even though only few species were largely planted. Overall, the most commonly planted trees were exotics, producing timber for sale and valuable non-timber forest product (NTFPs), used both for sale and house consumption.

The most commonly planted tree, *Mangifera indica* L., has an important nutritional value and large market demand, despite its low survival rates recorded in our study sites, generally attributable to planting in unsuitable soils or to insufficient watering. Another exotic tree species largely planted, *Anacardium occidentale* L., seemed to be poorly adapted to the environmental conditions of the Central area of Burkina Faso and presented extremely low survival rates. However, this species was favored by many farmers due to its expanding market. Most farmers interested in planting this species witnessed success in its cultivation while they were working in tree plantations in Ivory Coast or got to know about it through relatives who migrated to Ivory Coast. The second most planted species, also an exotic tree, *Eucalyptus camaldulensis* Dehnh., supplies construction material, largely demanded in urban centers. Its fast growth, rustic characteristics, and high market value make it an interesting tree species for income generation. It releases allelopathic compounds, therefore farmers tend to plant it in high density, with no other trees or crops in close proximity. The most planted indigenous species was *Acacia senegal*, Willd. planted in large numbers, especially by those farmers partnering with the association tiipaalga, to form live fences that gradually replace the metallic barriers used to fence farmers' plots. This indigenous species is highly adapted to the environmental conditions of the Central area of Burkina Faso. The second and third favorite indigenous tree species, *Parkia biglobosa* Jacq. and *Adansonia digitata* L., have both a huge nutritional importance, contributing to diet diversification, largely consumed at home and partly sold.

A preference for exotic versus indigenous trees in small scale planting (especially *Mangifera indica* L. and *Anacardium occidentale* L.) has been observed in previous research carried out in Burkina Faso [28,35]. In studies conducted in other African countries, income generation has emerged as a critical consideration in choosing what tree species to plant [36,37]. In our study, the average number of tree species planted was higher than in other cases presented in the literature, but only a few farmers planted a very large number of tree species. The decision to also plant indigenous tree species seemed related to the increasing scarcity of some important local NTFPs and the progressive disappearance of some useful tree species (e.g., *Securidaca longepedunculata* Fres.). Forest resources in the proximity of the villages investigated were indeed described by farmers as largely degraded.

4.2. Factors Influencing Planted Tree Diversity

In our study, both the analyses of planting choices of individual farmers (or women's groups) and, separately, the analysis of the characteristics of the capabilities and assets of these farmers, revealed that the observations tended to cluster around three main groups, within which farmers had both similar planting strategies and similar characteristics. This seemed to indicate that planting choices could be partly predicted based on a set of variables describing individual farmers' capabilities and assets. The establishment of fences emerged as a critical factor in predicting the relative proportion of indigenous tree species planted. Farmers who established fences planted a higher diversity of tree species and more trees of indigenous species in their plots. Thus, fenced plots tend to host generally more tree diversity if in addition to the enrichment planting also the spontaneous regrowth of the vegetation, attributable to the reduced pressure of grazing, is taken into account.

Most farmers interviewed in our study belonged to the main ethnic group in Burkina Faso, therefore acquired the right to use their lands largely through inheritance. Other arrangements were observed but regarded a small number of farmers interviewed, in particular, four women's groups and an individual woman; these borrowed land from other farmers in the village. The establishment of fences clearly has constituted an incentive to tree planting and management by increasing land tenure security and contributing to its formalization (in the case of partnership with tiipaalga, the 'contract' with the association lasts at least seven years). Across forest restoration projects in Burkina Faso and other countries, land tenure security is definitely emerging as a critical factor for their successful implementation together with clear legal frameworks that recognize usufruct rights for households on restored lands [35,38–41]. Similarly, a survey on fruit tree planting practices in Nigeria and Cameroon revealed that the most influencing factors in tree planting decisions were land tenure security, access to markets, and access to forest resources [42].

The ecological implications deriving from the implementation of fences have been described in a number of case studies from different regions of the world. The benefits consist in enhanced regeneration of natural vegetation, reduction of runoff and erosion, land stabilization, increase in water availability and improvement in soil physical and chemical properties [43–48]. Prolonged exclusion of livestock grazing produces over time a significant increase in aboveground and belowground biomass and species richness [49,50]. In some cases, an increased richness of woody species can be observed after less than 10 years since establishment of exclosures [51]. In our study, the release of pressure from grazing within the fenced plots generated significant spontaneous regeneration of several species present in the soil seed bank (not only trees and shrubs, but also herbaceous species), or present in the form of resprouting stumps, despite the extremely dry environment, and created ideal conditions for enrichment planting. Thus, fenced plots tended to be more diverse than external areas, primarily thanks to spontaneous regeneration and secondarily to tree planting. In the most successful cases, livelihood benefits in fenced plots were already materializing in the first years after fencing, through the sale of forage harvested within fenced areas and in the exploitation of NTFPs [52].

Given their higher diversity, resulting from a combination of natural and artificial regeneration, small fenced areas in the landscape could play the role of conservation units, protecting species otherwise seriously threatened and difficult to find in the landscape. These small plots could also function as seed sources for tree species less commonly found in nurseries, primarily indigenous trees, and could foster secondary succession in abandoned farmlands [53]. Biodiversity conservation could be enhanced by increasing landscape connectivity among these plots, allowing the movement of tree species and genes between habitats within degraded landscapes. Movements of small animals were apparently not limited by the presence of fences, as traces of rabbits and jackals were found within the plots. Furthermore, in the specific context investigated, given the extreme pressure from grazing animals, the protection offered by fences encouraged the spontaneous regeneration of a large diversity of plants inside the plots, potentially dispersing their seeds also outside the fences. In the study sites investigated, beekeeping activities were implemented within fenced plots, contributing to sustaining pollination, an important ecosystem service.

The planting choices of farmers not using fences were compared. The hypotheses was that the exposure of villagers to the best practices implemented inside fenced plots would have had an influence on practices adopted by other farmers not directly engaged in small scale fencing. The expectation was that these farmers could also benefit from better access to seed of indigenous trees available inside the fenced plots and could have an opportunity to observe the effectiveness of traditional agroecological practices implemented inside the plots, which favour tree establishment by enhancing soil fertility and improving water retention. The comparison of the two groups of farmers not using fences revealed some differences but they were not significant, with a slightly higher diversity of tree species planted by farmers in the same villages where tiipaalga was active.

4.3. Seed Sources Used by Farmers

The results revealed that, in addition to the use of fences, other important factors had a prominent role in influencing farmers' choices in tree planting: availability of land and labour, and availability of sufficiently diverse seed sources. These two sets of factors played a key role, respectively, on tree planting densities and on the number of tree species planted. A wide variety of seed sources were commonly used by farmers. Plantations contributed the largest amounts of seed but exclusively for exotic tree species, while fenced plots, NGOs and CNSF were the most significant seed sources for indigenous species. NGOs and the forest department derive from CNSF a significant part of the seed they supply to users, therefore the amount of seed supplied by the national tree seed centre is greater than what emerges by looking at seed sources cited by final users. Woodlands provided lower quantities of seed but an important diversity of indigenous tree species of medicinal value.

Reliance on self-procured reproductive material was found to be considerable, but very few farmers appeared to apply optimal seed collecting practices. Seed collection criteria were mainly focused on the phenotype of the mother tree and neglected important characteristics of the tree population sourced. The limited use of population-level criteria for seed collection has been observed in studies about quality of seed collected by farmers and small scale nurseries in some other African countries [54–56]. More generally, a neglect of appropriate collection practices has been observed in forest restoration projects globally [22,24].

These findings raise concern about the evolutionary potential of planted woodlots, especially in the light of unpredictable future climatic conditions. The capacity of natural vegetation to provide the seed required for both large restoration projects and several small scale, locally based planting efforts has been subject of concern [22,57–59]. The need to broaden the genetic base of forest reproductive material has been recognized as crucial in order to maximize the adaptive potential of restored populations [24,60]. Local tree populations targeted for seed sourcing, particularly for rare or highly threatened tree species [61], may be genetically impoverished or too degraded and fragmented. Furthermore, the timing and amount of seed produced by natural populations can vary over the years, making availability unpredictable. In addition, relying on few, more abundant and easy to collect tree species for tree planting may progressively lead to homogeneous landscapes. Finally, a further risk is posed by the successive use of seed collected from planted stands with low genetic diversity [55,62]; this practice would lead over time to more pronounced effects of a narrow genetic base in subsequent populations.

Farmers in drier regions recognize the importance of diversifying tree species on farms because by doing so they minimize risks of failure [63]. Various guidelines on how to capture a minimum level of genetic variation in seed collection have been developed, providing guidance on selection of mother trees [27,64–67]. Selection criteria partly depend on the reproductive biology of the species sampled but, as a general rule, it is preferable to collect small amounts of seed from several individuals than large amounts of seed from few trees and it is recommendable to sample individuals sufficiently far apart to increase the chance of collecting from unrelated individuals [68].

These guidelines are generally overlooked as they impose more efforts in seed collection and the negative consequence are not immediately visible but strengthened dissemination efforts, also targeting rural populations, would enhance local capacity in seed collection and consequently ensure a greater genetic diversity of planting stocks [64]. Dawson et al. [69] highlighted the potential of small private nurseries as entry points for the development and distribution of good quality tree germplasm, as they can easily reach all local farmers willing to plant trees. In Burkina Faso, a regulatory framework is in place for production of forest productive material, which prescribes the registration of small commercial nurseries and compliance to guidelines of the forestry department, but the enforcement of the legislation is weak, challenging the establishment of a sound tree seed supply system.

4.4. Accessibility of Seed

In this study, the most common issues reported in relation to tree seed supply were the high price and a limited availability of seed of a broad range of species. Farmers have a low willingness to pay for seed and tend to collect it on their own when possible or to look for cheaper sources. In addition to concerns about the potential level of degradation of the populations targeted as seed sources by farmers, seeds from local tree populations may not always constitute the best option in light of uncertain, expected future climatic conditions [70]. Forest reproductive material collected from sources other than local, and growing under environmental conditions expected in future in the site targeted for planting, could be a better choice to enhance ecological resilience of planted trees [24].

Given the limited knowledge of the performance of many tree species, the tests of genetic material of different origins conducted in provenance trials are still the most informative experiments that can assist in addressing questions about suitability of forest reproductive material to specific current and future site conditions, about its adaptation to constraining factors (e.g., limited soil fertility, drought, diseases, etc.) and about commercially important traits. However, there is a risk that high quality forest reproductive material, fully tested, could be less affordable than seed from other sources.

Farmers' willingness to pay for quality forest reproductive material depended on the profitability of planting. For exotic tree species with high economic return (e.g., *Mangifera indica* or *Psidium guajava*) farmers were ready to travel to access superior cultivars available in nurseries in the capital city. For less common indigenous trees (several of these with medicinal use), own-collection of seed and seedlings by farmers was the only option because seedlings were not available in nurseries due to a low demand. However, as pointed out by various authors [71,72], seed collectors and nurseries need to run commercially profitable activities and this often leads to a narrowing of the range of species grown in nurseries, for various reasons including a limited accessibility of some seed sources, a desire to avoid risk of unsold material, etc.. For tree species subjected to overexploitation or with a challenging biology, even direct seed collection by farmers can be an endeavour.

Important *in situ* sources of forest reproductive material (e.g., old fallow and forest remnants where less commonly available tree species can be found) could be mapped, characterized and safeguarded. An integration of traditional regulatory systems (e.g., harvesting rules for NTFPs) and additional conservation measures applied to sites of potential value as seed sources, could be an efficient way to maintain tree diversity in the landscape. They could also sustain an adequate decentralized supply of high quality germplasm to meet the ambitious forest restoration targets that Burkina Faso has identified at the country level and to provide livelihood options locally [21,73,74].

In the sites investigated, small flows of forest reproductive material were observed, in the form of sales or gifts, through seed exchange networks active at the level of municipality. Some authors expressed the view that supporting these kind of networks and their expansion could be a viable option to increase the adaptation potential of planted trees [75]. Kindt et al. [64] illustrated the difference in tree species compositions across several villages in Kenya and proposed an approach by which forest reproductive material of tree species would spread from villages where some species are abundant to sites where they are less abundant. Those villages where the occurrence of these target species is relatively higher, and early domestication processes are at play, would function as seed sources.

The potential of establishing community nurseries and developing nursery networks for the long-term support to farmers and for their capacity building has been documented [76]. Similarly, the creation of favourable market conditions for seed sales, accompanied by a clear definition of benefit sharing arrangements, have been described as crucial elements to support the long-term success of collective action of farmer's groups engaged in production of high quality seed [77]. Furthermore, the role of "innovators" among farmers could be strengthened and integrated into strategies for the implementation of forest landscape restoration initiatives to spread best tree planting practices sustaining farmers to farmers diffusion of knowledge [36,78–80].

The development of a sound seed production system requires an appropriate enabling environment. Unsecured land tenure has been identified as a limiting factor in African countries that affects income opportunities of small nurseries development [81]. In a survey on the development of nurseries for production of agroforestry species in Southern Africa, Böhringer et al. [82] found that provisions of information and training was important in determining the production capacities of the nurseries. However, the extension services appear to fail in their provisions and farmers rely more on networks of NGOs.

5. Conclusions

This study showed that small-scale planting in the Central Plateau of Burkina Faso tends to focus primarily on exotic tree species that produce income. The use of fencing to promote forest restoration appears to support the planting of a more diverse portfolio of tree species than other small scale efforts and includes a greater representation of indigenous trees. Fenced plots have therefore a conservation value in landscapes where the diversity of tree species is progressively declining. In addition to the use of fences, some other key factors affect the diversity, the type of tree species planted and the extent of tree planting. These factors are land tenure, availability of diverse seed sources, availability of land and labour, and training received in seed collection and handling. Farmers tend to collect directly most of the planting material they need but in the majority of cases, they do not follow those best practices (e.g., seed collection from a minimum number of mother trees) that would favour adequate quality and diversity in the seed lots and could sustain adaptation and resilience of planted individuals. A wide promotion of capacity building of smallholder farmers seems crucial in maintaining diversity in forested landscapes. The establishment of networks of small-scale nurseries could help broaden the diversity in the supply of forest reproductive material. *In situ* sources of high-quality germplasm should be properly mapped and new ways of setting in place a sound and geographically distributed seed supply system should be designed in order to provide livelihood benefits to rural communities, reduce seed prices, and maintain a diversity of tree species in the landscape. Given the ambitious forest restoration targets of Burkina Faso and the need to provide diverse options to rural communities to enhance their resilience vis-à-vis increasing environmental challenges, the findings from this study indicate that strengthening the capacity farmers and establishing a robust tree seed system are crucial targets.

Supplementary Materials: The following are available online at http://www.mdpi.com/1999-4907/10/3/227/s1, Table S1: List of tree species planted by farmers in each group identified: farmers who fence their plots, assisted by the association tiipaalga (Group 1), farmers who do not fence their plots, located in the same municipality of action of tiipaalga (Group 2) and farmers who do not fence their plots, located in different municipality from those where tiipaalga is active (Group 3), Table S2: Proportions of farmers from each of the three farmers groups identified, reporting a specific set of issues affecting their tree plantations practices.

Author Contributions: Conceptualization, B.V. and M.V.; methodology, B.V., M.V., D.T. and E.L.Y.-O.; software, M.V.; validation, B.V.; formal analysis, M.V and B.V.; investigation, M.V.; resources, B.V., A.T.T. and D.T.; data curation, M.V.; writing—original draft preparation, M.V. and B.V.; writing—review & editing, M.V., B.V., D.T., E.L.Y.-O., A.T.T. and F.K-M.; visualization, M.V. and B.V.; supervision, B.V.; project administration, B.V.; funding acquisition, B.V.

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