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FARMERS' PREFERENCES FOR TREE FUNCTIONS AND SPECIES IN THE WEST AFRICAN SAHEL

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ABSTRACT

Surveys were conducted in villages in five regions of Burkina Faso, Mali, Niger and Senegal to determine priority tree functions and species. Villagers listed eight priority functions and 116 important species. The most important functions were essential products (human food, medicines, animal food, wood/energy/fiber) followed by environmental services (soil fertility improvement, soil/water conservation, shade) and sale to generate revenue. The relative importance of most functions and several species differed significantly among some regions. There were significant positive or negative associations between functions. Villagers used significantly more species in Niger, the driest region, in order to diversify options and minimize risk.

Key words: participatory tree domestication, products, environmental services, revenue

INTRODUCTION

Parkland agroforests are mixtures of trees and shrubs that farmers select for certain functions and cultivate together with staple food crops. In the West African Sahel, parkland trees and shrubs provide essential products and services for rural communities, and thereby contribute to poverty alleviation and food security (e.g., Faye *et al.* 2010). The principal products include wood for energy, construction, furniture, household and farm implements; fruits and leaves for food; numerous traditional medicines; fibers for roofs, mats and fencing. Environmental services

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of parkland trees and shrubs, such as soil and water conservation, are crucial because the region is semi-arid and the soils are generally infertile. Rural people have used parkland trees and shrubs for generations, so they have a collective wealth of knowledge about their uses. For example, women know which species are best for fire wood, food and condiments; traditional healers are experts in the use of medicinal plants for human use; and pastoralists know which species provide the best fodder and medicines at different times of the year for their livestock (Sanon *et al.* 2007)

Improving the productivity and management of parkland agroforests is essential in order to ensure that current and future generations continue to derive the livelihood benefits from the trees and shrubs. In that context, understanding which species are most important to rural communities and why they are important is a prerequisite to the development of participatory projects for sustainable management and domestication of the species that farmers are most likely to conserve (Simons and Leakey 2004).

A participatory project aiming to improve the management and productivity of native tree and shrub species in parkland agroforests was initiated in the West African Sahel in 2006 (ICRAF 2007). The first major activity was to determine farmers' preferences for tree functions and the priority species for these functions. In this paper, we present results of preference surveys conducted in Burkina Faso, Mali, Niger and Senegal, and some recommendations for participatory tree domestication programs in the four countries.

MATERIALS AND METHODS

Study zone and survey methodology

The study was conducted in five regions where the ICRAF project operates in the West African Sahel (Table 1). The regions correspond to the zones of intervention of collaborating development projects. Nine villages were selected in each region based on recommendations from the collaborating development projects. Selection criteria targeted poor villages that had demonstrated a strong spirit of collaboration with the development projects. Three groups of villages, each containing three villages, were selected to sample the ethnic and environmental variation in each region (Table 1).

A participatory approach was used in each village to identify priority tree functions and species, and collect information about the products and services provided by the species. The process was carried out in two stages – group meetings in the villages, followed by individual meetings with key informants in each village.

During the group meetings, information was obtained in three steps. (1) The villagers (men and women) listed the species that they considered important and all the products and services provided by each species. Preferences reflect the usefulness of the species, and may also reflect the abundance of the species in the region. Relative abundance of the species was not evaluated. (2) The villagers discussed and reached a general consensus on five priority tree functions. (3) The villagers assigned a score to each species for each function (range = 0 to 3, where 0 = not useful and 3 = very useful for the function), referred to hereafter as tree function scores. The importance of each species was estimated by calculating the sum of the five tree function scores, referred to hereafter as species importance value. The species importance values were then used to select priority species in each village.

In the second stage, key informants were identified and individual interviews were conducted to provide detailed information about preferences for products, their uses, the revenue earned, resource availability and specific constraints faced by the farmers. In each village, the key informants included farmers, processors and sellers of tree and shrub products. In total, 425 key informants were interviewed (267 women and 158 men) in the five regions.

Statistical analysis

Five variables were computed for each village: number of important species, number and proportion of species per function, tree function scores and species importance values. The number of important species reflects the diversity of products and services that a village depends upon, and the number and proportion of species per function reflects the relative importance of the function in the village. Tree function scores and species importance values indicate the relative importance of the species for each function and across the five functions, respectively. If a particular function was not cited as a priority in a village, then tree function scores and the number of species for that function were treated as missing values for the analysis. Data were analyzed using the SAS® statistical package version 9.1 (SAS Institute Inc. 2004). Departure from the normal distribution and homogeneity of variance were tested for the residuals in the analysis of variance (below) using statistics provided by the UNIVARIATE procedure. The number of important species, and the number and proportion of species per function in each village were transformed [square root for numbers, angular transformation ($\arcsin\sqrt{p}$) for proportions] in order to satisfy the assumptions of the analysis of variance. The significance level for all tests was $\alpha \leq 0.05$.

Analysis of variance was used to determine if there were significant regional differences in the number and proportion of important species per village, the number of species per function and species importance values (MIXED procedure, restricted maximum likelihood estimation method). The model included the following sources of variation: region (R), village group within region [G(R)] and residual variation [pooled variation among villages within G(R)]. R and G(R) were considered fixed factors. Tukey's "honestly significant difference test" of least squares means was used to determine which regions differed significantly.

TABLE 1

Villages where preferences for tree species and functions were surveyed in the West African Sahel.

Region	Village group (latitude, longitude)	Village	Dominant ethnic groups	Estimated population	Mean annual rainfall (mm)
1: Western Senegal			Wolof, Serer	2,475,100	550–650
	Thiès (14°47’N, 16°56’W)	Keur Sara Badiane			
		Keur Mor Ndiaye			
		Keur Daouda Cissé			
	Fatick 14°21’N, 16° 25’W)	Tataguine			
		Keur Mangari			
		Mbelangouth			
	Kaolack (14°8’N, 16°6’W)	Keur Backa			
		Koné Sèrère			
		Sinthiou Mboutou			
2: Southeastern Mali			Bambara	2,336,300	500–700
	Samènè (13°10’N, 6°6’W)	Mantana			
		Samènè			
		Douna			
	N’Golobabougou (13°51’N, 6°13’W)	Kolobèlè			
		NGolobabougou			
		Kango			
	Sadian (13°14’N, 4°30’W)	Sadian			
		Safienso			
		Sokoro			
3: Northwestern Burkina Faso			Mossi	692,500	500–650
	Loroum (13°42’N, 2°9’W)	Todiam			
		Sillia			
		You			
	Bam (13°4’N, 1°36’W)	Barsa			
		Tontenga			
		Sindri			
	Passoré (12°49N, 2°6’W)	Tibou			
		Yarsi			
		Sibalo			

4: Southeastern Burkina Faso			Gourmantchés	1,053,700	750–850
	Gourma 12°0'N, 0°1'W)	Koulwoko Yantinga Tangaye			
	Gnanga (13°10'N, 0°3'W)	Ouarpassi Dionfirga Kossougdou			
	Tapoa (12°14'N, 3°10'W)	Moredeni Kindikoumbou Moabou			
5: Southern Niger			Haoussa	2,187,900	350–450
	Sajamanja (13°13'N, 7°29'E)	Sajamanja Banéné Charindawa			
	Elgueza (13°16'N, 7°32'E)	Elgueza Guidan Adamou Dandamo			
	Dansaga (13°25'N, 7°26'E)	Dansaga Guidan Bakoye Kokaye			

Notes: Estimated population obtained from Wikipedia. Estimated range in mean annual rainfall obtained from the WorldClim database (http://www.worldclim.org/), described by Hijmans *et al*. 2005.

Spearman's rank-order correlation coefficients were used to determine if there were significant positive or negative associations between trees' values for different functions (CORR procedure). Coefficients were calculated between tree function scores.

RESULTS AND DISCUSSION

Villagers' preferences for tree functions

In general, the highest priority tree functions were the essential products. Across the 45 villages surveyed in this study, villagers listed eight priority tree functions and 116 important tree and shrub species (Appendix 1). The functions and percentage of villages that cited them as one of the five priority functions were human food (91%), medicines (96%), wood/energy/fiber (78%), animal food (60%), soil fertility improvement (53%), soil and water conservation (27%), shade (29%) and product sale for revenue (47%). The fact that nearly all villages cited human food and medicines as priority functions, and nearly all species listed by the villagers provide food (90%) and medicines (93%) underscores the well-known importance of nutritional and health security in rural poor communities (IFAD 2001). Similar results were reported in other participatory priority setting exercises in Africa (e.g., Maghembe *et al.* 1998, Adeola *et al.* 1999). In addition, it is not surprising that wood/energy/fiber were cited as priority by the majority of villages and that most species (94%) provide these products, as these are essential for construction, farm and household implements and fuel in rural communities (FAO 2006). The provision of animal food from trees and shrubs was a priority in fewer villages, but most of the species listed by villagers (88%) provide this function, which is particularly important during the long dry season when grasses and other forage plants are not available.

Given the low level of soil fertility and the semi-arid climate in the West African Sahel (Hijmans *et al.* 2005, FAO 2007), farmers often use trees and shrubs for environmental services. Although environmental services were lower priorities than the essential products mentioned above, many species in the villages were used for these services (soil fertility improvement 86%, soil and water conservation 69%, shade 53%). Soil fertility improvement could be due to nitrogen fixation, mycorrhizal associations that permit nutrient capture from deep soil layers and recycling in the crop rooting zone, increased organic matter resulting from litter fall and mineralization, etc. (e.g., Kessler 1992). Farmers indicated that shade was needed to reduce soil surface temperatures, and also to provide shelter for humans and animals, particularly during the hottest period of the dry season.

Revenue from the sale of tree/shrub products is clearly important for rural-poor livelihoods (e.g., Faye *et al.* 2010). Products from a large percentage of the species (59%) provide revenue, but the majority of villages did not cite revenue as one of the five priority functions. This reflects the fact that other revenue sources exist (sale of cereal crops, off-farm labor, etc.) and that market opportunities for tree/shrub products are often limited due to poor infrastructure, inadequate product quality, insufficient knowledge about markets and value chains, and agricultural policies that do not facilitate market development for tree/shrub products.

Rainfall is not very predictable in the West African Sahel, so farmers in rural poor communities have adopted strategies to minimize risks to their livelihoods. For example, they typically plant several varieties of staple food crop species (millet and sorghum), knowing that certain varieties will produce better in drier years with shorter growing seasons. Our results indicate that farmers apply a similar logic with respect to trees and shrubs: they typically use more species in drier zones, thereby diversifying their options and minimizing risks. The mean number of important species used by villagers and the number of species per function were greatest in the driest region (i.e. Niger: Table 2). As farmers explained in Niger, increasing the number of species per function minimizes the risk of "function failure", i.e. at least some species will provide the function even in the driest years. In contrast, the proportion of species per function generally

TABLE 2

Analysis of variance of the mean number of tree and shrub species cited as important and the mean number used for different functions in villages in five regions in the West African Sahel.

	Mean number per village in regions 1-5					
	1	2	3	4	5	P/Df
Mean number of species for all functions	13.7	17.1	20.2	20.3	33.8	***
	a	ab	b	b	c	4,30
Mean number of species for each function						
Human food	10.4	11.2	15.2	15.0	20.7	***
	a	a	b	b	c	4,26
Medicine	13.2	16.2	19.2	19.9	31.0	***
	a	b	b	b	c	4,28
Animal food	7.9	12.2	LP	17.0	29.7	***
	a	ab		bc	c	3,15
Wood/energy/fiber	13.7	12.7	12.8	15.3	31.1	***
	a	a	a	a	b	4,21
Soil fertility improvement	4.8	8.2	NP	10.9	20.9	***
	a	ab		b	c	3,14
Sale	9.7	13.7	15.5	LP	NP	*
	a	ab	b			2,11

Notes: Regions: 1 = western Senegal, 2 = southeastern Mali, 3 = northwestern Burkina Faso, 4 = southeastern Burkina Faso, 5 = southern Niger. P = Probability of F ratio to test regions: ***$P < 0.001$, * $P < 0.05$. Df = degrees of freedom for F ratio. Regions with the same letter do not differ significantly ($P > 0.05$, Tukey test of least squares means). NP = function was not cited as priority in any village in the region. LP = function was low priority in the region (cited as priority in only one village) and was not included in the analysis. Numbers for soil/water conservation and shade are not tabled because they did not differ significantly among regions ($P > 0.05$).

did not differ significantly among regions: the only exception was wood/energy/fiber (significantly greater in Niger and Senegal than in the other regions, $P < 0.001$).

Associations between tree functions

Most tree and shrub species have several functions, as indicated above and noted by others (e.g., Boffa 1999), so one would expect positive associations among many of the functions. In this study for example, species that had high function scores for human food also tended to score high for medicine, shade and sale (Table 3). The principal human foods are the fruits and leaves, and many of these also have medicinal properties (Arbonnier 2000), hence the positive association. The association with sale reflects the fact that many food products are sold in the markets. The association with shade relates to the size of the tree canopy: trees with larger canopies theoretically can produce more fruits and leaves and cast more shade.

TABLE 3

Spearman's rank-order correlation coefficients between tree function scores in the West African Sahel.

	HFood	Med	AFood	WEF	SoilF	SoilWC	Shade
Med	0.086* (779)						
AFood	–0.237*** (475)	NS					
WEF	–0.138*** (652)	0.139*** (707)	0.146** (480)				
SoilF	NS (451)	0.182*** (339)	0.311*** (436)	0.358***			
SoilWC	NS (93)	NS (219)	0.297** (89)	0.349***	0.554***		
Shade	0.249*** (257)	0.220*** (257)	NS	0.366*** (199)	0.451*** (57)	0.269** (135)	
Sale	0.493*** (352)	0.132* (352)	NS	NS	NS	NS	0.339** (82)

Notes: Tree function scores = score (0-3) of species for the function. Functions: HFood = human food; Med = medicine; AFood = animal food; WEF = wood/energy/fiber; SoilF = soil fertility improvement; SoilWC = soil/water conservation; Shade = shade; Sale = revenue. Probability of correlation coefficients: *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$, NS $P > 0.05$. Sample size is given in parentheses.

In contrast, species with higher scores for human food tended to have lower scores for animal food and wood/energy/fiber. Foods valued for human consumption typically are not fed to animals, so there is a negative association. If farmers cut the stems or prune branches for wood and energy, this reduces the potential fruit and leaf production, so there is a negative association between these two functions. In contrast if farmers prune branches, the leaves and succulent branches can be fed to the animals, so there is a positive association between wood/energy/fiber and animal food.

Species that scored high for wood/energy/fiber also tended to score high for the three environmental service functions (soil fertility improvement, soil/water conservation, shade). This relates to the relatively rapid growth, large canopy, coppicing ability and abundant litter from leaves and small branches of many of these species. Together, these characteristics contribute to ameliorating the microclimate, stabilizing the soil, improving its fertility and physical properties, reducing erosion caused by wind and water, and increasing water penetration. This association also helps explain why villagers in Niger, the driest zone with very infertile and sandy soils, listed so many species important for wood/energy/fiber (Table 2).

The associations among functions scores discussed above illustrate that farmers have selected certain species as "ideotypes" to provide a set of essential functions. Participatory tree domestication programmes can build upon this "ideotype" approach to select and improve cultivars for specific sets of functions (Leakey and Page 2006).

Villagers' preferences for tree and shrub species

Species preferences differed among regions. For example, the ten species with the highest rankings in each region and their function rankings across regions are given in Tables 4a and 4b, respectively. All 26 species listed in Table 4 were present in all five regions, but the relative abundance of the species (not quantified) was not necessarily the same in all regions. Fourteen of the 26 species listed were preferred in only one region: the majority of these were valued primarily for human food or medicine in Senegal, Mali and Burkina Faso but for wood/energy/fodder in Niger. None of the species listed was ranked in the top ten in all regions, and only six were ranked in the top ten in four regions. Based on analysis of variance, there were significant differences in importance values of five of the 16 species that were cited as priority in all five regions (Table 5).

As mentioned above, these species provide essential products and services. For example, leaves, fruits and/or seeds from *Adansonia digitata*, *Balanites aegyptiaca, Lannea microcarpa*, *Parkia biglobosa*, *Tamarindus indica, Vitellaria paradoxa* and *Ziziphus mauritiana* are consumed and processed by women into oil, soap and/or condiments for sale. In Mali, for example, the sale of such products generates 26% to 73% of the household's annual revenue (Faye *et al.*

TABLE 4a

Ranking of the preferred tree and shrub species in each study region in the West African Sahel.

	Ranking of species in regions 1–5				
Species	1	2	3	4	5
Acacia macrostachya	NP	NP	**8**	51	61
Acacia nilotica	27	15	30	22	**7**
Adansonia digitata	**1**	**4**	**4**	**6**	28
Anogeissus leiocarpus	39	19	35	**9**	16
Balanites aegyptiaca	**4**	**5**	**9**	15	**6**
Bauhinia rufescens	32	NP	NP	NP	**9**
Bombax costatum	NP	18	**10**	**10**	58
Cordyla pinnata	**5**	22	NP	NP	NP
Detarium microcarpum	**8**	20	35	14	30
Diospyros mespiliformis	12	14	16	**8**	**10**
Faidherbia albida	**6**	**7**	**7**	18	**5**
Ficus gnaphalocarpa	**9**	33	11	NP	NP
Guiera senegalensis	21	24	22	NP	**3**
Khaya senegalensis	17	15	17	**3**	42
Lannea microcarpa	NP	11	**4**	**6**	18
Parkia biglobosa	**6**	**6**	**2**	**2**	25
Piliostigma reticulatum	17	17	13	**5**	**3**
Prosopis africana	NP	28	43	NP	**1**
Pterocarpus erinaceus	NP	**9**	30	21	51
Pterocarpus lucens	NP	**8**	20	NP	NP
Saba senegalensis	NP	**9**	14	NP	NP
Sclerocarya birrea	31	12	15	12	**8**
Tamarindus indica	**3**	**3**	**3**	**4**	14
Vitellaria paradoxa	NP	**1**	**1**	**1**	21
Vitex doniana	**10**	25	21	19	17
Ziziphus mauritiana	**2**	**2**	**6**	13	**2**

Notes: Rankings of the top-ten species in each region are underlined in bold font, and rankings of the other species are shown in regular font. Regions: 1 = western Senegal, 2 = southeastern Mali, 3 = northwestern Burkina Faso, 4 = southeastern Burkina Faso, 5 = southern Niger. Species ranking is based on the sum of function scores (0-3) of tree species for five functions in each region. If the sum of function score is the same for two species, then they have the same ranking (e.g., *P. erinaceous* and *S. senegalensis* in region 2). Total number of species cited as important in regions 1-5, respectively: 1= 40, 2 = 42, 3 = 45, 4 = 53, 5 = 73. NP = species was not cited as priority in any village in the region.

2010). Utensils and agricultural equipment are derived primarily from the wood of *B. aegyptiaca, Cordyla pinnata*, *Khaya senegalensis* and *Pterocarpus erinaceus*. Fruits and leaves of *Faidherbia albida* and fresh leaves of *P. erinaceus and Pterocarpus lucens* are important sources of animal food and revenue for many farmers, particularly in Mali. *F. albida* was one of the highest ranking species for fodder: it produces fruits at the end of dry season when forage grasses are scarce, thereby providing food for animals at a critical time of the year. Men harvest and sell most of the fruits, but children also collect and sell small quantities. Many other species provide animal food but in smaller quantities. *F. albida* was also highly valued for soil-fertility improvement, as reported earlier

TABLE 4b

Ranking of functions of the preferred species across the five study regions in the West African Sahel.

Species	Ranking of functions for species across regions							
	HFood	Med	AFood	WEF	SoilF	SoilWC	Shade	Sale
Acacia macrostachya	1	2	6	5	–	4	7	3
Acacia nilotica	6	2	3	1	5	4	–	–
Adansonia digitata	1	2	4	8	6	6	5	3
Anogeissus leiocarpus	–	2	4	1	2	–	5	6
Balanites aegyptiaca	2	1	5	3	7	6	7	4
Bauhinia rufescens	6	4	2	1	3	5	–	–
Bombax costatum	1	2	8	4	3	7	5	5
Cordyla pinnata	1	2	4	3	5	–	–	5
Detarium microcarpum	2	1	–	4	–	–	–	3
Diospyros mespiliformis	3	2	7	1	5	6	4	8
Faidherbia albida	8	3	2	6	1	4	7	5
Ficus gnaphalocarpa	1	2	3	4	5	–	–	–
Guiera senegalensis	6	2	4	1	3	5	–	–
Khaya senegalensis	–	1	4	2	5	6	3	6
Lannea microcarpa	1	3	8	4	5	6	2	7
Parkia biglobosa	1	2	8	4	7	6	4	3
Piliostigma reticulatum	5	2	4	1	2	6	6	8
Prosopis africana	5	2	3	1	4	6	–	–
Pterocarpus erinaceus	–	2	2	1	2	5	5	5
Pterocarpus lucens	–	4	1	2	7	5	6	3
Saba senegalensis	1	2	8	6	4	4	8	3
Sclerocarya birrea	4	2	3	1	5	6	–	–
Tamarindus indica	1	2	6	5	8	7	4	3
Vitellaria paradoxa	1	2	8	3	6	6	5	4
Vitex doniana	2	1	5	3	6	–	–	4
Ziziphus mauritiana	1	2	3	3	6	7	8	5

Notes: Functions: HFood = human food; Med = medicine; AFood = animal food; WEF = wood/energy/fiber; SoilF = soil fertility improvement; SoilWC = soil/water conservation; Shade = shade; Sale = revenue. Function ranking is based on the sum of function scores (0–3) of the species across regions. "-" = species was not used for the function.

(Boffa 1999). Farmers also commented that the extensive root system of *F. albida* helps reduce soil erosion during the rainy season, and thereby plays an important role in the crop production system.

Most villages did not have modern medical facilities and pharmacies, and the villagers could not afford to pay for medical treatment and modern medicines even if they were available. Therefore, traditional medicines from trees and shrubs were essential for the villagers. For example, bark powder of *T. indica* mixed with butter from *V. paradoxa* fruits was used to treat sprained ankles.

Many of the preferred species have disappeared or are relatively rare due to several factors. Villagers noted that many species have suffered high mortality due to the hotter, drier conditions in the region; and that overharvesting of stems, branches and fruits have reduced the species' ability to regenerate

TABLE 5

Analysis of variance of the mean importance value of tree and shrub species cited as priority in all five study regions in the West African Sahel.

	Mean importance value per village in regions 1–5					
	1	2	3	4	5	P/Df
Species with significant differences in mean importance value among regions						
Adansonia digitata	11.7	8.4	8.4	6.5	2.9	***
	a	a	a			4,30
Balanites aegyptiaca	10.7	8.0	6.80	3.6	7.9	**
	a	ab	b		ab	4,28
Parkia biglobosa	6.4	10.2	11.9	10.9	3.2	***
		a	a	a		4,28
Tamarindus indica	8.6	9.0	11.6	7.7	4.6	***
	a	a		a		4,33
Ziziphus mauritiana	11.7	9.1	7.9	4.0	8.9	***
		a	a		a	4,30
Species with non-significant differences in mean importance value among regions						
Acacia nilotica	2.7	6.2	2.0	2.7	7.0	NS
	a	a	a	a	a	4,18
Acacia senegal	1.7	6.0	2.9	3.3	2.3	NS
	a	a	a	a	a	4,18
Cassia sieberiana	1.7	1.3	4.0	1.3	0.7	NS
	a	a	a	a	a	4,12
Combretum micranthum	4.3	3.0	1.7	1.7	3.1	NS
	a	a	a	a	a	4,14
Detarium microcarpum	4.7	3.5	1.7	5.5	8.0	NS
	a	a	a	a	a	4,17
Diospyros mespiliformis	4.7	4.4	5.3	6.1	6.4	NS
	a	a	a	a	a	4,28
Faidherbia albida	9.7	6.7	7.3	7.0	8.6	NS
	a	a	a	a	a	4,24
Khaya senegalensis	2.7	4.1	4.3	8.2	4.0	NS
	a	a	a	a	a	4,24
Piliostigma reticulatum	5.3	3.8	5.8	6.8	8.8	NS
	a	a	a	a	a	4,26
Sclerocarya birrea	2.0	6.8	5.4	7.2	5.8	NS
	a	a	a	a	a	4,25
Vilex doniana	5.2	1.6	1.8	3.3	4.9	NS
	a	a	a	a	a	4,26

Notes: Mean importance value = village mean for the sum of tree function scores (0-3) of species across five functions. Regions: 1 = western Senegal, 2 = southeastern Mali, 3 = northwestern Burkina Faso, 4 = southeastern Burkina Faso, 5 = southern Niger. P = Probability of *F* ratio to test regions: ***$P < 0.001$, **$P < 0.01$, NS $P > 0.05$. Df = degrees of freedom for *F* ratio. Regions with the same letter do not differ significantly ($P > 0.05$, Tukey test of least squares means).

naturally. Where natural regeneration does occur, it is generally not managed and protected by the villagers, and this exposes the young seedlings to animal browsing. In addition, very few villagers plant trees, due to uncertainty about tree and land tenure. Participatory tree domestication programs need to work with rural communities to address these issues. For example, introduction of tree germplasm from drier zones could improve the genetic adaptation of parkland species to the hotter, drier conditions (Weber *et al.* 2008). Methods for sustainable management of natural regeneration (Larwanou *et al.* 2006), as well as control of parasitic plants on *V. paradoxa* (O. Samaké, pers. Comm.) have been developed with rural communities in some regions, and these should be tested and adapted with rural communities in other regions. In addition, policy dialogues have been initiated among villagers and other stakeholders to discuss and clarify land and tree tenure issues in order to facilitate tree planting and management by rural communities (Yatich *et al.* 2008).

Conclusions

In conclusion, villagers' used native tree and shrub species for several functions in the West African Sahel. In general, the product functions (e.g., food, wood, medicine) were relatively more important than the environmental service functions (e.g., soil fertility and soil/water conservation). Preferences for tree functions and species differed among some of the study regions. In addition, villagers used significantly more species in the driest sample region. There were significant positive or negative associations among tree functions, illustrating that farmers have selected certain species as "ideotypes" to provide a set of essential functions. Based on this research, we recommend that tree domestication programs work on priority species that respond to the functional needs of each specific region, rather than focus on a few species that are considered priority across all regions. Focusing on a few high-value species common to the five regions may significantly increase the incomes of rural communities, but it would not necessarily diversify their sources of income. Working on a large number of species will require greater human and financial resources, but this approach is likely to have a greater positive impact on rural livelihoods in the long term by diversifying income sources, providing income throughout the year, and buffering incomes when prices for the trees' products are low. Diversification is a particularly important adaptive strategy to climate change (Dawson *et al*. 2010): this includes not only increasing the diversity of species and products, but also increasing the genetic variation within species.

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APPENDIX 1

Tree and shrub species cited as priority by villagers in five regions in the West African Sahel. The sum of the species importance values across villages and the functions of the species in each region are given for 102 of the 116 species.

	Species importance values and functions in regions 1–5				
Species	Region 1	Region 2	Region 3	Region 4	Region 5
Acacia ataxacantha DC.	NP	NP	NP	NP	4: WEF-AFood
Acacia dudgeoni Craib. ex Hall.	NP	NP	NP	6: Med, HFood, WEF	NP
Acacia gourmaensis A. Chev.	NP	NP	NP	2: Med-AFood	NP
Acacia macrostachya Reichenb.	NP	NP	64: HFood, Med, Sale, SoilWC, WEF, AFood, Shade	1: Med	4: Med-WEF
Acacia nilotica (L.) Willd. ex Delile	8: Med, AFood-Sale, SoilF	37: WEF, Med, AFood, Sale, SoilWC	6: AFood, Med, Sale	22: Med, WEF, Shade, SoilF, AFood-SoilWC	63: WEF, Med, AFood, SoilWC, SoilF, HFood
Acacia raddiana Savi.	NP	14: Med, HFood-AFood, WEF-SoilWC	NP	NP	NP
Acacia senegal L. (Willd.)	5: Med, AFood, SoilF	18: Med, WEF-AFood-SoilWC-Sale	26: SoilWC, Med, WEF, AFood-Sale, HFood, Shade	10: WEF, HFood-Med-AFood	21: WEF, Med-AFood, SoilWC
Acacia seyal Del.	NP	NP	10: WEF-AFood, SoilWC-Sale	NP	NP
Acacia sieberiana DC.	NP	NP	NP	NP	10: WEF, Med-AFood
Adansonia digitata L.	105: HFood-Med-Sale, AFood, WEF, SoilF	76: HFood, Sale, Med, AFood, SoilF, Shade, SoilWC, WEF	76: HFood, Med-Sale, SoilWC, Shade, WEF, AFood	59: HFood, Med, AFood, SoilF-Shade, SoilWC-Sale	26: HFood, Med, AFood, SoilWC, WEF, SoilF
Afzelia africana Smith.	NP	NP	NP	7: Med, WEF, HFood	NP
Albizia chevalieri Harms	NP	NP	NP	NP	39: WEF, Med, AFood-SoilWC, SoilF, HFood

Annona senegalensis Pers.	10: HFood-Med, SoilF, WEF-AFood	NP	4: Med, HFood	9: HFood-Med, WEF	38: WEF, SoilF, Med, HFood-SoilWC
Anogeissus leiocarpus DC. Guill. & Perr.	1: Med	23: Med, WEF, AFood-HFood, Shade, SoilF-Sale	5: AFood, Med-Sale	47: WEF, Med-SoilF, AFood, Shade, Sale	45: WEF, Med, AFood, SoilF, SoilWC
Aphania senegalensis (Juss. ex Poir.) Radlk.	25: Med, HFood, WEF-SoilF-Sale, AFood	NP	NP	NP	NP
Balanites aegyptiaca (L.) Delile	64: HFood-Med, Sale, AFood, WEF, SoilF	72: Med-AFood, HFood, Sale, WEF, SoilF-Shade	61: Med, HFood, Soil-WC, WEF-Shade, Sale	32: HFood-Med-AFood, WEF, SoilF-SoilWC, Shade-Sale	71: WEF, AFood, Med-SoilF, HFood, SoilWC
Bauhinia rufescens Lam.	5: Med, AFood	NP	NP	NP	59: WEF, AFood, SoilF, Med, SoilWC, HFood
Bombax costatum Pellegr. & Vuillet	NP	32: HFood-AFood-Sale, Med, WEF-SoilWC, SoilF	60: HFood, Med-Sale, Shade, SoilWC, WEF, AFood	45: HFood, Med, WEF, SoilF, AFood, Shade, SoilWC	5: Med-Afood, WEF
Borassus aethiopum Mart.	15: Sale, HFood, Med-AFood	41: HFood, Sale, Med, WEF, SoilF, AFood	NP	NP	16: WEF, HFood, Med-SoilF
Boscia salicifolia Oliv.	NP	NP	NP	NP	24: WEF, SoilF, HFood-Med-AFood, SoilWC
Boscia senegalensis (Pers.) Lam. ex Poir.	NP	14: Med-AFood, HFood-Sale	21: HFood-Med, Sale, AFood, SoilWC-Shade	8: HFood-Med, AFood-Shade	20: WEF-SoilF, AFood-SoilWC, HFood-Med
Boswellia occidentalis Engl.	NP	NP	13: Med, SoilWC-Shade, WEF	8: Med, AFood, HFood-WEF	NP
Boswellia odorata Hutch. P.P.	NP	NP	NP	NP	8: Med-WEF, SoilF-SoilWC
Burkea africana Hook.	NP	NP	4: Med, WEF-SoilWC	NP	NP
Cadaba farinosa Forsk.	NP	NP	4: Med, HFood	NP	NP
Calotropis procera (Aiton) R. Br.	NP	NP	NP	NP	7: WEF, AFood-SoilWC

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Species	Region 1	Region 2	Region 3	Region 4	Region 5
Capparis corymbosa Lam.	NP	NP	4: HFood-Med-SoilWC-Shade	8: Med, AFood, HFood-WEF	NP
Capparis tomentosa Lam.	NP	NP	NP	NP	3: HFood-Med-AFood
Cassia sieberiana DC.	5: Med, WEF	4: Med, WEF	12: Med-Shade, WEF-SoilWC	8: Med, WEF, SoilF	2: WEF-SoilWC
Cassia singueana Delile	NP	NP	NP	NP	16: WEF, Med-SoilF-SoilWC
Ceiba pentandra (L.) Gaertn.	3: AFood, Med	8: WEF-AFood-SoilWC, HFood-Med	NP	3: Med	NP
Celtis integrifolia Lam.	5: AFood, HFood-Med	NP	NP	NP	NP
Combretum aculeatum Vent.	NP	7: AFood-SoilF-Sale, Med	NP	NP	NP
Combretum glutinosum Perr.	24: Med, Sale, WEF, HFood, SoilF	NP	NP	7: Med-WEF, Shade	55: WEF, SoilF, Med-AFood, SoilWC, HFood
Combretum micranthum G.Don	13: Med, HFood, Sale	9: WEF, Med-SoilF-Sale	5: WEF, Med-Sale	5: WEF, Med-AFood-SoilF	28: WEF, Med-SoilF, AFood-SoilWC
Combretum nigricans Lepr. ex Guill. & Perr.	NP	7: Med-WEF-SoilWC, AFood	NP	NP	NP
Commiphora africana (A. Rich.) Eng.	NP	NP	NP	NP	11: WEF, AFood-Soil-WC, HFood-Med-SoilF
Cordyla pinnata (Lepr. ex A. Rich.) Milne. Redh.	62: HFood, Med, WEF, AFood, SoilF-Sale	17: WEF, Med, HFood-Shade, AFood	NP	NP	NP
Crotalaria podocarpa DC.	NP	NP	NP	NP	18: WEF, SoilF, Med, HFood, AFood-SoilWC

Daniellia oliveri Rolfe Hutch.& Dalziel	NP	5: Med-SoilF, HFood	NP	15: AFood, Med-WEF, SoilF, Shade	3: WEF, AFood
Delonix regia (Hook.) Raf.	NP	NP	NP	6: WEF, HFood-Med-AFood	NP
Detarium microcarpum Guill. & Perr.	38: Med, HFood, Sale, WEF	21: Med, HFood-AFood-Sale, WEF	5: WEF, AFood-Med-Shade	33: WEF, Med, HFood, SoilF, AFood	24: Med, WEF, HFood, SoilF, AFood
Detarium senegalensis J.F. Gmel.	27: HFood, Med, Sale, WEF, AFood	NP	NP	NP	NP
Dichrostachys cinerea (L.) Wight & Arn	NP	NP	NP	NP	10: WEF, SoilWC, AFood, Med
Dioscorea cayenensis Lam.	NP	NP	NP	NP	10: SoilF, Med-WEF: SoilWC, AFood
Diospyros mespiliformis Hochst. A.DC.	28: HFood, Med-Sale, WEF	40: HFood, Med, WEF, Sale, Shade, SoilF, AFood	48: Shade, Med, HFood, WEF, SoilWC, Sale	55: WEF, Med, HFood, Shade, SoilF, SoilWC, Sale	58: WEF, HFood, Med-SoilF, SoilWC, AFood
Entada africana Guill. & Perr.	NP	7: WEF, Med-AFood	NP	NP	12: SoilF, WEF, AFood-SoilWC, Med
Euphorbia balsamifera Aiton	NP	NP	NP	NP	5: SoilWC, WEF-AFood
Euphorbia kamerunica Pax	NP	NP	NP	NP	2: Med-WEF
Faidherbia albida (Delile) A. Chev.	58: SoilF, Afood, Sale, Med, WEF	60: AFood, Med, WEF, Sale, SoilF, Shade, SoilWC	66: SoilWC, Med, Shade, Sale, WEF, AFood	21: SoilF, Med, AFood, Shade	77: SoilF, WEF, AFood, Med, SoilWC, HFood
Feretia apodanthera Delile	NP	NP	4: HFood-Med-SoilWC-Shade	2: Med-WEF	4: WEF-AFood-SoilF-SoilWC
Ficus abutilifolia (Miq.) Miq.	NP	NP	NP	NP	3: WEF, Med

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Species	Region 1	Region 2	Region 3	Region 4	Region 5
Ficus dedeckena (Miq.) A. Rich.	NP	NP	NP	NP	23: WEF, HFood-AFood, Med, SoilF-SoilWC
Ficus gnaphalocarpa (Miq.) Miq.	31: HFood, Med, AFood, WEF, SoilF	8: AFood, Med-Shade, HFood	55: Med, Shade, SoilWC, WEF, HFood, Sale	NP	NP
Ficus iteophylla Miq.	14: Med-AFood, WEF, HFood-SoilF	NP	NP	NP	6: WEF, AFood, Med-SoilF
Ficus phatyphylla Delile	NP	NP	NP	NP	38: Med, WEF, AFood, HFood, SoilF, SoilWC
Ficus sycomorus subsp. gnaphalocarpa (Miq.) C.C.	NP	NP	NP	NP	27: Med, WEF, AFood, SoilF, HFood
Ficus thonningii Blume	5: AFood, HFood-Med	NP	NP	NP	6: WEF, Med-AFood-SoilWC
Gardenia erubescens Stapf & Hutch.	NP	4: Med, HFood-AFood	9: Med-WEF, HFood-SoilWC-Sale	22: HFood-Med-WEF-AFood, SoilF	12: Med, WEF, SoilF, SoilWC
Grewia bicolor Juss.	9: Med, WEF-Sale, HFood-AFood	NP	2: HFood-Med	NP	6: WEF, HFood-Med-AFood
Grewia mollis Juss.	NP	NP	NP	NP	26: WEF, HFood-AFood, SoilF, Med-SoilWC
Grewia villosa Willd.	NP	NP	NP	NP	11: WEF, AFood, HFood, SoilF-SoilWC
Guiera senegalensis J.F. Gmel.	15: Med, Sale, WEF-SoilF	15: Med, WEF, AFood-Sale, SoilF	15: Shade, Med-SoilWC, HFood-Sale, WEF	NP	79: WEF, Med, SoilF, AFood, SoilWC, HFood
Hyphaene thebaica (L.) Mart.	NP	NP	NP	NP	55: WEF, SoilF, AFood, HFood, SoilWC, Med

Indigofera tinctoria L.	3: Med	NP	NP	NP	NP
Khaya senegalensis (Desr.) A. Juss.	16: WEF, AFood	37: Med, WEF, AFood, Sale, SoilWC, SoilF	39: Med, Shade, WEF, SoilWC, Sale, AFood	74: Med, WEF, Shade, AFood, SoilF, SoilWC-	12: WEF-SoilWC, Med-SoilF
Lannea acida A. Rich.	7: AFood, Med, WEF	5: Med-AFood, HFood	NP	11: HFood-Med-WEF, SoilF-Shade	NP
Lannea microcarpa Engl. & K.Krause	NP	42: HFood, Sale, Med-WEF, AFood, SoilWC, SoilF	76: HFood, Shade, Med, SoilWC-Sale, WEF, AFood	59: HFood, Med, WEF, Shade, SoilF, AFood, SoilWC, Sale	41: WEF, Med, HFood-AFood, SoilWC, SoilF
Lawsonia inermis L.	16: Sale, Med, AFood, SoilF	NP	NP	NP	NP
Leptadenia lancifolia (Schumach. & Thom.) Decne.	NP	NP	7: SoilWC, HFood, Med-WEF	NP	NP
Leptadenia pyrotechnica (Forsk.) Decne.	NP	NP	NP	NP	5: SoilWC, WEF-AFood-SoilF
Maerua angolensis DC.	NP	NP	NP	1: HFood	3: WEF-AFood-SoilWC
Maerua crassifolia Forsk.	NP	NP	NP	NP	54: WEF, HFood, SoilF, Med, AFood, SoilWC
Maytenus senegalensis (Lam.) Excell	NP	NP	NP	NP	4: WEF-AFood-SoilF-SoilWC
Moringa oleifera Lam.	7: Med, AFood-Sale	NP	NP	NP	7: HFood, AFood, Med-SoilWC
Mytragina inermis (Willd.) Kuntze	NP	12: Med-WEF-Shade, AFood	6: Med, Sale, AFood	7: WEF-AFood-SoilF, Med	20: WEF, AFood, Med
Nauclea latifolia Sm.	3: Med	NP	NP	NP	NP
Neocarya macrophylla (Sabine) Prance.	30: HFood, Sale, Med, WEF	NP	NP	NP	39: Med, WEF, HFood, SoilF, AFood-SoilWC

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Species	Region 1	Region 2	Region 3	Region 4	Region 5
Newbouldia laevis Seem. ex Bureau	8: Med-WEF-SoilF, HFood-AFood	NP	NP	NP	NP
Parkia biglobosa (Jacq) R. Br. ex G.Don	58: HFood, Sale, Med, WEF, AFood-SoilF	61: HFood, Sale, Med, WEF, AFood, SoilF-SoilWC	107: HFood, Med, Shade, Sale, WEF, SoilWC, AFood	90: HFood, Med, WEF, SoilF-Shade, AFood, SoilWC, Sale	29: WEF, HFood, Med, AFood, SoilF, SoilWC
Parkinsonia aculeata L.	NP	NP	NP	NP	4: WEF, AFood, SoilWC
Piliostigma reticulatum (DC.) Hochst.	16: Med-WEF, Sale, AFood	34: WEF, Med, AFood, SoilF-Sale, HFood	52: Med-SoilWC, Shade, HFood, Wood, Sale, AFood	61: Med, SoilF, WEF, AFood, HFood, SoilWC, Sale	79: WEF, SoilF, Med, AFood, HFood-SoilWC
Piliostigma thonningii (Schumach.) Milne. Redh.	NP	NP	NP	8: Med, SoilF, WEF-AFood	NP
Prosopis africana (Guill. & Perr.) Taub.	NP	12: Med, WEF-Shade, HFood-AFood	2: Med	NP	83: WEF, Med, AFood, SoilF, HFood, SoilWC
Pterocarpus erinaceus Poir.	16: Med-AFood, WEF	48: WEF, Med-AFood, SoilWC-Shade-Sale, SoilF	6: AFood, HFood, Med	21:AFood, Med, WEF, Shade, HFood-SoilF	9: WEF, AFood, SoilF-SoilWC
Pterocarpus lucens Lepr.	NP	58: AFood, WEF, Sale, Med, SoilWC, Shade, SoilF	19: Med, WEF, AFood, HFood-Shade, Sale	NP	NP
Saba senegalensis (A. DC.) Pichon	NP	58: HFood, Med, Sale, SoilF-SoilWC, WEF, AFood-Shade	51: Shade, HFood-Med, Sale, WEF, SoilWC, AFood	NP	NP
Sclerocarya birrea (A. Rich.) Hochst.	6: Med-AFood, HFood-WEF	41: AFood, HFood-Med-Sale, WEF, SoilF	49: HFood-Med-SoilWC, Sale, Shade, WEF, AFood	43: WEF, HFood, Med-AFood-SoilF, Shade, SoilWC	61: WEF, Med, AFood, HFood, SoilF, SoilWC

Securidaca longipedonculata Fresen.	NP	8: Med, Sale	12: Med, HFood-SoilWC, WEF-Shade	3: Med, HFood	16: Med, WEF, SoilWC, SoilF, AFood
Securinega virosa (Roxb. ex Willd.) Baill.	NP	NP	NP	NP	2: AFood-SoilWC
Sterculia setigera Delile	23: HFood, AFood-Sale, Med, WEF	NP	7: AFood, WEF-Sale	NP	NP
Stereospermum kunthianum Cham.	NP	NP	NP	NP	23: WEF, AFood, SoilF, Med-SoilWC
Strychnos spinosa Lam.	NP	NP	6: Med, HFood-WEF-	5: HFood-Med, WEF	20: WEF, Med, SoilF-SoilWC, HFood-AFood
Tamarindus indica L.	77: HFood, Med, Sale, AFood, WEF	81: HFood, Med, Sale, AFood, SoilWC, WEF, SoilF	104: HFood, Med, Shade, Sale, WEF, SoilWC	69: HFood, Med, Shade, WEF, AFood, SoilF-Sale	54: WEF, Med, HFood, AFood, SoilWC, SoilF
Terminalia avicennioides Guill. & Perr.	NP	NP	NP	6: WEF-SoilF, Med-Shade	37: WEF, Med-AFood, SoilF, SoilWC
Terminalia laxifolia Engl. & Diels.	NP	NP	NP	8: Med, WEF-SoilF	NP
Terminalia macroptera Guill. & Perr.	NP	9: WEF, Med-AFood-SoilWC	NP	NP	NP
Vitellaria paradoxa C.F. Gaertn.	NP	105: HFood, Med, Sale, WEF, SoilF, AFood, SoilWC, Shade	119: HFood, Med, Shade, Sale, WEF, SoilWC, AFood	106: HFood, Med, WEF, Shade, SoilF, AFood, SoilWC, Sale	38: WEF, Med, HFood-AFood, SoilF, SoilWC
Vitex doniana Sweet	31: Med, HFood, WEF, Sale, AFood, SoilF	14: Med-AFood-Sale, HFood-WEF, SoilF	16: Med-SoilWC-Shade, HFood, WEF-Sale	20: HFood, Med, AFood, WEF, Shade	44: WEF, HFood, Med, SoilWC, AFood, SoilF
Ximenia americana L.	NP	10: Med, HFood-Sale	53: Med, HFood, Soil-WC, WEF, Shade-Sale, AFood	22: Med, HFood, AFood, WEF, SoilF	11: Med, WEF-SoilWC, HFood-AFood-SoilF

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Species	Region 1	Region 2	Region 3	Region 4	Region 5
Ziziphus mauritiana Lam.	105: HFood, Med, Sale, AFood, WEF-SoilF	82: HFood-AFood, Med-Sale, WEF SoilF, Shade	71: Med, SoilWC, HFood, WEF-Shade-Sale, AFood	36: Med, HFood-AFood, WEF, SoilF, Shade, SoilWC	80: WEF, AFood, SoilF, Med, HFood, SoilWC
Ziziphus spina christi (L.) Desf.	NP	NP	NP	NP	56: WEF, AFood, SoilF, Med, SoilWC, HFood

Notes: Regions: 1 = western Senegal, 2 = southeastern Mali, 3 = northwestern Burkina Faso, 4 = southeastern Burkina Faso, 5 = southern Niger. Species importance value = sum of tree function scores (0-3) of species across five functions in each village in the region. Functions: HFood = human food; Med = medicine; AFood = animal food; WEF = wood-energy-fiber; SoilF = soil fertility improvement; SoilWC = soil-water conservation; Shade = shade; Sale = revenue. Functions are listed in order of magnitude of the tree function scores: functions with the same value are separated by "-". NP = species was not cited as priority in any village in the region. The botanical names of 14 species could not be verified and are not included in the table: all 14 species had relatively low importance values.