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Trees and windbreaks in the Sahel: establishment, growth, nutritive, and calorific values

J.P.A. LAMERS[1], K. MICHELS[2], and R. J. VANDENBELDT[3,*]
[1] *Institute of Agricultural Economics and Social Sciences in the Tropics (490) and*
[2] *Institute for Plant Production in the Tropics and Subtopics (380), University of Hohenheim, 70593 Stuttgart, Germany;* [3] *Winrock International Institute for Agricultural Development, F/FRED Project, P.O.B. 1038, Kasetsart, Bangkok 10903, Thailand; *Former Agroforester at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Sahelian Center, Niamey, Niger*

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Abstract. Tree and windbreak species considered for the Southern Sahelian Zone (SSZ) of West Africa have to be evaluated following multiple criteria such as fast establishment, shelter efficiency, production of feed for livestock, and firewood. An on-station experiment was conducted on a sandy soil in southwest Niger between 1988 and 1993 to assess the establishment, growth, nutritive, and calorific values of seven species considered for windbreaks: *Andropogon gayanus, Bauhinia rufescens, Acacia holosericea, Acacia nilotica, Acacia senegal, Faidherbia albida,* and *Azadirachta indica.* Mortality and stem diameter were monitored twice a year. From 20 months after planting (MAP) onwards, species were annually trimmed to 2 m height and to 1 m sidewards of the main stem. Fresh and dry weight of leaves, twigs, wood, and fruits were recorded. Leaves were analyzed for crude protein (CP) and metabolizable energy (ME) content. Wood was analyzed for its gross calorific value and its ash content. At 56 MAP, all species had less than 5% morality, except for *A. holosericea*, which had a mortality rate of 15.9%. *A. indica* and *A. holosericea* showed the highest stem diameter among species with 12.2 and 11.8 cm, respectively, at 56 MAP. *A. senegal* had the highest dry matter production with 22.3 t ha^{-1} at 56 MAP, followed by *A. indica* (12.0 t ha^{-1}), *A. holosericea* (11.7 t ha^{-1}) and *B. rufescens* (11.2 t ha^{-1}), but *A. holosericea* was most productive at earlier harvests. Only *A. senegal* (6.4 t ha^{-1}) and *A. indica* (5.1 t ha^{-1}) had a significant wood production, whereas *A. holosericea* (5.7 t ha^{-1}) had the highest phyllodes production. Leaves of *A. senegal* and *A. indica* had highest CP contents of 258 and 214 g kg^{-1}, respectively. The leaves of all species except *A. gayanus* had a higher CP:ME ratio than natural pasture in the region. The calorific values of firewood did not differ significantly among the species. *A. nilotica*, the species with one of the lowest firewood production, had the highest Fuelwood Value Index of 6.6. The choice of species for planting trees and windbreaks in the SSZ must be oriented along these criteria. Further research should be directed towards cost-benefit analyses, land tenure and property rights in combination with surveys on local knowledge of rural people.

Introduction

In the Southern Sahelian Zone of West-Africa (SSZ), wind erosion [Michels et al., 1994] is under several circumstances in addition to the low soil fertility, the erratic rainfall, and frequent droughts periods [Fussell et al., 1987], a major threat for cereal production. An often proposed solution to ease the constraint of wind erosion is the use of windbreaks (WBs). Wbs are planted strips of trees and shrubs that, if well designed and maintained, reduce wind speed and decrease the amount of air-blown soil [Rocheleau et al., 1988]. Trees are supposed to have also beneficial effects on the micro-climate and thus to improve conditions for crops [Vandenbeldt and Williams, 1992]. In addition they may be valuable in protecting crops from domestic and wild animals. However, the results from the different regions on crop yields indicated that yield increments of the protected crops were not consistent and assured under all circumstances [Banzhaf et al., 1992; Kessler and Breman, 1991]. In the past, WBs in Niger had contrasting effects on millet grain yields [Lamers et al., 1994], although statistically significant results are still lacking.

Besides the indirect effects, WBs offer long-term solutions to other problems in the SSZ such as the supply of firewood and livestock fodder. WBs have therefore more values, and need thus more than one method of evaluation. The criteria by which farmers and their wives in western Niger judged trees demonstrated that the preferences of local people was also directed towards a multiple use of trees [Lamers et al., 1994]. Farmers in traditional systems are only with exception interested in a single benefit of trees and shrubs regardless of the scope of a specific problem [Wiersum, 1985].

When considering the rehabilitation of the vegetation by trees and shrubs, there is an urgent need to address the firewood supply as well. The rural population of Niger uses firewood principally to satisfy domestic energy demands for cooking and heating. Currently 0.8 kg wood per capita is consumed daily in the capital Niamey [Projet Energie II, 1991]. The consumption of firewood is bound to increase with population growth, which has been 3.2% per year since 1977. Firewood is therefore likely to become a scarce product in the immediate future. In order to supplement a scarcity of firewood, millet stalks, animal manure or household refuse are used in Niger [Angstreich, 1991].

Trees and shrubs might also play a major role in animal production. During the rainy season animals consume grasses and herbaceous plants. During the dry season, the diet consists of senescent grasses, stover from coarse grains and, if available, the diet is enriched with hay from pulses such as cowpea, and groundnut. However, millet stover has low organic matter digestibility, and low contents of metabolizable energy and crude protein [Höfs, 1992, Reed et al., 1992]. Moreover, Nigerian farmers face declining stover yields since the use of stalks as mulch or animal feed competes with notable alternative uses such as fencing or other building activities, domestic fuel for cooking, or sales [Speirs and Olsen, 1992]. Livestock keepers are therefore in need of an alternative feed resource for livestock production especially in more arid regions. The leaves from trees and shrubs could fill in the gap of feed scarcity and serve as a fodder bank. On the other hand, it seems that the leaf production of trees *per se* is insufficient to relieve bottlenecks in livestock production in arid and semi-arid regions [Torres, 1989]. Yet, because of the higher contents of nutritive substances, leaves and fruits of trees could be used to supplement the low quality roughages outside the rainy season. It is known that by complementing low quality diets with more protein rich material, the digestion of the millet and sorghum remnants is increased [Höfs, 1992; Le Houérou, 1980b].

There is a lack of data on different tree characteristics important to the rural population in the Sahel, and in Niger. More data would allow the formulation of strategies and policies with respect to planting trees in general or windbreaks in particular. When the planting of multi-purpose trees and shrubs is envisioned, knowledge about the establishment and growth potential of the species as well as the energy provision by firewood, and the nutritive value as fodder for livestock, are indispensable to back-up a wise choice. This study was conducted to determine these specific characteristics of seven tree and shrub species that are considered for use as windbreaks in Western Niger.

Materials and methods

Experimental design

In August 1988, a windbreak experiment was established at ICRISAT's experimental research station (ISC) at Sadoré (13° N, 2° E), 45 km south east of the capital Niamey, in the SSZ of West Africa. Seven WB species were planted in north-south strips of 50 m length perpendicular to the eastern wind storms. One shelter consisted of one species of each 34 trees, planted in a doubled staggered row configuration at 3 m distance in the row and at 1.5 m between the rows. Three month old stock from a nursery were used for planting. 3.8 g of N, P and K as 15-15-15 fertilizer as well as 5 g Furadan were mixed with the excavated soil and returned into the planting holes. After planting, the stock received once 2 liters of water. Strips were weeded manually twice each rainy season. The experimental layout was a randomized block design with the following seven shelter species in each of the three blocks: the perennial grass *Andropogon gayanus* Kunth., the local trees *Bauhinia rufescens* Lam., *Azadirachta indica* A. juss., *Acacia senegal* (L.) Willd., *Faidherbia albida* Del., *Acacia nilotica* var. adansonii, and the exotic (Australian) *Acacia holosericea* A. Cunn. ex G. Don.

Trimming, estimation of mortality rate, stem diameter, and dry matter production

The purpose of trimming was to obtain detailed information about the dry matter (DM) production of different species and tree components such as leaves, fruit, twigs, and firewood (defined as wooden branches superior to 15 mm in diameter), and to simulate browsing and wood harvest during a period of relative pasture shortage and firewood demand. Beginning in spring 1990, the canopy of the hedges has been trimmed annually, 1–2 months before the onset of the rainy season, to 2 m height and 1 m sidewards measured from the main stem. Thus every tree occupied 5.15 m^2. The number of surviving and dead trees were counted twice a year. Prior to trimming, the diameter of all trees at 10 cm height (d_{10}) was measured with a calliper rule.

To determine the DM production of the tree components, four trees out of a total of 34 were selected randomly, and leaves, fruits, twigs, and firewood were harvested separately. From the remaining trees, total fresh weight was recorded. The selected leaves and fruits (pod plus grain) were dried to constant weight at 50 °C. Twigs and firewood were longitudinally cut prior to drying and subsequently shredded. The grounded material was dried to constant weight at 65 °C. Total DM production per tree and per component was calculated on the basis of the fresh weights and the DM:fresh weight ratio of the tree components.

Crude protein and metabolizable energy content of leaves, and calorific values of firewood

Subsequent to DM determination at 44 months after planting (MAP), the leaves were grounded and analyzed for dry matter digestibility and crude protein content (CP). CP content was determined using the Kjeldahl method (CP = nitrogen content * 6.25). The digestibility and the metabolizable energy (ME) content of the leaves were determined *in vitro* based on the gas (carbon dioxide and methane) production of leaves incubated with rumen liquor according to the Hohenheim gas test [Menke et al., 1979], and using the multi-regression equation for roughages [Menke and Steingass, 1987]. For the estimation of the gross calorific value at 56 MAP, wood samples were burnt in an oxygen bomb calorimeter. The ash content was estimated by burning samples at 550 °C for 5 hours in a muffle furnace. Wood densities were obtained from CIRAD.[1] The Fuelwood Value Index (FVI) was calculated according to Bhatt and Todaria [1992].

Soils and climate

Trees and shrubs were planted on an acidic, sandy soil (psammentic Paleustalf) with low organic matter, cation exchange capacity, and minerals such as phosphorus and nitrogen [West et al., 1984]. Rainfall at the research site occurred between May/June and September/October and total annual rainfall amounts were 699, 623, 399, 603, and 585 mm from 1988 to 1992, respectively. Rainfall for 1991 and 1992 was similar to the long-term average rainfall 545 mm. The 1988 and 1989 rainfall were above the average and in 1990 it was clearly below average. The highest average monthly maximum temperature of 40.9 °C is recorded in April, and the lowest average monthly minimum temperature of 15.9 °C in January [Sivakumar et al., 1993].

Data analysis

Analyses of variance were performed on all estimated parameters using the general linear model (GLM) procedure of the Statistical Analysis System [SAS, 1988]. When the ANOVA analysis showed a significant difference among tree species at $p = 0.05$, the least significant difference (LSD) was calculated (Fishers' protected LSD). In the case of missing values, the least square means (LSMEANS) are reported.

Results and discussion

Mortality rate and growth

At 8 MAP, all species except *Azadirachta indica* and *Acacia holosericea*, showed a low mortality rate (Table 1). Until 26 MAP, the number of dead trees for most species remained unchanged except for *A. holosericea* and *Acacia nilotica*. After 32 MAP only *A. holosericea* showed further mortality, and at 56 MAP, 16% of all trees were dead, the highest mortality rate among all species. All indigenous species had less than 5% dead trees at 56 MAP.

The fastest growing tree species, indicated by the absolute increase of d_{10}, were *A. holosericea* and *A. indica* (Table 2). Slow initial growth was observed in virtually all local species except the perennial grass *Andropogon gayanus*. Once established, the local species showed a good survival rate and could cope better with dry periods. This was less the case with the exotic *A. holosericea* as indicated by the notable decrease in the growth rate of this species during the relatively dry year of 1990 (from 0.3 cm month^{-1} at 20 MAP to 0.12 cm month^{-1} at 27 MAP, and 0 cm month^{-1} at 32 MAP). Monthly growth rates for all other species were much more stable. Monthly diameter growth rates declined for all species after 20 MAP, although sharp differences between the species occurred. The annual increments in d_{10} for *A. indica*

Table 1. Mortality (%) of seven windbreak species during the first five years of establishment.

Species	Months after planting					
	8	20	26	32	44	56
Andropogon gayanus	0	0	0	0	0	2.9
Bauhinia rufescens	0	0	0	0	0	0
Azadirachta indica	4.9	4.9	4.9	4.9	4.9	4.9
Acacia senegal	1.0	1.9	1.9	1.9	1.9	1.9
Acacia holosericea	7.0	8.8	9.0	9.0	13.7	15.9
Faidherbia albida	0	0	0	0	0	0
Acacia nilotica	1.0	1.0	1.9	1.9	1.9	1.9
LSD (0.05)	5.8	7.6	6.5	6.6	8.5	8.0

Table 2. Stem diameter (cm) of seven windbreak species at 10 cm height above the soil surface during five years of establishment. N.A. = Not Available.

Species	Months after planting						
	12	20	26	32	44	50	56
Andropogon gayanus	N.A.	45.8	77.9	N.A.	77.2	77.1	82.8
Bauhinia rufescens	3.1	4.8	5.3	5.8	6.8	7.7	7.0
Azadirachta indica	3.0	5.5	7.1	7.8	10.7	11.7	12.2
Acacia senegal	2.4	4.0	5.1	5.8	8.2	9.2	9.3
Acacia holosericea	5.1	7.5	8.2	8.2	10.8	11.4	11.8
Faidherbia albida	2.8	4.9	5.0	6.0	7.1	7.3	7.5
Acacia nilotica	2.4	3.6	4.1	4.8	6.0	6.6	6.5
LSD (0.05)	0.4	0.8	1.1	0.5	0.8	1.1	1.2

and *Acacia senegal* were at 20 MAP higher than for *F. albida, A. nilotica,* and *B. rufescens.*

Fast growing but short-lived species such as *A. holosericea* thus have good potential when immediate and rapid growth is needed. After several years, such trees might be eliminated and their purpose can be taken over by other species characterized as slower starters but with a higher live expectancy such as *B. rufescens* and *F. albida* which showed 100% establishment at 56 MAP. It might be that the specific *A. holosericea* cultivar under study is less suitable for the harsh agro-climatological conditions in Niger [House and Harwood, 1992]. The increase in mortality rate, and the sharp decrease in growth rate coincided indeed with the dry year during the period of observation.

Dry matter production

The DM production of tree components differed significantly among species (Table 3). Most productive were initially *A. holosericea* and *A. indica*, but at 56 MAP, *A. senegal* became most the productive species. *F. albida* and *A. gayanus* were the least productive. However, the results for *A. gayanus* should be taken with caution. Traditionally, farmers harvest *A. gayanus* at the start of the dry season by cutting at about 10 cm above the soil surface. However, in order to secure its function as a windbreak, this local management strategy was not possible. If only the parts above the 2 m height are harvested, DM production must be very low and actually should not be compared with the other species. In an experiment at ISC, the perennial grass *A. gayanus* showed good anti-erosive quality as it trapped about 2,000 t ha^{-1} of sand during three years [Renard and Vandenbeldt, 1990]. Despite this positive feature and the high growth rate, the total DM production of *A. gayanus* was the lowest of all species in this study. Farmers who favor this species have to choose between its windbreak characteristics or its valuable products, but can rarely have both.

Table 3. Dry matter production (t ha^{-1}) of different tree components of seven windbreak species during the first five years.

Species	Twigs			Leaves			Wood		Fruit		Total			
	Months after planting													
	32	44	56	32	44	56	44	56	44	56	20	32	44	56
Andropogon gayanus	0	0.1	0.1	0	0	0	0	0	0	0	0	0	0.1	0.1
Bauhinia rufescens	1.1	4.5	6.7	0.2	0.6	0.8	1.0	1.9	2.2	1.7	0.7	1.3	8.3	11.2
Azadirachta indica	2.7	3.8	4.5	1.0	1.4	2.3	2.4	5.1	0	0	2.2	3.7	7.7	12.0
Acacia senegal	1.4	8.4	14.1	0.6	0.4	1.8	0	6.4	0	0	0.5	2.1	8.8	22.3
Acacia holosericea	2.6	8.2	5.7	5.9	6.2	5.7	0	0.3	0	0	5.5	8.5	14.4	11.7
Faidherbia albida	0.5	1.3	1.8	0.1	0.3	0.5	0	1.0	0	0	0.4	0.6	1.6	3.3
Acacia nilotica	0.5	2.8	5.6	0.1	0.3	0.5	0	0.7	0	0	0.3	0.6	3.1	6.8
LSD (0.05)	1.1	3.2	3.9	1.5	1.5	2.1	0.6	1.9	0.7	0.8	3.3	2.4	4.3	6.4

A ranking based on the assessment of DM of different components would change over the years, indicating that species selection based on production data of the first 2–3 years may be misleading. Moreover, all tree species were harvested at fixed times and not on a continuous basis. Yields for certain parts such as leaves and particularly fruits might therefore be underestimated. During trimming in April, fruits could only be collected from *B. rufescens*. Nevertheless, species such as *A. holosericea* or *F. albida* are known to produce high quality fruits suitable for consumption by humans and livestock but at other times of the year [House and Harwood, 1992; Reed et al., 1992]. Some fruit production was monitored outside the period of interest and thus not considered. Under farmers' conditions they nevertheless could be taken into account.

With respect to the production of the different components, all species produced mainly twigs and small branches with annual trimming in most years. Although these parts are often considered as less important, they can play an important role in erosion control and recovering eroded spots. A mulch with branches from trees and shrubs stimulated re-vegetation on bare Sahelian forest soils, seriously over-exploited by sedentary farmers and migrant herders in Niger [Chase and Boudouresque, 1987]. The applied mulch captured eolian material such as sand and seed of herbaceous plants and trees, which consequently led to an increase of the ground cover immediately during the first rainy season. Due to the changes in the micro-environment, surface crusting as a direct result of wind erosion was hampered. Twigs and branches used in this way could replace scarce millet crop residues currently used as mulching material.

Firewood production of trees at 56 MAP was still modest except for *A. indica* and *A. senegal*. In order to increase the amount of firewood, a prolongation of the harvest intervals is more appropriate. Leaf production for livestock fodder increased with advancing years although the absolute increments differed among the species (Table 3). *A. holosericea* had the highest leaf production in all years (the leaves of *A. holosericea* are not real leaves in the botanical sense; they form phyllodes). Total biomass production of *A. senegal, A. indica, A. holosericea,* and *B. rufescens*, exceeded dry matter production of a millet crop (8 t ha^{-1}) at the research site even under the best management conditions [ICRISAT, 1992]. *F. albida*, with a 'reversed' phenology, was the least productive and carried during the period of trimming hardly any leaves.

Nutritive content of the leaves

The leaves of all browse species had relatively high contents of CP at 44 MAP, except for *A. gayanus* (Table 4). The CP content was highest in *A. senegal*. The leaves of *A. nilotica* and *F. albida* contained lower CP contents despite their ability to fix nitrogen. The ME content among the browse species was highest in the leaves of *A. indica* and was lowest in the leaves of *A.*

Table 4. Contents of crude protein, metabolize energy, and the ratio CP:ME in leaves of seven windbreak species, 44 months after planting.

Species	Crude protein ($g\ kg^{-1}$ DM)	Metabolizable energy ($g\ kg^{-1}$ DM)	CP:ME ($g\ CP\ MJ^{-1}$)
Andropogon gayanus	23	5.14	4.5
Bauhinia rufescens	139	5.42	25.7
Azadirachta indica	214	5.80	36.9
Acacia senegal	258	5.11	47.8
Acacia holosericea	122	3.36	36.4
Faidherbia albida	132	5.67	23.4
Acacia nilotica	150	5.71	26.2
LSD (0.05)	18	0.44	4.4
LSD with missing values	19	0.46	4.6

holosericea. The high contents of CP and the modest contents of ME and organic matter digestibility, indicated that the species are potentially a good feeding stuff. The CP:ME ratios varied between 23 and 47 g CP MJ^{-1} (Table 4) for all species except *A. gayanus*, and were much higher than the CP:ME ratio of 8–10 g CP MJ^{-1} estimated for cattle (*Bos indicus*) grazing natural pasture in central Mali [Mahler, 1991].

Because of the relatively high CP content, the ME content of browse species is likely to be the limiting factor during the dry season. The high CP contents of the leaves confirm that it would be unwise to waste this relatively high quality material as main or basic food, and that it would offer an attractive supplementary product to low quality roughages such as millet crop residues. The CP and ME contents of pearl millet harvested at the same time as the browse material were respectively 72 [$g\ kg^{-1}$ DM] and 4.2 [$MJ\ kg^{-1}$ DM] for stalks, and 68 [$g\ kg^{-1}$ DM] and 6.6 [$MJ\ kg^{-1}$ DM] for leaves. The results with *A. indica* were ambiguous. Although the CP and ME contents were high, it is known that the leaves contain components which give an astringent taste and are only eaten during periods of food scarcity [Höfs, 1992].

Despite the high phyllodes DM production of the Australian *A. holosericea* at 44 MAP, the chemical analysis indicated that the phyllodes were less suitable as livestock feed. However, such analyses are merely an indication of the potential nutritional value as they have some limitations [Höfs, 1992; Le Houérou, 1980a]. For instance, the digestibility of CP can be reduced by secondary compounds in leaves such as phenols and tannins that inhibit in the rumen the breakdown of macromolecules such as proteins or carbohydrates by interfering with the enzymatic system, and/or by forming relatively inert complexes with macromolecules [Cissé and Koné, 1992; Makkar, 1993]. High contents of tannins might further reduce palatability, another important criteria that is not reflected in chemical analyses [Makkar, 1993]. On the other hand, high levels of tannins in leaves of *B. rufescens*, *Ziziphus mauritiana* and

Combretum aculeatum did not influence the palatability with sheep in Niger [Höfs, 1992].

Calorific values

In Sahelian countries such as Niger, hardly any alternative to firewood exists to fulfill domestic energy demands. Farm planting programs are therefore very well advised to take this requirements into consideration during species selection. Important hereby are the gross calorific values of non-dried wood which however hardly differed among species, not only in this particular study (Table 5), but also in general [Harker et al., 1982]. A more practical indication could be obtained from the amount of firewood production, which was significantly different among the species in this survey, times the gross calorific value, here expressed as the total available calorific value per tree. Total calorific values per tree were highest for *A. senegal* and *A. indica.*

However, selection criteria based on calorific values alone are inadequate for the selection of the better firewood species [Bhatt and Todaria, 1992; Harker et al., 1982]. Characteristics such as the ash content and the wood density are additional features that are not considered during the estimation of the calorific value using a calorimeter, but by which firewood properties of the species are defined as well. More appropriate was therefore the FVI that considered several quantitative characteristics at the same time, and indicating the best firewood properties of the species [Bhatt and Todaria, 1992]. Nevertheless, chemical analysis did not yet consider the ability of wood to burn without sparks or toxic smokes, two very important features for rural people. These characteristics still have to be defined before a final advise is worked out. Using the FVI as a criteria, one of the least productive species in this experiment, *A. nilotica*, showed the best firewood properties, mainly due to a low ash content (Table 5). *A. senegal* showed the lowest FVI. Considering the wood production and the FVI at the same time, *A. indica* showed the best firewood potential among the species under study.

Conclusions

As there exists a need to rehabilitate the lost vegetation in Sahelian countries to stop desertification and to recover eroded and abandoned soils, windbreaks, consisting of trees or shrubs, can play an important role in this process. However, the choice of trees species for planting is crucial for a successful introduction as trees and shrubs provide useful products to satisfy many needs in rural households such as in Niger. With respect to features such as establishment and growth, especially *A. senegal* and *B. rufescens* showed an excellent potential during the first five years of this experiment. Considering the nutritive values, the phyllodes of *A. holosericea* cannot be recommended as feeding stuff for livestock whereas the leaves of *A. senegal* and *B. rufescens*

Table 5. Firewood production, gross calorific value, ash content, wood density, and total available calorific value of seven tree species 56 months after planting in Niger. N.A. = Not Available.

Species	Firewood production (kg DM $tree^{-1}$)	Calorific value (MJ kg^{-1} DM)	Ash content (%)	Wood density[a] (g cm^{-3})	Total calorific value (MJ $tree^{-1}$)	Fuelwood value index (FVI)
Andropogon gayanus	0	N.A.	N.A.	N.A.	N.A.	N.A.
Bauhinia rufescens	1.0	19.4	3.7	0.7	19.2	4.1
Azadirachta indica	2.6	19.4	3.4	0.7	51.1	3.9
Acacia senegal	3.3	18.9	5.9	0.8	61.5	2.6
Acacia holosericea	0.1	N.A.	N.A.	N.A.	N.A.	N.A.
Faidherbia albida	0.5	18.9	3.8	0.5	10.0	2.7
Acacia nilotica	0.4	18.6	2.4	0.8	7.0	6.6
LSD (0.05)	1.2	N.S.	–[b]	–	21.1	0.6

[a] Communicated by P. Detienne, Departement Forestier, CIRAD-Forêt, Montpellier, France.
[b] Ash contents were determined for one replication only.

can be taken into consideration, subject to the absence or low levels of tannins. Taken into account the total available calorific values of wood to satisfy domestic energy demand, especially *A. senegal* and *A. indica* are high ranking. *A. nilotica*, although showing the best firewood properties as indicated by the FVI, was one of the least productive species after 5 years. Considering the wood production and the FVI at the same time, *A. indica* showed the best firewood potential. With respect to the production of by-products such as twigs usable for mulching purposes, no specific species can be recommended. Before drawing final conclusions on the Australian *A. holosericea*, a more drought tolerant cultivar should be studied when the introduction of exotic species are considered.

Outlook

Prior to planting windbreaks, the economics, consisting of the site specific costs and benefits, should be estimated. Costs involve mainly labor and material for soil preparation, planting, plant protection such as enclosures, and maintenance. In addition, windbreaks take land out of production and compete with crops for water and nutrients, especially in the interface between hedge and crop. Benefits can be expected directly from additional tree products such as fuelwood, fodder, and fruit as shown in this study. An indirect benefit is expected from the protective effects of windbreaks on plants and soil. However, economic analyses cannot be restricted to monetary aspects but should include the risk involved for interested farmers. It is therefore necessary that experiments which aim to evaluate windbreak systems are combined and/or complemented with on-farm surveys so that site specific experiences and knowledge of rural people can be included in evaluations. This concerns as well land tenure and property rights issues of planted trees and shrubs. Agroforestry research, which is by nature often a long term project, can gain substantially from the local knowledge of men and women. This approach has been started for western Niger and results will be available in the near future.

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Note

[1] Communicated by P. Detienne, Chef du laboratoire Anatomie des Bois. Département Forestier, Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD-Forêt), Montpellier, France.

References

Angstreich M (1991) Are trees effective against desertification? Experiences from Niger and Mali. In: Baxer PTW (ed) When the Grass Is Gone. Development in Intervention in African Arid Lands. pp 141–151. Scandinavian Institute of African Studies, Uppsala

Banzhaf J, Leihner DE, Bürkert A and Serafini PG (1992) Soil tillage and windbreak effects on millet and cowpea: I. Wind speed, evaporation, and wind erosion. Agron J 84: 1056–1060

Bhatt BP and Todaria NP (1992) Firewood characteristics of some mountain trees and shrubs. Commonw For Rev 71(3/4): 183–185

Chase R and Boudouresque E (1987) Methods to stimulate plant regrowth on bare Sahelian forest soils in the region of Niamey, Niger. Agric Ecos Environ 18:211–221

Cissé MI and Koné AR (1992) The fodder role of *Acacia albida* Del.: Extent of knowledge and prospects for future research. In: Vandenbeldt RJ (ed) *Faidherbia albida* in West African semi-arid tropics: proceedings of a workshop. 22–26 April 1991, Niamey, Niger, pp 29–37. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP 502324, India and International Centre for Research in Agroforestry, Nairobi, Kenya

Fussell LK, Serafini PG, Bationo A and Klaij MC (1987) Management practices to increase yield and yield stability of millet in Africa. In: Proceedings of the International Pearl Millet Workshop. 7–11 April 1986, ICRISAT Center, India, pp 255–268 ICRISAT, Patancheru, AP 502324, India

Harker AP, Sandels A and Burley J (1982) Calorific values for wood and bark and a bibliography for fuelwood. Report of the Tropical Products Institute, G 162, 20 pp

Höfs S (1992) Evaluation of various indigenous supplements in millet leaves based diets for sheep in the Sahel. PhD dissertation, D38 Technische Universität Berlin, Institut für Tierproduktion, Fachgebiet für Internationale Agrarentwicklung, 239 pp

House APN and Harwood CE (eds) (1992). Australian Dry Zone Acacias for Human Food Production. Canberra, Australian Tree Seed Center, 145 pp

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Sahelian Center (1992) ICRISAT West African Programs Annual Report 1991. ICRISAT Sahelian Center, Niamey, Niger

Kessler JJ and Breman H (1991) The potential of agroforestry to increase primary production in the Sahelian and Sudanian zones of West-Africa. Agroforestry Systems 13: 41–62

Lamers JPA, Michels K, Allison BE and Vandenbeldt RJ (1994) Agronomic and socio-economic aspects of windbreaks in Niger. Paper presented at the 4th International Symposium Windbreaks and Agroforestry, 26–23 July 1993, Viborg, Denmark (in press)

Le Houérou HN (1980a) Planting and management methods for browse trees and shrubs. In: Le Houérou HN (ed) Browse in Africa – The Current State of Knowledge. Proceedings of a Symposium held at ILCA, Addis Ababa, 8–12 April 1980, pp 351–359. International Livestock Centre for Africa, Addis Ababa, Ethiopia

Le Houérou HN (1980b) Agroforestry techniques for the conservation and improvement of soil fertility in arid and semi-arid zones. In: Le Houérou HN (ed) Browse in Africa – The Current State of Knowledge. Proceedings of a Symposium held at ILCA, Addis Ababa, 8–12 April 1980, pp 433-435 International Livestock Centre for Africa, Addis Ababa, Ethiopia

Mahler FC (1991) Natürliche Weiden und Nebenprodukte des Ackerbaus als Ernährungsgrundlage für die Rinderhaltung am semiariden Standort Westafrikas, PhD dissertation. Universität Hohenheim, Institut für Tierproduktion in den Tropen und Subtropen, 136 pp

Makkar HPS (1993) Antinutritional factors in food for livestock. In: Gill M, Owen E, Pollott GE and Lawrence TLJ (eds) Animal Production in Developing Countries, Vol 16, pp 69–85, British Society of Animal Production

Menke KH und Steingass H (1987) Schätzung des energetischen Futterwertes aus der in vitro mit Pansensaft bestimmten Gasbildung und der chemischen Analyse. II. Regressionsgleichungen. Tierernährung 15: 59–94

Menke KH, Raab A, Salewski A, Steingass H, Fritz D and Schneider W (1979) The estimation of the digestibility and metabolizable energy content of ruminant feeding stuffs from gas production when they are incubated with rumen liquor in vitro. J Agric Sci, Camb 93: 217–222

Michels K, Sivakumar MVK and Allison BE (1993) Wind erosion in the Southern Sahelian Zone and induced constraints to pearl millet production. Agric For Meteorol 67: 65–77

Projet Energie II – Energie domestique (1991) Volet Offre. Schema Directeur d'Approvisionnement en Bois Energie de Niamey. République de Niger, Ministère de l'hydraulique et de l'environnement. Groupement SEED-CTFT, 127 pp

Reed JD, Rittner U, Tanner J and Wiegand O (1992) Nutritive value of leaves and fruits of *Faidherbia albida* and their use for feeding ruminants. In: Vandenbeldt RJ (ed) *Faidherbia albida* in West African Semi-Arid Tropics Proceedings of a workshop, 22–26 April 1991, Niamey, Niger, pp 43–49. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP 502324, India and International Centre for Research in Agroforestry, Nairobi, Kenya

Renard C and Vandenbeldt RJ (1990) Bordures d'*Andropogon gayanus* Kunth. comme moyen de lutte contre l'érosion éolienne au Sahel. Agronomie Tropicale 45(3): 227–231

Rocheleau D, Weber F and Field-Juma A (1988) Agroforestry in Dryland Africa. International Council for Research in Agroforestry (ICRAF), Nairobi, 310 pp

SAS Institute Inc SAS/STAT (1988) Guide for Personal Computers, Version 6. SAS Institute Inc, Cary, NC, 1028 pp

Sivakumar MVK, Maidoukia A and Stern RD (1993) Agroclimatology of West Africa: Niger. Second edition. Information Bulletin no 5. International Crops Research Institute for The Semi-Arid Tropics, Patancheru, AP 502324, India and Direction de la metéorologique nationale du Niger, Niamey, Niger 116 pp

Speirs M and Olsen O (1992) Indigenous integrated farming systems in the Sahel. World Bank technical paper 179, Africa Technical Department Series, World Bank, Washington, DC

Torres F (1989) Tree-fodder and silvopastoral systems. In: Nair PKR (ed) Tree-Fodder and Silvo-Pastoral Systems. Agroforestry Systems in the Tropics, pp 553–565. Kluwer Academic Publishers, Dordrecht, the Netherlands, in co-operation with ICRAF, Nairobi, Kenya

Vandenbeldt RJ and Williams JH (1992) The effect of soil surface temperature on the growth of millet in relation to the effect of *Faidherbia albida* trees. Agric For Meteorol 60: 93–100

West L, Wilding LP, Landeck JK and Calhoun FG (1984) Soil Survey of the ICRISAT Sahelian Center, Niger, West Africa. Texas A & M University, Soil and Crop Sciences Department/ TropSoils, 66 pp

Wiersum KF (1985) Trees in agricultural and livestock development. Neth J Agric Sci 33: 105–114