Faidherbia albida

in the West African Semi-Arid Tropics

International Crops Research Institute for the Semi-Arid Tropics
International Centre for Research in Agroforestry

Abstract

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This workshop brought together scientists and development workers, primarily those working in the West Africa region, to: review past and present research findings on *Faidherbia alhida;* discuss development issues and "lessons learned" from past and present; list research priorities for the future; and promote collaboration between research and development programs.

These proceedings summarize the state of knowledge on the species and provide a comprehensive list of ongoing research. Papers are divided into sessions on: botany and distribution; uses; genetics, provenance trials, and vegetative propagation; site effects, silviculture, and rhizosphere; and development issues. Recommendations from Working Groups for future research and multidisciplinary linkages are included.

Résumé

Faidherbia albida ***dans les zones tropicales semi-arides de l'Afrique occidentale—comptes rendus d'un atelier, 22–26 avril 1991, Niamey, Niger.*** **Cet atelier a regroupé des chercheurs et des coopérants, essentiellement ceux qui travaillent en Afrique de l'Ouest. Il a été destiné à: faire le point sur les résultats des recherches faites sur *Faidherbia albida* dans le passé et à présent; débattre des sujets concernant le développement et des 'leçons tirées' du passé et du présent; dresser la liste des priorités pour l'avenir; et promouvoir la collaboration entre les programmes de recherche et de développement.**

Ces comptes rendus résument l'état actuel des connaissances sur les espèces et fournissent une liste complète des activités de recherche en cours. Les communications présentées sont divisées en sessions sur: botanie et distribution; utilisations; génétique, essais de provenance et multiplication végétative; impact du site, rhizosphère et sylviculture; et problèmes liés au développement. Les recommandations des Groupes de travail sur les recherches futures ainsi que sur les collaborations multidisciplinaires y sont également incluses.

Cover: *Faidherbia albida* growing in West Africa. [A computer-scanned negative of a photo by C. Barbier (CTFT 1988), used with permission of the Centre technique forestier tropical.]

Faidherbia albida in the West African Semi-Arid Tropics

Proceedings of a Workshop

22-26 Apr 1991
Niamey, Niger

Edited by

R.J. Vandenbeldt

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
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ICRAF

International Centre for Research in Agroforestry
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Preface

The original objective of this workshop was to assemble a small group of researchers and development persons-20 or so-with experience of and interest in *Faidherbia alhida* in order to define mutually desirable research goals and forge feedback linkages to facilitate and influence each other's work. Other objectives included reviewing research findings and "lessons learned" from development programs, past and present. The objectives remained the same throughout, but the workshop participant list quickly expanded to 120! Over 35 presentations were made in sessions on botany, use, genetics, site effects, and socioeconomic issues. Working groups on genetic improvement; site effects, silviculture, and rhizosphere; and socioeconomics prepared recommendations that are included in this volume as presented at the final plenary session.

Many issues were discussed, and there was disagreement among the delegates on a number of these. Several development workers argued that enough is known now about the technical side; what is lacking is information on the socioeconomic aspects of the species in the context of Sahelian agronomic and pastoral systems. Some researchers argued quite the opposite; development programs featuring the species have had little success because insufficient knowledge exists on the processes underlying the celebrated "albida effect" of the tree, its genetic variation, botany, management and establishment, feed value, and a host of other topics.

Faidherbia albida (Del.) A. Chev. is now accepted over *Acacia albida* Del. as the correct epithet for the species by most taxonomists. However, there was reluctance by many, including several knowledgeable scientists who have devoted years of study to the species, to adopt this name in their papers. The title of these proceedings indicates the preference of ICRISAT and ICRAF. Nevertheless, the authors' preference has been retained when requested. This indicates that taxonomists need to provide further evidence that the separation of F. *albida* from Acacieae is justified or warranted.

There are gaps in the sessions. For example, the session on uses included mainly information on feeding value, and there were no papers on pests and diseases. Nevertheless, I am sure readers will recognize the reawakening of interest in the species, and will agree that the diversity and quality of work in the new phase of research presently in progress will be productive.

A word about the reference lists following each paper is necessary. One of the hidden objectives of the workshop was to reveal, through citation, the vast amount of "grey literature" that exists on F. *albida.* This objective was met, but in many cases full citations were not available. Readers are advised to bear this in mind and are asked to correspond directly with the authors if questions arise.

The Working Group sessions were fruitful, although there was considerable overlap in their output. Rather than attempt to consolidate and reduce this overlap, it has been retained to emphasize the consensus that future research and development on F. *albida* must be multidisciplinary. It is very clear that gaps remain in our knowledge about the species in the entire range of the biophysical and socioeconomic sciences. These gaps will be most efficiently addressed only if the linkages and feedback mechanisms between development and research efforts are implemented as proposed during the workshop.

I would like to take this opportunity to thank the other scientific editors, C. Renard, who read and critiqued the French papers, and E.G. Bongkoungou, who provided crucial advisory input during the early stages. Thanks are also due to the French-English translator, J.E. Rampant, and to B. Gerard and G. Renard, who assisted in many ways. The input and support of the Planning Committee—Aboubacar Issa, E.G. Bongkoungou, P.N. Sall, and G. Taylor—are gratefully acknowledged. Finally, I wish to thank P. Torrekens and S. Gambo for arranging the field tour.

I must also thank the authors, who in most cases presented original unpublished data. Several papers had to be edited to meet length requirements, and/or to limit the number of topics covered. Every effort was made to consult authors and the other editors about this, but I take full responsibility for the final result.

R. J. Vandenbeldt
Editor

Opening Paper

Sociocultural and Economic Functions of *Acacia albida* in West Africa

E.G. Bonkoungou[1]

Abstract

Populations in Sudano-Sahelian Africa have developed agrosilvipastoral production systems in which trees and shrubs play a vital role in crop and animal production. Acacia albida *is one of the most favored trees in such production systems. It is revered by the local people and is central to various popular myths and religious belief. The mythology of the Bambara people, for example, associates* A. albida *with the creation of the world. In the Bailor Maouri region of Niger, the species is part of the inheritance which the rural people pass on to their children. Yet, current research programs focus mainly on the biology of the species, leaving socioeconomic issues largely unexplored. This paper highlights the importance of some of the sociocultural and economic functions of A.* albida *in West Africa and argues that future development should focus more on socioeconomic research.*

Introduction

Throughout the temperate countries, current practices allocate separate domains to agriculture, forestry, and animal production. For centuries, however, populations in Sudano-Sahelian Africa have developed and preserved an integrated agrosilvipastoral production system in which trees and shrubs play a vital role in crop production. According to Pelissier (1980), changes in African agriculture have not been accompanied by the elimination of the tree, but rather by its association with crops.

Agrarian lands of Sudano-Sahelian Africa are frequently associated with the following park types: *Acacia albida, Butyrospermum paradoxum,* subsp *parkiilParkia biglobosa,* the "dim" tree (*Cordyla pinnata*), and "gum gardens" (*Acacia Senegal*). In certain cases, palm-tree formations dominate the tree stratum, e.g., the borassus palm (*Borassus aethiopium*), doum palm (*Hyphaene thebaica*), and, in oasis areas, the date palm (*Phoenix dactylifera*). For centuries, these traditional agroforestry systems have carried out important sociocultural and economic functions for populations that have, in turn, continually regenerated them. Unfortunately, agricultural research has been organized on a sectoral basis. The agronomists are focusing solely on crops in the field and the foresters on trees in a forest. This approach limits the potential role of trees in agriculture.

Today, the international scientific community, through the Consultative Group on International Agricultural Research (CGIAR), proposes expanding the organization in order to include optimal land management by integrating agriculture and forestry. Hence, the role that field trees play in the agricultural production and rural economy of Sudano-Sahelian rural farmers has been recently recognized by the scientific community. The current workshop on *A. albida* is an important contribution to this new agricultural research approach, since this is one of the principal tree species particularly favored by the rural farmer. The workshop is being held almost 30 years

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Bonkoungou, E.G. 1992. Sociocultural and economic functions of *Acacia albida* in West Africa. Pages 1-6 *in Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

after the first research program on *A. albida* was initiated at the agronomic research station in Bambey, Senegal.

This paper will start the discussion by addressing research and development done on trees (particularly *A. albida)* in agrarian systems of Sudano-Sahelian Africa so as to pinpoint the current extent of knowledge on the species and to outline a few perspectives indicating the direction for future efforts.

Functions of Trees in Sudano-Sahelian Africa

In all times and in all civilizations, trees have been a subject of symbolic thought and have inspired myths and religions. In West Africa, numerous legends relate the founding of villages near large trees. *L'arbre a palabre,* a well-known meeting place in villages, is often a reminder of the founding ancestor and even sometimes shelters his grave. The tree has therefore been considered as a sacred intermediary between the living and their ancestors, and sometimes receives worship and offerings. Certain trees are said to be endowed with magical powers and move at night.

In addition to their important place in myth and religion, trees also serve an economic purpose that closely links them to man. Besides providing timber and firewood, trees furnish a great variety of non-woody products, some of which are sold on international markets: *Butyrospermum paradoxum* nuts, gum arabic, incense, and various resins. Numerous other nonexported products, as well, play a fundamental role in the diets and health of man and animals: fruits, flowers, leaves, bark, roots, tubers, sap, etc. In addition to being important to dietary balance in daily life, a number of these products are critical to the survival of entire populations during periods of food scarcity or famine. Considering the great importance of trees in the socioeconomic life, it is not surprising to see their full use in agricultural and food production strategies. They are not merely a curiosity for ethnologists or anthropologists, but rather a true economic factor affecting the great majority of populations of Sudano-Sahelian Africa, including city dwellers. These products, apart from being consumed at home, are also traded on local markets both in villages and in the towns.

For domestic animals and wildlife, forest and field trees represent rare sources of protein during the dry season. They provide a highly sought-after fodder, replacing the grasses, which diminish in quality and quantity during this period.

The long tradition of integrating trees into agrarian systems in Sudano-Sahelian Africa has unfortunately been limited to preserving existing trees. This has not evolved into directly regenerating trees on agricultural lands. With the exception of live hedges (generally propagated vegetatively), Sudano-Sahelian Africa has not developed a planting tradition comparable to that which gave rise to the huge olive orchards in the Mediterranean basin. Today, many tree stands in West Africa are being degraded by the combined effects of land pressure and drought, and the absence of a planting tradition constitutes, at least in part, a serious constraint to regenerating existing parks or establishing new ones.

Sociocultural and Economic Functions

The general functions of trees outlined above apply to *A. albida* to varying degrees, depending on the location. The functions of *A. albida* differ widely from one region to another within its vast natural distribution area, which covers the whole of semi-arid Africa, north and south of the equator.

In eastern and southern Africa for example, *A. albida* occurs with natural vegetation along temporary and permanent watercourses. Its integration into agrarian systems by traditional practice is unknown. Except for the use of its seeds, which are consumed in certain regions during times of famine, the socioeconomic uses of *A. albida* are unknown as well. In West Africa, however, it is socially important. This is evident in cultural and religious life as well as in economic activities. The species is a mainspring of agrosilvipastoral production systems for many agrarian civilizations. This is largely due to its reverse phenology and its abundance in fields; field population density is considerably higher than those of natural stands in southern Africa.

Because of the unique benefits it confers and its strange phenological behavior, *A. albida* is often associated with divine powers. Man has sought to win favors of this divine power through worship and offerings and by reserving for *A. albida* a special place in myths and religious beliefs. The mythology of the Bambara people, for example, associates *A. albida* with the creation of the world. It is said that the initial mass that gave birth to the earth was then transformed into a seed of *A. albida.* Among the Dogon people, the elderly lie on a board of *A. albida* wood to extend their lives; corpses are carried on a stretcher made of its branches.

A. albida is also valued for its shade and quality fodder. A stand of this tree allows intensive farming without the need for a fallow period. Beneath this tree, crops, especially cereals, produce good harvests. Traditional practices integrating *A. albida* into the agricultural production system have been perfected by the Haussa of Niger (Giffard 1974), the Seres of Senegal (Pelissier 1966), the Bwaba of Burkina Faso (Savonnet 1959; Capron 1965), the Dogon of Mali (Gallais 1965), and diverse agrarian civilizations of the Niger River Delta (Gallais 1967). The importance of *A. albida* in the region of Zinder in Niger (circa 1860) was reflected in the sultan's decrees, which dictated: "he who cuts an *A. albida* tree without authorization will have his head severed; he who mutilates it without reason will have an arm cut off (Giffard 1974). The importance of this species is so well established in rural economies that, in dividing fields, certain ethnic groups take into account the number of *A. albida* trees.

Assessment of Past Studies

Modern science came to be interested in the agronomic merits of *A. albida* around 40 years ago, but experimental research on it did not start until 1966, at the Institut senegalais de recherches agricoles, in Bambey, Senegal. The following institutes participated:

- The Institut francais de recherche scientifique pour le developpement en cooperation (ORSTOM) was in charge of studying soil microbiology beneath the tree and the nitrogen-fixing action of A. *albida;*
- the Institut de recherches agronomiques tropicales et des cultures vivrieres (IRAT) studied the influence of the microclimate created by the tree as well as the effect of shade on soil and on crop yields;
- the Institut de recherches pour les huiles et oleagineux (IRHO) focused on the impact of the species on groundnut development and pod yields; and
- the Centre technique forestier tropical (CTFT) studied traits of the wood and tree growth, and defined a planting technique for the species.

The results of this vast program were published by Charreau and Vidal (1965); Dancette and Poulain (1968); Jung (1969); Giffard (1974); and Felker (1978). The principal conclusions indicate important differences under and outside the cover of A. *albida,* notably in terms of soil, microclimate, and crop yields. For example:

- the percentages of total nitrogen and carbon are twice as high under *A. albida* than outside its cover,
- biological activity is two to five times greater under *A. albida* than outside its cover;
- on lands where millet yields around 500 kg ha^{-1}, the yields approach 1000 kg ha^{-1} at the limits of *A. albida* foliage and can attain 1700 kg ha^{-1} near the boles.

Up to the present, these improvements were thought to be caused by the presence of *A. albida;* however, a recent hypothesis proposed by Vandenbeldt (1991, personal communication) suggests that it is rather the preexistence of favorable microsites on these different locations that facilitates establishment of *A. albida* (Geiger et al. 1992).

The end of the Bambey program was followed by a 10-year period during which interest in *A. albida* appeared to flag. Neither research nor development took new initiatives. Furthermore, the Bambey research remained solely technical and did not have any major impact on development projects.

It was after 1979 that scientific interest in *A. albida* revived, with the implementation of a project sponsored by the Food and Agriculture Organization of the United Nations (FAO), focusing on the genetic resources of several tree species. This project was not started specifically for *A. albida,* but it contributed to reviving scientific interest in this species (Bonkoungou 1985). Unlike the previous period which was particularly marked by a preoccupation explaining and quantifying the impact of *A. albida* on soil characteristics, microclimate, and crop yields, this new period—which is still current—is characterized by a concentration of research efforts on genetic resources and stock improvement. The principal activities are provenance comparison trials, vegetative propagation, symbiosis studies, and electrophoretic analyses of gene frequencies.

In addition to the FAO project, tree seed centers in Burkina Faso, Senegal, and Zimbabwe have advanced knowledge on *A. albida* (and other species) by identifying natural stands from which to collect seed, seed harvesting, and phenological monitoring. This new period has also been characterized by:

- a large diversification of funding sources, which include France, the International Development Research Centre (IDRC) of Canada, the European Economic Community (EEC), and the World Bank;
- the first implementation of a multi-institutional approach involving non-African [Oxford Forestry Institute (OFI) in the UK, CTFT and the Ecole

nationale du genie rural des eaux ct des forets (ENGREF) in France] as well as African partners like the Institut de recherches en biologie et ecologie tropicale (IRBET) in Burkina Faso, the Institut senegalais de recherches agricoles (ISRA), and the University of Dakar in Senegal;
- the publication of two monographs (Bonkoungou 1987; CTFT 1988), which readily provide the scientific community and the public with information on the state of research on A. *albida.*

The principal results of experimental research during this period can be summarized as follows:

Provenance Comparison Trials. Provenance trials were conducted in several countries, including Senegal, Burkina Faso, and Zimbabwe. The largest of these trials, one being installed by IRBET/CTFT in Burkina Faso (Bonkoungou et al. 1988) and the other set up by the Forestry Research of Zimbabwe (Sniezko and Stewart 1989), were composed of more than 30 provenances each.

These trials showed extreme variability in terms of growth between as well as within provenances. In each region, the local provenances of that region gave the best results. Thus, in West Africa, the West African provenances performed better than those of southern Africa; in southern Africa, the provenances harvested locally gave better results than those from West Africa.

Vegetative Propagation trials. Vegetative propagation trials gave positive results for macro-cuttings planted under glass panels as well as for micropropagation by in vitro culture; similar field trials, however, have not been fully evaluated.

Research on Symbiotic Systems. *Rhizobium,* endomycorrhiza, or both simultaneously as a double inoculation gave very encouraging results in the laboratory and in the nursery in Burkina Faso and Senegal. Field trials have been recently installed and cannot be presently evaluated.

Progeny trials. Provenance comparison trials were recently supplemented by progeny trials to study germplasm. Isoenzymatic analyses by electrophoresis, which will supplement results of the provenance comparison trials, are being carried out by Joly (1992) in France.

Vandenbeldt (1991, personal communication) has proposed a new hypothesis that suggests that higher levels of fertility found at the bases of *A. albida* are not caused by the tree; rather, the preexistence of good microsites favored the establishment of the tree. This hypothesis, if verified, will have serious implications for research and development.

Thoughts for the Future

The assessment of past experience has led to the following observations:

- Research on *A. albida* was essentially devoted to technical aspects and not enough to socioeconomic problems.

  The initial direction taken in studying the impact of human geography (Pelissier 1966) on agrarian civilizations of Cayor and Casamance was lost in subsequent studies, which focused solely on the tree rather than the people and their use of the tree.

  Socioeconomic studies are needed to account for the highly variable behavior of populations vis-a-vis *A. albida.* Montagne (1984) gave the following example of two villages in Niger. In the Dallol Maouri, *A. albida* is part of the inheritance which the rural people pass on to their children. In the Dallol Boboye, however, *A. albida* does not come into play in the division of fields inherited from the father: only the baobab (*Adansonia digitata*) is taken into account. Thus it is evident that the people of these two villages will not respond similarly to an *A, albida* regeneration project. The presence *of A. albida* to relic stands may not reflect the local attitude towards the species. Some stands of the tree were in fact relic stands without any connection with the people, who do not know or feel the need to ensure their regeneration.

  Future programs that focus on *A. albida* should give particular attention to socioeconomic considerations.
- Technical research should, in pursuing stock improvement, integrate more genetic and symbiotic aspects, since the infectivity and the effectiveness of certain microorganism strains vary considerably, both between trees of different provenances and between progenies of the same provenance.

  More research effort should be devoted to mature trees. Most development projects have emphasized regeneration by planting or by protecting natural regeneration. These efforts deserve to be supplemented by work on the management of mature trees. Part of this approach would involve testing different types and intensities of cuts during different times of the year in order to determine optimum pod and foliage production.

Phenological studies, which have for too long focused on the reverse phenology of *A. albida,* need to be expanded to include studies on biology of reproduction (allogamy/autogamy, controlled pollination, etc.). Lastly, there remains the question of whether the species belongs to the genus *Acacia* or to the monospecific genus *Faidherbia.*

- The new hypothesis according to which the higher level of fertility at the base of the species is caused not by the presence of the tree but rather by the preexistence of microsites favoring the establishment of the tree will have a considerable impact on future action, once it can be verified. Planting strategies will have to bear in mind whether the aim is research or development.

Conclusion

By deciding to emphasize the interaction between forestry and agriculture, the CGIAR is establishing research priorities on systems to which the empirical experience of diverse agrarian civilizations of Sudano-Sahelian Africa can contribute.

Besides presenting the important sociocultural and economic relationships that exist between *A, albida* and man, the previous discussion outlines the results of principal interventions of the past and present and suggests a number of options for future efforts, which must involve partners of national and international research institutions.

The International Centre for Research in Agroforestry (ICRAF), which has recently been vested with the responsbility for research in agroforestry within the CGIAR, will play a major role in future research on *A. albida.* Research on this species has already been integrated into the activities of several ICRAF networks of collaborative programs in Africa.

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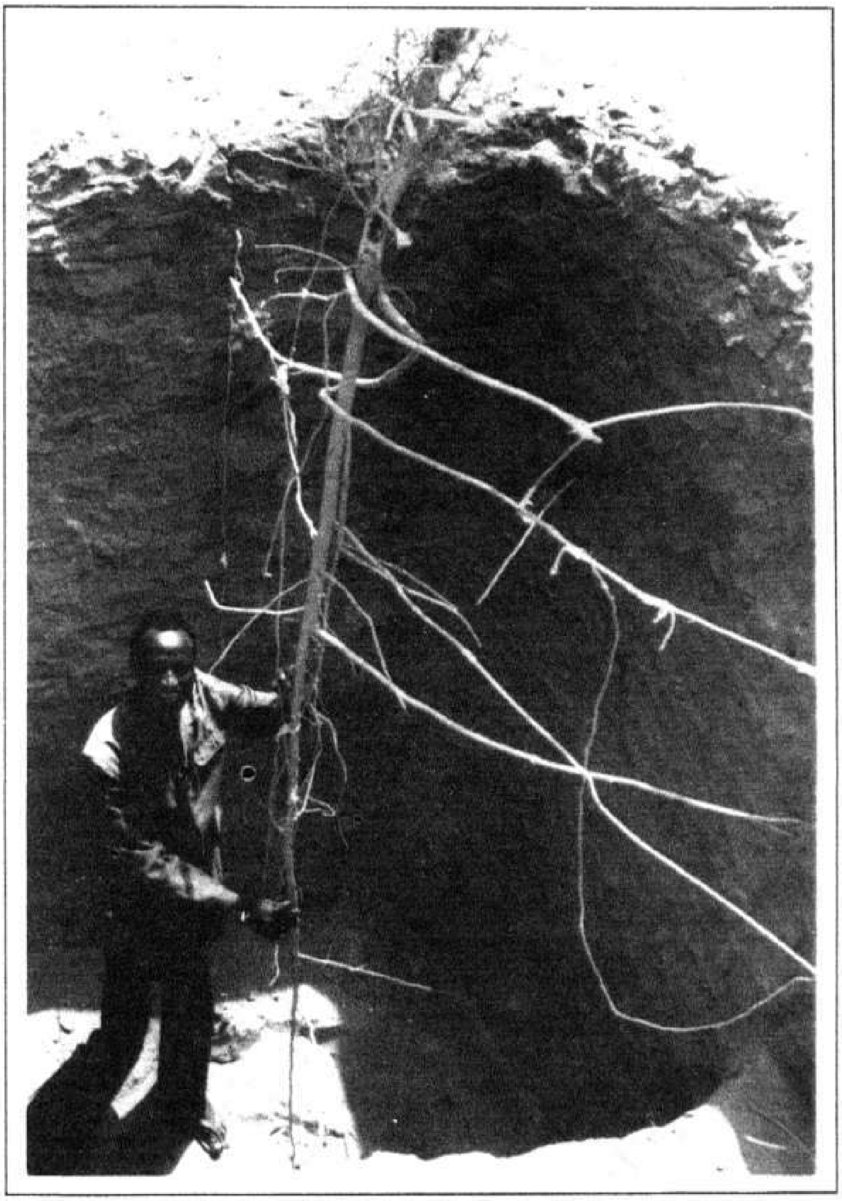
Session 1
Botany and Distribution



Cover photo: Root excavation studies at ICRISAT Sahelian Center have demonstrated marked differences in rooting patterns between *Faidherbia albida* provenances from the Sahel and eastern Africa. (Photo: R.J. Vandenbeldt.)

The Botany and Distribution of *Faidherbia albida*

P.J.Wood[1]

Abstract

Faidherbia albida *(syn. Acacia albida) is a unique member of the Acacieae tribe of the Mimosoideae. It is mainly a species of the Sudanian and Sahelian zones of Africa, reaching into the Sahara and beyond, along watercourses. It is particularly well adapted to use as an agrcforestry tree, and its ecological optimum is on sites with deep sandy soils and an annual rainfall of 500-1000 mm. This applies equally to western, eastern, and central Africa. It is a plant that loses much water by evaporation and therefore can only develop on moist soils or on soils that allow the development of an extensive root system down to the water table where it can obtain adequate moisture.*

Introduction

Faidherbia albida Del. A. Chev. (syn. *Acacia albida)* is widely distributed throughout the dry zones of tropical Africa. Although of the Acacieae tribe, it has many unique botanical and phytochemical features, as well as botanical naming, that justify its classification as a separate genus.

In western Africa, though not always in eastern, central, or southern Africa, the species has the unique characteristic of shedding its foliage at the start of the rainy season, and of coming into leaf in the dry season. This unexpected "inverted" phenology means that its presence in farmers' fields does not interfere with agriculture, and, indeed, makes it an ideal agroforestry tree for use in combination with crops. It also provides animal fodder in the dry season. These qualities are traditionally well known in rural West Africa, where generations of small farmers have deliberately encouraged it in a kind of cultivated parkland (Pelissier 1980). In southern Africa, monospecific stands are also thought to result from past cultivation (Fagg and Barnes 1990).

Botanical Characteristics

Morphology and General Features

Under favorable conditions, *F. albida* can attain a very large size; heights of over 30 m and a diameter of 1.5 m have been noted along the Cunene River on the Namibia-Angola border (NAS 1975). More usually it reaches 15 to 20 m in height and a breast height diameter of up to 1 m. The crown tends to be shaped like an inverted pyramid in young trees, becoming hemispherical with age. The lifespan is generally about 70 to 90 years, although some individuals of over 150 years are reported from Zambia.

The bark of the tree is characteristically dull brown to whitish grey, smooth when young, more fissured and flaky and more cork-like in older specimens. The slash is fibrous, pink to light brown.

Botanical Description

Leaves. The leaves are typical of the Mimosoideae, compound and bipinnate with leaflets borne along

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the pinnae. They are highly variable: the petiole varies from 0.5 to 3.7 cm long. The rachis is 3-7.5 cm long and carries 2-12 pairs of pinnae, each of which is 2.5-5.5 cm long and carries 6-23 pairs of leaflets. Leaflets are glabrous to pubescent, bluish green, oblongate and occasionally submucronate, overlapping slightly, 2.5 to 12 mm in length and 0.7 to 5 mm in width (Fig. 1) (CTFT 1989).

Thorns. Thorns occur in pairs at the base of the leaves and are modified, spiny stipules. They are straight and robust, thickened at the base and often (particularly when juvenile) orange or brown at the tip and are 0.2-3.2 cm long. They may be distinguished from those of *Acacia* species with long thorns, such as *A. tortilis* subsp *raddiana, A. nilotica,* or *A. seyal,* by their basal thickening.

Flowers. The flowers are borne in dense axillary panicles 3.5-16 cm long, with a peduncle 2-4 cm long. They appear about 2 months after the tree comes into leaf and are sessile or with a pedicel of up to 2 mm. In color they are successively white, cream, and then yellow, and are strongly perfumed. The calyx is 1-1.7 mm long, glabrous to pubescent, consisting of five sepals. The corolla, 3-3.5 mm long, carries five free petals. The stamens, numbering 40 to 50, are 4-6 mm long and their filaments are fused for about 1 mm. There is also partial fusing between the stamens and the bases of the petals, (epipetaly). The anthers are 0.2-0.4 mm in diameter, lacking glands even in the bud. The ovary is lightly stipitate and bears small hairs. Flowering commences towards the seventh year (Nongonierma 1976; McGahuey 1985).

Fruits. The fruit is an indehiscent pod varying from bright orange to reddish brown and 7-9 mm thick, 6-35 cm long, and 1.4-6 cm wide. It falls from the tree about 3 months after flowering. The pod surface is convex on one side and becomes concave on the other, and as the fleshy mesocarp lignifies, it tends to roll into a spiral resembling dried apple peel, hence the common name "Apple Ring *Acacia"* There is much variation in pod shape both within and between trees.

Seeds. Each pod contains 10-29 dark brown shiny seeds, separated by thin septa. They are ovoid, 10 x 6 mm in size and are characterized by an elliptic areolus or hilum measuring about 8 x 5 mm. The seed coat is tough, waterproof, and leathery, and maintains seed viability for many years.

Taxonomic Classification

Identification and Classification

The first botanical determination of the species under the name A. *albida* Del. was made by Delille in 1813 and was based on a specimen obtained in Egypt. Bentham (1875) recognized the species as belonging to the Mimosoideae subfamily of the Leguminosae in the Gummiferae series (Table 1), which is characterized by possessing spiny stipules.

Acacia comprises some 1200 species and is the sole genus in the tribe Acacieae, which are characterized by possessing stamens either free or united only at the base.

Table 1. Taxonomic classification after Bentham (1875).

Classification	Taxonomic name
Family	Leguminosae
Subfamily	Mimosoideae
Tribe	Acacieae
Genus	*Acacia*
Series	Gummiferae
Species	*Acacia albida*

Botanical Nomenclature

Because *A. albida* (F. *albida)* is quite distinct botanically, having no other species closely related to it, its classification has given rise to a number of taxonomic studies. Baillon (1863) concluded that the staminal filaments were indeed joined at the base, but that this feature was not sufficiently important to justify separating the species from the genus *Acacia.* On the other hand, Chevalier (1934), using the same distinctive characteristic as well as other features (which are discussed further below), preferred to exclude the species from the genus *Acacia* and place it in the new monospecific genus *Faidherbia.* This move established the link between the tribes Acacieae and Ingeae, the latter being another tribe of the subfamily

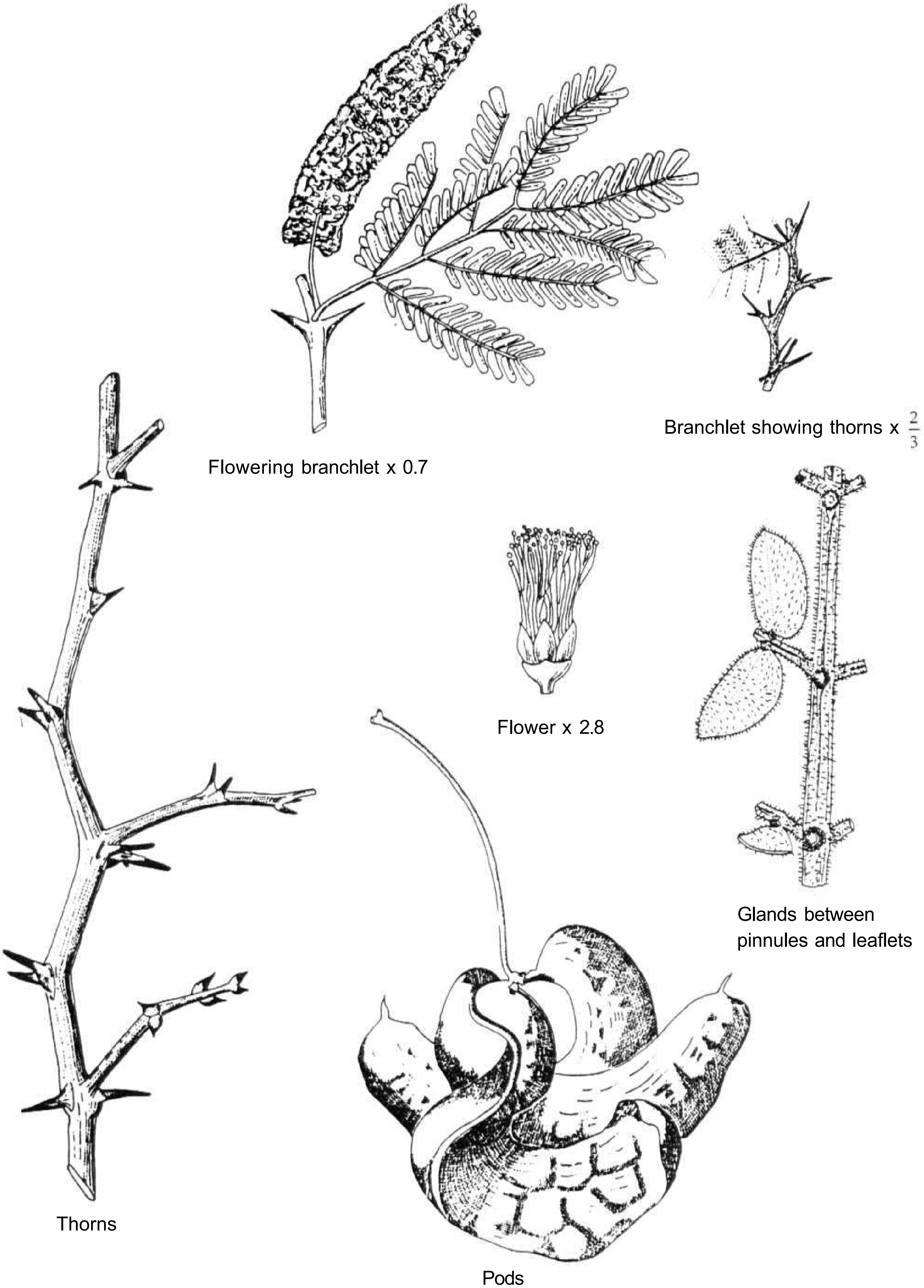

Figure 1. Botanical illustrations of *Faidherbia albida.* (Source: CTFT 1989.)

Mimosoideae characterized by the stamens being more or less fused into a single ring. This taxonomic classification has since been followed by a large number of authorities quoted in CTFT (1989).

While accepting the distinct nature of the species, some authorities still prefer to keep the name *A. albida* after nonetheless pointing out the differences between this species and other acacias:

> "Although different from the other African acacias, *A. albida* has nevertheless many features in common with them. It could ultimately turn out to be preferable to transfer the species to the genus *Faidlierbia"* (Ross 1966).

Hutchinson and Dalziel (1958) retain the name *A. albida.* However, Brain (1987) points out that the chemical constituents of the species are quite different from those of other acacias, and Robbertse (1974) has shown that the pollen also differs. Some authorities still have reservations about keeping *Faidlierbia* separate from the genus *Acacia* but on balance it seems logical to put the species into the genus proposed by Chevalier (1934), which links the tribes Acacieae and Ingeae. This paper therefore uses the specific epithet *F. albida* (Del.) A. Chev.

Distinguishing Characteristics. The characteristics distinguishing this species from other Gummiferae may be summarized as follows:

- Phenology: deciduous in the wet season, foliated in the dry.
- Cotyledons: cotyledons are sessile, whereas all the other Gummiferae have petiolate cotyledons (Robbertse 1974; quoted in Ross 1979).
- Foliage: the primordial leaves are bipinnate, whereas all the other known members of the Gummiferae have at least one simple pinnate primordial leaf (Vassal 1979).
- Pollen grains! without ridges, unlike those of other Gummiferae, are of four pores and with an exine like those of the Ingeae.
- Wood anatomy: layered structure, and straight rays (Robbertse et al. 1980; Fahn et al. 1986) differ from those of other African accessions.

Natural Distribution

Africa

The main area of natural distribution of *F. albida* is Africa, as shown in Figure 2. The species occurs right across the African continent from Senegal and Gambia to the Red Sea (Egypt, Sudan, Ethiopia, Somalia, and Kenya). Further south, it is distributed through eastern and central Africa as far as Natal in South Africa, and westwards to Lesotho, Angola, and Namibia, though it is absent from a corridor in the eastern parts of the last two countries. Apart from this area, its distribution corresponds precisely with the Guinean forest zone of Africa.

The natural distribution does not appear always to follow the climatic zone that characterizes the Guinean zone, however, because the species also occurs along watercourses and in other areas where groundwater is present, or where there is residual water in the alluvium of a seasonal water course. In such places, the distribution is discontinuous, and includes sites in the mountain massifs of the Sahara (Air, Tibesti, Ennedi, and Hoggar, for instance). It also occurs along the Nile in Egypt.

Outside Africa

Outside Africa, spontaneous occurrences of the species are found in Yemen, Israel, Jordan, and Lebanon, where the northernmost is 30 km north of Beirut. The species does not occur in Madagascar.

Introductions have been made to Ascension Island, the Cape Verde Islands (Wickens 1969), Cyprus, and Pakistan (Brenan 1983). More recent introductions have been made to other countries, notably Peru and India; in India, it is of interest as occupying an ecological niche similar to that of the indigenous *Prosopis cineraria.*

With a species that has been cultivated so widely and for such a long period, it is now difficult to determine its actual origin. Aubreville (1937) considered that it was originally a riverine tree of eastern and southern Africa, and was introduced into the northern part of its range in West Africa, where it is only found on cultivated or previously cultivated lands. Chevalier (1934) was of the view that it originated in the Sahara before the current desertification, and that it would have become domesticated in the Sudanian zone. Trochain (1969) claimed to have identified a "semi-climax of *F. albida* in the south-western part of Senegal," where the species would have been brought in by nomadic peoples (through the effects of their animals) in particularly hard times. Human influences thus developed "stable tree populations which, on the sandy clay soils, replaced the different natural open forest climax formations of the Sudanian zone, these being *Combretum glutinosum* on the lighter, sandier

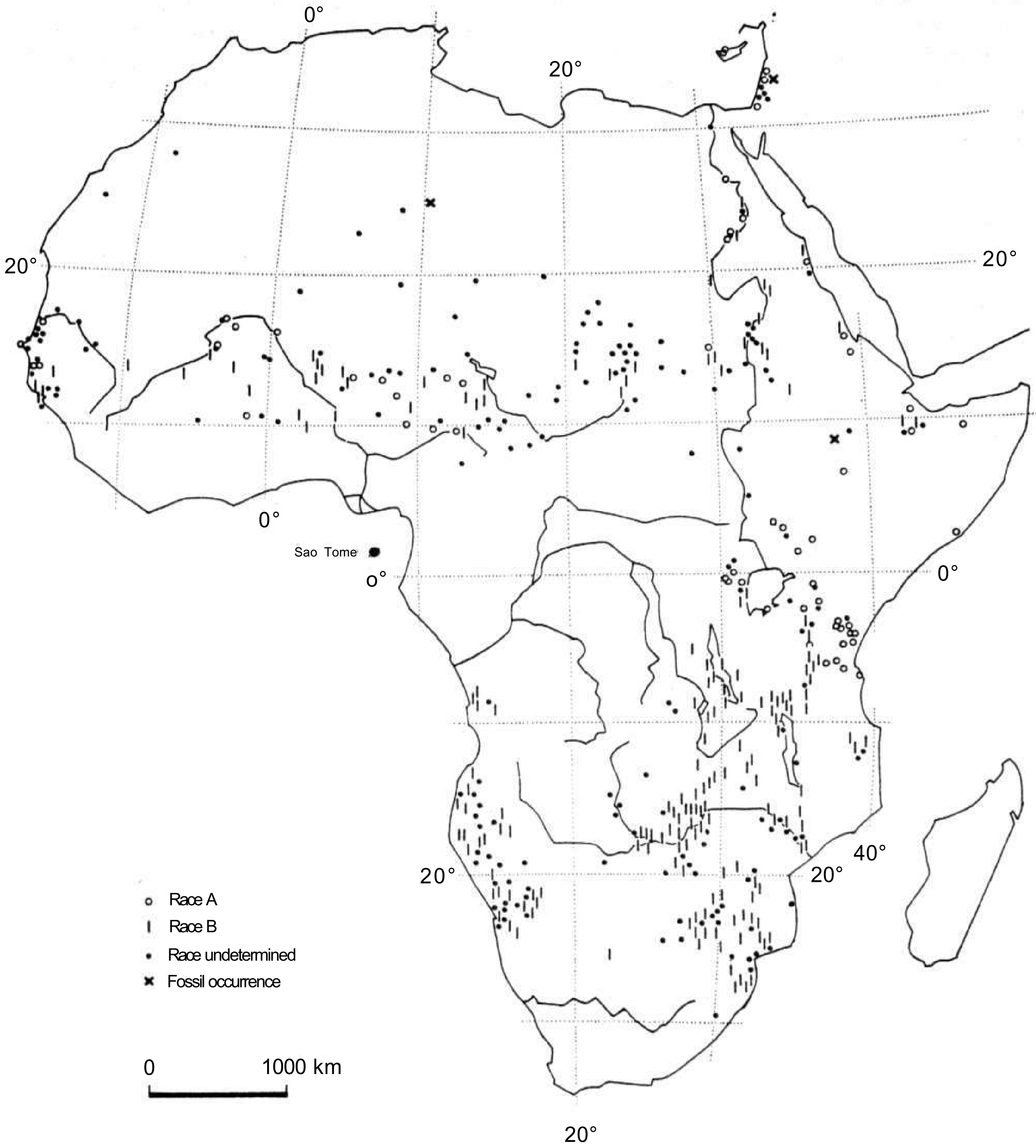

Figure 2. Distribution map of *Faidherbia albida.* (Source: CTFT 1989.)

soils and *Acacia* seyal on the heavier sandy clays" (Felker 1978).

Many foresters also believe that the species is not indigenous to the natural forest areas of West Africa, having been introduced there through pastoralism and agriculture. Many of the places where it is common today can be identified as old animal compounds, water holes, or common grazing grounds. It is also found in religious forests, where it may have been planted in the past, though there are no records of this.

On the other hand, the two separate races of the species are regarded by Wickens (1969) as an indication of a northern origin for the species.

Intraspecific Variation

Fagg and Barnes (1990) report great variation between provenances of the species both in morphology and phenology. The existence of two well-defined races of *F. albida* in eastern Africa has been described by Brenan (1959):

- Race A: young branches glabrous or nearly so, similarly the inflorescence, peduncle, calyx, and corolla. Leaflets ciliate along the margins, otherwise glabrous or nearly so, and generally small, up to 6 mm long by 1.5 mm wide.
- Race B: young branches pubescent, similarly the inflorescence, peduncle, calyx, and often the corolla. Leaflets pubescent on the surface, generally larger than in Race A, up to 12 mm long and 4 mm wide.

The two races are not distinguished taxonomically because a large number of intermediate forms are encountered in certain parts of the range. Ross (1966) states that the characteristics of the two races described by Brenan are not strongly correlated and, as Brenan points out, they appear more as heterogeneous features to the extent that intermediate forms show peculiarities of both races. However, there is confusion only in some regions. Ross indicates that most specimens from the southern part of the range fall within Race B, which is the only one represented in Lesotho, Namibia, Zambia, Zimbabwe, Mozambique, Malawi, and most of Tanzania.

Race A is found in northern and eastern Tanzania, Kenya, Uganda, Somalia, and Ethiopia. In Sudan and in West Africa, Race B is common, but many specimens combine characteristics of both races; i.e., large leaves and glabrousness or small leaves and pubescence. In Egypt and in the northern populations, most specimens appear to be intermediate between the two races, being generally more or less pubescent but with smaller leaves than normal in Race B. The situation is probably the same in the Yemen, but botanical material is currently inadequate. In Cyprus, glabrous leaves predominate, but they are larger than usual in Race A.

Nongonierma (1976) identified four intraspecific taxa, which do not, however, compare with Brenan's races, and are based only on northern and western African material (Fagg and Barnes 1990). The identified varieties *(Acacia albida* var *senegalensis* Benth., *A. albida* var *microfoliata* De Wild, and *A. albida* var *variofoliata* De Wild.) all belong to Race B (Brenan 1983).

Ecology

The wide natural distribution of F. *albida* has already been noted. It is clearly a species with considerable ecological adaptability and it is important to examine the relationship between climate, soil, and growth and, if possible, to define an ecological optimum.

Climate

Trochain (1969) gives climatic diagrams for natural sites for *F. albida* (Figure 3). These are:

- Dry Mediterranean: long summer, dry season with long days, and annual rainfall between 100 and 400 mm (e.g., Gaza).
- Tropical: dry season with short days and rainfall varying from less than 300 mm to over 1000 mm (Northern hemisphere: Dakar and Sahr (southern Chad), with a rainy season from May to October-November. Southern hemisphere: Lusaka, with a rainy season from September-October to April-May.

These climatic diagrams illustrate the wide range of climatic conditions in which the species will grow, the only constant feature being a long and well-defined dry season. Saturation deficit, particularly in the Sudan and Sahelian Zones, is an important parameter, not often included in climatic records. Obviously the species will stand very low air humidities, as in the mountains of the Sahara. In some countries, however, the air humidity in the dry season is often relatively

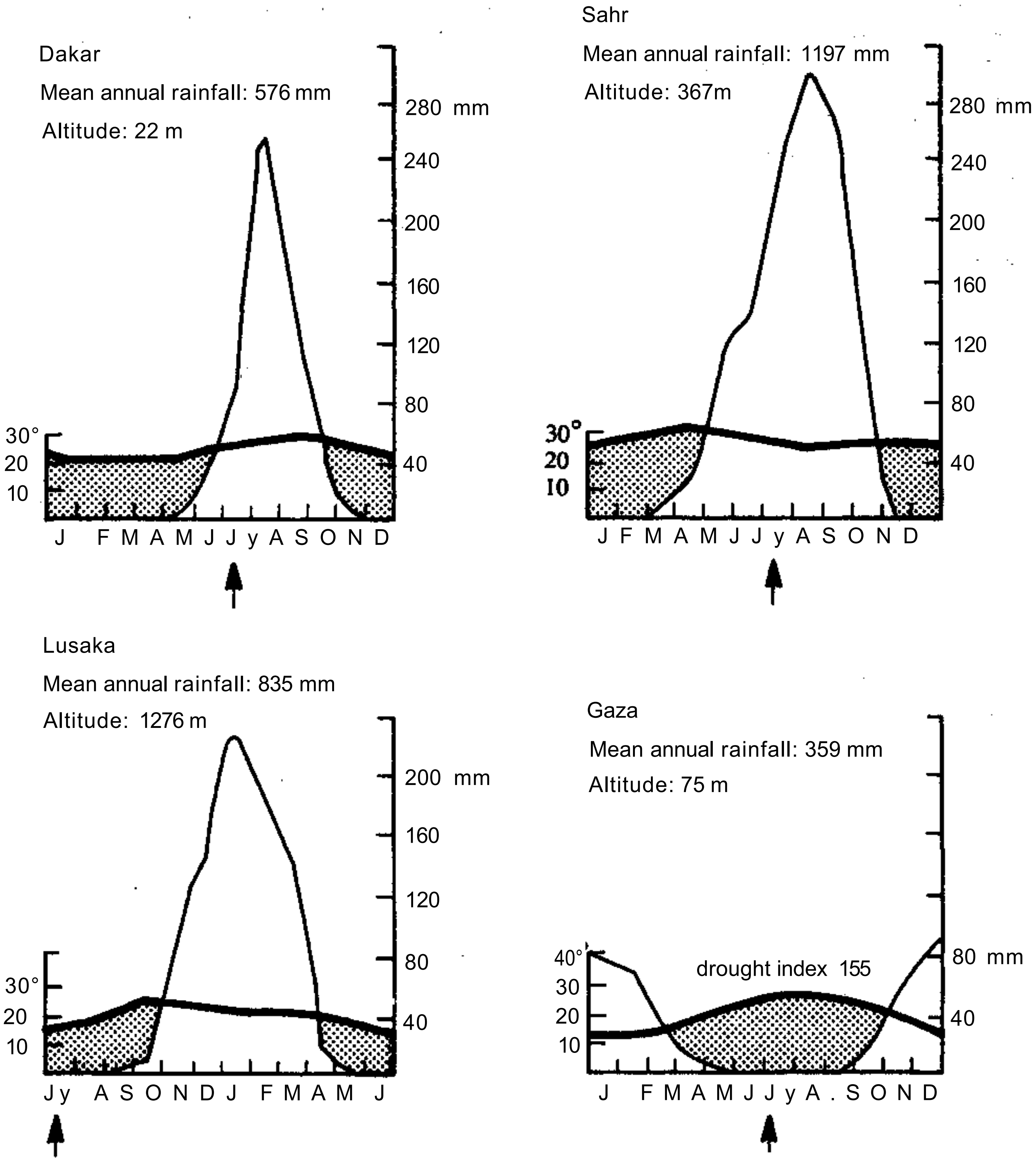

Figure 3. Climatic diagrams for four sites of origin for *Faidherbia albida.* (Source: Trochain 1969; reproduced from CTFT 1989.)

high, as in eastern Africa. In the eastern Mediterranean, the species survives frost.

Recent seed (17 collections) and botanical collections in southern and eastern Africa, including Namibia (Fagg and Barnes 1990) have recorded the species in less than SO mm of rainfall as well as in a zone receiving over 1500 mm.

Altitude

F.albida will grow at a wide range of altitudes, from 270 m below sea level near the Dead Sea in Palestine to over 2000 m in Ethiopia and the Jebel Marra of the Sudan.

Soil Requirements

In eastern, southern, and central Africa the species is often found growing near sources of water, such as along rivers, on the shores of lakes, and in gullies and ravines. In all these situations, the soils tend to be alluvial or hydromorphic. These seem to be the ideal sites; in Sudan, for instance, the greatest concentrations of the species occur in wide belts along the sandy alluvia of the drainage basin of the Jebel Marra (Wickens 1969). It is also found on stabilized sand dunes. In western Africa, as we have seen already, the distribution of the species is generally a result of human activity. Here, it prefers deep, lighter sandy or silty soils, though occasionally it is found on lateritic soils with a shallow pan.

Water Requirements

The tree does not conserve moisture but is effective in obtaining water for transpiration, as amply demonstrated by its vegetative vigor in the dry season, in the total absence of rain, when temperatures are high, humidity is low, and evapotranspiration is at a maximum. To achieve this, its root system has a taproot that grows very rapidly and will reach the water table if it is within range; depths of about 40 m have been recorded (Lemaftre 1954). When on its preferred sites, notably in association with water, the species prefers deep sandy soils easily exploited by its root system.

Acknowledgment. The bulk of this paper relies heavily on the standard monograph on the species produced by the Centre technique forestier tropical (CTFT 1989), to which grateful acknowledgment is made.

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Germplasm Collection of *Faidherbia albida* in Eastern and Southern Africa

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Abstract

The Oxford Forestry Institute is making systematic range-wide collections of Faidherbia albida *(Del.) A. Chev. in undercollected areas of eastern and southern Africa to assemble germplasm for international provenance trials. The wide and discontinuous distribution suggests there may be complex patterns of genetic variation. There is also variation in morphology. Highly significant differences in size and weight of pods were found between trees, within and between provenances, indicative of an outcrossing species. The large variation in phenology is also expected to be under genetic control. The wide use of the trees in farming systems in parts of its southern range and the influence of human disturbance on its distribution introduce complications that must be taken into account. A sampling strategy has been devised. In collaboration with other institutes a broad range-wide seed collection is becoming available for testing.*

Introduction

Faidherbia albida (Del.) A. Chev., syn. *Acacia albida,* is widely distributed throughout the dry zones of Africa and parts of the Middle East. It occupies a wide range of different habitats, indicating wide patterns of genetic variation. It is one of the four African acacia species identified—with *A. tortilis, A. nilotica,* and *A. Senegal*—as having particular potential for community forestry in dry areas (Palmberg 1981). They are priority species within the project sponsored by the Food and Agricultural Organization of the United Nations and the International Union of Forestry Research Organization (FAO/IUFRO), for exploration, evaluation, and conservation of genetic resources of dry zone species in 16 countries in the Sahelian and northern Sudanian zones (IUFRO1988). While some seed collections of these species have been made, particularly in West Africa, the Oxford Forestry Institute (OFI) has initiated a project aimed at systematic range-wide collections in under-collected areas, notably in eastern and southern Africa, and assembling range-wide germplasm for international provenance trials and related research/Extensive field trips have been made in the natural range of these species in eastern and southern Africa, and a large number of provenances identified.

Taxonomy and Variation

F. albida has many characters which in combination make it a very distinct species, and for this reason it has been placed in the monotypic genus *Faidherbia* (Wood 1992). The most notable variation is in pod morphology. Pods can vary considerably in size, color, and form (curled in a circle, falcate, or twisted) between neighboring trees in a population, but appear to be unrelated to other morphological characters (Ross 1966). To test the variation in this character, 4 provenances from Malawi and Zimbabwe were sampled. Ten pods were randomly sampled from about 20

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selected tree canopies. Length, taken from the central axis; mean width, taken at one-third and two-thirds of the length; and mass were measured. Highly significant differences were found between trees and provenances for pod dimensions and mass. Variation has also been found in seed mass between eastern, western, and southern African provenances (Sniezko and Stewart 1989).

Leaf phenology of *F. albida* is very variable (Wickens 1969) both within the same locality and between localities, so that some trees in the same locality can be in full leaf and completely leafless. In the arid Namibian desert, trees rarely lose their leaves except for about a 2-week period every year. Evidence from trials both in West Africa and Zimbabwe indicates large differences in flushing times between provenances, suggesting genetic control of this trait.

Distribution and Ecology

After a tentative distribution of the species was deduced by logging a large number of herbarium specimens, suitable populations were identified during collaborative fieldwork in most eastern and southern African countries; the provenances identified are shown in Figure 1.

The species occurs in a wide range of habitats and is most successful either on sandy alluvium or where land has been disturbed by man or livestock. It frequently colonizes sandbanks in rivers because of its ability to withstand flooding. It will also sucker, especially in loose, sandy soils, as has been noted in Namibia and Zambia. While it occurs more commonly in riverine and lakeshore habitats, nonriverine, hilly, and plateau populations have also been found.

The tree is found on a wide range of alluvial soil types. For example in Malawi, the majority of provenances occur on alluvial calcimorphic soils, but populations can also be found on ferruginous soils (sandy clays), weathered ferallitic soils, Vertisols, and gleys. Trees have been noted in saline areas such as near Lake Chilwa (Malawi) and near the Sowa Pan (Botswana).

In Somalia, Kenya, Uganda, and northern Tanzania, race A (Brenan 1983; Wood 1992) is not generally gregarious, and it is usually found thinly scattered in riverine woodland, whereas race B, which occurs from southern Tanzania southwards, can form large extensive monospecific stands over parts of its range (Malawi and Zambia) similar to those found around Wadi Azum in western Sudan. These areas support large populations, and the trees may have spread in part due to the influence of man and his livestock.

Cultivation

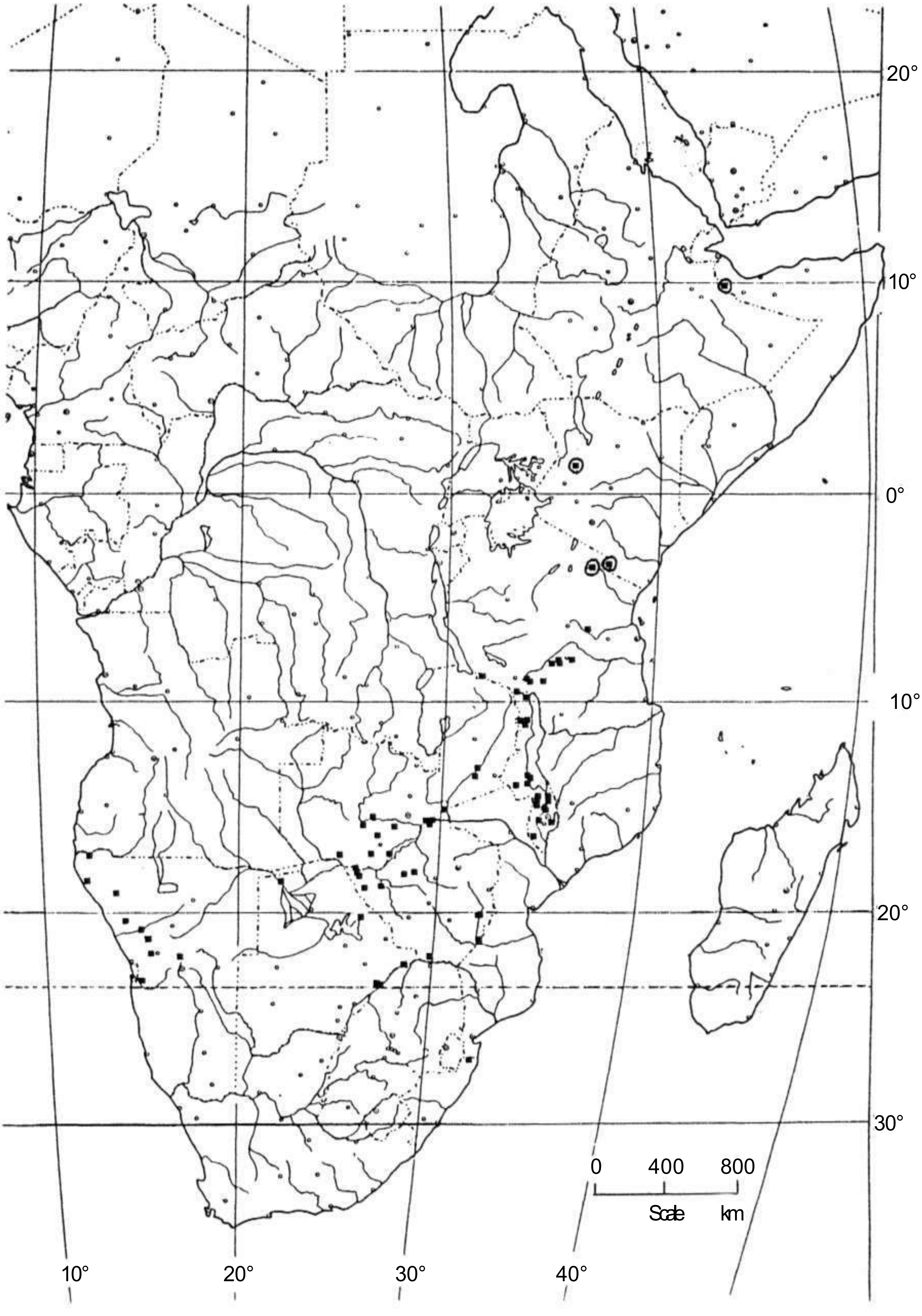
While it has a very widespread distribution throughout Africa and the Middle East, *F. albida* was known primarily as a Sahelian farm tree, but it has also been used in traditional farming systems in many countries in eastern Africa. Little tree planting takes place, but naturally regenerating seedlings are pruned and encouraged to develop in farmer's fields. Seeds can regenerate near the mother trees, or can be spread by animals or water.

In Zambia, the largest populations are found on alluvial soils in the fringes and in the surrounding areas of the Kafue flats. A survey of the area indicated that *F. albida* farmed parkland covers approximately 770 km^2 (Pullen 1974). Larger stands can be found in a triangle from Namwala to Masabuka and down towards Choma. Traditionally, the Tonga farmers own large herds of cattle, which graze on the floodplain grasses of the Kafue flats when the floodwater recedes and return to the higher ground, where the trees are frequent, during the flooded period. Then the farmers also cultivate beneath the trees. Around Namwala, considerable regeneration takes place even within the kraals, dispersal being aided by the livestock.

In Malawi, the benefits of cultivation under *F. albida* trees are well known and appreciated (Saka et al. 1990). In some areas the trees are known to provide "God-given fertilizer", and maize yields are known by experience to be better under the trees. More importantly, in "poor rainfall years, usually some harvest occurs under the trees where there may be failure in open fields." Most Malawian soils are impoverished, particularly in nitrogen and phosphorus, and preliminary research (Saka and Bunderson 1989) has shown similar increased maize yields under the trees in Ethiopia (Poschen 1986). Some of the largest populations are found along the lakeshore plains surrounding Lake Malawi, or on the medium altitude plateau.

In Kenya, distribution is more scattered, and only a large population around Tot appears to be integrated into the farming system. The traditional irrigation canals of the Pokot, which divert water from the watershed of the Cherangani hills, feed into fields with scattered trees of F. *albida.* The trees are also heavily lopped for fodder.

Cultivation is also common under the trees at the Usungu flats, in southern Tanzania. More recently,



■ Race A, visited by the author

(■) Race B, visited by the author

Figure 1. Provenances of *Faidherbia albida* in eastern and southern Africa.

the trees have been used as shade over coffee in the Arusha district of northern Tanzania.

In parts of southern Africa, outside the native range of the species, farmers and gardeners have planted individual specimens. Once established, the trees flourish; although there are indications that they do not necessarily flower in these offsite plantings. Human influence does have a significant effect on the genetic distribution of the species and must be taken into account in the sampling strategy.

Seed Collections

Sampling Strategy

The methodology for seed collection of nonindustrial tree species has been developed over the past decade at the OFI and is outlined by Hughes (1987). Collections are as broad-based as possible to gain the widest variability for the multiple traits that the recipient farmer may require. A number of broad guidelines have been adopted specifically for the seed collection strategy of *F. albida:*

Provenance Selection

- Geographical discontinuity from other populations.
- Sites with differences in climate, altitude, soils, and ecology.
- Selection from both undisturbed natural populations and populations in agricultural systems where there is a choice.
- Distinctive morphological and phenological attributes.
- Cover differences suggested by isoenzyme studies and established trials.

Seed Collection in Provenances

- General provenance collection. 25 or more trees, spaced at least 100 m apart, from which comparable amounts are bulked to provide 5-10 kg of seed.
- Progeny collection. 25 or more individual trees randomly selected, 100 m apart, pods from all parts of the crown.
- For breeding system studies, collecting every tree in a defined population of 100-200 trees.
- For genetic variation in isozyme studies, 100 individual trees randomly selected more than 30 m apart, 10 pods from over the crown, providing 50 viable seeds.

A pragmatic approach to seed collection is needed as it is not always possible to follow the ideal strategy because of poor seed years, difficulties in locating sufficient trees with pods, logistical constraints, and timing.

As well as seed and botanical voucher specimens, other materials, and associated site information (exact location, vegetation, soil, and tree characteristics) are also collected. Nodules have been collected from young seedlings, placed in small glass vials with a desiccant, and sent to the University of Dundee (Prof. J. Sprent), for isolating and culturing the rhizobial strains. Nodules can be easily collected only in the rainy season, and as seed collections occur during the dry season, only those seedlings in or beside rivers have been found with nodules. An alternative method, germinating the seed in a nursery with soil collected under the trees, has proved much easier for isolating the nodules. Wood and insect pollinators and predators have also been collected.

One problem in seed collection is the predation of seed by bruchid beetles, though infestation rates on *F. albida* appear to be less than with other acacia species, such as *A. tortilis.* The species of bruchids also vary depending on the taxa they attack, and specimens of them and their parasites are being collected, to identify the number of species involved. Variation in susceptiblity between trees and between provenances is seen in the field. The adult bruchids lay their eggs on or in the young green pods, and the larvae enter the young seed a few weeks after to pupate. Some will emerge before collection, but even if seed is meticulously cleaned during extraction, inevitably, further emergence of the weevils from within apparently "viable" seed can occur up to 16 months after collection (Ernst et al. 1989). Seed can be x-rayed to determine the infestation, and later cleaned on a gravity table separator at the seed bank.

Conservation Status

While the *F. albida* species is not under direct threat, a number of its populations have been eliminated or severely depleted. In Malawi, where there are very high demographic pressures, the demand for dugout canoes has reduced the provenances to a few solitary individuals in the eastern shores of Lake Malawi. Large numbers of Mozambican refugees have contributed to deforestation in the Lower Shire, and very few trees now remain. In other areas of Malawi, extensive populations appear to be protected and not threatened to the same extent. Some of the populations also suffer from little regeneration in other parts of the range, particularly where the wild life and game pressures are severe.

Seed Availability

Although collections are still in progress, some seed is now available for the establishment of species field trials (Table 1). For species trials, several provenances should be tried, as a single locality is unlikely to provide a good indication of the potential of the species. A choice of at least three provenances widely distributed geographically is recommended: (1) a site that closely matches the trial site, (2) an area where it reaches its finest development, and (3) a more marginal site. Seed should be accompanied by detailed site description forms.

Range-wide provenance collections are expected to be available for trials within a year, including sites from West Africa.

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Table 1. Summary of seed collection sites of *Faidherbia albida,* in eastern and southern Africa, 1990-1991.

Provenance	Location	Altitude (m)	Mean annual rainfall[1] (mm)	Mean annual tempearature (°C)	No. of dry months[2]
Taupye, Botswana	23°29'S27°14'E	850	471	20.8	8
Voortrekker, Botswana	22°34'S 28°24'E	823	392	20.5	10
Mana Pools, Zimbabwe	15°45'S 29°20'E	360	628	25.1	8
Sesame River, Zimbabwe	17°57'S 28°46'E	1100	787	20.5	7
Devure, Zimbabwe	20°10'S32°10'E	550	516	21.6	7
Hwange N.P., Zimbabwe	18°44'S26°16'E	950	630	22.3	7
Chipinda Pools, Zimbabwe	21°18'S 32°21E	170	627	24.5	8
Msaizi, Zimbabwe	20°12'S 32°15'E	500	470	22.3	8
Manyoni River, Zimbabwe	18°04'S 28°15'E	750	660	22.2	7
Chinzombo, Zambia	13°07'S 31°48'E	550	958	24.0	7
Kafue Flats, Zambia	15°31'S26°40'E	1000	871	21.0	7
Kuiseb, Namibia	23°34'S 15°02'E	400	< 50	15.2	12
Lupaso, Malawi	9°55'S 33°53'E	500	1165	24.8	7
Bolero, Malawi	10°58'S 33°43'E	1100	701	21	8
Mwanza River, Malawi	16°10'S34°46'E	100	811	26.3	7
Chawanje, Malawi	14°39'S 34°48'E	600	824	24.2	8
Bolgatanga, Ghana	10° 46'N 01°00'W	20	1057	28.2	7

1. All sites have unimodal rainfall.
2. Number of months with less than 60 mm rainfall.

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Pollen Studies on *Faidherbia albida* in Sudan

S.E. Goda[1]

Abstract

A study in the Department of Forestry, University of Khartoum, has shown that Faidherbia albida *'is distinct from* Acacia *spp in pollen structure. Characteristically, the stipitate gland in the apex of the anther is absent in* F. albida *while it is found in all the acacias tested in the study. Also, the anther sac is much wider than in other acacias.*

Introduction

In Sudan, *Faidherbia albida* is most common on silty loams with sufficient subsoil moisture, e.g., along rivers. It is found in most parts of Sudan but its best development is in the western part of the country, particularly in the Jebel Marra area. The tree is usually found in cultivated fields rather than as natural forests. It does not grow on iron soils or waterlogged sites. *Acacia nilotica* and *A. seyal* can be found mixed with F. *albida* in Sudan.

The species (called *haraz* in Sudan) is distinguished from *Acacia* spp by a great many morphological, ontological, and cytological characteristics. It is more logically classified within a monospecific genus of the Ingeae *(Albizia,* etc.), a transition towards the Acaceae.

Pollen Studies

A study of *F. albida* was done by Yagi (1988) at the University of Khartoum. The study confirmed that *A. albida* differed from the other Sudanese acacias in quantitative and qualitative pollen characteristics. Data obtained from the pollen morphological studies and phytochemical analyses are similar to those obtained by El Amin (1972).

Microscopic examination of 19 acacia species showed that 8 polyads were found in each anther with 4 polyads in each chamber. Polyads consisted of 16 monads with the exception of *A. albida* and *A. laeta,* which had centrally placed monads surrounded by 8 peripherals. Monad shape and size varied in each group. These were oval in *F. albida, A. nubica, A. polyacantha, A. laeta,* and *A. macrothyosa,* while they were circular in the rest of the 19 acacias.

The genus *Faidherbia,* based on *A. albida,* is distinct from other acacias in having exceptionally large polyads, with a length of 187 μ and width of 155 μ.

Inflorescence is spicate in *A. albida, A. mellifera, A. laeta,* and *A. Senegal,* whereas it is capitate in *A. tortilis, A. seyal, A. nilotica,* and A. *ehrenbergiana.* The anther sac width in *F. albida* is 910 μ compared with 72-187 μ in other acacias. Moreover, the stipitate gland, which is found in all other acacias, is absent in the apex of the anther of *F. albida.*

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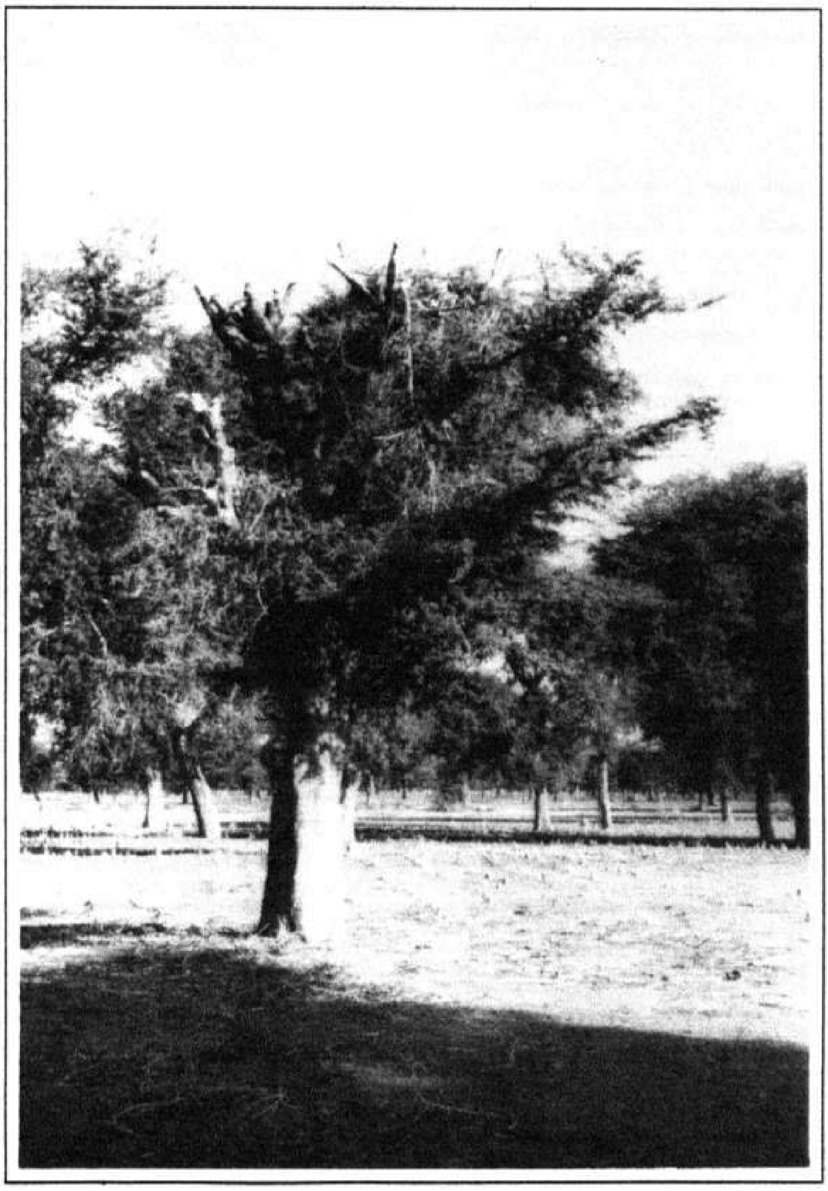
Session 2
Uses



Cover photo: *Faidherbia albida* is lopped for fodder throughout West Africa. However, little is known about optimum management techniques for this use. Also, the effect of lopping on growth or decline of mature trees is unknown. (Photo: H. Joly.)

The Fodder Role of *Acacia albida* Del: Extent of Knowledge and Prospects for Future Research

M.I Cisse[1] and A.R. Kone[2]

Abstract

The current knowledge presented in this paper on the fodder role of Acacia albida *is drawn from an extensive compilation of studies carried out in West Africa. The discussion focuses on the fodder production, chemical composition, and nutritive value of A.* albida. *Placing future research within a multidisciplinary program aimed at evaluating the agroforestry and agropastoral contribution of* A. albida *is stressed.*

Introduction

In the semi-arid regions of West Africa, trees play an essential role in the life of rural populations and in traditional agrarian systems. In Sudanian and Sahelo-Sudanian zones, *Acacia albida* is regularly associated with the most intensively cultivated lands ("Soforo" in the Bamanan dialect; "Lara" in Dogon). According to Pelissier (1979), *A. albida* stands are critical to the lives of farmers dependent on rainfed cereal agriculture and breeding of domestic animals. *A. albida* is at the foundation of this agropastoral system. Seignebos (1978) indicates the importance of this species:

"Thanks to its reverse [phenology], [*A. albida* provides] a...microclimate favorable to crops. By its litter, it enriches the soil and permits increased millet and sorghum yields [without requiring] fallow periods. The nutritive value of its fodder is as important as its [fodder role in the dry season]. [And despite intensive exploitation], it tolerates delimbing."

In other respects, the seeds, gum, bark, and wood are utilized for many purposes—food, traditional medicine, construction, furniture, canoes, and other domestic uses—making *A. albida* the "miracle" tree of the Sahel.

This paper summarizes the knowledge compiled on the fodder role of *A. albida* while focusing on the close relationships that exist between this species and domestic animals. Because of its highly nutritional leaves and fruit, *A. albida* provides domestic animals with excellent fodder in the dry season; in return, cattle assure its regeneration by pretreating the seeds in their digestive tract and then acting as disseminators.

Problems in Evaluating the Fodder Potential of Leguminous Species: The Case of *Acacia albida*

In West Africa, references to *A. albida* as a fodder tree are numerous (Curasson 1953 and 1958; Gillet 1960; Adam 1966; Audru 1966; Boudet 1970 and 1972; Diallo 1968; Mosnier 1961 and 1967; Peyre de Fabregues 1963; Naegele 1971; Touzeau 1973; Giffard 1974; Le Houerou 1980b). All of these authors agree that *A. albida* leaves and pods serve as fodder for cattle, sheep, goats, and camels; however, they make no mention of the production of this species.

Interest in evaluating fodder production of tree species is recent (Bille 1977 and Poupon 1980 in Senegal; Nebout and Toutain 1978 in Burkina Faso; and Cisse 1980 in Mali). Such evaluation involves problems linked to:

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Cisse, M.I., and Kong, A.R. 1992. The fodder role of *Acacia albida* Del.: extent of knowledge and prospects for future research. Pages 29-37 *in Faidhcrbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

- traits distinct to tree species: notably, longevity, production cycles, and size, which limit the trees accessibility for domestic animals and make it necessary to use particular forms of exploitation (pruning, delimbing, and coppicing);
- defining fodder production of *A. albida.* Except for the wood, all canopy material is edible.

Besides the pods, which have obvious fodder value, a number of other tree components may warrant attention. The fodder value of tree bark, which is generally of little or no interest to domestic animals, has rarely been evaluated, and never for *A. albida.* The branches, usually evaluated with the leaves, may have distinct fodder potential and therefore deserve a separate evaluation. The flowers of *A. albida* do not appear to be much sought after by domestic animals; however, the fruit has fodder potential. The production of *A. albida* fruit was evaluated in Niger (Lemaitre 1954), Senegal (Jung 1967) and Sudan (Wickens 1969). Tree leaves, generally the most browsed part of the tree, are an important fodder source. Cisse (1980) evaluated the foliar production of *A. albida* in Mali, and many other similar studies have been done on other species.

Due to the relative abundance of research done on the fodder potential of *A. albida* leaves and pods, the following discussion will be limited to these two components.

Pod Production of A. *albida*

A. albida bears fruit between January and April, a critical period in terms of fodder availability. Fallen fruit are consumed and, as this period progresses, they are knocked down and then collected, and fed to animals or sold in markets.

Pods of *A. albida* mature slowly. In Niger, Baumer (1983) found that, under very exceptional conditions, pod development begins between the 2nd and 4th years but in general, fruit-bearing commences around the 15th year. In Senegal, Nongonierma (cited by Felker 1978) observed that the first pods appear during the eighth year; in Niger, Lemattre (1954) observed that they appear between the 8 th and the 12th year.

Reports of A. *albida* pod production are sometimes unreliable. Based on an average established on twenty 30-year old trees, Lemaitre (1954) estimated a production of 6 to 8 kg tree-^{1} around Zinder in Niger. In Bambey, Senegal, Jung (1967) estimated fruit production of one tree (crown surface area = 230 m^2) at 125 kg. Wickens (1969) harvested 135 kg from a mature tree in Sudan.

Evaluating these diverse results, Felker (1978) concluded that "because of marked differences between Lemaitre's results and those of others, the absence of information on the method used by Wickens and the serious limitations of Jung's method, we should consider the average pod production per tree and per hectare as unknown." Thus, these data do not have indicative value.

The evaluation of pod production, therefore, requires the adoption of a viable method. One method may be to determine whether correlations can be established between pod production and physical parameters, for example, crown size (Lemattre 1954). Referring to evaluations done on *Acacia tortilis* in Kenya, Cisse (1983), noted positive correlations between pod production and height (r = 0.72), trunk circumference (r = 0.92) and crown area (r = 0.85). Applying these allometric relationships to inventory data would allow evaluation of stand production.

To establish allometric relationships, individual tree production was evaluated in the following order: aerial harvesting of pods; estimation of areas over which the pods were gathered; evaluation of collected pod density by counting over an area of 12 x 0.25 m; estimation of pods remaining on the tree in relation to those collected; and evaluation of mass of pods sampled relative to the total number of pods.

According to Bille (1977) and Poupon (1980), fruit production fluctuates from year to year among Sahelian tree species. To allow for these variations, the evaluation of pod production should take into account only trees bearing fruit at the time of sampling.

Foliar Production of A. *albida*

Seasonal Distribution

Cisse (1980) compared foliar biomass at peak production (B) using data based on five trees per trunk-circumference class (10-cm classes) with the following parameters:

- the trunk circumference (C) measured at 40 cm from the base on single-trunk individuals and at the base of immature trees;
- total height (H);
- crown surface area (S) (the average of two perpendicular diameter measurements).

The most significant physical parameter linked to foliar biomass was analyzed using a log-log linear model on data derived from 50 subjects. The correlation matrices (Table 1) indicate strong positive correlations between the physical parameters as well as between each of the physical parameters and foliar biomass. The linear regression is acceptable ($0.90 < R^2 < 0.96$), and the resulting adjustment curves indicate an exponential relationship (Table 2).

Table 1. Matrix of correlations between log of physical parameters and log of foliar biomass of A. *albida.*

	Log parameter			
Log parameter	B	C	H	S
Foliar biomass (B)	-	0.98	0.95	0.96
Trunk circumference (C)	0.98	-	0.97	0.97
Total height (H)	0.95	0.97	-	0.95
Crown area (S)	0.96	0.97	0.95	-

Table 2. Ratios between foliar biomass (B) (g DM[1]) and physical parameters[2] of *A. albida.* (Source: Cisse 1980.)

Regression equations	R^2	Equations of adjustment curves
Log B = 2.08 log C	0.96	$B = C^{2.08}$
Log B = 2.77 log H - 4.01	0.90	$B = 98.10^{-6}H^{2.77}$
Log B= 1.26 log S-0.50	0.92	$B = 0.32S^{1.26}$

1. Dry matter.
2. C = Circumference of trunk at 40 cm from the ground; H = total height (cm); S = crown surface area (dm^2).

Large seasonal fluctuations of fodder production among tree species (Cisse 1982) necessitate production evaluation by season. Changes in foliation of *A. albida* were monitored over the course of 1 year on 20 heavily exploited and 20 unexploited individuals. Samples of standard-size twigs (diameter 20 mm at the base) were taken from each tree every month. The biomass of the twigs, which were chosen to represent the phenological state of the subject, constituted an index of foliation. The ratio (σ) of the foliation index in a given month (bt) to the foliation index at its maximum (bo) expresses variations in foliar biomass over the course of a year. These ratios, expressed as a percentage, were used to form foliation patterns.

In contrast to other deciduous species, the maximum foliation of *A. albida* occurs in January during the cold period of the dry season. In the rainy season (July-August), the tree is totally defoliated. Botanists become lost in conjecture and speculation when considering the "aberrant" phenology of this species (Porteres 1957; Lebrun 1968; Trochain 1969). However, *A. albida* owes its importance to this very phenology and provides green fodder during periods of fodder scarcity. Fodder exploitation extends the foliating period of *A. albida* and enhances foliation in the rainy season. This may be detrimental to crops and provide little benefit to domestic animals, which prefer highly nutritious green grasses during this period.

The foliation curves indicate foliage availability on the stump as well. The difference between maximum availability and availability on the stump reflects the extent of defoliation.

Foliar Exploitation in Mali

Foliar production figures represent foliar biomass of a tree as a function of its physical characteristics. They are utilized in descriptive forest inventories to estimate foliar biomass of a stand.

In Mali, *A. albida* is found in pure stands or in stands associated with *Vitellaria paradoxa, Borassus aethiopium, Sclerocarya birrea,* and *Lannea microcarpa.* These occur in the natural stands of Goudo-Mondoro, the Bandiagara-Houbou plateau, in the agroecological zones of the Bas Plateau Bobo, the Koutiala Falo plateau in Falo region, and in the dry Central Delta zone of the Niger River.

Forty samples were taken in chosen stands; locations (distances from villages) and soil types were noted. The density, cover, and foliar biomass of the *A. albida* population in each of these stands were estimated. For every stand, the biomass of A. *albida* was calculated by summing the contribution of all the clumps from one of the allometric relationships.

On the average, *A. albida* represented 48% of stems and 64% of total cover of these stands and annually produced 300 kg ha^{-1} of foliar dry matter. These averages, however, mask important differences between stands. As hypothesized, the location of the stand and the type of soil on which it developed also had an impact on foliar biomass production (Table 3).

Table 3. Influence of the location of the stand and soil types on total foliar production (kg DM ha^{-1}) of A. *albida* in different stands in Mali.

	Stands[1]					
Factors	A	A/B	A/V	A/L	A/S	Mean
Location						
Near village	400	230	50	580	60	330
Far from village	350	300	40	70	-	230
Soil type						
Sandy silts	380	580	60	580	30	340
Loam	240	-	20	70	-	110
Sandy	400	180	40	-	90	270

1. Stands: A = *Acacia albida;* A/B = *A. albida + Borassus;* A/V = *A. albida + Vitellaria;* A/L = *A.albida + Lannea microcarpa;* A/S = *Acacia + Sclerocarya.*

Using maximal biomass estimates, which were derived using allometric relationships, the monthly foliar availability was evaluated by multiplying by the factor σ(σ = bt/bo). As an example, Table 4 shows the seasonal changes and extremes in foliar availability of *A. albida* by stand and *(A. albida + Vittellaria)* A/V, which demonstrates the extreme foliar biomass.

Effect of Lopping on Production of A. *albida*

Only a small part of foliar production is directly accessible to animals and herders who delimb *A. albida.* In the short run, this affects fodder production. The frequency and intensity of lopping has a marked impact on the foliar production of *A. albida* (Cisse 1984).

For unlopped individuals, repeated pruning during periods of peak average biomass stimulates foliar production. Resulting regrowth is especially vigorous in the first year, but it decreases as exploitation continues. Pruning in January produces more leaves than pruning done in June; however, pruning in June extends the foliation season. A. *albida* tolerates two prunings per year, but the trees show signs of stress at the end of 6 years.

Delimbing was shown to decrease pod production. This is critical not only because of the decrease in fodder potential but also because the pods constitute a commercial commodity for farmers and herders. Rational management of fodder production of A. *albida* must take into account both pod and leaf production.

Fodder Value of A. *albida*

The interest in tree species as a food source for domestic animals lies in the fact that they offer green fodder rich in protein in a period when animal feed is scarce. Behavior studies on cattle and sheep/goat herds in millet agropastoral systems around Niono in southern Sahelian zones of Mali (Dicko 1981) showed that all three types of animal consume browse: about 87% of the goat diet, 36% of the sheep diet, and 11% of the cattle diet are browsed material.

The fodder trees are distinguished from forage grasses by their high total protein (TP) content, which ranges from 60 to 250 g kg^{-1} of dry matter (DM). Some samples have contained up to 330 g kg^{-1} of DM in certain young sprouts and leaves (Riviere 1977; Diagayete 1981; Kone 1987). Tree fodders are high in lignin content, comprising up to 20% of the mass (Kone 1987).

The leaves of A. *albida* contain an average of 200 g TP kg^{-1} dry matter (Fall 1978; Le Houerou 1980a;

Table 4. Estimation of the seasonal distribution of foliar biomass (kg DM ha^{-1}) of A. *albida* in two stands in Mali.

	Seasonal foliar biomass production (kg DM ha^{-1})				
Stand[1]	Prerainy (May-Jun)	Rainy (Jun-Sep)	Postrainy (Oct-Nov)	Cold (Dec-Feb)	Hot dry (Mar-Apr)
Acacia albida	175	76	266	360	296
A. *albida + Vittellaria paradoxa*	18	8	28	38	31

1. These stands comprise both exploited and unexploited individuals; the coefficient *(σ)* used results from an average established on the base of *a* for the months considered for both exploited and unexploited individuals.

Diagayete 1981; Kong 1987), the pods contain an average of 150 g, and the seeds an average of 240 to 280 g (A.R. Kone, CRZ personal communication; Wickens 1969, cited by Felker 1978), Following ingestion of *A. albida* pods, however, only 34% of seeds (which contain a large percentage of TP) are digested (Wickens 1969, cited by Felker 1978). The seed:pod ratio, ranging between 1:2 and 1:8, explains the great variability observed in the chemical composition of these types of fodder (Table 5). The TP includes diverse protein and nonprotein matter which is not discernible in a simple portion of TP, The protein content that is apparently nondigestible can be very high.

Table 5. Total protein content, residual, and parietal contents of pods and leaves of A. *albida*[1].

Material Season	TP	CC	NDF	ADF	ADL
Green leaves					
December	1.0	18.2	35.5	22.1	7.9
February	15.2	19.6	39.8	22.9	9.4
March	1.6	15.5	30.9	19.7	9.5
Green pods					
March	1.5	30.7	47.1	35.6	8.6
Whole pods					
February	9.2	16.7	43.5	30.1	9.1
April	0.5	32.3	67.0	41.9	8.8
Pods without seed					
February	0.6	29.5	47.4	36.4	12.1
Seeds					
February	2.0	10.4	45.8	14.6	2.4

1. TP = total protein; CC = crude cellulose; NDF = neutral detergent fiber; ADF = acid detergent fiber; ADL = acid detergent lignin.

Feed Value of A. *albida*

It is difficult to determine the feed value of A. *albida* just by determining dry-matter, protein, and crude cellulose contents. Estimate of crude cellulose and TP content allows us to evaluate fairly accurately the digestibility of forage grasses with less lignin. Tree species require more detailed analyses of parietal content (method of Van Soest (1983)) and protein content (Kong 1987), Preliminary studies have shown a good correlation between the degradability of TP and the nondegradable protein contents in the acid detergent fiber (ADF) residue (Kone 1987). Measuring the rate of enzymatic breakdown *in sacco* (in the rumen) of the organic matter and/or proteins is another way of determining digestibility. The results can be compared with those obtained *in vitro.*

The proteins are degraded in the rumen into more soluble products. The extent of degradability varies greatly with the nature of the food and the type of animal. Fall (1978) found that in sheep, solubilization and degradation rate of *A. albida* pod proteins were higher than those of leaves (Table 6). In goats, however, the intraruminal breakdown of leaf proteins was higher than that of pods (Kone 1987). The dry matter digestibility of *A. albida* leaves ranges from 14 to 53%. Total protein digestibility varies from 67 to 72%. Dry matter digestibility of whole pods ranges from 50 to 57%; total protein digestibility can reach 73% (Dicko 1979; Fall 1978; Diagayate 1981).

Table 6. Intraruminal degradation (%) of *A. albida* fodder in small ruminants. (Source: Fall 1978.)

Time (h)	Degradability	Pods	Leaves
0	Dry matter	32	37
	Protein	54	16
9	Dry matter	48	46
	Protein	58	20
24	Dry matter	70	56
	Protein	69	42
48	Dry matter	74	69
	Protein	71	55
72	Dry matter	76	75
	Protein	-	66
DT[1]	Dry matter	57	52
	Protein	63	64

1. Actual degradation (takes into account the duration of passage of small particles in the rumen: K = 0.06)

The reduced digestibility of protein is linked to two complementary factors. The first is the inhibiting effect of tannins on protein breakdown in the rumen and *in vitro* (Palo 1985, Barry and Marley 1986). The pods of *A. albida* contain 36.5% of phenolic substances and 0.27 A. 550 of insoluble proanthocyanidians (Tanner 1988), Tannins affect the entire enzymatic system (Milic 1972) and have a negative impact on ingestion and, as a result, on animal growth. The second is interspecific variation of protein distribution between the cellular contents and the paries. The non-digestible proteins are to a large extent linked to the acid detergent fiber (ADF) (Mason 1969; Van Soest 1983) because of high lignin content.

Fodder Efficacy

Despite the presence of tannins, A. *albida*—notably the pods—may be used as a supplement in animal diets because it is rich in protein and digestible energy (77%). Such an energy value would explain the results obtained in Mali (Dicko 1979), where incorporating pods into a sheep feed of sorghum leaves gave an increase in the quantity of dry matter ingested from 40.4 to 61.6 g $kg^{-0.75}$ in sheep weighing an average of 37.5 kg. The ingestion of leaves by goats was only 41.3 g $kg^{-0.75}$ per day.

In Senegal, Fall (1978) tested the quality of pods and leaves of *A. albida* on sheep (weighing on average 22 kg) which received as much rice straw as desired, 100 g of bean cake day^{-1} per head and bone meal. In addition, one lot of animals received 100 g of A. *albida* leaves, another 100 g pods, and a third 200 g pods per head. After 92 days, the results were as follows:

- the rice straw had a Refusal rate of 10% and a consumption level of 43 g $kg^{-0.75}$ (lot 1), 41 g $kg^{-0.75}$ (lot 2), and 36 g $kg^{-0.75}$ (lot 3). Large quantities of pods lowered the level of consumption of rice straw.
- pod supplements resulted in slight growth in sheep. The level of 100 g day^{-1} per head appeared to be more profitable than that of 200 g (GMQ = 18.5 for lot 2 and 20.6 for lot 3). Lot 1 lost weight (GMQ = -27) because of poor digestive utilization of leaves.

This suggests that incorporating pods of A. *albida* into a low-quality feed enhances digestion without reducing the digestibility of the ration.

Future Research

Much remains to be learned about the fodder role of *A. albida.* Because of the multiple-use potential of A. *albida,* research on its fodder production must take the form of a multi-disciplinary program to improve the contribution of this species to agroforestry systems.

In the A. albida-soil-animal association, the mutual benefits can be generally illustrated; however, the returns—whether they be in the form of nutrition, fertilization, or growth—have yet to be fully understood, let alone fully evaluated. To determine the role of fodder in this association, future research should:

- evaluate fruit production of A. *albida* using a viable method;
- evaluate total and seasonal fodder production (leaves and fruit) as a function of diverse ecological factors such as rainfall, soil type, and frequency and intensity of exploitation;
- determine the chemical composition of fodder as a function of its phenological stage (including dating samples), focusing in particular on parietal content (Van Soest 1983) and content of anti-nutritional substances such as tannins;
- study ingestion and digestibility of A. *albida* fodder to create models to forecast food value; and
- evaluate performance resulting from rations containing and/or rations composed purely of A. *albida* components on different types of animals (sheep, cattle, goats, and camels).

Conclusion

A species more Sudanian than Sahelian, A. *albida* derives its importance in fodder production from the fact that it drops its leaves in the rainy season and refoliates in the dry season. Hence, it benefits domestic animals by providing fodder in the form of leaves and pods.

Although a method has been developed to evaluate foliar biomass and its seasonal changes as well as the impact of exploitation on foliar production, fruit production has not received the same attention.

Feed-value analyses have revealed that pods and leaves are rich in parietal content. Leaves, pods, and seeds contain respectively 200, 150, and 260 g TP kg^{-1} of dry matter. Antinutritional substances such as tannins limit the digestibility of the abundant protein; however, in spite of the presence of tannins, A. *albida* components—particularly pods—can be incorporated into low-quality fodder to enhance ingestion without reducing digestibility.

Future research on the role of A, *albida* as a fodder needs to be done as part of a multidisciplinary research effort that evaluates the contribution of this species to agroforestry systems.

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Faidherbia albida in the Traditional Farming Systems of Central Ethiopia

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Abstract

Faidherbia albida *is a component of the traditional farming system (teff, mixed cereal, and livestock) of the southeastern Shewa region of Ethiopia. In this high-potential cereal zone, it is found on seasonally waterlogged ground, along riverbanks, and in woodland areas. The tree produces more leaves during the dry season than in the wet season and normally bears fruit once a year (November-January), with an average of 3-5 kg seed per tree. Generally farmers severely prune the species every 3-4 years for fencing and fuelwood. In coffee-growing areas, the trees serve as shade. They also provide feed and shade for animals and medicine for some diseases.* F. albida *is also revered as a holy tree. Farmers have different views on the beneficial effects ofF.* albida *on crop yields. Those using commercial fertilizer do not appreciate its traditional role as soil-improver. Current research, especially on the regeneration and management of F.* albida *is inadequate. More studies should be undertaken to entrance germination, improve establishment techniques and management systems, and promote the organization of a research network on F.* albida.

Introduction

Faidherbia albida, an indigenous tree species in Ethiopia, is widely distributed throughout the country, except in the wet humid southwestern region. It is normally dominant and codominant in riparian forests and woodlands on floodplains where the water table is near the surface (Breitenbach 1963). Because of its wide range of distribution, the species is known by a variety of local names: *garbi* in Orominga, *grar* in Amharic, *garsha* in Tigringa, *qeretor* in Gamonga, and *bura* in Sidaminga.

The species is managed and utilized by the farmers in different ways, depending on the farming system. The value attached to the species by different groups of farmers also varies accordingly. This paper presents the cultural practices and mode of utilization of *F. albida* in the southeastern Shewa region of central Ethiopia. The discussion is based on the author's personal observations and findings from informal interviews with some farmers of the region.

Ecology of the Region and Characteristics of the Tree

According to Ethiopia's agroecological zoning, the southeastern Shewa region is within the high-potential cereal zone (HPC), with mean annual rainfall 700-1200 mm; mean annual temperature, 16-21°C; and altitude, 1500-2000 m above sea level. The topography is mostly flat, with extensive bottom lands where Vertisols predominate. The seasonal rainfall pattern is weakly to strongly bimodal. The small rains (April-May) are generally too unreliable to allow a second crop to be grown prior to the main rains (June-September). The main farming system of the region is teff (*Eragrostis tef* (Zucc.) Trotter) with other cereals in combination with livestock.

F. albida in this region is found scattered on the seasonally waterlogged ground along riverbanks and in woodland and grassland areas. It forms pure stands only in farmlands where farmers deliberately maintain it to the exclusion of other tree species. Usually,

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in its natural habitat, *F. albida* is associated with *Acacia tortilis, Acacia sieberiana, Acacia etbaica, Acacia seyal, and Balanites aegyptiaca.*

The phenology of the species in this area follows the same general pattern in Sahelian countries. Normally, the trees produce the greatest amount of leaves in the dry season and very few during the rainy season. The trees bear fruit once a year, between November and January, with an average seed production of 3-5 kg $tree^{-1}$.

Some trees, however, produce pods during other months, although not consistently.

The regeneration of *F. albida* in the region is normally achieved by seed propagation, although some root suckering does occur on older trees. In spite of the large amount of seed produced, seedlings can seldom be found, even under mature *F. albida* trees. We have found an average of only 2-4 seedlings or young saplings on a hectare bearing 20 or more mature trees. Germinating seedlings are usually browsed by animals or plowed under unnoticed during cultivation of the land for crop production. Those that remain are encouraged to develop and mature.

Cultural Practices and Utilization of *F. albida*

Natural stands of *F. albida* in Ethiopia are generally managed in two ways, depending on the type of farming system and area where it grows. In the coffee-growing region of Hararghe (eastern Ethiopia), particularly in the Gelemso area, farmers usually maintain and protect *F. albida* in their coffee plantations for shade. Pods of the trees are collected and fed to livestock. On the other hand, mature trees found in cereal-based farming systems (southeastern Shewa region and the Fedis area of Hararghe) are regularly pollarded at intervals of 3-4 years. Whole canopies are cut right back to the trunk, leaving the trees completely bare. Farmers use the branches for fuelwood and for fencing their compounds and barns. Except for very old trees, which no longer pollard properly, *F. albida* trees are not normally felled. In this region, *F. albida* generally is not used for construction because it is prone to termite attack and does not last more than 3 years. However, farmers living in Fedis, Hararghe region, prefer *F. albida* branches for constructing their houses, and have no serious problems.

F. albida is also used in the region as a source of shade for animals during the dry season. Its pods are widely preferred by animals. Leaves are usually browsed only by goats. Extracts from the bark are said to be used for treating toothache and sore throat in humans and eye disease in animals.

Besides the economic value attached to the species, *F. albida* is also revered as a holy tree, and is therefore protected by all members of the community. In the absence of F. *albida,* either *A. tortilis* or some *Ficus* spp are revered.

An informal survey to assess the impact of social forestry in some parts of the central region (Modjo area), showed that 74% of the respondents maintain trees on their farmland for different uses. The most protected species is *F. albida,* followed by *A. etbaica* and *A. tortilis* (Kahurananga 1990). In this locality, most of the farmers recognize the beneficial effects of *F. albida* to crops. The survey also showed that 54% of the respondents claim that where *F. albida* exists on the farm, crops perform better than in areas without the trees. This has been confirmed by research done in the same area by the Forestry Research Center (FRC), where an increase of 43% in wheat yields was obtained near an *F. albida* tree (FRC, unpublished data). Similar results were also reported earlier in Gelemso, Hararghe region (Poschen 1986).

In the neighboring localities, however, farmers do not necessarily appreciate the attributes of *F. albida* and its effect on crop yield. They simply protect the trees on the farm for wood production. In fact, these groups consider *F. albida* as only the third most important species in their area. According to some farmers who were interviewed, the reason why *F. albida* is the only species now found in the farms is because it was not favored by the farmers even for firewood in past years. In spite of the different values attached to *F. albida,* no attempt has been made so far to plant the species on any reasonable scale, either by farmers or by government or private institutions. The survey disclosed that only 2% of the respondents were planting any trees on farmland, and those were mostly *Eucalyptus* spp. It is interesting to note, however, that very recently some non-governmental organizations and state farms have started planting *F. albida* as an agroforestry species On farmlands as well as on some abandoned farms. For this and other purposes, a total of 308 kg of F *albida* seed has been distributed by the seed center of the FRC in 1990 alone (Getahun et al. 1990a).

Ongoing and Completed Research

So far, there have been only a few investigations done on *F. albida* in Ethiopia. The beneficial effects of the species in improving crop yield have been evaluated in Hararghe region with different crops (Poschen 1986), and increased yields of maize and sorghum grown within the vicinity of *F. albida* have been observed.

F. albida was also tried in an alley-cropping trial in Hirna, Hararghe region. It was found too slow-growing to give the expected minimum biomass to be used as green manure. In addition, its lateral growth and its thorns, which make it unworkable for the bare hands of the farmers, made its use in alley cropping problematic (Getahun et al. 1990b). Bekele (1990b), in his study of the impact of *F. albida* on soil properties and undergrowth, found more plant species (17 species) under the tree canopies than on open land (8). Another study to investigate the germination behavior of *F. albida* seeds was conducted by Bekele (1990a), who reported that of the different treatments used to break seed dormancy, mechanical scarification and acid treatment (HNO_3, H_2SO_4) were found effective. Other treatments using ethanol, locally made alcohol, and boiling water were not effective.

The response of *F. albida* seedlings to *Rhizobium* inoculation was evaluated by Laike (1988), who found that *F. albida* responds positively if proper *Rhizobium* strains are used. Performance of 3.5-month old seedlings inoculated with a *Rhizobium* strain isolated from the nodules of A. *mangium* grown in Nueva Ecija, the Philippines, was comparable with the performance of seedlings treated with chemical nitrogen (400 mg kg^{-1} of soil). Total biomass obtained was 2.9 g and 3.1 g. respectively.

At present, the FRC is conducting a national comparative provenance trial of *F. albida* in the eastern Shewa region. Seeds of F. *albida* have been collected from representative stands in six regions. The seedlings are being raised in the FRC nursery for outplanting in Jun 1991. Data on survival and growth rate will be collected over the 10-year period of the experiment.

Conclusion and Recommendations

It has been proved by different researchers in many countries that *F. albida* improves the yield of crops grown under its canopy; this also holds true in the Ethiopian situation. Yet, most farmers of the central region do not necessarily appreciate this quality of the species. This is perhaps due to the inherently high level of fertility of the soil and the regular use of chemical fertilizers. In areas where the natural fertility is relatively lower, however, farmers do appreciate the role of the species in cropping systems. This appreciation and protection of the species is mainly limited to naturally grown trees; not much attention is paid to young seedlings.

Existing stands of *F. albida* are mostly dominated by mature trees of more or less similar age. The number of seedlings and saplings observed are too few to guarantee the sustainability of the species in the area. Older trees are also cut for fuelwood and construction purposes. This situation, coupled with the lack of interest by farmers in planting the species or protecting the naturally growing seedlings, foreshadows the gradual disappearance of the species from the region. Such a consequence may be aggravated by the existing fuelwood crisis, where more and more F. *albida* trees may be cut.

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Nutritive Value of Leaves and Fruits of *Faidherbia albida* and their Use for Feeding Ruminants

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Abstract

Grasses available on nonarable land and cereal crop residues are the most important feed resources available to farmers in the semi-arid zone of West Africa. Cell-wall carbohydrates (cellulose and hemicellulose) account for more than 70% of the dry matter in these feeds but their use is limited, because they are deficient in protein.

Research was conducted at the International Livestock Centre for Africa (ILCA) to determine the nutritive value of important trees, with emphasis on their use as sources of protein in diets for ruminants. The use of leaves and pods of Faidherbia albida *for feeding ruminants was compared with other multipurpose trees, legume forages, and oilseed cakes.*

The tannins and related phenolic compounds in F. albida *did not lower performance of sheep fed* F. albida *leaves and pods in comparison with sheep fed oilseed meals or legume hay in diets based on cereal crop residues. More research is required on the use of pods because of potential toxicity. More research is also needed to determine the variability in nutritive value of leaves and pods that exist among provenances and races of* F. albida *in order to find germplasm with superior characteristics.*

Introduction

Vegetation available on nonarable land and crop residues from cereals and grain legumes are the most important feed resources available to farmers in the semi-arid zone of West Africa. Feed grains are not produced, and livestock receive grain only under exceptional situations. Farmers seldom cultivate forages. Grazing on nonarable land is seasonal and consists of unimproved species. Herbaceous legumes and other dicotyledons are important during the growing season but grasses are usually dominant. During the dry season, only senescent grasses and crop residues, both low in protein, energy, and minerals, remain in the herb layer. In many areas they are completely grazed before the beginning of the next growing season. Browses from woody legumes are important livestock subsistence components of the vegetation.

Agroforestry with multipurpose trees (MPTS) that provide fodder could be integrated with the farming system as a way to improve livestock productivity (Torres 1983). *Faidherbia albida* and other native trees are important in the agrosilvipastoral farming systems of semi-arid West Africa. These trees produce both leaves and fruits in the dry season which are used as feed for sheep, goats, cattle, and camels.

Intake and digestibility of energy and protein are the most important parameters which determine the nutritive value of feeds. Cell-wall carbohydrates (cellulose and hemicellulose) account for more than 70% of the dry matter in cereal crop residues and represent a large source of energy for ruminant feeding. However, the ability of rumen microorganisms to digest these carbohydrates is limited, because cereal crop residues are deficient in protein. This deficiency is also responsible for their low intake. Forage from leguminous trees is usually high in protein and can be

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Reed, J.D., Rittner, U., Tanner, J., and Wiegand, O.1992. Nutritive value of leaves and fruits of *Faidherbia albida* and their use for feeding ruminants. Pages 43-49 *in Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

an important protein supplement to the normal ruminant diet of grasses and cereal crop residues—which are otherwise deficient in protein—improving their intake and digestibility.

Nutritive Value of Leaves from *F. albida*

Twenty *F. albida* leaf samples were collected at the ICRISAT Sahelian Center, Niamey, Niger, from individual 7-month old plants. Four half-sib progeny grown from each of five different mother trees were sampled to determine the effect of parent tree on content of phenolic compounds and nutritive value. Samples of leaves of 20 other important browse species from the region were also collected. Four introduced acacia species from Australia *(Acacia cowleana, A. holosericea, A. laccata,* and *A. tumida)* were collected at Dosso, Niger.

There was a large range in parameters of nutritive value among the samples of leaves from these tree species (Rittner and Reed, in press). *F. albida* had values that were similar to the mean of the other African species sampled but had a higher content of crude protein (CP, nitrogen x 6.25) and a lower content of lignin and soluble phenolics than the Australian species (Table 1).

Parent tree did not have a significant effect on chemical composition, content of phenolic compounds, or degradability of protein in their young progeny (1-1.5 m height). However, because the parent trees were from only one population (Sadore, Niger), these results may not represent the genetic variation in content of phenolic compounds in *F. albida,* which has a very large geographical distribution.

Microbial degradation of protein decreases as concentrations of phenolic compounds increase, because tannins and related phenolic compounds form indigestible complexes with protein and inhibit enzymes (Reed 1986; Reed et al. 1985). Protein degradability of leaves from *F. albida* was lower than that of other types of feeds, e.g., oilseed meals and common forage legumes, which have more than 50% protein degradability. This may be related to the content of phenolic compounds. The Australian species contained high levels of all phenolic fractions, and the protein was nondegradable in the in-vitro system used (Table 1).

Table 1. Content (% DM) of nitrogen (N), neutral detergent fiber (NDF), lignin (L), soluble phenolics (SP), proanthocyanidins (PAC) and protein degradability (PD) *of Faidherbia albida,* other western African acacia species, and 5 Australian acacia species, International Livestock Centre for Africa, 1989.

Tree species	N	NDF	L	SP	PAC	PD
F. albida						
Mean	2.4	34.2	10.3	27.3	2.4	11.0
SD	0.2	3.6	2.2	3.8	0.7	3.6
Minimum	2.0	26.5	6.7	19.2	1.3	6.1
Maximum	2.8	39.0	15.5	33.5	4.4	18.6
W. African acacias						
Mean	3.2	40.1	11.7	24.7	2.8	13.4
SD	1.0	13.2	6.2	10.3	3.3	13.9
Minimum	1.6	15.3	2.7	8.1	0.1	-3.0
Maximum	6.1	63.2	22.3	52.1	9.7	43.5
Australian acacias						
Mean	1.7	42.6	16.0	37.9	1.8	-1.4
SD	0.4	6.5	2.1	2.9	3.0	0.9
Minimum	1.3	34.4	12.0	32.5	0.3	-2.5
Maximum	2.6	55.9	19.1	41.8	9.3	-0.1

Table 2 shows the composition of leaves from multipurpose trees, alfalfa hay (*Medicago sativa*), oilseed meals, and cereal crop residues used in the feeding trials described below. These feeds vary widely in their content of crude protein, fiber, and phenolic compounds (lignin, soluble phenolics, and insoluble proanthocyanidins). Tree leaves in general tend to have higher phenolic compounds than forage legumes or oilseed cakes; in crude protein, they are lower than oilseed cakes but comparable to forage legumes. Of the MPTS we tested, *Leucaena leucocephala* and *Sesbania sesban*—with the highest content of crude protein and low levels of fiber and phenolic compounds—are the best sources of protein for diets based on cereal crop residues. *Carissa edulis* and *Dichrostachys cinera*—low crude protein and high phenolics—were the least useful as protein sources.

Although *F. albida* can contain high levels of crude protein, it also contains phenolic compounds that may reduce protein digestibility. Cereal crop residues contain low levels of CP (Table 2), which are below the maintenance requirements (>7% CP) for adult ruminants. Cereal crop residues contain much higher amounts of cell-wall carbohydrates than leaves from multipurpose trees but much lower amounts of lignin and other phenolic compounds. Lignin is covalently bound to cell-wall carbohydrates and limits digestibility. The potential digestibility of the cell-wall in many cereal crop residues is high when adequate protein is supplied in the diet.

Dried leaves of *F. albida, A. seyal,* and *Balanites aegyptiaca* and cottonseed meal were fed to 48 yearling male sheep in a 70-day growth trial (Rittner and Reed 1989). Sorghum stover was fed to all sheep at 50 g kg^{-1} of bodyweight, and the amount offered was adjusted weekly. Leaves and cottonseed cake were fed to supply 30 and 45 g of CP day^{-1}.

Differences in growth rate were not large (Table 3). Intake of sorghum stover was highest on the cottonseed meal diet. Less cottonseed meal was fed in order to obtain the required CP level. Substitution of supplement intake for stover intake was least on the

Table 2. Content of crude protein (CP), neutral-detergent fiber (NDF), acid-detergent lignin (ADL), soluble phenolics (SP) and insoluble proanthocyanidins (IPAC) in leaves from multipurpose trees, forage legumes, oilseed meals, and cereal crop residues used in feeding trials, International Livestock Centre for Africa, 1989.

Type of feed	CP (% DM)	NDF (% DM)	ADL (%DM)	SP (%DM)	IPAC (A_{550}/gNDF)
Multipurpose trees					
Faidherbia albida	20.1	31.8	10.7	22.6	51.9
Acacia seyal	18.1	32.6	11.8	41.2	31.2
Balanites aegyptiaca	16.9	34.0	13.7	23.0	6.6
Leucaena leucocepnala	25.6	25.2	6.0	15.6	22.6
Sesbania sesban	26.6	18.6	4.8	14.5	18.3
Carissa edulis	8.7	41.3	18.3	21.5	455.1
Dichrostachys cinera	14.1	49.8	21.0	31.0	51.7
Forage legume					
Medicago saliva	19.9	44.9	7.8	9.3	1.7
Oilseed meals					
Noug	34.8	36.6	12.7	14.0	7.0
Cottonseed	28.1	45.7	9.0	11.5	32.4
Cereal crop residues					
Teff straw	3.1	79.9	6.9	-	-
Maize stover	2.4	71.6	4.9	9.9	3.2
Sorghum stover	5.6	69.2	6.1	12.1	3.6

Table 3. Growth rate and feed intake of sheep fed leaves from *Faidherbia albida, Acacia seyal,* and *Balanites aegyptiaca* in comparison with cottonseed meal as sources of two levels of protein (CP, crude protein) in diets of sorghum stover, International Livestock Centre for Africa, 1989.

Feeding parameter		*Faidherbia albida*	*Acacia seyal*	*Balanites aegyptiaca*	Cotton Seed Meal
Growth rate (g day^{-1})					
30 g CP	day^{-1}	44	45	55	54
45 g CP	day^{-1}	56	62	61	68
Sorghum stover intake (g day^{-1})					
30 g CP	day^{-1}	499	477	474	523
45 g CP	day^{-1}	515	447	436	562
Leaf or cottonseed meal intake (g day^{-1})					
30 g CP	day^{-1}	131	167	185	110
45 g CP	day^{-1}	197	244	275	165

Table 4. Growth rate and feed intake of sheep fed leaves from *Faidherbia albida, Sesbania sesban, Leucaena leucocephala, Dichrostachys cinera,* or *Carissa edulis* in comparison with hay from *Medicago sativa* as sources of protein in diets of teff straw with or without 100 g day^{-1} of maize grain, International Livestock Centre for Africa, 1989.

Feeding parameter	*Faidherbia albida*	*Sesbania sesban*	*Leucaena leucocephala*	*Dichrostachys cinera*	*Carissa edulis*	*Medicago sativa*
Growth rate (kg day^{-1})						
- maize	23.4	21.1	27.6	-48.4	-71.6	19.4
+ maize	53.8	50.5	50.6	5.9	6.0	40.7
Teff straw intake (g day^{-1})						
- maize	302	442	412	278	258	290
+ maize	371	422	428	251	249	366
Leaf or hay intake (g day^{-1})						
- maize	206	170	164	60	95	203
+ maize	211	170	164	66	56	203

diet containing cottonseed meal. Sheep fed *F. albida, A. seyal,* and *B. aegyptiaca* had similar levels of stover intake at both levels of protein. Browse did not have a significant effect on total intake. These results indicate that the leaves of these three multipurpose trees can substitute for cottonseed meal as sources of protein for feeding in combination with sorghum stover. However, stover intake will decrease, because more leaf material than cottonseed meal is required to obtain the equivalent intake of protein.

In another trial, leaves from *F. albida* and four other MPTS were compared with alfalfa (*M. sativa)* as sources of protein in diets based on teff (*Eragrostis abyssinica*) straw (Wiegand et al. 1991). Forty-eight rams were randomly assigned to six sources of protein (leaves from *F. albida, L. leucocephala, S. sesban, C. edulis,* and *D. cinera,* and alfalfa hay) and two levels of energy (no maize grain and maize grain fed at 100 g day^{-1}).

Rams fed *F. albida* grew at rates similar to rams fed *L. leucocephala,* 5. *sesban,* and alfalfa hay (Table 4). Rams fed C. *edulis* and *D. cinera* with no maize grain lost weight throughout the trial and rams fed these leaves with maize grain only maintained their bodyweight. Teff straw intake was highest for rams fed *L. leucocephala* and S. *sesban.* Teff straw intake for rams fed *F. albida* was similar to alfalfa hay. *F. albida* and alfalfa hay had similar levels of crude protein. Teff straw intake was the lowest for the rams fed C. *edulis* and *D. cinera* because they consumed less than 30% of the leaves offered.

Nutritive Value of *F. albida* Pods

Acacia pods are fed to animals in the dry season when they are ripe. In many areas, pods are collected and brought back to the village to feed cattle, sheep, and goats or sold in organized fodder markets. In other regions, animals are taken to the trees and pods are consumed as they fall naturally or are knocked down by herders. Thus, circumstantial evidence indicates that acacia pods are of high nutritive value; however, few studies have been conducted to quantify the animal response to diets containing them.

An experiment was designed to examine the nutritive value of pods from *F. albida,* A. *nilotica,* A. *sieberiana,* and A. *tortilis* (Tanner and Reed 1990). The fruits of these four species were compared with the meal produced by industrial extraction of oil from noug (*Guizotia abyssinica*). These feeds were compared as sources of protein when fed in combination with maize stover (*Zea mays*).

Forty yearling rams of the Menz breed (common to the Ethiopian Highlands) were blocked according to their initial body weights (20-22 kg) and randomly assigned from the blocks to five treatments (8 sheep per treatment). Each treatment received maize stover (1 kg fresh mass for each sheep), fed in combination with pods of *F. albida,* A. *nilotica,* A. *sieberiana,* A. *tortilis,* and noug meal.

The diets were formulated to provide approximately 8 g N day^{-1} to each animal. A daily intake of all the pod or noug meal offered and half the maize stover offered would supply 6 g N day^{-1}, which is sufficient for an average daily gain of 50 g day^{-1} in male sheep of around 20 kg live weight.

Whole pods of A. *nilotica* had the highest content of insoluble proanthocyanidins, which were primarily located in the pod (Table 5); whole pods of A. *sieberiana* had the next highest content, evenly distributed between the pod and seed. Pods of *F. albida* and A. *tortilis* had a lower content of soluble phenolics and insoluble proanthocyanidins than A. *nilotica* and A. *sieberiana.*

The sheep consumed all of the pods and noug meal offered throughout the growth trial (Table 6) The variation in N intake between treatments was caused by differences in the quantity of maize stover ingested.

Sheep fed noug meal and A. *tortilis* had the highest growth rates but were not significantly different

Table 5. Content of nitrogen (N), neutral-detergent fiber (NDF), acid-detergent lignin (ADC), soluble phenolics (SP) and insoluble proanthocyanidins (IPAC) in fruits from *Faidherbia albida, Acacia nilotica, A. sieberiana,* and *A. tortilis,* International Livestock Centre for Africa, 1989.

Feed Type	N (%DM)	NDF (%DM)	ADC (% DM)	SP (%DM)	IPAC (A_{550}/gNDF)
Whole pods					
F. albida	2.3	37.4	4.5	36.5	26.8
A. nilotica	2.1	31.6	5.3	43.6	89.2
A. sieberiana	2.0	37.0	5.8	40.6	37.4
A. tortilis	2.1	32.4	4.8	37.3	31.4
Separated pods					
F. albida pod	1.2	44.3	7.1	35.6	32.2
F. albida seed	4.5	27.9	4.5	53.4	50.2
A. nilotica pod	1.6	29.8	6.4	43.5	133.4
A. nilotica seed	3.4	39.8	4.4	49.0	8.8
A. sieberiana pod	1.6	40.5	9.6	42.1	51.4
A. sieberiana seed	3.1	39.9	2.6	37.6	56.6
A. tortilis pod	1.2	39.4	7.5	32.9	38.0
A. tortilis seed	3.0	33.7	1.9	46.4	13.0

Table 6. Growth rate and feed Intake of sheep fed acacia pods and noug meal in combination with maize stover, International Livestock Centre for Africa, 1989.

Feeding parameter	Noug meal	*Acacia tortilis*	*Faidherbia albida*	*Acacia nilotica*	*Acacia sieberiana*	SE
Growth rate (kg day^{-1})	32a	32a	21ab	16b	4c	±16
Maize stover intake (g day^{-1})	483a	430b	401b	347c	320c	±74
Pod or noug intake (g day^{-1})	80	206	194	204	211	
N intake during growth trial (g day^{-1})	6.3	6.1	5.9	5.5	5.5	

1. Means in a row followed by the same letter do not differ significantly ($P < 0.05$).

Table 7. Growth rate and feed intake of sheep fed pods from *Faidherbia albida* and *Acacia tortilis* in comparison with cottonseed meal as sources of two levels of crude protein (CP) in diets of teff straw and vetch hay, International Livestock Centre for Africa, 1989.

Feeding parameter	*Faidherbia albida*	*Acacia tortilis*	Cottonseed meal
Growth rate (g day^{-1})			
30 g CP day^{-1}	39	42	48
45 g CP day^{-1}	57	49	52
Teff straw intake (g day^{-1})			
30 g CP day^{-1}	189	185	265
45 g CP day^{-1}	180	156	237
Pod or cotton seed meal intake (g day^{-1})			
30 g CP day^{-1}	195	225	114
45 g CP day^{-1}	283	327	170

from those fed *F. albida* (Table 6). Sheep fed *A. nilotica* grew at a lower rate but were not significantly different from those fed *F. albida.* Sheep fed *A. sieberiana* had the lowest growth rate.

Intake of maize stover was high for sheep fed noug meal, A. *tortilis,* and *F. albida* and low for sheep fed *A. sieberiana* and *A. nilotica.* The differences between diets in intake of N and energy were not large during the growth trial and yet significant differences were observed in growth rate. Browse species, including acacias, often contain tannins and related polyphenolic compounds. The results indicate that the phenolic compounds present in acacia pods have an effect on the N balance.

The growth rates of sheep fed *F. albida* and *A. tortilis*were not significantly different from sheep fed noug meal, indicating that these pods could replace noug meal in ruminant diets. Most oilseed meals are produced in centralized oil extraction plants and are not easily available to smallholders, who either cannot afford to purchase them or are farming in remote areas to which transport of animal feeds is not possible. The pods from *A. tortilis* and *F. albida* could constitute a low-cost, widely occurring alternative to oilseed meals.

The growth rate of rams fed *F. albida* and *A. tortilis* pods was similar to that of rams fed cottonseed cake when these feeds were used as sources of protein in diets based on a combination of vetch hay and teff straw (Table 7). Feeding acacia pods at over 50% of total intake produced no adverse effects; however, when *F. albida* pods Were fed to sheep and goats as the sole ration, there appeared to be some toxicity problem. Goats had higher intake and lost less weight than sheep when fed on *F. albida* pods (Fig. 1). All animals were slaughtered after 84 days of feed, and

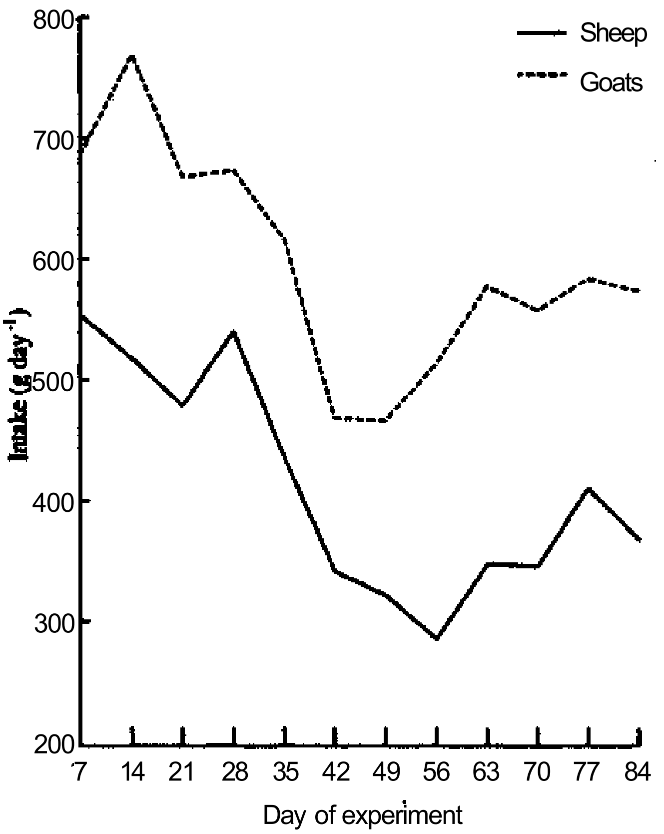

Figure 1. Intake by sheep and goats fed solely on *Faidherbia albida* pods for 84 days.

analyses were conducted on digestive tract content and histology. All animals receiving *F. albida* pods had ulcerations in the ventral sack of the rumen. However, in goats, papillae were normal and dense, whereas in sheep, they were eroded in patches in the ventral sack and the remaining ones were abnormal. *F. albida* pods probably contain a digestive tract toxin, the nature of which is presently unknown. There appears to be a large difference between sheep and goats in their ability to adapt to this toxin.

Conclusion

The leaves and pods of *F. albida* appear to be good sources of protein in diets for ruminants. Our research on *F. albida* indicates that the tannins and related phenolic compounds in leaves and pods have an effect on protein metabolism, but these effects do not lower performance of sheep fed leaves and pods in comparison with sheep fed oilseed meals or legume hay in diets based on cereal crop residues. More research is required on the use of the pods as the sole feed because of the potential toxicity. However, the practice of feeding ruminants only pods is not likely to be common. The leaves and fruits used in the trials described in this paper were from two areas, the Debre Zeit region of Ethiopia (feeding trials) and trees established at the ICRISAT Sahelian Center, Niger. This is a very limited sample of a species that spans most of the continent, and more research is needed to determine the variability in nutritive value in order to find germplasm with superior characteristics.

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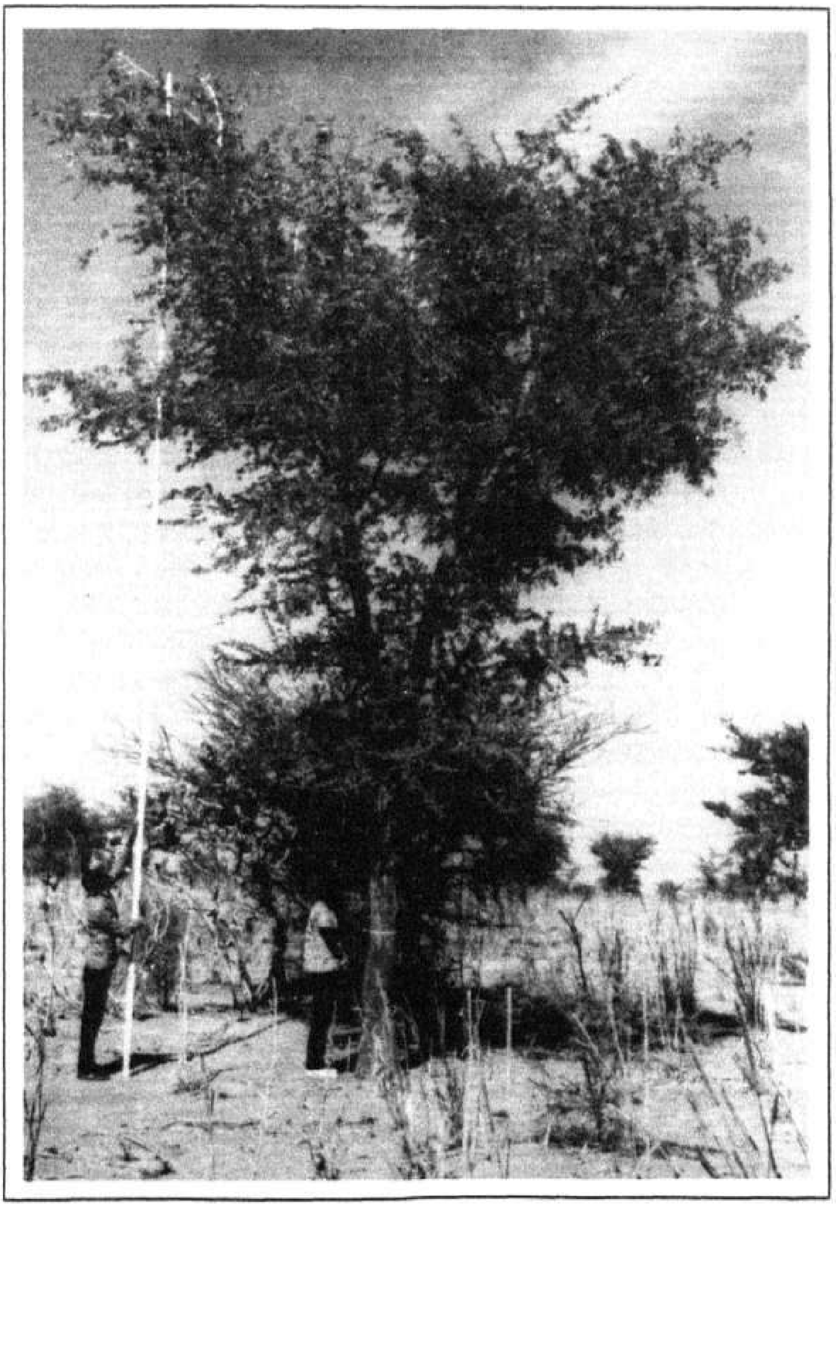
Session 3
Genetics, Provenance Trials, and Vegetative Propagation



Cover photo: A superior tree in a 15-year old *Faidherbia albida* plantation in Abala, Niger, Progeny studies at the Institut de recherche en biologic et ecologie tropicaie (IRBET), Burkina Faso, from single tree collections are yielding valuable information on heritability of desired traits. (Photo: R.J. Vandenbeldt.)

The Genetics of *Acacia albida* (syn. *Faidherbia albida)*

H.Joly[1]

Abstract

Current studies concerning Acacia albida *genetic resources focus on differences between western African provenances and those of eastern and southern Africa. These differences include growth rate, drought tolerance, phenology, and the degree of heterozygosity. The article stresses the degree to which lack of fundamental knowledge in all pertinent biological fields—reproduction, phenology, water utilization—proves limiting for an effective management of the considerable variability of the species, whether it be to develop breeding programs or to establish genetic resource conservation strategies.*

Introduction

Acacia albida (syn. *Faidherbia albida*) is a diploid (2n=26) species (Atchison 1948) although a tetraploid form has been seen in Israel. African acacias are for the most part, however, polyploid. The classing of *A. albida* in the genus *Acacia* has been discussed for many years. In 1934, Chevalier suggested placing the species in a monospecific genus *Faidherbia.* Since then, several works (Vassal 1967 and 1969; Guinet and Lugardon 1976; Brain 1987, Dreyfus and Dommergues 1981) have shown that A. *albida* possesses a combination of unusual characteristics among acacias. Several authors have therefore adopted the name *Faidherbia albida.* Whether this is the definitive taxonomic position of this species is not yet clear, certain authors consider that the genus *Faidherbia* is part of the family *Acacia* whereas others state that it would be more appropriately classed in *Ingeae.*

Ecology

The range of *A. albida* extends throughout Africa from Senegal to Ethiopia, then southward to Zimbabwe and to the northern part of the Republic of South Africa. It is also found in Namibia and Angola. Relic populations exist in Israel and Lebanon and fossilized trees have been found in the Hoggar Mountains (Wickens 1969). Papulations in West Africa have already been, at least partially, collected and a large collection effort is underway in East Africa (Fig. 1). These collections should be expanded to include Chad, Sudan and, if possible, relic stands in various areas to permit a better understanding of the species diversity. The horn of Africa, extended to Sudan, is most probably a zone of major diversity of African acacias and could also be the center of origin of A. *albida.*

The presence of this species over such a large range cannot be possible without its adaptation to a great diversity of ecological conditions. *A. albida* is generally found on alluvial soils particularly in southern Africa, but it also grows on poorer soils where the water table is deeper. *A. albida* can also be encountered in very different rainfall zones; for example, it is found in Senegal where it receives 400 mm of rain annually during a 3-month rainy season as well as in Zimbabwe and Burundi where 1000 mm of rain falls in a bimodal pattern. It is also found at altitudes varying from sea level to 2000 m in Ethiopia (CTFT 1988). It was thought until recently that western and eastern African populations were limited to river beds and that only western African populations were

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Joly, H. 1992. The genetics *of Acacia albida* (syn. *Faidherbia albida).* Pages 53-61 *in Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

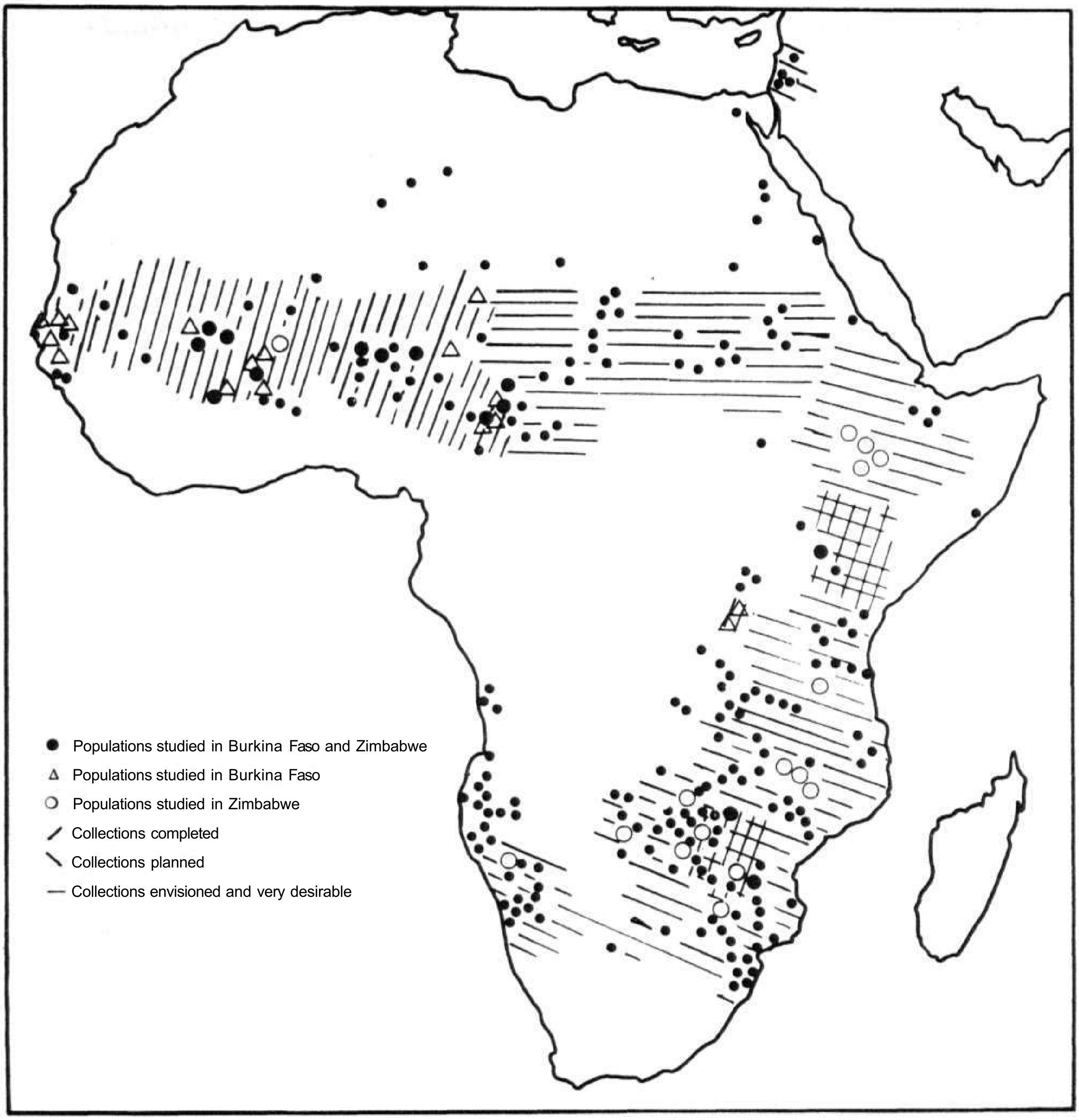

Figure 1. Distribution of *Acacia albida,* showing locations of known populations and status of collection and testing. [All circles and triangles are populations described in Wickens (1969).]

associated with agriculture; such stands were, however, observed recently in Malawi (Fagg and Barnes 1990). In the Sudano-Sahelian zone, *A. albida* is characterized by a defoliation in the rainy season and by a taproot system. This is not systematic throughout its remaining range. Immature trees in southern and eastern Africa may remain green throughout the year and, in certain zones, the trees are completely defoliated, as in the desert of Namibia (Fagg and Barnes 1990). *A. albida* may not always be taprooted; shallow-rooted trees have been observed in Senegal and throughout certain eastern African stands.

Quantification of Genetic Diversity

Besides the adaptation of *A. albida* to such diverse ecological conditions, there is considerable morphological variation of characters such as tree or pod form. In support of development activities, breeding programs and gene resource conservation strategies for *A. albida* must quantify the variability and determine how much of this is due to genetic or environmental differences. The spatial structure of this genetic diversity must also be studied. Despite the importance of *A. albida,* very little information exists on the genetic diversity of numerous traits of agronomical or pastoral interest. Since pertinent traits have not yet been defined, there is nothing known regarding the range of their variability and their heritability.

Phenotypic Variability

Numerous trials have been planted as part of development programs in Senegal since 1964, and in Niger in 1973 and 1974 (Montagne 1984; Cazet 1987). However, the first provenance trials were not installed until 1985 in Burkina Faso and 1986 in Zimbabwe (Table 1). The Burkina Faso trials were located in Dinderesso (950 mm rainfall) and Gonse (800 mm) utilizing seed origins from Burkina Faso, Mali, Niger, Senegal, more central provenances (Cameroon) and eastern Africa (Burundi, Ethiopia, Zimbabwe). Some

Table 1. Origins of *Acacia albida* provenances of trials conducted in Burkina Faso (1985), in Cameroon (1984), and in Zimbabwe (1986).

				Trial sites[1]				
Provenance	Location	Altitude	Rainfall	Di	Go	Ha	Ma	Zi
Burkina Faso								
Banfora	10°38'N 03°03'W	270	1 000	*				
Kokologho	12°10'N01°52'W	300	600	*	*			*
Kongoussi	13°30'N 01°6'W	280	650	*	*			
Korsimoro	12°49'N 01°04'W	315	600	*	*			
Nafona	10°42'N 04°42'W	300	700					*
Ouahigouya	13°35'N 02°26'W	325	650	*	*			
Oursi	14°10'N 00°10'W	300	300					*
Safane	12°08'N 03°13'W	290	800	*				
Zogore	13°40'N 02°60'W	325	630	*				
Burundi								
Gihanga	03°15'N 29°15'E	820	650	*	*			*
Rumango	04°00'S 29°05'E	800	1 160	*	*			
Cameroon								
Adoumri	09°16'N 13°50'E	220	875	*	*			
Bogo	10°43'N 14°32'E	300	780	*	*		*	*
Doukoula	10°07'N 14°58'E	300	815	*	*		*	*
Guetaie	10°57'N 13°55'E	450	850	*	*	*	*	*
Makari	12°34'N 14°28'E	290	500	*	*			
Maroua	10°40'N 14°15'E	400	720		*			
Mayo-sava	10°58'N 14°12'E	450	780					

Continued

Table 1. *Continued*

Provenance	Location	Altitude	Rainfall	Trial sites[1]				
				Di	Go	Ha	Ma	Zi
Ethiopia								
Awassa	07°05'N 38°25'E	1 6S0	1 150			*	*	*
Debre-Zeit	08°44'N 38°58'E	1900	730			*	*	*
Meki	08°48'N 37°39'E	1 600	700			*	*	*
Wenji	08°26'N 39°15'E	1 540	800	*	*	*	*	*
Kenya								
KerioVal.	Not available		350		*			
Lodwar	01°14'S 35°09'E	2 130	1 280		*	*	*	*
005K9	Not available			*				
Malawi								
Bwanje	14°36'S 34°45'E	600	900			*	*	*
Chilandga	14°50'S 35°15'E	500	750			*	*	*
Chiyenda	15°02'S 35°02'E	600	760			*	*	*
Mali								
Baroueli	13°05'N 06°51'W	250	800	*	*		*	*
Kemeny	12°58'N 05°40'W	270	760	*	*		*	*
Mio-kolongotomo	13°49'N 05°48'W	280	650		*			
Saro	13°42'N 05°15'W	250	585	*	*	*	*	*
Namibia								
Caprivi	17°27'S 24°10'E	700	650			*	*	*
Hoanib	19°15'S 13°50'E	700	200				*	*
Niger								
Bouza	14°25'N 06°07'E	300	450	*	*		*	*
Kollo	13°18'N 02°21'E	210	600	*	*			
Madarounfa	13°19'N 07°09'E	360	600	*	*	*	*	*
Matameye	13°25'N 08°28'E	450	560	*	*		*	*
Tera	14°00'N 00°45'E	240	460	*	*			
Rep. South Africa								
Messina	22°20'S 30°03'E	540	340			*	*	*
Senegal								
Bambey	14°42'N 16°28'W	20	670		*			
Bellokho	15°20'N 16°20'W	38	375	*	*			*
Bignona	12°45'N 16°25'N	10	1 100	*	*			*
Louga Nayobe	Not available			*				
Merina	15°06'N 16°32'W	30	600	*	*			
Tanzania								
Iringa	07°49'S 35°39'E	1 400	750				*	*
Zambia								
Nanga	Not Available					*	*	*
Zimbabwe								
Chipinda Pools	21°18'S 32°21'E	170	510		*	*	*	*
Hwange	18°44'S 26°16'E	950	475			*	*	*
Mana Pools	15°45'S 29°20'E	360	780		*	*	*	*
Manyoni R.	18°04'S 28°13'E	800	790					*
Middle Sabi	20°21'S 32°18'E	440	450				*	*

1. Di = Dinderesso, Burkina Faso; Go = Gonse, Burkina Faso; Ha = Harare, Zimbabwe; Ma = Matopos, Zimbabwe; Zi = Provenances included in seed mass study. Zimbabwe.

of these same seedlots were raised in greenhouses in Zimbabwe for other traits. One trial, which focused more on agroforestry was laid out in Cameroon in 1984 to evaluate the tree's impact on rotated crops (sorghum, cotton, groundnuts) (Peltier and Eyog-Matig 1988) and to compare different provenances.

The Burkina Faso trials focus only on survival traits and growth from 6 months to 5 years. The Zimbabwe trials involved younger stock and focused on production traits and fodder quality. In both trials, provenances of eastern and southern Africa showed better initial growth than those of western Africa. Yet, the Burkina Faso trials showed that these provenances were poorly adapted to a Sudano-Sahelian climate because the mortality rate at Gonse approached 100% by the second dry season. In Dinderesso, where the annual rainfall is greater and the rainy season longer, the Burundi provenance remains vigorous (Billand and de Framont 1990), but this provenance also failed in Mouda, northern Cameroon (Peltier and Eyog-Matig 1988). It should be noted that these results were obtained at a juvenile stage of the plants and may be partially due to a difference in seed size. Seeds of southern African provenances are two to three times larger than seed of western African provenances. Sniezko and Stewart (1989) also show that western African provenances, consisting of 3-month old noninoculated stock in a nursery, had poorer nodulation than eastern and southern African provenances. Root:shoot ratios averaged 50% for all the provenances, and were slightly higher for western African provenances.

These initial results are interesting for evaluating response of different seed origins under varied ecological conditions; they do not, however, provide much useful information on the heritability of the traits studied and hence on the potentials of selection for these traits in a breeding program.

Progeny trials have recently been set up in Burkina Faso to evaluate variation of traits. These trials include three provenances—Kagnobon (Senegal), Kongoussi (Burkina Faso), and Matameye (Niger)—which are all represented at the other trials in Burkina Faso. The first trial was laid out in 1987 for the Kongoussi provenance. Heritability at 6 months was 38% for height and 22% for diameter (at the root collar); at 18 months, heritability was 19% for height and 16% for diameter (IRBET-CTFT 1989).

All these results focus on the differences between western African provenances and those of eastern Africa (Table 2); it is difficult to evaluate which part can be attributed to genetics in these differences. Together, these measurements describe growth traits and form at the juvenile stage. It would be desirable to expand this type of study to include essential physiological differences of the species at maturity, such as shedding of leaves in the rainy season or water utilization.

Table 2. Summary of principal differences between *Acacia albida* provenances of western and eastern Africa.

Characters	Western African Provenances	Eastern African Provenances
Seed weight	Low	High
Juvenile growth rate	Slow	Fast
Tolerance for long dry season	Good	Poor
Nodulation[1]	Medium	Good
Level of heterozygosity[2]	Medium	Weak

1. Results of a study carried out in Zimbabwe. 1986.
2. Mean F value = 0.27 for western African provenances, 0.40 for eastern African provenances.

Genetic Variability

The expression of important agronomic, morphological, or physiological characteristics depends on the interaction of environmental and genetic parameters. Thus, complementary studies of variability of species that emphasize purely genetic traits which are not directly susceptible to environmental pressures, are useful.

A study of the enzymatic variability of A. *albida* is being undertaken in France (Danthu and Prat 1991; Zeh-Nlo et al., in press) and in the UK at the Oxford Forestry Institute. Trials have been conducted with eleven provenances, including three from western Africa (Mali, Niger, and Senegal); two from Cameroon and two from eastern Africa (Burundi and Zimbabwe). Eleven enzymatic systems representing 16 loci were studied using 20 trees per provenance. This study has conclusively demonstrated the great diversity of A. *albida,* particularly between eastern and western African provenances (Fig. 2). A large separation is evident in eastern African populations relative to others vis-a-vis the absolute genetic distance (Fig. 3) (Joly and Zeh-Nlo, in press). A study of stands in the region surrounding Sudan should determine

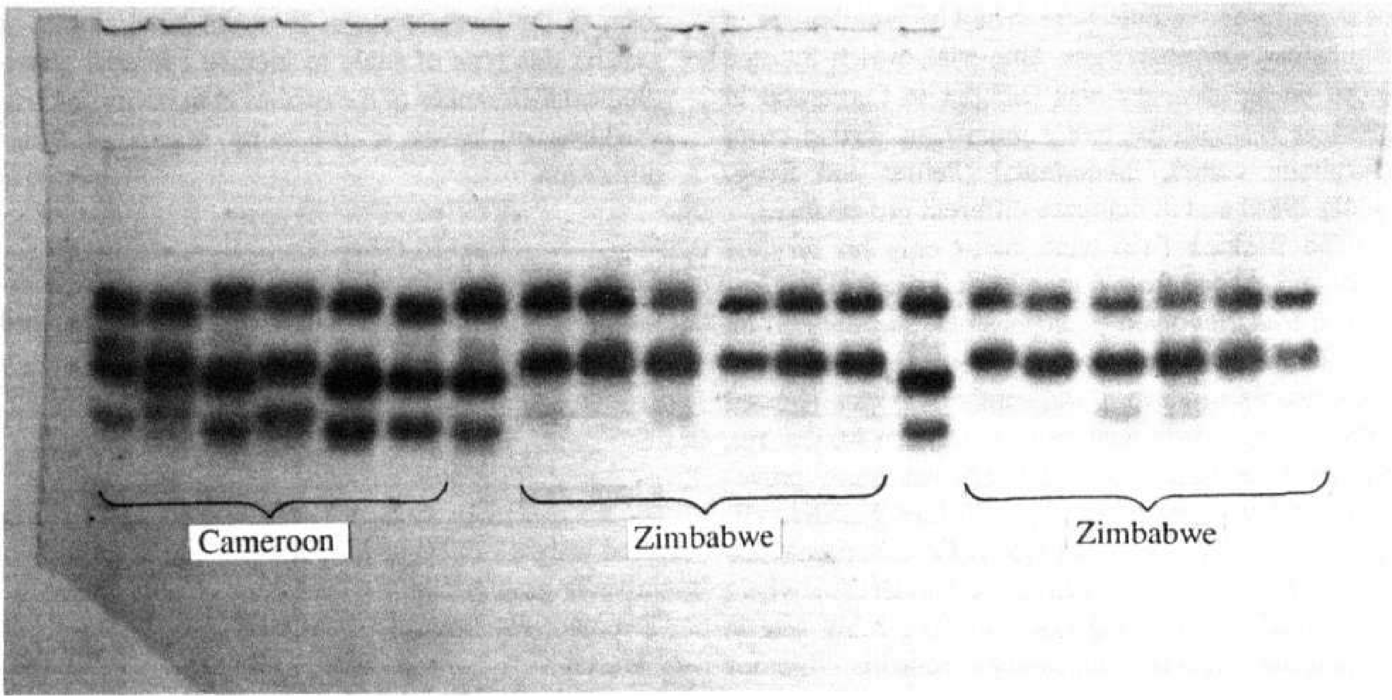

Figure 2. Electrophoretic differences in leucine amino-peptidase between provenances of Mana Pools, Zimbabwe (columns 8-13 and 15-20) and Guetale, Cameroon (columns 1-6). Columns 7 and 14 are a mixture of seeds for comparison.

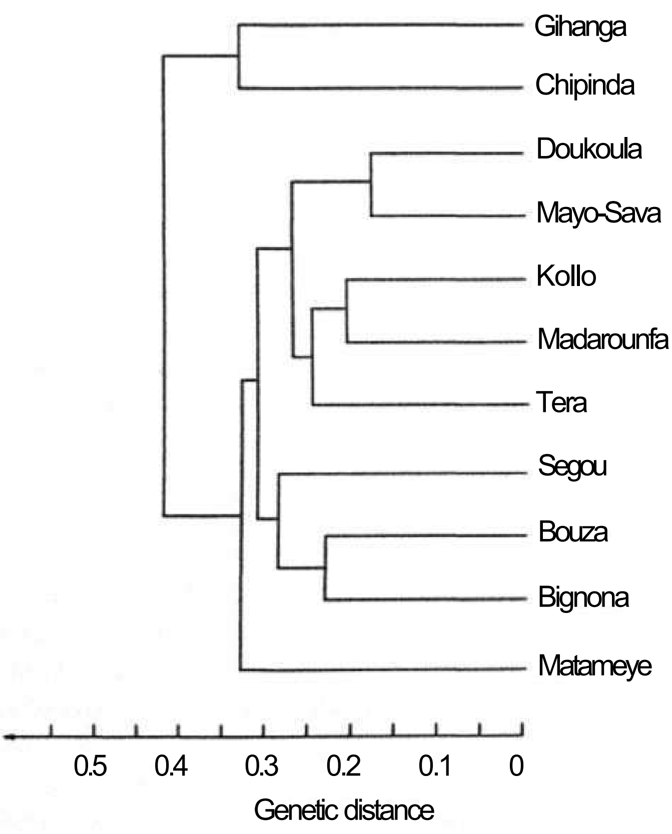

Figure 3. Dendrogram of genetic distances for *Acacia albida* provenances from Burundi (Gihanga), Zimbabwe (Chipinda), Cameroon (Doukoula and Mayo-sava), Niger (Kollo, Madarounfa, Tera, Bouza, and Matameye), Senegal (Bignona and Segou). (Source: Joly and Zeh-Nlo, in press.)

whether western African populations are derived from the eastern populations or vice versa or—a, more likely proposition—whether they are derived from a common source located in this zone.

Reproductive Biology and Organization of Genetic Diversity

Sexual Reproduction

The reproduction of *A. albida* is poorly known. Its pollen is a polyad of 30 monads (Guinet 1969). The species is pollinated by entomophilous means. Recent studies (Tybirk 1991) show that the pollinators belong to numerous families of which *Scoliidae* and *Eumonidae* (hymenopterae), and *Lycanidae* and *Danaidae* (leptidopterae) are the most frequent. Isolated trees produce seed, therefore it appears likely that A. *albida* does not possess a strict self-incompatibility system. However, the level of self-fertilization is not known. Flowering of individual trees is often not uniform and, therefore, the rate of self-fertilization within a stand may vary from tree to tree through the flowering stage. The study of enzymatic systems may also allow estimation of the rate of a tree's self-fertilization and the level of a population's homozygosity. Studies of enzymatic systems done at

ENGREF show that all *A. albida* populations studied reveal a deficit in heterozygotes one would not expect in a completely panmictic population. It should be noted that eastern African populations present a larger deficit than those of western Africa.

Vegetative Reproduction

Under certain conditions, *A. albida* can reproduce by vegetative means. Establishments by runner cuttings were monitored in Israel (Karschon 1976) where, despite considerable flowering, each pod produced contained no more than one or two very small seeds. It is probable that a combination of conditions for good germination did not exist because of cold temperatures during the rains. In certain areas of West Africa the regeneration of natural parks could also be done at least partially by runner cuttings. Studies of the spatial structure of the genotypes obtained by electrophoresis for stand establishment are planned in Senegal; this will permit evaluation of vegetative multiplication in regenerating tree stands (Personal communication, *A. albida* Research Program, Bernard Dreyfus, Coordinator, ORSTOM, Dakar).

Organization of Genetic Diversity

The biology of reproduction and means of seed dispersion defines the spatial nature of genetic diversity. Entomophilous pollinization in *A. albida* suggests that pollen dispersion is of little consequence. However, the pods are consumed by livestock and wildlife and can therefore be disseminated over several hundreds of square kilometers, often to areas where cattle rest. The practice of selection by the farmer in his field can also affect the level of order of genetic diversity of *A. albida.* Preliminary electrophoretic studies of this hypothesis show that the differences between populations is a considerable (F_{ST}=0.23) part of total variability (F_{IT}=0.44) (Joly and Zeh-Nlo, in press).

Genetic Improvement and Conservation of Genetic Resources

Designing a breeding strategy for a multipurpose species is always difficult when traits to be selected are numerous. The simultaneous selection of several traits may prove to be impossible if these traits are negatively correlated. Furthermore, the highly diverse conditions under which the species is grown should be taken into consideration because lines bred for maximum growth on an optimum site may not be sufficiently hardy for adaptation elsewhere.

Clearly, the evaluation of genetic diversity is necessary in order to define breeding programs as well as to establish a genetic resource conservation strategy. For that reason basic knowledge on the species must be compiled and several tools well understood in advance. Some of these are described below.

Controlled Crossings

The mastery of controlled crossings is important for any breeding program. Pod production from such crossings is one of the principal interests in *A. albida* breeding; a thorough knowledge of flowering and fruit-bearing process is therefore particularly important.

Vegetative Propagation

Several cutting trials are under way in Burkina Faso (Bonkoungou et al. 1988) and in Senegal (Danthu, personal communication). A few grafting trials have also been undertaken in Burkina: the initial results have not been encouraging. Trials have also been carried out in order to develop micropropagation techniques from juvenile crown material (Duhoux and Davies 1985) and adult stage crown material (Gassama and Duhoux 1987). A new method which appears very promising involves multiplication by root fragments. These initial efforts are yielding good results with juvenile material. Work with cuttings is in progress (Duhoux and Gassama, personal communication).

It is likely that material will soon be available for clonal testing and for establishing conservation orchards of certain endangered stands.

Interactions with Microorganisms

Studies are under way to evaluate the degree of nodulation under natural conditions and to study rhizobium-mycorrhiza interactions and their effects on A. *albida* growth. The works of Lajunie et al. (1990) show that *A. albida* nodulates with *Bradyrhizobium* rather than with *Rhizobium* as most African acacias do. In Burkina Faso, a strong interaction has been shown between *Rhizolmtm* stock and mycorrhizae (Dianda 1990).

A breeding program is being developed in Burkina Faso by IRBET-CTFT with the aim to produce sufficiently homogenous planting material and better initial growth. A seed orchard will be established and clonal testing is planned. Studies will be carried out on the floral biology *of A. albida* with the focus on the tree-*Rhizobium*-endomycorrhiza interaction (Bonkoungou et al. 1988). To improve such activities, further studies should be carried out on water use and the phonological rhythm of A. *albida* to provide better selection criteria.

Conclusion

Pooled results show that despite African farmers' and herders* longstanding interest in this species, and the importance placed on it by the scientific community, there is a lack of basic knowledge on *A. albida.* The role of *A. albida* in agroforestry systems, its impact on the water balance, and on mineral element cycling have not been elucidated. Leaf fall during the dry season is an important characteristic. It remains to be confirmed whether the phenomenon is due to environment or genetic factors. This lack of knowledge makes it difficult to choose useful traits for selection. Furthermore, negative or positive correlations may exist between these physiological characteristics as well as other important characteristics such as initial growth, production, and quality of fodder produced.

Ignorance of adaptive mechanisms of *A. albida* also makes *in situ* protection of genetic resources difficult since the impact of environmental modifications on these mechanisms and on the reproductive systems of *A. albida* is ignored.

The need for effective applied and sustained research cannot be stressed enough. All integral development plans for A. *albida* are hampered by failure to recognize the biological nature of this species.

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First Observations on the Phenology of *Acacia albida*: Study of a Population in Northern Cameroon

M.Zeh-Nlo and H.Joly[1]

Abstract

In a study on the evaluation of intrapopulation variability and gene flows in Acacia albida, *we monitored the flowering and pod setting cycle of a population in northern Cameroon. Results of the first two years are presented here.*

At the population level, the flowering period was variable. It peaked at the beginning of the dry season, followed by a pod setting peak which did not include the end of the flowering period. Pollination seemed to be a critical stage; after pollinating pods matured with relatively low losses.

At the level of the individual tree, different behavior was noted from annual variations. Almost all individual trees of different growth duration showed signs of pruning.

Introduction

In Cameroon, *Acacia albida* is found throughout the wooded savannas from the 6th parallel north in the Sudano-Zambesian zone. It predominates the thorny steppes between 10* and 11°N latitude from the Mandara Mountains in the intensely cultivated zones to the southeast borders of Waza Park. Throughout this range, *A. albida* exists most frequently in mixed stands with *Balanites aegyptica, Acacia seyal, Zizyphus* spp, and *Combretum* spp but also as vast, continuous stands (e.g., Koza plain, Mora plain) with densities attaining or surpassing 400-500 trees ha^{-1}.

Above 11°N latitude in the Sahelian zone this species is distributed in a scattered fashion and more heavily exploited due to larger human population. To the north of Makaroi, towards Lake Chad (Doumgounsilio), its presence is threatened by abusive delimbing, felling, and fire.

This relatively adaptable species has spread throughout northern Cameroon where annual rainfall ranges from 150-1000 mm and soil conditions are highly variable. *A. albida* generally loses its leaves at the beginning of the dry season (Giffard 1974; Miehe 1986). Flowering (October-December) starts approximately 2 months after the foliating season (Nongonierma 1976) and can extend into January or February. The fruit-bearing cycle of *A. albida* is poorly understood.

Along with other tree species, *A. albida* is protected under the Cameroonian forestry code but this is not often respected by the people. Old trees are heavily pruned in stands located in agricultural zones, and destruction of seedlings at the time of field clearing is common (Montagne 1984). Fire and cutting pressures are particularly strong in sparse stands, and there is danger of the species disappearing in these areas.

In order to develop a conservation strategy for this species, phenological and genetic studies emphasizing intra-population gene flux and genetic structure were started in 1990. We used an *A. albida* population in Kongola, northern Cameroon. Practically speaking, results of this stands can be used to manipulate variation in pod production. This is important because of the high fodder quality of the pods (Riviere 1971), which can be more efficiently harvested and stored than leaves.

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Materials and Methods

Population

In this region, the dry season begins in October and lasts until May. The rest of the year is marked by the wet season. Annual rainfall varies from 600-800 mm.

The 162 trees of the stand studied were distributed over a 2000 m^2 area characterized by sandy-clay soils. This stand was chosen because the trees were generally healthy. Also, there was an adequate number of flowering trees, access to the site was good, and the density of the stand was, on the average, higher than others of the region.

Data Collection

After every tree on the site was mapped, each was identified by species and numbered. Total height (TH) and crown height (CH) were measured using a Blum-Leiss mensuration device. Circumferences, taken at a height of 1.30 m, were measured with a graduated tape.

Only one series of observations was done in 1990 (22-26 Jan). To add precision to the study, observations were carried out over 6 periods (Table 1) in 1991. The base of each crown was sectioned into wedges by axes perpendicular to the tree trunk. Vertically, the crown was usually divided into three parts (lower-middle-upper). Crowns higher than 12 m but lower than 16 m were divided into 4 parts. Those higher than 16 m were sectioned into 5 parts. Each part within every wedge was separately evaluated for quantities of flowers, green pods, and mature pods on a scale of O (none) to 5 (maximum).

Data were analysed)with Statgraphics on an IBM PC. Pearson's coefficients of correlation were used to determine the relationships existing between the growth traits. Spearman's coefficients of correlation were used to study flowering and fruit-bearing traits.

Results

Growth Traits

The population was characterized by an average total height of 14.50 ±3.75 m, a crown height of 10.75 ±3.05 m, and a circumference (1.3 m) of 1.95 ±0.55 m. If diameter is positively correlated with age, there were few different age classes in the population.

The correlation between total height and crown height (r= 0.94) is stronger than that between either of these and circumference (r = 0.56 in both cases). It is possible that pruning of some trees altered the relationship between the circumference and total height and thus weakened the correlation.

Description of Flowering and Fruit Bearing

In 1990 and 1991, the phenological state of the trees in the population was recorded on 7 occasions (Table 1). More flowering trees with green pods were counted in 1990 than in 1991 during the same time of the year. However, trees with mature pods were fewer in 1990. It appears that, overall, trees were late in bear-

Table 1. Number of trees per phenological type, Kongoia, Cameroon, 1990-91.

	Period of observation						
Phenological type	S01[1]	S11	S12	S13	S14	S15	S16
Flowers	22	1	0	0	0	0	0
Green pods	1	4	4	3	0	0	0
Flowers + green pods	6	41	41	53	57	69	106
Flowers + mature pods	17	3	3	2	0	0	0
Green pods + mature pods	2	2	2	1	0	0	0
Flowers + green pods +	46	54	58	54	59	53	27
Mature pods	32	33	30	25	22	16	5
Total	126	138	138	138	138	138	138

1. SOI = 21-26 Jan, 1990; S11 = 05-09 Jan 1991; S12 = 11-15 Jan 1991; S13 =17-21 Jan 1991; S14 = 25-27 Jan 1991; S15 = 15-20 Feb 1991; S16 = 23-27 Feb 1991.

ing pods in 1990 than in 1991; more trees bore pods during the course of the last year (Table 1). In 1991, more than 60% of the trees continued to produce pods from January to February.

Discussion

The fact that the trees studied bore pods later in 1990 than in 1991 could be due to differences in climatic conditions between the two years. Relative humidity was 29.9% for Jan and 28.6% for Feb 1991, higher than the values of 22.2% and 24% for the same months in 1990. Air temperatures were 26.6°C in Jan and 30.6°C in Feb 1990, whereas these were 23.6°C and 30.8°C for the same months in 1991. It is therefore likely that low relative humidity, even if extreme, does not negatively affect flowering. More detailed meteorological data and closer monitoring will be necessary to substantiate this.

In spite of the annual difference in phenological behavior of this stand, 35 trees were observed to be in the same phenological state between years, except pod production which varied between trees.These individuals were scattered within the population, but nearly all were larger trees (total height 12 m, circumference 1.50 m).

The number of flowering trees with green and/or mature pods diminished with time. But in the last series of observations (S16), only five trees still possessed flowers (Table 2), an indication that the period of flowering was ending.

In order to explain these results with more precision, correlations between levels of flower production, green fruit, and ripe fruit for the various observation periods were made. The weak correlation (r = 0.15-0.23) for all the parameters between the two years confirmed differences in behavior of the trees from one year to another. In 1991, correlation coefficients for traits observed from one series to another decreased over time, with those for flowers having the lowest values (Table 2).

These observations revealed that the onset and completion of flowering, pod setting, and fruit maturity, which is asynchronous from one individual to another differed from tree to tree. It appears that there was a differential loss of flowers and/or pod setting from one individual to another.

Spikes, which have about 100 flowers, were estimated to produce between 1-5 pods. Since the pod maturity stage proceeds with less abortion and dehiscence than the flowering to pod setting stage, it is probable that pollination and/or pod formation is the critical point in the reproductive process.

There was no correlation noted between height and circumference, and flowering or pod bearing (Table 2), although the correlation between these parameters was higher for the number of mature pods than for the number of flowers. The tallest (and presumably the oldest) trees appeared to be more consistent in terms of mature pod production.

The average level of flowering of the population in 1990 was higher than that of 1991 for the same period (Table 3). The level of flowering in 1991 reached,

Table 2. Correlations between flower and fruit production for various periods of observation, Kongola, Cameroon, 1990-91.

	Flower production								
Fruit production	S01	S11	S12	S13	S14	S15	S16	HT[1]	CBH[2]
S01		0.19	0.20	0.19	0.17	0.12	0.03	0.20	0.14
S11	0.24		0.94	0.84	0.78	0.57	0.22	0.18	0.21
S12	0.24	0.99		0.89	0.82	0.61	0.24	0.14	0.16
S13	0.25	0.96	0.96		0.92	0.69	0.28	0.05	0.12
S14	0.23	0.95	0.95	0.97		0.74	0.31	0.05	0.13
S15	0.21	0.91	0.91	0.95	0.97		0.44	0.08	0.12
S16	0.22	0.86	0.87	0.91	0.93	0.96		0.10	0.06
HT	0.06	0.30	0.30	0.30	0.32	0.34	0.35		0.60
CBH	-0.03	0.19	0.19	0.22	0.25	0.29	0.28	0.60	

1. Tree height
2. Circumference breast height.

Table 3. Changes in the average level of flower, green pods, and mature production of pods of A. *albida*, Kongola, Cameroon, 1990-91.

	Observation period[1]						
Parameter	S01[2]	S11	S12	S13	S14	S15	S16
Flowers	3.08	1.12	1.47	0.93	0.88	0.69	0.81
Green pods	1.97	1.81	1.82	1.53	1.29	1.12	0.88
Mature pods	2.26	2.02	2.08	2.39	2.64	2.64	2.68

1. See Table 1 for definitions of codes.
2. Production index: 0 = low, 5 = high. Values are averages derived from all trees of the population.

before the beginning of that year's observations, a value comparable with that observed in Jan 1990, and then progressively decreased in subsequent periods. Therefore, early flowering peaks may result in heavier pod sets. However, a few trees maintain a relatively high level of flowering even at the end of the flowering cycle.

In 1991, mature pods were most abundant in January. At the end of that month, the average quantity of mature pods was higher than that of the same period in 1990. However, the average level of flowering was lower than that of 1990 (Table 3). We hypothesize that a lower flowering level may, in the following year, yield a larger quantity of fruit than a higher average level of flowering. It is possible that late flowering in 1990 did not coincide with meteorological conditions favorable to pod filling, such as high temperatures and low relative humidity.

During cutting of A. *albida* branches, herders do not distinguish between flowering and vegetative branches. It would be interesting to know if different intensities of branch cutting influence flowering and pod production. We observed that the most intensely cut trees display the most flowering activity.

Conclusion

Over the course of a year, the trees in the population, although very similar in circumference, exhibited quite different phenological behavior. Further, the behavior of individuals varied from year to year.

The onset of flowering appeared to be linked to meteorological or ecological conditions which might also influence flower development and fruit maturation. The largest, and most probably, oldest individuals tended to be more consistent in pod production. Pod production varied among subjects even if they had similar phenological traits.

The critical period for phenology was pollination. The ratio of the number of pods to amount of flowering was low, but the ratio of green pods to mature pods was high. The flowering peak probably occurs at the beginning of the dry season, and results in mature fruit after about two months.

It will be important to develop a pruning technique compatible with the physiological capacities of A. *albida* by studying the phenological behavior of a stand virtually unexploited by herders. In the case of this study, 70% of the trees showed signs of cutting.

We will continue this study to determine the factors influencing flowering and fruit bearing cycles and levels of the populations. This understanding will allow gene exchange mechanisms to be studied, providing new information with the ultimate goal of improving genetic management of pod production.

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Morphological Variability of Pods of Four *Faidherbia albida* Provenances in Senegal

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Abstract

Pods of four Faidherbia albida *provenances from Senegal, each with 20-30 progenies, were analyzed for morphological variability. Pod traits (size and form) were measured and interpreted using analysis of variance, multivariate analysis, principal component analysis, factorial analysis of correspondences, and discriminant factor analysis. Pod dimensions exhibited the greatest morphological variability among the traits measured. Intra-provenance diversity was generally significant, so characterization of geographic origins was difficult. Nevertheless, morphological characteristics of the Bode pods contrasted significantly with those of Kagnobon. The Ovadiour pods were significantly different from the other provenances.*

Introduction

Over the last decade, management of tree genetic resources in Senegal has diminished. A number of recent projects have begun the task of conserving, protecting, and improving these resources (FAO 1980). *Faidherbia albida,* due to its value in Senegalese agriculture, was one of the priority species chosen for the program (FAO 1980; Louppe 1989). Diverse studies have since been carried out by international organizations throughout the range of this species. The Direction des recherches sur les productions forestieres (DRPF)/Institut senegalais de recherches agricoles (ISRA) has implemented a program to collect and evaluate genetic resources of *F. albida* in Senegal.

This study focused on the biometry of pods. Prior work has shown significant variability in pod form and size of different acacia species as well as of *F. albida* (Nongonierma 1977).

Materials and Methods

In 1990,7 provenances of *F. albida* from northern to southern Senegal were collected. Seeds and pods were used from the following four provenances by separate progenies: the Merina Dakar provenance from northern Senegal (28 progenies); the Ovadiour provenance from the Groundnut Basin (30 progenies); the Kagnobon provenance from Casamance (20 progenies); and the Bode provenance from Casamance (22 progenies). One hundred progenies in total and ten pods per progeny were studied.

Nine traits were measured and four indices were calculated from these (Table 1). Data were interpreted using analysis of variance, principal components and correspondence analysis, and discriminant factor analysis.

Results

Pod size for all the provenances was extremely variable. This was due to large differences in outside pod length (112-270 mm) inside pod length (44-112 mm), distance between pod tips (12-71 mm), pod width (17-67 mm), and pod mass (292-989 mg). Pods contained 7-23 seeds. Among the important indices calculated, the spiraling index ranged from 0.17-0.90 with an average of 0.53, the surface area index from

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Table 1. Measured traits and derived indices for *F. albida* pods, Dakar, Senegal, 1991.

Parameter		Abbre-viation
Traits		
Pod mass (mg)		PMS
Outside length (dorsal cleft) (mm)		LDC
Inside length (sutural cleft) (mm)		LSC
Length between pod tips (mm)		LEX
Pod width (mm)		PWD
Number of seeds per pod		GPP
Thickness[1]		PTH
Number of angles		NBA
Form[2]		FOR
Indices		
Mean length (mm)	(LDC + LSC) + 2	LOMO
Surface index (mm^2)	LOMO + PWD	SURF
Spiraling index	LEX + LSC	SPIR
Density index	LOMO + PMS	PDEN
Form index	PWD + LOMO	FORM

1. Thickness indices are: 1 = thin; 2 = average; 3 = fleshy.
2. Angle indices are: 1 = sickle-shaped; 2 = wavy, straight; 3 = spiraled; 4 = tightly spiraled.

1613-9502 mm^2 and the ratio of width to average length from 0.13-0.54.

Analysis of variance done showed a significant provenance effect for all the variables with the exception of density index and number of angles (Tables 2 and 3). Differences between provenances were highly significant for length between pod tips, pod width, number of seeds per pod, and surface area index. Certain variables characterize each provenance. For example, the Ovadiour provenance had the largest and straightest pods among the provenances studied as well as the fewest number of seeds per pod.

In order to determine correlations between variables, multivariate analyses were carried out using correlation matrices of all the variables. A first analysis was done on the traits measured; the second was done on the calculated indices.

Principal Components and Correspondence Analysis

Principal components analysis is a descriptive statistical method which is often used to examine the inter-

Table 2. Means, standard errors, and CV for seven measured *F. albida* pod characters, Dakar, Senegal, 1991.

	Pod characters						
Provenance	PMS[1] (mg)	LDC (mm)	LSC (mm)	LEX (mm)	PWD (mm)	GPP	PTH
Kagnobon							
Mean	664	179	73.3	42.7	26.2	2.3	18.6
SE(σ)	167	40	15.4	8.0	5.5	1.0	2.4
CV (%)	26	22	21	19	21	44	13
Ovadiour							
Mean	545	172	74.4	25.3	46.9	2.0	12.6
SE(σ)	102	12	11.9	2.6	12.0	0.9	3.6
CV(%)	19	7	16	10	26	43	28
Bode							
Mean	489	154	61.0	33.7	24.4	1.6	15.3
SE(σ)	121	29	12.5	13	2.6	0.7	3.0
CV(%)	25	19	21	39	11	41	20
Merina							
Mean	507	157	67.9	44.4	30.2	2.0	17.5
SE(σ)	102	18	10.3	7.8	4.9	0.7	2.9
GV(%)	20	11	15	18	16	36	17
Total							
Mean	542	165	69.4	36.0	33.1	2.0	15.8
SE(0)	134	27	13.5	11.6	12.0	0.8	3.9
CV(%)	25	16	19	32	36	43	25

1. See Table 1 for abbreviation codes.

Table 3. Means, standard errors, and GV for 5 calculated *Faidherbia albida* pod characters, Dakar, Senegal, 1991.

Provenance	Pod characters				
	LOMO[1] (mm)	SURF (mm^2)	SPIR	PDEN	FORM
Kagnobon					
Mean	126	3326	0.61	0.20	0.22
SE(σ)	27	1005	0.15	0.04	0.05
CV(%)	22	30	25	21	23
Ovadiour					
Mean	123	5832	0.35	0.23	038
SE(σ)	10	1754	0.07	0.04	0.09
CV(%)	8	30	19	16	23
Bode					
Mean	107	2613	0.56	0.23	0.23
SE(σ)	19	543	0.19	0.05	0.05
CV(%)	18	21	33	21	20
Merina					
Mean	113	3395	0.66	0.23	0.23
SE (σ)	12	641	0.10	0.05	0.05
CV (%)	11	19	16	20	20
Total					
Mean	117	3941	0.53	0.22	0.28
SE(σ)	19	1710	0.18	0.04	0.09
CV(%)	16	43	34	20	32

1. See Table 1 for abbreviation codes.

relationships among several variables. The first principal component defines a new variable that explains as much as possible of the variability in the original data. The second principal component is made to be independent of the first and in such a way that it explains as much as possible of the variability that remains. Often the first two components explain a large proportion of the total variability and the data are then usually displayed in a two dimensional plot.

In this study a principal component analysis was conducted on both the traits measured and on the derived indices. The first two axes on the measured traits explained 62.1% of the variation. A display of the data showed that the progenies of Ovadiour could be distinguished from the remaining progenies. A distinguishable contrast also existed between the Bode and Kagnobon progenies. The results from an analysis of the derived variables did not give results that were as clear as with the original variables.

Correspondence analysis was also performed, since this method permits use of the qualitative as well and the quantitative variables. The latter are transformed into classes. This analysis yielded results that were identical to those of the principal components. The quantitative variables were used in the first component. The qualitative variables were used in the second component and did not help in separating the different groups of data.

Discriminant Factorial Analysis

In order to determine the relationship of progenies to their provenances of origin and to test the provenance effect determined by the analyses of variances, a discriminant factorial analysis was done on the traits measured. Only 71% of the progenies were definitely classed in their provenance of origin (Table 4).

Table 4. Classification of progenies into provenances by the discriminant factorial analysis performed on measured traits.

	Allocated provenance				
Provenance of origin	Kagnobon	Ovadiour	Bode	Merina	Correctly classified (%)
Kagnobon	15[1]	0	3	2	75.0[2]
Ovadiour	3	22	5	0	73.3
Bode	2	0	13	7	59.1
Merina	3	0	4	21	75.0

1. Values are numbers of progeny classified in each group, e.g., in the first row of data, 15 Kagnobon progenies were correctly classified in the analysis. Five were incorrectly classified.
2. Percentage of progeny correctly classified in its provenance of origin.

Among the provenances, Bode was the most heterogeneous since 41% of its progeny were classed as Kagnobon and Merina. None of the progenies of Bode, Kagnobon or Merina resembled those of Ovadiour. Ovadiour progenies exhibited specific traits in terms of pod width, length between extremities, pod mass, and number of seeds (Table 2).

Discussion

The great variability in *F. albida* pod morphology shown by this study confirmed results of a study by Nongonierma (1977).

The following traits revealed the greatest diversity of *F. albida* pods collected throughout the Senegalese range of the species: inside and outside pod length between pod tips; pod width; pod mass, and number of seeds per pod. The different form indices (qualitative or calculated variables) and number of angles, provided little benefit to the analysis. In any case, it was very difficult, at the time of measuring, to class the often variable and complex forms of the observed pods.

Intra- and interprovenance variability were of the same order; therefore, it was very difficult to characterize provenances according to their geographic origin. Nevertheless, pod size of the Bode provenance contrasted with that of the Kagnobon provenance. Pods of the Ovadiour provenance were characteristically stubby. To verify if this particular trait of the Ovadiour provenance is unique to its location, three other provenances in the same region will be studied. Also, pods from provenances located at the northern and southern extremes of the Senegalese range of F. *albida* will be analyzed. Finally, the comparison of morphological variability and that obtained from enzymatic markers of the same origin will permit a more complete evaluation of genetic resources of F. *albida* in Senegal.

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Variability of *Faidherbia albida* in Progeny Trials in Burkina Faso

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Abstract

Faidherbia albida *progenies were selected from provenances of Kongoussi* (*Burkina Faso*), *Matameye* (*Niger*), *and Kagnobon* (*Senegal*) *through the* 1985-87 *IRBET/CTFT field provenance trials. The Kongoussi provenance was planted in 1987 and the others in 1989 at Gonsi station near Ouagadougou, Burkina Faso. Single-tree balanced complete block designs were used. Variability of height and collar diameter between progenies is analyzed. Yearly values for individual and provenance heritability for growth* (*height and collar diameter*) *and branching* (*length, number, and height to first branch*) *are presented. Heritability decreased regularly from 6 to 42 months for the Kongoussi provenance, but this provenance consistently had the highest heritability values. Matameye had the lowest values. Branching parameters had low heritibility values* (*under 10%*).

Introduction

Breeding strategy of *Faidherbia albida* at IRBET was defined by de Framont (1985). Range-wide provenance trials were established in 1985,1986, and 1987 at the Gonse and Dinderesso field stations to compare 35 provenances from 8 countries (IRBET/CTFT Annual Reports 1985-88). Early results led to new trials with 25 other provenaces on three climatically different sites in 1990 (Billand 1991). Juvenile growth showed strong heterogeneity within provenances.

Three progeny field trials were set up in 1987 and 1989 to study phenotypic variability, with the objective of proportionally quantifying genetic and site effects. The first progeny trial was set up in 1987 to examine the Kongoussi provenance (used in our studies as a local control) from Burkina Faso (Billand 1988). Two other progeny trials were set up in 1989 to study provenances showing the best growth (Matamaye, Niger and Kagnobon, Senegal).

Materials and Methods

Seeds and Site

Seed for the trials was obtained from various seed centers (Table 1). All three trials were established at the Gonse station, 30 km east of Ouagadougou. Gonse has an altitude of 315 m, average annual rainfall of 800 mm, and average temperature of 28°C (maximum 35°C, minimum 22°C). The ferruginous soils have a clayey-sand texture, with a buried laterite layer.

Experimental Design

Trials consisted of 20 progenies with single-tree balanced complete block designs (i.e., each block had one tree from each progeny). The Kongoussi provenance had 20 progenies in 24 blocks, Matameye 19 progenies in 41 blocks, and Kagnobon 21 progenies in

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Table 1. Information of the *Faidherbia albida* progenies, Gonse, Burkina Faso, 1985-87.

Provenance Country	Institution/ Lot number	Location	Altitude (m)	Rainfall (mm)
Kongoussi, Burkina Faso	CNSF	13°30N, 1°59W	602	650
Matameye, Niger	CTFT 86/5661-68N, 5670-80N	13°25N, 8°28E	450	560
Bignona, Senegal	ISRA/DRPF 88/2110-88/2130	12°45N, 16°25W	10	1170

40 blocks. Tree spacing was 4 m x 4 m, and planting was done in Jul 1989.

Measurements and Analysis

Measurements of the 1987 trials were taken every December/January at 6, 18, 30, and 42 months. Heights were measured with a cm ruler; collar diameter with a mm calipers. The 1989 trials were measured at planting and at 6 and 18 months. Branching variables (height to first branch, length of longest branch, number of branches, and canopy diameter) were collected at 6 months.

The analysis of variance was computed on each variable with a General Linear Model. Genetic models for heritability calculations considered each progeny as a half-sib family. Each family had the same mother tree, and pollination was assumed to be panmictic.

Narrow sense heritabilities were computed as follows:

$$h^2_{ss} = V_A/V_P$$

where V_A = additive variance
= $4\sigma^2_A$ (half-sib hypothesis)
and V_P = phenotype (total) variance.

Precision within heritabilities was calculated with the formula (Wright 1976) [sic]:

$$\sigma^2_{h^2} = \frac{(1-h^2/4)(1+bh^2/4)}{b((f-1)/2)^{0.5}}$$

Where b = number of blocks and
f = number of families.

It should be noted that an unknown proportion of full-sibs and offspring from self-breeding leads to an overestimation of heritability (Kedhamath and Vakshasya 1977).

Results

Mortality

At the age of 42 months, progenies from Kongoussi provenance had mortalities ranging from 6% (progeny 16) to more than 50% (progeny 1). Mortality was low at 6 and 18 months but increased at 30 and 42 months. Progenies from Matameye and Kagnobon had less than 8% mortality.

Growth

Progenies from Kongoussi provenance at 42 months ranged in average height from 1.93 ±0.08 m (progeny 16) to 1.11 ±0.07 m (progeny 4) and collar diameter ranged from 4.45 ± 0.59 cm (progeny 16) to 2.47±0.48 cm (progeny 4) (Table 2).

Height increased by 200% between 6 and 18 months, by 50% between 18 and 30 months, and by 30% between 30 and 42 months. The most significant period of diameter growth appeared to be one year later, between 18 and 30 months, representing 50% of the total diameter measured at 42 months.

Progenies from Matameye provenance at 18 months had heights ranging from 0.73 ±0.03 m (progeny 5) to 0.51 ±0.02 m (progeny 12) and collar diameters ranging from 1.40±0.02 cm (progeny 1) to 0.92±0.13 cm (progeny 12). As with Kongoussi provenance, increments between 6 and 18 months were larger for diameter than for height.

Heights at 18 months for Kagnobon provenance ranged from 0.96±0.10 m (progeny 17) to 0.67±0.06

Table 2. Heights (±5% confidence interval, in m) of progenies of Kongoussi provenance at 6,18,30, and 42 months. Gonse, Burkina Faso. 1987-1990.

Progeny number	Height (m)			
	6 months	18 months	30 months	42 months
1	0.38 ± 0.01	0.78 ± 0.10	1.09 ± 0.17	1.49 ± 0.05
2	0.43 ± 0.01	0.82 ± 0.11	1.09 ± 0.17	1.47 ± 0.07
3	0.32 ± 0.01	0.71 ±0.10	0.97 ± 0.16	1.18 ± 0.04
4	0.35 ± 0.01	0.63 ± 0.07	0.84 ± 0.15	1.14 ± 0.05
5	0.39 ± 0.01	0.76 ± 0.07	1.07 ± 0.13	1.49 ± 0.06
6	0.41 ± 0.01	0.79 ± 0.08	1.04 ± 0.15	1.44 ± 0.06
7	0.42 ± 0.01	0.75 ± 0.09	1.19 ± 0.22	1.39 ± 0.07
8	0.52 ± 0.01	0.95 ± 0.12	1.29 ± 0.17	1.81 ± 0.10
9	0.38 ± 0.01	0.88 ± 0.10	1.31 10.18	1.74 ± 0.06
10	0.45 ± 0.01	0.73 ± 0.07	0.92 ± 0.12	1.17 ± 0.08
11	0.49 ± 0.01	0.79 ± 0.10	1.03 ± 0.16	1.27 ± 0.09
12	0.39 ± 0.01	0.87 ± 0.09	1.25 10.17	1.50 ± 0.06
13	0.39 ± 0.01	0.74 ± 0.09	1.06 ± 0.15	1.43 ± 0.06
14	0.44 ± 0.01	0.77 1 0.09	1.13 ± 0.20	1.48 ± 0.08
15	0.44 ± 0.01	0.83 ± 0.11	1.12 ± 0.15	1.43 ± 0.08
16	0.48 ± 0.01	0.98 ± 0.09	1.42 ± 0.19	1.93 ± 0.08
17	0.45 ± 0.01	0.78 ± 0.09	1.14 ± 0.19	1.49 ± 0.08
18	0.44 ± 0.01	0.94 ± 0.11	1.37 10.16	1.76 ± 0.07
19	0.41 ± 0.01	0.84 ± 0.09	1.15 10.15	1.50 ± 0.07
20	0.36 ± 0.01	0.87 ± 0.10	1.1710.17	1.40 ± 0.05
Analysis of Variance F Test	3.71*	3.27*	3.141*	2.80*

m (progeny 3), diameters ranked from 2.29±0.30 cm (progeny 6) to 1.62±0.23 cm (progeny 11). Analysis of variance showed better growth within Kagnobon progenies than within those from Matameye.

Branching

Branching parameters had low but significantly different values. Branching parameters, total height, and collar diameter were analyzed with principal components analysis based on 21 progenies of Kagnobon provenance at 6 months. Three groups of variables sufficiently described these 21 progenies. Two growth parameters (height, collar diameter) and two branch length parameters (canopy diameter, length of longest branch) described 53.3% of total variability on axis 1. Height to first branch described 18.9% of variability on axis 2, and number of branches described 11.3% of variability on axis 3.

Heritability

Heritability was calculated from the time of planting to 42 months for Kongoussi provenance (Table 3),

Table 3. Narrow sense heritability ($h^2ss\pm\sigma$) for total height and collar diameter for the Kongoussi provenance from 6 to 42 months, Gonse, Burkina Faso, 1987-90.

Variables	6 months	18 months	30 months	42 months
Total height	0.38 ± 0.04	0.34 ± 0.04	0.31 ±0.04	0.26 ± 0.03
Collar diameter	0.22 ± 0.03	0.27 ± 0.03	0.25 ± 0.03	0.22 ±0.03

Table 4. Narrow sense heritability differences between the Kongoussi, Matameye, and Kagnobon provenances at the time of planting, and at 6 and 18 months, Gonse, Burkina Faso, 1987-90.

	At planting			6 months			18 months	
Variable	MAT[1]	KAG	KON	MAT	KAG	KON	MAT	KAG
HT[2]								
h^2ss	0.03	0.11	0.38	0.15	0.19	0.34	0.12	0.24
± σ	0.01	0.02	0.04	0.02	0.02	0.04	0.02	0.03
DIA								
h^2ss	0.27	0.44	0.22	0.14	0.24	0.27	0.12	0.21
± σ	0.03	0.04	0.03	0.02	0.03	0.03	0.02	0.01
DCan								
h^2ss	-	-	-	0.05	0.10	-	-	-
± σ				0.01	0.02			
LB								
h^2ss	-	-	-	0.05	0.10	-	-	-
± σ				0.01	0.02			
IHB								
h^2ss	-	-	-	0.28	0.12	-	-	-
± σ				0.12	0.02			
NB								
h^2ss	-	-	-	0.09	0.06	-	-	-
± σ				0.02	0.01			

1. MAT = Matameye; KAG = Kagnobon; KON = Kongoussi.
2. HT = total plant height; DIA = collar diameter, DCan = canopy diameter, LB = length of longest branch; HB = height to first branch; NB "number of branches.

and for Kongoussi, Matameye, and Kagnobon at 6 and 18 months (Table 4). Heritability for Kongoussi provenance decreased regularly each year. Heritability for height and collar diameter was highest for Kongoussi and lowest for Matameye.

Branching variables from Kongoussi and Matameye provenances had low heritability (values under 0.10). Height to first branch for Matameye was an exception with a narrow sense heritability of 0.28±0.03.

Conclusion

Fart of the phenotypical variability observed in field trials can be explained by genetic effects. Values of narrow sense heritability presented here are close to those cited in literature from outside Africa. In Africa, only exotic species such as *Eucalyptus* spp have been studied. Van Wyk (1977) calculated a heritability of 0.16 for height on 6-month old *Eucalyptus grandis* in the Republic of South Africa.

A principal component analysis concerning seven growth and branching variables on twenty one 6-month old progenies from Kagnobon provenance showed that three groups of characters described the progenies—growth and branch length; height to first branch; and number of branches.

Yearly increments for collar diameter were strongly reduced for Kongoussi provenance between 30 and 42 months, but height increments at the same ages were not reduced. This was probably caused by competition between the trees. This seemed to vary between progenies and could be a factor for selecting trees for high density field plantations.

The trials studied here were young and had not flowered, so interesting characters such as pod and leaf production or yields of associated understory crops could not be measured. Yearly measurements from youth to maturity will allow the establishment of juvenile-adult correlations that could be used to shorten breeding cycles.

Progeny of mother trees from these provenances are well identified and their seeds are available. They could be used to examine variability at the progeny level with electrophoresis, as has been done at the provenance level (Zeh-Nlo 1989).

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Trial of Nine *Acacia albida* Provenances in Dosso, Niger

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Abstract

In 1986, d trial composed of nine Acacia albida *provenances in four replications was established by the Projet pilote de diveloppement agroforestier (PPDAF) in Dosso in collaboration with the Institut national de recherches agronomiques du Niger (INRAN).*

The A. albida *provenance trial provided invaluable information concerning the response of the species on sandy dune soils. The test demonstrated differences in survival rates and heights of several provenances. Provenances from Niger and Mali performed best. The Karofane (Niger) provenance merits attention.*

Introduction

Acacia albida is highly favored by farmers of the Dosso region of Niger due to its soil-improving effects and fodder. Its artificial and natural regeneration in fields is poor because of its high mortality rate and slow growth. To identify provenances with low mortality and rapid initial growth, a trial representing nine *A. albida* provenances was installed in collaboration with INRAN. After 2 years of growth, differences between provenances were negligible (PPDAF 1988). In 1988, observations were continued to compare growth rates and mortality rates over a longer period. Evaluations done in 1991 demonstrated significant differences between provenances.

Methodology

Seed of nine *A. albida* provenances was provided by the Department of Forestry Research of INRAN (Table 1), which installed a similar trial on clay soils in the Tillabery Department of Niger. Seedlings were raised in a nursery and outplanted at 10 weeks in Jul 1984. The trial site, Djado Kaine I, is part of an annually cultivated field located a few kilometers northwest of Dosso. The field is characterized by sandy soils of poor to average fertility. The terrain is undulating. Elevation difference between the experimental blocks was 10 m. The sparse non-agricultural cover is composed of a few mature trees, including *Piliostigma reticulatum, Butyrospermum parkii,* and *A. albida.* Farming continued during the trial, and the farmer was asked to avoid harming the seedlings during tillage and weeding. Animal influences (browsing and trampling) were considerable because of the proximity to Dosso.

Because of unfamiliarity of experimental procedure by project personnel at that time, the trial was planted in four blocks of identically distributed plots. Square plots consisted of 36 plants spaced at 8 x 8 m, for a total of 1296 seedlings.

At the time of planting, the seedlings were protected by wooden stick exclosures, but all were later destroyed by storms and termites and were not replaced. After that, no protection measures were taken. In any case, the exclosures provided little protection against careless tillage and animals.

The trees were measured by a 6-man observation team who followed assigned lines and were guided by the original spacing between planted hills. Locating seedlings was an arduous task, especially after the enclosures were destroyed. At the end of the rainy season, crop residue and weeds often covered the plants. Preceding every evaluation, teams had to search for and stake hidden seedlings.

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Table 1. Average survival (%) and height (cm) of nine *Acacia albida* provenances after 5 years of growth, Dosso, Niger, 1991.

Provenance	Survival (%)	Height (cm)
Tera, Niger	58.5	46.3
Karofane, Niger	40.8	47.5
Matameye, Niger	38.8	33.5
Baroueli, Mali	47.8	37.3
Kemeny, Mali	55.8	45.5
Saro, Mali	65.5	32.5
Bogo, Cameroon	29.8	29.0
Doukoula, Cameroon	42.5	26.8
Guetela, Cameroon	44.5	28.0
SE(±)	6.21	4.55
CV(%)	26.3	25.0

During the first three years of the trial (1986-88), trees were not measured but rather classed into one of four categories: 0 (dead or not found), 1 (stunted or otherwise stressed), 2 (average vigor), and 3 (good vigor with well-developed stem or several branches). This system was criticized during project reviews for being too subjective. For this reason, stems were measured with a ruler after 1989.

It is probable that many seedlings evaluated as 'dead or not found' were actually alive. This was confirmed by observations made on some stems which resprouted 6 months after being browsed right to the collar-level at the onset of the rainy season.

Results

Mortality

The mortality rate between 1986 and 1991 remained relatively constant. The average mortality rate per year for the nine provenances ranged between 6% for the Tera, Niger accession and 15.3% for the Bogo, Cameroon accession. Table 1 shows the average survival rates observed on 27 Mar 1991 in the 36 plots. There was a significant difference between blocks because of topography. The two downslope blocks had a higher survival rate than the upslope blocks. Generally, accessions from Niger and Mali had better survival rates than accessions from Cameroon.

Variation in Height

Height is critical for the survival of *A. albida,* which is browsed by many types of animals. The higher the plant, the more likely will it be able to avoid damage by animals and weeding/tillage operations.

Average seedling height of the entire trial was 30 cm in Mar 1991; 56% of the remaining plants were less than 30 cm tall. A few large plants (height >90 cm, or 4.3% of those remaining) were found on a site occupied by several termite hills which presumably improved soil conditions.

The height distribution among the provenaces did not appear to be even. This indicates the existence of other factors influencing height.

Conclusion

After 6 years of growth, it may be safely stated that *A. albida* did not live up to expectations. Fifty percent of all trees planted died; the remaining trees averaged less than 50 cm in height. Although the area around the experiment has several mature trees, it is evident from this trial that greater effort must be made to locate development projects using this species in areas where it can establish.

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Faidherbia albida in Northern Cameroon: Provenance Trials and Crop Associations

J.M. Harmand[1] and C.F. Njiti[2]

Abstract

At Mouda, Cameroon (850 mm annual rainfall), a 5-year old Faidherbia albida *agroforestry trial with dominant 4-m trees showed very heterogeneous growth due to ferruginous and stony soils. At this age the stand did not have a significant impact on yields of associated crops. Intraprovenance variability on this site masked any differences between six provenances from the Sudano-Sahelian zone. The Burundi (eastern Africa) provenance proved to be unadopted to the site. Plantings of* F. albida *in a mechanically cultivated crop system was shown to be feasible when planted at a wide and fixed spacing.*

Introduction

Faidherbia albida parks in northern Cameroon, often associated with agropastoral systems, are principally found on alluvial soils north of Maroua. These naturally regenerating stands exist throughout numerous formerly cultivated areas. However, the species is rarely found in recently cleared farmlands south of the 900 mm-isohyet. Studies of the effect of *F. albida* on associated crop systems have been carried out by the Centre de recherche forestiere (CRF) in collaboration with the Institut de la recherche agronomique (IRA) since 1985 (Peltier and Eyog Matig 1988).

The objectives of the Mouda-Gazal trial were to:

- determine the age and stage of development at which *F. albida* has a positive effect on soil fertility and yields of associated crops;
- compare tree-crop interactions in an intensive system (groundnuts, cotton, and fertilized sorghum) and a traditional extensive system (cotton and non fertilized sorghum);
- identify constraints in the tree/crop system in order to develop *F. albida* systems in farmlands;
- compare performances of different local and introduced provenances of the species.

Materials and Methods

Mouda is situated in the Sudano-Sahelian zone at an altitude of 500 m. Annual rainfall averages 850 mm and the potential evapotranspiration is 1832 mm. The soil, formed over gneiss and quartzite, is ferruginous and stony, with a depth of 1.70 m. The sandy clay soils at the surface become more clayey at greater depth. Soil water-holding capacity is low (35-50 mm 50 cm^{-1}), as is the organic matter content (1-2.5%) (Brabant 1988). Tree savannas dominated by *Anogeissus leiocarpus* typify uncultivated sites. Excessive drainage and a high erosivity limit the value of this soil.

The trial was installed in a 7-ha area cleared of tree savanna utilizing a split-plot design with four replications. The treatments involved three factors. Main plots were 4 cropping systems in rotation comparing improved varieties with a local crop rotation. The improved rotation treatments were composed of groundnut (var 28206), cotton, and sorghum (var S35) on 3-year rotations. Treatment 1 started with sorghum in 1985, and then groundnut in 1986, cotton in 1987, back to sorghum in 1988, etc. Treatments 2 and 3 had the same rotation, but Treatment 2 started

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with groundnut and Treatment 3 with cotton in 1985. In this manner, each crop was represented every year. The traditional treatment involved local sorghum *(djigari)* and cotton in a 2-year rotation.

Groundnut was fertilized with 200 kg ha^{-1} single super phosphate (SSP), cotton with 200 kg ha^{-1} complete fertilizer (22-10-15), and sorghum with 50 kg ha^{-1} complete and 150 kg ha^{-1} KCl at planting and 50 kg ha^{-1} urea as a split dose. In the traditional cropping system, *djigari* sorghum was not fertilized. Subplots were *F. albida* provenances, which were planted on an 4 x 4 grid within the field and along the borders. Eight provenances were used (4 local and 4 ex-Cameroon, Table 1). Subplots measured 20 x 24 m. At the edge of each block, control plots (38 x 24 m) of each cropping system was included without the trees. From 1985 to 1989, crops were mechanically cultivated between tree rows. In order to avoid seedling damage, 50-cm strips were left unplanted along both sides of row—a 25% loss in arable area.

Crop production was measured annually. Soils were sampled to a depth of 40 cm on all plots and analyzed at the CIRAD soils laboratory in Montpellier, France. Tree heights and mortality were observed.

Results and Discussion

Growth of *F.albida*

In the first year, the Burundi provenance had the best growth (Table 2). Five and a half years after planting (Dec 1990), the six local and introduced provenances of the Sudano-Sahelian zone (in order of performance, Bogo, Mokyo, Mokolo, Mali, Senegal, and Burkina Faso) performed better than the Ngong and Burundi provenances. In 1990, remaining trees of the declining Burundi provenance (29% survival versus 83% from other 7 provenances) exhibited stagnated growth.

Table 1. Descriptions of *Faidherbia albida* provenances used in a cropping trial, Mouda Gazal, Cameroon, 1985-91.

Provenance Country	Location		Altitude (m)	Annual rainfall (mm)
Mokolo, Cameroon	13°48'E	10°44'N	600	900
Mokyo, Cameroon	14°16'E	10°51'N	440	700
Bogo, Cameroon	14°36'E	10°44'N	350	780
Ouagadougou, Burkina Faso	1°31'W	12°21'N	304	850
Keur Wadiale, Senegal	10°02'W	15°44'N	50	450
Giahansa Mpanda, Burundi	29°15'E	3°15'S	800	675
Mio-kolongotomo, Mali	5°48'W	13°49'N	280	650
Ngong, Cameroon,	13°30'E	9°02'N	320	950

Table 2. Height of *F. albida* provenances by year, Mouda Gazal, Cameroon, 1985-90. (Source: Peltier 1988; Harmand 1989).

Provenance	Year						CV
	1985	1986	1987	1988	1989	1990	
Mokolo, Cameroon	40c	58	76	100ab	163ab	200ab	60%
Mokyo, Cameroon	38c	61	80	112a	182a	221a	56%
Bogo, Cameroon	37c	53	79	113ab	187ab	231ab	57%
Ouagadougou, Burkina Faso	38c	56	72	89abc	149ab	181ab	55%
Keur Wadtale, Senegal	45b	60	85	103ab	163ab	191ab	47%
Giahansa mpanda, Burundi	57a	69	66	68c	108c	107c	51%
Mio-kolongotemo, Mali	41c	59	80	101ab	165ab	200ab	55%
Ngong, Cameroon	32d	49	61	72c	122bc	143bc	50%
Means	41	58	75	93	153	181	

1. Numbers in columns followed by the same letter are not significantly different at *P* 0.05.

Intraprovenance variability (CV = 47-60%) was much higher than interprovenance variability (CV = 16%), so distinctions could not be made between provenances. Further, intraprovenance variability of height was high due to soil heterogeneity. Fractures in the lateritic upper horizon resulted in a spatial heterogeneity of tree growth over the entire trial site. The larger trees (3 m in height) of Block 1 formed a relatively distinct group independent of the provenances.

After 5 years of growth, the dominant tree height of the stand (average height of the 100 largest trees) was 4 m, twice the overall average height (Table 3). This showed that *F. albida* can develop well on fissured, lateritic soil. A height gradient between Block 4 (average = 1.45 m) and Block 1 (2.12 m) was due to a corresponding increase in soil depth across the gradient. Lateritic outcroppings were more evident in Block 4 than in Block 1.

Table 3. Average height (m) of different tree subpopulations in the *Faidherbia albida* trial, Mouda Gazal, Cameroon, 1987-90. (Source: Peltier 1988; Harmand 1989.)

	Year			
Population variables	1987	1988	1989	1990
Dominant trees, whole trial	1.45	2.17	3.32	4.02
All trees, whole trial	0.75	0.93	1.53	1.81
Boundaries and erosion strips	0.75	0.63	1.10	1.42
Trees inside plots	0.80	1.16	1.80	2.16

Trees planted along the borders of vegetated strips exhibited poorer growth (-36%) and had a lower average survival rate than those planted within the plots. Despite annual weedings around seedlings planted along plot borders, root competition with grasses within the strips suppressed tree development. The fact that few *F. albida* are encountered in tree savannas or even in the vicinity of farmlands constitutes further proof of its requirement for animal husbandry by farmers.

At this stage in development, tree crowns were small and low foliar biomass production had no discernable positive impact on soil fertility or crop yields (Table 4). In fact, the tree density (500 trees ha^{-1}) hindered plowing operations and diminished arable area.

Table 4. Crop yields (t ha^{-1}) in a study, Mouda Gazal, Cameroon, 1990.

Crop	Non-tree control	Crops+ trees	Yield reduction
Groundnut	0.77	0.50	-34%
Cotton	1.11	0.98	-11%
Sorghum	1.24	0.75	-40%

Conclusion

The Burundi provenance was not adapted to Sudano-Sahelian conditions. Because of great variability within provenances, differences in performance of six *F. albida* provenances of the Sudano-Sahel zone could not be distinguished. Dominant trees of *F. albida* planted on ferruginous and lateritic soil lacking a high water table attained a height of 4 m in 5.5 years and exhibited heterogeneous growth. At this time, no positive impact of the species on associated crops was evident.

Further studies on this site should focus on available mineral nutrients and the water budget in the soil water utilization by trees and crops, and quantities of biomass returned to the soil.

Planting of *F. albida* at a fixed spacing of 10 x 10 m in a mechanically-cultivated crop system would be feasible. Plantings along borders of vegetated strips existing between crop plots, however, resulted in poor survival rates due to competition with weeds.

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Problems with Range-Wide Provenance Trials of *Faidherbia albida* on Sandy Soils in Niger

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Abstract

A Faidherbia albida *provenance study consisting of 32 seed origins from western Africa and 9 from eastern and southern Africa was established in Aug 1988 at the ICRISAT Sahelian Center in Niamey, Niger to compare variability between and within the two groups of seed lots. Mortality of the southern and eastern African provenances was total by the end of the second dry season. Analysis of height growth of the remaining western African provenances was continued; however, selection of superior seed origins was complicated by a high degree of site microvariability which confounded plot growth data. Caution is urged to those establishing or analyzing data from provenance studies planted on sandy soils in the Sahel.*

Introduction

There has been much effort in the past 15 years to introduce and/or reintroduce *Faidherbia albida* in farmers' fields, especially in Sahelian Africa. Introduction of seed origins from southern Africa into the Sahel was expected to be of benefit to these efforts. A study was started in 1988 to better understand differences in early growth rates and survival of eastern and southern African versus Sahelian seed origins of *F. albida.*

Materials and Methods

The experiment was located at the ICRISAT Sahelian Center (ISC), 45 km south of Niamey, Niger at 13°N 2°E. Niamey receives an average of 562 mm of rainfall (standard deviation = 134 mm), most of which falls during June-September. Average potential evapotranspiration during the dry months of October-May is 1820 mm (Sivakumar 1986).

The soil was a Labucheri series of the Psammentic Paleustalf (sandy, siliceous, isohyperthermic) family. The Labucheri series is characterized by a high sand fraction (90%), moderate acidity, poor water retention (<10%), and low nutrient status. The soil has a clear depth of 3-4 m, overlying a gravelly lateritic layer (West et al. 1984). Depth to water table is about 20 m.

Seed of 32 origins of *F. albida* were obtained from various international and national research institutes in western and southern Africa. The 9 seed origins obtained from eastern and southern Africa covered the area from Kenya to the Limpopo River (Republic of South Africa), a N-S distance of nearly 3000 km. A similar 3000-km E-W distance was represented by-the western Africa origins, which ranged from eastern Chad to western Burkina Faso.

Seed were hand-scarified by nicking the edge, and sown three to a pot (100 pots per seed lot). Three-month-old seedlings were outplanted on 15 Aug 1988, irrigated with 2 L of water, fertilized with 30 g of 15-15-15, and given a 3.5 g dose of Carbofuran (3% a.i.), all mixed thoroughly with the backfill. Seedlings were weeded twice during the 1988 rainy season and once during the 1989 season.

Because of poor germination of several seed lots, not all origins could be replicated equally in the trial. Thus, a randomized incomplete block design was used, consisting of 18 core entries present in all 4

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replications; with the remaining 13 seed lots assigned randomly to replications depending on the number of available seedlings. This made an average of 26 plots per replication. Plots consisted of 10 trees planted in single rows, unbordered, spaced at 2 m within plot rows and 3 m between plots.

Live height (dead tops were not measured), basal diameter, and survival were recorded monthly for all trees during the first 4 months and thereafter at half-yearly intervals. Data were analyzed using the SAS General Linear Modeling procedure for personal computers (SAS 1985). Plot averages, based on the number of surviving trees at the time of data collection, were used.

Results

The first 2-years' performance of the various provenances has been reported elsewhere (Vandenbeldt 1991). Briefly, early above-ground growth of seedlings of the southern origins exceeded that of Sahelian origins. However, as soil moisture became limiting during the first dry season, plants of the southern entry began dying. By the end of the second dry season (1990), all individuals of the southern entries had died, whereas survival of the western African accessions still exceeded 95%. Root excavations showed that, although above-ground biomass was similar, this was primarily due to a three-fold difference in root biomass between provenances of the two respective regions.

Despite this dieback, measurements were continued to compare height growth between the western African provenances on the assumption that, since plots of the eastern and southern African provenances were randomly assigned, their absence would in turn have a random effect on the experimental error. Data for height at 2.5 years (Table 1) show that two Burkina Faso provenances (Soubaka and Zorkoum) had the greatest average height, followed by the local Sadore, Niger accession. The General Linear Model used in analysis weighs entries on the basis of the number of replications in the experiment.

However, when data from the analysis was compared with the trees in the field, it was apparent that the location of the best accessions was more important than any inherent ability to grow faster than other accessions. The field was characterized by groups of plots with exceptional growth and other groups with very poor growth. Figure 1 shows these plot clusters in relation to microrelief of the field and proximity to eroded termite mounds.

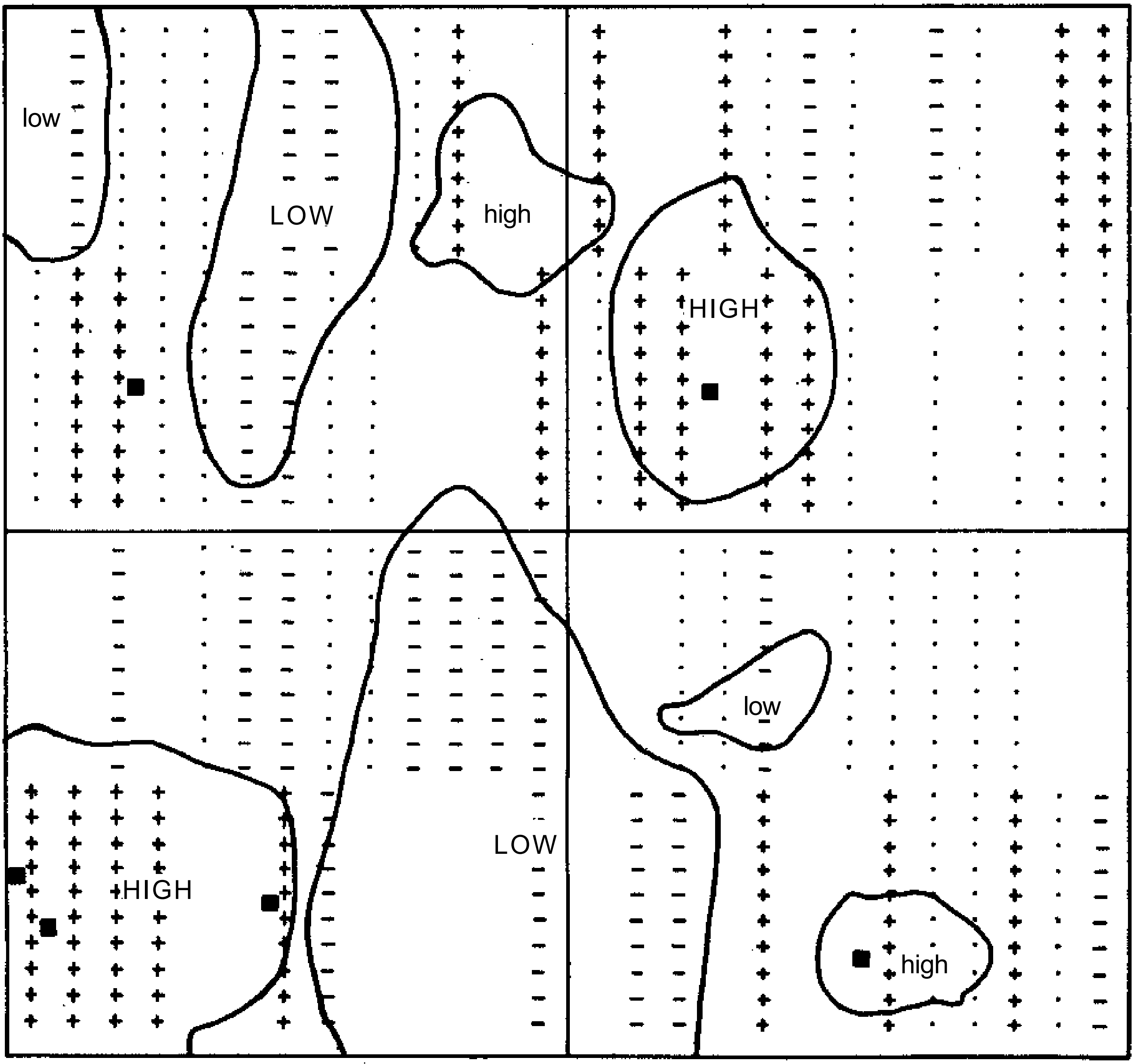
The 20 best plots (represented by '+' in Figure 1) clustered around microhighs and termite mounds, while the 20 worst plots ('-'m Figure 1) were clustered around microlows and sheet-eroded surfaces. The 'best' accessions (Soubaka and Zorkoum, Burkina Faso) happened to have both of their respective entries on the best parts of the field. Similarly, the worst accessions (Sion and Diou, Burkina Faso) were planted on low, infertile microsites. Thus, any ranking procedure of provenances was more an exercise in plot ranking rather than provenance superiority.

Table 1. Height of surviving western African F. *albida* provenances, (age = 2.5 years), Sadore, Niger, 1988-90.

Provenance	No. of replications (m)	Height (m)
Soubaka, Burkina Faso (B.F.)	2	2.25
Zorkoum Kaya, B.F.	2	1.86
Sadore, Niger	4	1.75
Kossara, B.F.	2	1.75
Mopti, Mali	4	1.67
Kongoussi, B.F.	3	1.61
Matameye, Niger	4	1.59
Gomblora, Gaoua, B.F.	3	1.56
Markoye, B.F.	1	1.56
Madarounfa, Niger	4	1.53
Bouza, Niger	4	1.50
Tougan, B.F.	4	1.50
Am Sak (Batha), Chad	4	1.40
Am Zoer, Ouaddai, Chad	4	1.40
Dakoro, Niger	4	1.37
Bakim Birji, Niger	4	1.32
Woursom, Ouahigay, B.F.	4	1.27
Mesrido, Yako, B.F.	2	1.17
Dassouri, B.F.	4	1.10
Sion, Safane, B.F.	2	1.09
Diou, Leo, B.F.	3	0.78
Mean		1.45
SE		±0.55

Discussion

A more thorough discussion of effect of microsite variability on growth of *F. albida* on sandy Nigerien soils is presented elsewhere in these proceeding



+	Tree located in 20 best plots.
•	Trees located in 31 medium plots.
-	Trees located in 20 worst plots.
high, low	Slight elevational high or low.
HIGH, LOW	Pronounced elevational high or low.
■	Termite mound.

Figure 1. Layout of *Faidherbia albida* provenance trial showing the best and the worst plots in relation to field topography and termite mounds, Sadore, Niger, 1988-90.

(Geiger et al. 1992; Brouwer et al. 1992). It might be argued that correctly placing blocks inside the different zones of poor, medium, and good microsite soil fertility would have eliminated the problem from the start. However, other than subtle microtopographical differences and the occasional trace of clay on the soil surface (indicative of an eroded termite mound), there is no clear indication of just where such zones are before outplanting.

In such situations, one must be wary of the wisdom of establishing provenance trials and must clearly state the experimental objectives in advance. Soil microvariability occurs in many soil types of the Sahel, and this variability can severely affect results of such studies. Blocks and plots in many of these trials are so large that field microvariability is contained within them, ballooning intra-plot error and obviating effective analysis of variance.

Several possibilities exist to circumvent this problem. Among these are single-tree plots, lattice designs, and greater effort to delineate field variability. At ISC, we have tried the first two approaches without success and are now working on the third.

One method to delineate field variability is to sample soil pH—this parameter has a direct correlation with other soil parameters affecting growth of *F. albida.* However, one must sample to depths of over 1 m, which makes it difficult to collect sufficient samples to make the exercise worthwhile. Presently, we are investigating the use of the yield measurements from the previous seasons' millet crop to predict areas of good and poor potential *F. albida* growth. We also plan to remove old provenance trials and design blocks of new clonal and progeny trials around areas of good and poor tree growth as manifested by tree growth in the old trials.

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Vegetative Propagation of Adult *Faidherbia albida* by Branch and Root Cuttings

P. Danthu[1]

Abstract

Propagation of cuttings from adult Faidherbia albida *was done using lignified branch cuttings with diameters ranging from 7-15 mm at the bud breaking stage, and inverted root fragments. Easy clonal propagation of mature trees under field conditions is possible. Resulting growth may then serve as stock for cloning by horticultural or in vitro means.*

Introduction

Although it is easy to vegetatively propagate young *Faidherbia albida* in the nursery using root cuttings (De Fraiture and Nikiema 1989) or in vitro with cotyledon buds (Duhoux and Davies 1985), it is very difficult to clone adult trees. Trees generally lose their ability to vegetatively propagate as they age. *F. albida* resprouts from the stump and produces root suckers naturally (CTFT 1988). It is possible to propagate the species from adult trees utilizing these materials. Gassama (1989) cloned mature *F. albida* using root suckers with micropropagation techniques.

However, a number of factors make this propagation method tedious and expensive. Utilization of poorly lignified—and therefore fragile—stock that requires transport to and handling in the laboratory before establishment is costly and difficult under field conditions. Further, obtaining sprouts requires felling of selected individuals; all trees do not produce root suckers and it is often necessary to stimulate their production by injuring shallow roots. Protection of shoots from browsing poses another constraint, as does deterioration of cuttings during lengthy collection trips.

With these constraints in mind, trials were carried out to develop a horticultural method to clone adult trees with rapid and easy collection of material which can tolerate brief storage before being transferred to the nursery. Lignified branch cuttings harvested from the crown and segments of shallow roots were used.

Materials and Methods

Trials were carried out using adult trees 40 years old from the Bel Air Park in Dakar. Cuttings were collected in the morning and for the most part transferred the following day to the Hann nursery. No particular precaution was taken during transport and storage.

Cuttings were planted in clear polyethylene tubes (25 x 12 cm) or in wooden crates (55 x 55 x 20 cm) enclosed by shaded glass panels. The medium was a mixture of sand and crushed basalt (Badji et ah, in press). The temperature, which was not controlled inside the glass panels, varied from 18-28°C. The atmosphere within the panels was saturated twice daily by a mist sprayer. Two antifungal treatments, Benlate® (70 mg L^{-1}) and Aliette® (1 mg L^{-1}), were applied once a week on a rotating basis. Each cutting, 15 cm long with 5-6 nodes, was treated with a talc-based powder containing 4% IBA (ß-indole butyric acid) and pressed basally 5 cm into the medium. The first trial was to determine the optimum time for collecting cuttings from *F. albida.* Starting in September, cuttings of 7-15 cm diameter were collected on a monthly basis. Survival and rooting rates were esti-

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Danthu, P. 1992. Vegatative propagation of adult *Faidherbia albida* by branch and root cuttings. Pages 87-90 *in Faidhcrbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

mated 2,3, and 4 months after planting. A cutting was considered as rooted when at least one root became visible through the clear polyethylene tube. Cutting diameter was the second factor tested, and was divided into four classes (2-4 cm, 4-7 cm, 7-11 cm, and 11-15 cm). The measurements were identical to those of the first trial.

The root sections were about 10 cm long (De Fraiture and Nikiema 1989). Three nursery treatments were tested—shallow (covered by 1 cm of medium), deep (buried in approximately 8 cm of substratum), or inverted (the distal end of the root fragment was pointed upwards).

Analyses of variance and comparisons of averages (Newman-Keuls test at 5% confidence levels) were carried out following angular transformation of the frequencies.

Results

Branch Cuttings

Survival and rooting rates of *F. albida* cuttings was dependant on the time of collection (Table 1). Material gathered in July or in September when trees were totally defoliated failed to root. Branch cuttings collected in October at the bud breaking stage had 37% survival after 60 days and 19% rooting after 120 days. After October, cuttings showed declining tendency to survive or root as the collection time progressed towards foliating season. Leaf removal or retention at the time of planting had no influence on survival or rooting.

Small-diameter (<4 mm) cuttings taken in October had 4% survival rates at 90 days and 0% at 120 days. Larger cuttings 7-15 mm) gave the best results—approximately 20% survived and rooted after 120 days (Table 2).

Rooting of cuttings with diameters between 7-15 mm collected in October commenced after 3 months (Tables 1 and 2). The resulting root systems were fibrous, and numerous roots emerged from the base of the cutting without callus formation (Fig. 1). After rooting, cuttings developed 1-2 buds which generally sprouted a pair of axillary leaves. From these, branches emerged and proceeded to elongate (Fig. 2).

Root Cuttings

Only the inverted root cuttings gave relatively good results. Twenty-two percent of the inverted root sec-

Table 1. Survival and rooting rate (%) of *Faidherbia albida* cuttings 60,90, and 120 days after establishment as a function of the month of collection, Dakar, Senegal, 1990.

Month Collected	Phenological State	Survival (%)			Rooting (%)		
		60[1]	90	120	60	90	120
September	Defoliated	Od[2]	Od	0b	-	-	-
October	Bud break	37a	28a	23a	0a	5a	19a
November	Foliating	25b	11b	4b	0a	Ib	2b
December	Foliated	6c	3c	Ib	0a	Ib	0b

1. Values in this row are days after establishment
2. Values in column preceding the same letter are not significantly different (Newman-Keuls test at 5% confidence level.

Table 2. Survival and rooting rate (%) of *Faidherbia albida* cuttings 60, 90, and 120 days after establishment as a function of cutting diameter (mm) (length = 15 cm), Dakar, Senegal, 1990.

Cutting diameter (mm)	Survival (%)			Rooting (%)		
	60[1]	90	120	60	90	120
2-4	1b[2]	4b	0b	0a	0b	-
4-7	36a	27a	19a	0a	1b	4b
7-11	39a	31a	27a	0a	1b	21a
11-15	36a	24a	20a	0a	9a	19a

1. See Table 1.
2. Values in columns preceding the same tetter are not significantly different (Newman-Keuls test at 5% confidence level).

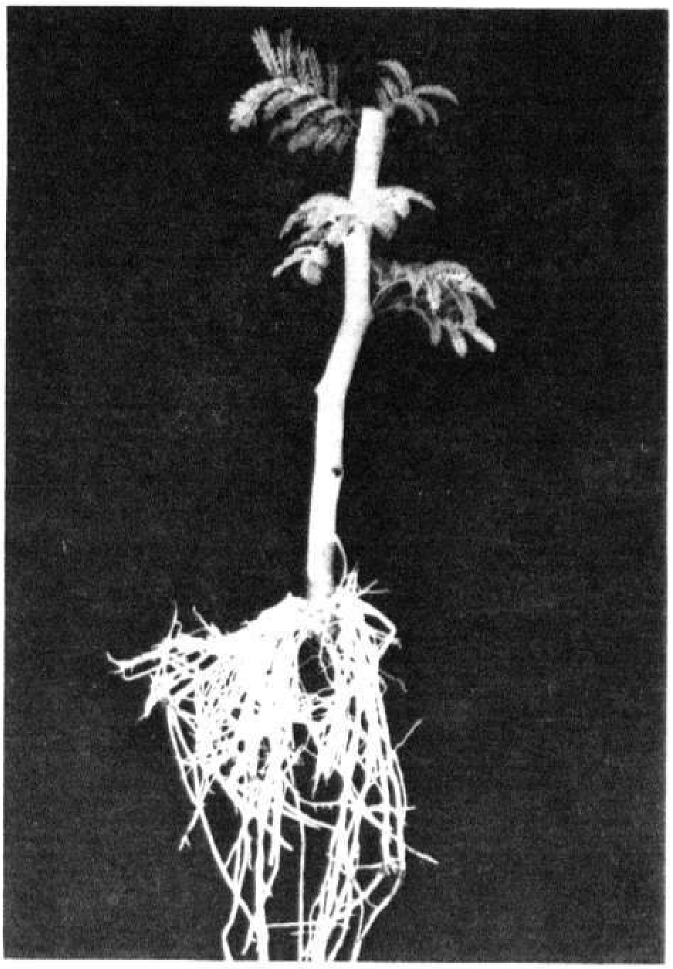

Figure 1. Branch cutting from an adult F. *albida* rooting 4 months after planting (x 0.3), Dakar, Senegal, 1990.

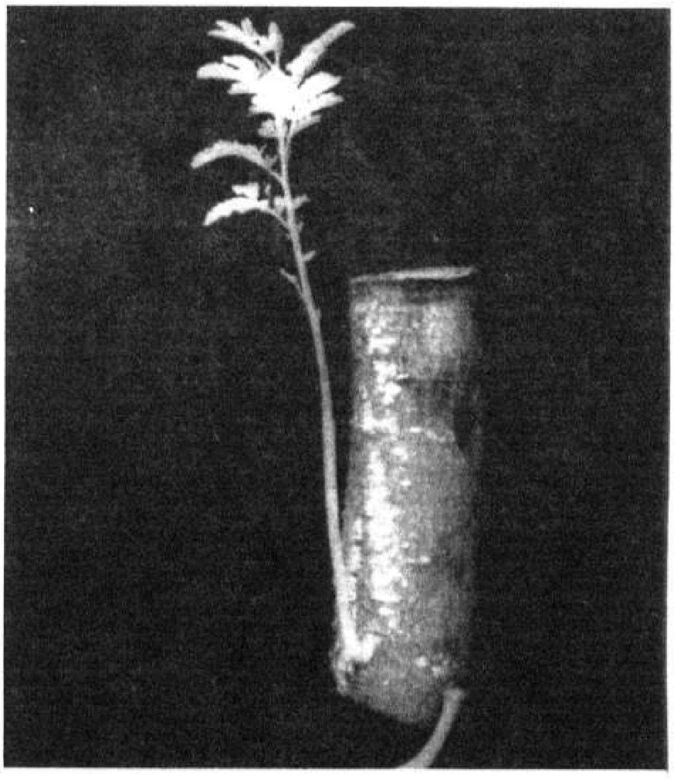

Figure 2. Emergence of an axillary branch (x 0.5) from a rooted cutting of F. *albida,* Senegal, 1990.

Figure 3. Emergence of root and root sucker (x 0.5) from a root cutting of an adult F. *albida,* Dakar, Senegal, 1990.

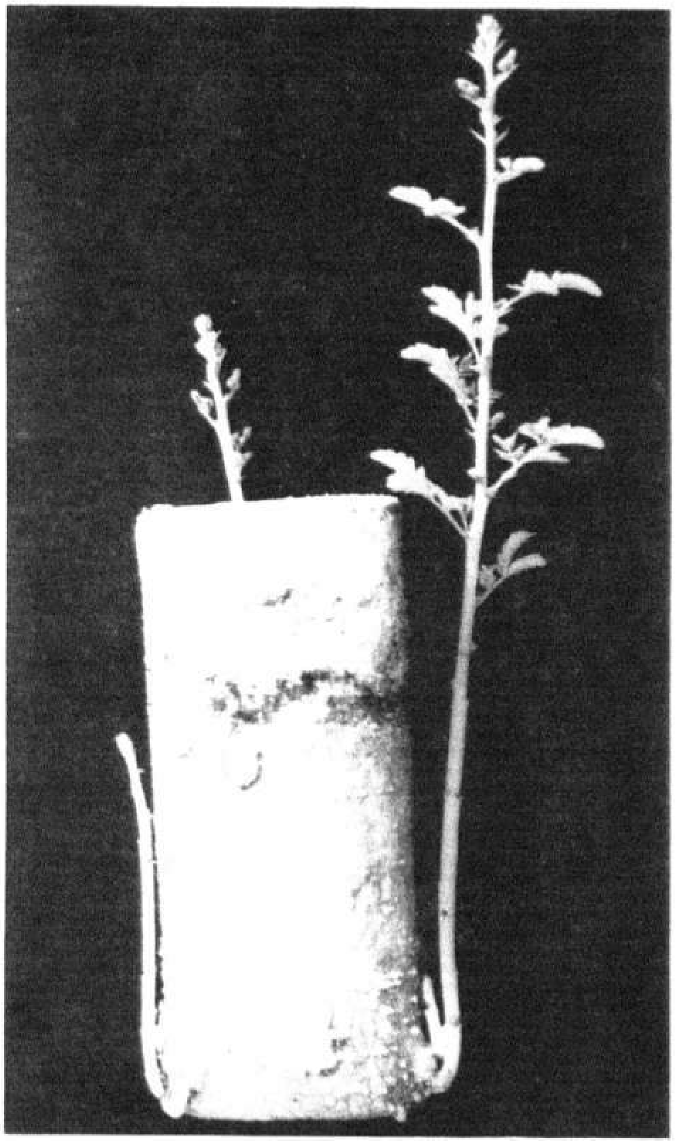

Figure 4. Multiple root sucker formation on a root cutting (x 0.5) from an adult F. *albida* after 4 months of culture, Dakar, Senegal, 1990.

tions formed at least one stem originating from the buried portion (i.e., the distal end) of the root sections (Figs. 3 and 4). In rare cases, root formation was observed (Fig. 3). Some individuals produced up to six stems (Fig. 4). Within the diameter range tested (10-40 mm), root diameter had no influence on frequency and time to shoot formation.

Discussion

Rapid clonal production of adult *F. albida* was accomplished in the nursery using branch cuttings and root cuttings. Previously, vegetative propagation was done with root fragments of 8-month old trees (De Fraiture and Nikiema 1989). Our work demonstrates that this can be done with material from adults as well. Propagation of lignified branches from the crown of adult trees is only effective for cuttings 7-15 mm in diameter and only when collected from trees in the bud breaking stage at the beginning of the dry season.

Rooting percentage of cuttings was generally low (20%). This must be improved through modification of culture conditions, such as better control of temperature, or more efficient use of growth hormones. Improvement of cultural techniques may also serve to lengthen the optimal time for collecting cuttings.

From a practical standpoint, the two types of material used are different—shoots from root fragments are juvenile material and, therefore can be immediately used for clonal multiplication in vitro (Gassama 1989). Rooted cuttings, on the other hand, are characterized by branch plagiotrophy, poor growth, and lack of a taproot, and therefore have less capacity to rejuvenate and can only be vegetatively propagated when young.

However, since cuttings are abundant, easier to collect than root sections, and tolerate up to 5-6 days* storage in a moist cloth, this material is of greater potential for clonal increase of selected genotypes. Shoots from rooted cuttings could be used in a 'rejuvenation' program, with propagation by 'chain' micrografting or with in vitro propagation as is now done with numerous other forestry species (Franclet et al. 1987).

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Meristem Micrografting of Adult *Faidherbia albida*

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N. Dupuy[1], P. Danthu[2], and B. Dreyfus[1]

Abstract

Meristems isolated from vegetative buds (apical or axillary) on branches of adult Faidherbia albida, *were grafted in vitro on 2-day old seedlings. Grafts began elongating after only 10 days in culture. Shoots obtained by this method were used for second- and third-generation micrografting cycles. Micrografted seedlings developed well after acclimatization in the greenhouse. This technique resulted in rapid multiplication of selected ortets on root stock derived from seed. This method may facilitate rapid clonal increase of selected adult individuals.*

Introduction

Faidherbia albida is characterized by great genetic variability. Clonal propagation would be a useful tool to exploit and analyze this variability. Production of selected clones could result in genetic improvement in a relatively short period and would facilitate the study of symbiotic fungal and bacterial relationships.

It is known that the cloning potential of trees diminishes as the material ages (Bonga 1987; Franclet et al. 1987). *F. albida* shoots obtained in vitro from cotyledon buds are easy to propagate, and the individuals readily take root (Duhoux and Davies 1985). However, microcuttings obtained from root suckers of adult trees do not root easily (Gassama 1989).

The state of tissue maturity at the time of removal from the adult tree can be partially and progressively reversed by various cultural practices, termed 'rejuvenation' (Nozeran 1978). The return to juvenile traits, which facilitates clonal propagation, can be achieved by successive grafting cycles (Franclet 1977; Franclet et al. 1987). It is based on this principle that the original 'chain micrografting' technique presented in this paper was developed.

Materials and Methods

Treatment and Germination of Axenic Seedlings

Seeds of four *F. albida* provenances (Kagnobon, Merina Dakhar, Bode, and Ovadiour) collected in Senegal by the Direction de recherche des productions forestieres (DRPF) of ISRA were scarified by immersion in concentrated H_2SO_4 for 1 h. They were then copiously rinsed in sterile water, immersed in 0.1% mercuric chloride for 30 seconds, and rinsed again in sterile water. Seeds were then soaked in sterile water for 3 to 4 h. The seeds were germinated on agar-agar water (0.8%) in the dark.

Choice of Ortets and Preparation of Grafts

Grafting stock was taken from three types of ortets: (1) axenic seedlings at the cotyledon stage; (2) 1- to 2-month old seedlings from the greenhouse; and (3) an adult tree (50 years, Bel-Air, Dakar). Ramets (leafy, soft-tissue branches, 5-7 cm long) from ortet types (2) and (3) were collected and sterilized in 0.1%

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Detrez, C., Ndiaye, S., Kerbellec, F., Dupuy, N., Danthu, P., and Dreyfus, B. 1992. Meristem micrografting of adult *Faidherbia albida.* Pages 91-95 *in Faidherbia albida* in me West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

mercuric chloride for 20 seconds. From these ramets, meristems, composed of meristematic domes and their bases trimmed to a bevelled edge, and protected by 1-4 young chlorophyllous leaves, were selected for grafting.

Root Stock and Micrografting Techniques

Two micrografting techniques were compared using 2-day old axenic seedlings as root stock: (1) top- or cleft-micrografting which consists of inserting the graft into an incision made in the terminal part of the hypocotyl after removal of the epicotyl and the cotyledons, and (2) lateral micrografting onto the hypocotyl whose cotyledons and meristem were left in place during the first 12 days following the implantation of the graft, after which they were decapitated to suppress apical dominance of the root stock.

Successive Micrografting Cycles—Adult Ortet

Shoots obtained after the first micrografting operation and the cauline elongation phase of the micrografted meristems provided a second generation of meristems for another cycle which used the top micrografting technique. This second micrografting was followed by a third, done under the same conditions.

The Culture Environment

After micrografting, the plants were grown in culture tubes (25 x 150 mm) containing 10 mL of nutritive medium. The culture medium was composed of the mineral base and vitamin mix of Murashige and Skoog (MS) (1962), with saccharose added (20 g L^{-1}). The pH was adjusted to 5.8, and the agar (Bacto Difco 0.8%) was incorporated. Media were sterilized by autoclaving for 20 min at 110°C.

Following each micrografting cycle and after a period of elongation, the grafts were separated from the root stock and their rooting ability was tested on the MS medium, with additions of either 60 g L^{-1} of sucrose (Duhoux and Davies 1985) or 20 g L^{-1} of sucrose and indole butyric acid (5 mg L^{-1}) (Gassama 1989).

Cultures were placed in a controlled-climate chamber maintained at 28 ±2°C and were continuously exposed to 3200 lux of artificial light. The grafted seedlings were acclimatized on a substratum (Bel Air soil:vermiculite; 3:1, v:v) in a greenhouse under humid conditions.

Results

Reactivation and Elongation of the Graft

For the three types of ortets studied, callus formation of the grafts occurred 7-10 days after insertion into the hypocotyl. The lateral cleft grafting technique (Figs. 1 and 2) and top-grafting technique (Fig. 3) were successful with both the juvenile and adult ortets. In the case of lateral grafting, it was necessary to

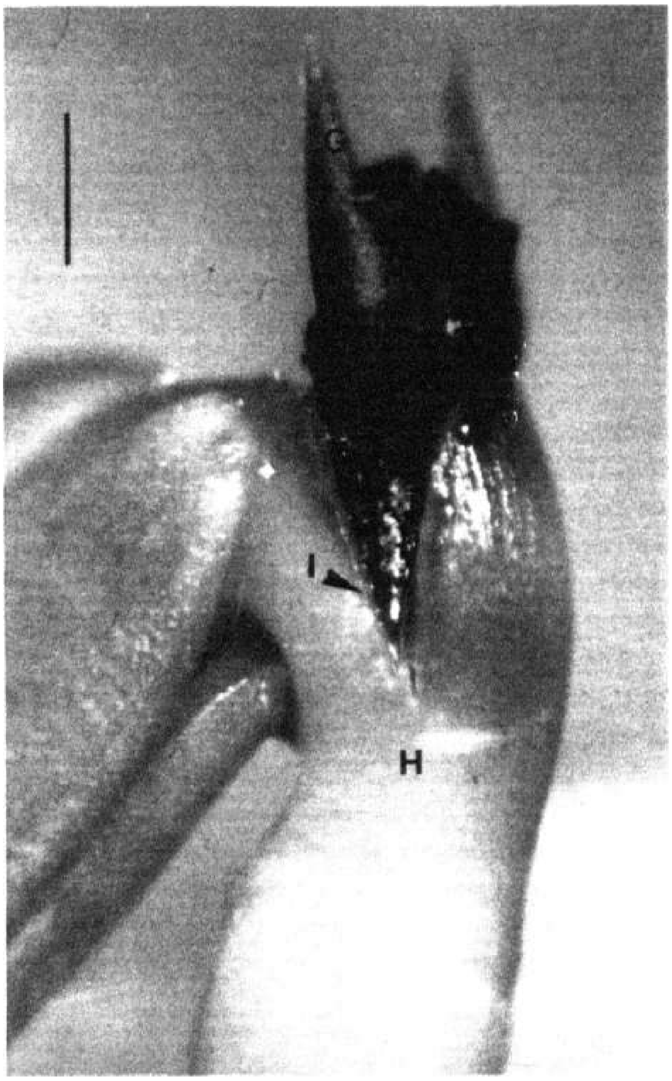

Figure 1. Insertion of a *Faidherbia albida* micrograft by the lateral-cleft technique. The graft (G), consists of a meristem removed from an axillary bud of a branch of an adult tree, trimmed basically to a bevelled edge, and inserted into an incision (I) made in the hypocotyl (H) of a 2-day-old seedling. (Bar = 1 mm.)

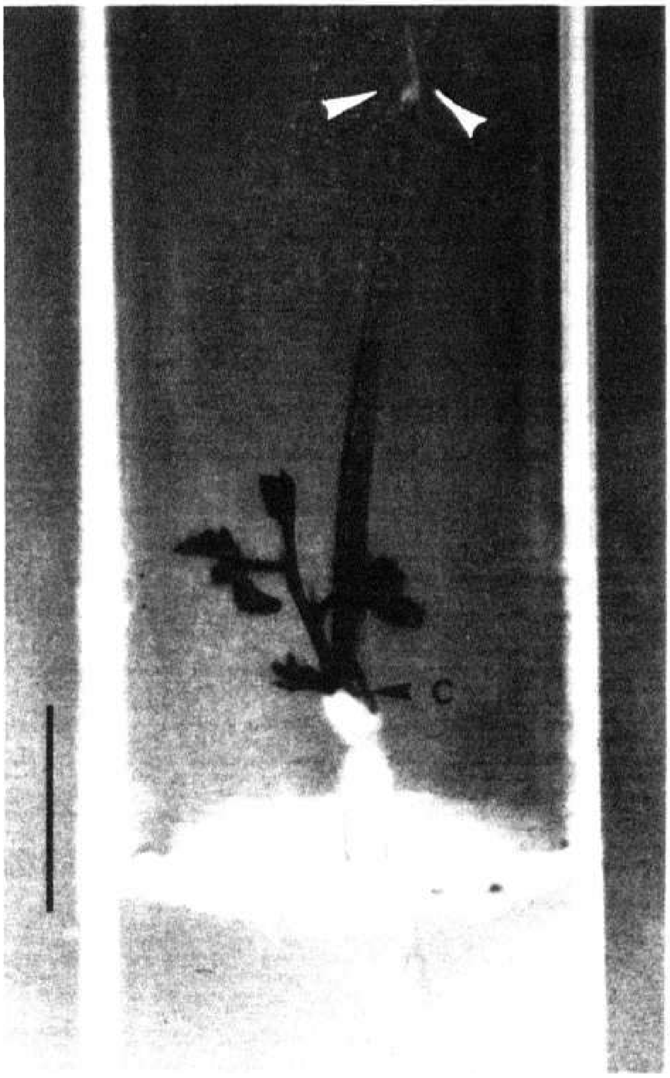

Figure 2. Elongation of a meristem removed from an adult tree and micrografted onto the hypocotyl using the lateral-cleft technique (3 weeks of growth). The meristem and the cotyledons of the root stock, kept in place for the first 15 days following the graft, were selected (see arrow) after the callus formation (C). (Bar = 1 cm.)

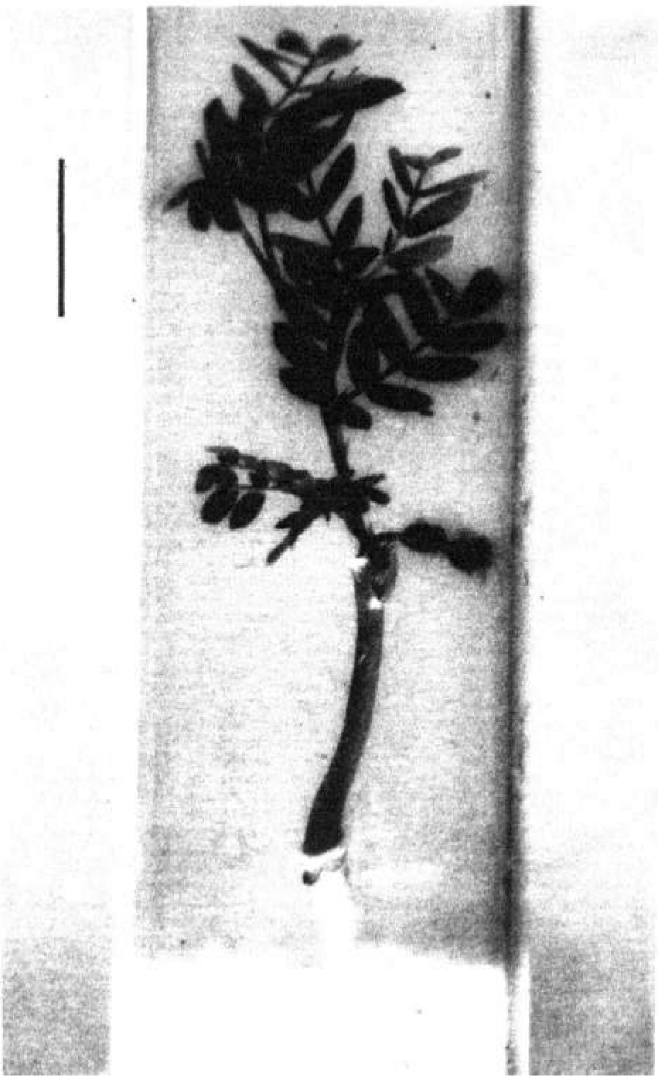

Figure 3. Elongation of a meristem taken from an adult tree, then micrografted using the top-grafting technique after removal of the cotyledons and the epicotyl of the root stock (6 weeks of growth). (Bar = 1 cm.)

remove the terminal bud of the root stock when callus formation began. This additional manipulation did not appreciably improve the degree of rooting of the graft. Therefore, the lateral grafting was discontinued and only top-grafting used.

On the juvenile ortets, callus formation was immediately followed by a foliar growth and the onset of cauline elongation after 10-12 days of growth. For the 2-day old ortets, graft elongation occurred for 23 of the 24 grafted plants. For the 1- to 2-month old ortets, elongation occurred on 22 of the 24 grafts.

In the case of the adult ortet, successful grafting appeared to be correlated with the date of ramet collection (Table 1). The best results were obtained with ramets collected at the beginning of the foliating season (Nov/Dec, Dakar region)-19 of 24 grafts observed showed cauline elongation. The placement of

Table 1. Frequency of elongation of grafts taken from an adult ortet of *Faidherbia albida* as a function of sampling period, Dakar, Senegal, 1990.

Sampling period	Phenological stage of ortet	Phenological state of ramets	Success frequency
Nov/Dec	Vegetative	Foliating	19/24
Jan/Feb	Foliating	Foliated	2/36
Mar/Apr	End foliation	Foliated	1/48

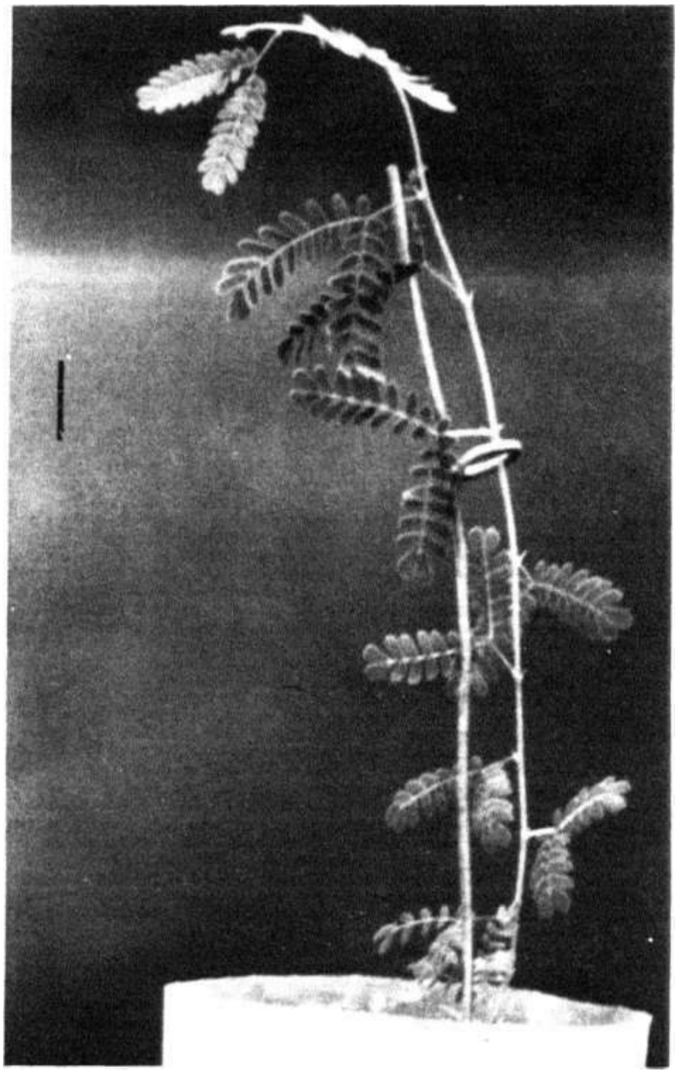

Figure 4. Growth and development of a micrografted individual after transplanting in the greenhouse (15 weeks after the micrografting operations). (Bar = 1 cm.)

the grafts, whether axillary or terminal on the branches of the ortet, made no difference in the rate of elongation. Starting in January, the ramets became highly infected with a fungus, despite treatment of the ramets with a fungicide (Benlate®, 70 mg L^{-1}) 2 days before collection. Treatment with $HgCl_2$ failed to completely control this problem.

Micrografted individuals were maintained in a greenhouse (Fig. 4). For the first 3 months of this acclimatization period, the plants had weak stems. This was supplanted by a second, more vigorous stem originating from a basal axillary bud.

Chain Micrografting of Adult *F. albida*

The frequency of graft elongation increased during chain micrografting (Table 2). Likewise, the graft coefficient of multiplication (i.e., the average number of nodes produced by the foliated shoots at the end of each of the three successive micrografting cycles) increased appreciably during the second and third micrografting cycles, maximizing at a value of 10.

Table 2. Frequency of elongation and coefficient of multiplication of grafts taken from adult *Faidherbia albida,* following three successive micrografting cycles (G1, G2, G3), Dakar, Sengal, 1990.

	Micrografting Cycle		
Parameter	GP	G2	G3
Frequency of graft elongation	19/24	6/8	10/10
Coefficient of multiplication[2]	5±0.24	8.5±0.32	10.2±0.27

1. Micrografting cycle started with meristem harvests done in November and December.
2. The average number of nodes produced by two foliated shoots after 6 weeks of culture (±SE).

Discussion

It is possible to graft in vitro meristems of *F. albida* on root stock obtained from seed. Both juvenile (3 month) and adult ortets can be used. Successful grafting with adult ortets allows immediate procurement of selected individuals grafted onto seedlings, which can be readily used in field trials. This micrografting technique is advantageous as any type of bud from the ramet can be used, and two grafting locations on the hypocotyl (top or lateral cleft) are suitable. The optimal collection period determined by this study is in accordance with observations made by Danthu (1992) for horticultural cutting establishment of *F. albida.*

Chain micrografting by the multiplication of axillary buds produces an abundance of newly formed shoots and shows a high coefficient of multiplication by 6 weeks. Extrapolating this result, 6 months of chain micrografting from one graft could result in 10 000 identical grafted individuals.

Although shoots have been propagated on root stock, a suitable technique for root formation has yet to be developed. We hope to achieve rooting through tissue rejuvenation during chain grafting. Investigations currently under way in the laboratory are aimed at obtaining rooted clones, a necessary condition for a stand improvement project of *F. albida.*

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Propagation *of Faidherbia albida* by Cuttings: Experience of the National Forest Seed Center

A. Nikiema and G.W. Tolkamp[1]

Abstract

This paper summarizes work on propagation of Faidherbia albida *by cuttings done at the Centre national de sentences forestieres (CNSF) in Burkina Faso from 1988 to 1991. The optimal period for collecting cuttings is during the rainy months of June to September, which corresponds to the period of maximum defoliation of* F. albida. *It was observed that cuttings from young plants root more readily than those from adult trees. Cuttings taken from the basal region of shoots had a greater tendency to root than those cut from other parts of the same shoot. Basal treatment of 1% indole butyric acid gave better rooting titan other hormone treatments. The best rooting medium mix consisted of 2 parts sand and 1 part compost. These results have made it possible to multiply selected* F. albida *individuals through propagation by cuttings. However, rooting rates remained low (38% on average) due, in part, to unresolved problems with temperature and fungus attacks.*

Introduction

This paper is a summary of studies on propagation of *Faidherbia albida* by cuttings carried out by the CNSF, Burkina Faso, which initiated a genetic improvement program for this species in 1984. Topics have included different propagation techniques, optimum medium mixture, and the feasibility of large-scale clonal plantations from cuttings.

Materials and Methods

Rooting Chamber

To maintain a relative humidity of 80-100%, a 168 m^2 rooting house was constructed with wooden frames covered with transparent plastic sheeting, buried in the soil at the base to a depth of 5 cm. The house was shaded overhead by reed mats and shade screen to reduce incoming radiation by 40%. The floor of the house consisted of back-filled gravel to facilitate drainage. An anti-termite treatment of Dyfonate® or Furudan® was applied. Inside the house, 16 mini-greenhouses measuring 30-50 cm in height, 92 cm in width and 130 cm in length were built of hermetically-sealed metal frame and glass paneling. These were placed on concrete supports 54 cm off the ground to facilitate access.

Vegetative Materials

Cuttings 10-15 cm long were taken from shoots and branches of *F. albida.* Leaves were removed and incisions of 1-2 cm in length were made in the bark of the cuttings to stimulate rooting. Cuttings were then soaked for a few minutes in fungicide (Benlate®, 0.5 g L^{-1}). Relevant hormone treatments were applied 2 cm from the basal end as determined by the experimental design.

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Root cuttings were taken from nursery-raised seedlings, and tended to form root lengths of 10,5, and 2.5 cm. Upper ends of root cuttings were cut horizontally and basal ends were cut with a beveled edge to distinguish between them. All root cuttings were soaked in a Benlate® mixture (0.5 g L^{-1}). No hormones were applied to root cuttings.

Results of Experiments

Root Emergence

Root emergence of branch cuttings occured after 2.5-5 months. Rooting rates were greater with cuttings taken from the basal part of shoots or branches. There was no relation between rooting and original position of cuttings in the canopy. We noticed that cutting quality and sanitation affected rooting rate greatly. There was a moderate correlation between rooting and cutting diameter (within the range of 4-9 mm) as well provenance of the cutting. Cuttings were often attacked by unknown stem-boring insects. For root cuttings, callus formation occurred on 50% of the cuttings after 45-70 days. Callus formed quickest on cuttings placed vertically in the medium. With this treatment, 50% of the cuttings sprouted stems between 45-56 days. Root cuttings 10 cm long budded faster than cuttings 5 and 2.5 cm in length. Root cuttings 10-cm long and planted vertically produced the highest number of roots per cutting (7). Ninety-three percent of these cuttings rooted after 3 months, versus only 53% for cuttings 2.5 cm long and planted horizontally. Table 1 shows the results for all treatments.

In the same trial, a sandxompost mixture (2:1) was compared with a pure sand medium. There was no difference in effect on rooting between the two media, however, nodule counts were higher on cuttings grown in pure sand.

Optimum Period for Collecting Cuttings

The optimal period for collecting cuttings from stump sprouts was between June and September, which coincided with maximum leaf fall. Rooting rates varied between 25 and 32%. The highest rooting rates for cuttings from branches of adult trees occurred between the end of defoliation and the beginning of foliation as follows: 27% in June; 17% in August; and 24% in September (Tolkamp 1990).

Rooting Medium

Balima (1989) conducted a study aimed at determining the type of substrate that best enhances rooting in cuttings. Seven media consisting of various mixtures of sand and compost were tested with a randomized complete block design with 4 replications. Plots consisted of 40 cuttings from trees more than 1-year old collected on 12 Jun 1989. After eight weeks average rooting rates ranged from 3.3 to 23.3% for the treatments.

No significant differences were observed between average rates of root elongation for the different treatments. However, the 2:1 sandxompost mixture showed the best rooting percentage (23.3%), and had relatively more roots per cutting than the others. This

Table 1. Effect of cutting length (cm) and position on rooting of branch cuttings of *Faidherbia albida,* CNSF, Burkina Faso, 1989.

Treatment		Days to 50% callus formation	Rooted cuttings (%)	Rooting index[1]
Cutting length (cm)	Cutting position			
10	Horizontal	59	83	4.5
10	Vertical	45	93	4.8
5	Horizontal	70	60	3.5
5	Vertical	52	86	4.2
2.5	Horizontal	70	53	3.9
2.5	Vertical	56	66	3.2

1. Rooting index of 1= 1 root produced; 2 = 2 roots; 3 = 3-4 roots; 4 = 5-7 roots; 5 = 8 roots.

medium also had a pH of 7.1, higher than the optimum reported in the literature (MacDonald 1986).

Effect of Hormone Treatment

A trial was carried out in 1989 to compare 13 hormone treatments and a no-hormone control on rooting of shoot cuttings of *F. albida* (Balima 1989). Seven of the treatments were/in powder form and six were in liquid form. A randomized complete block design with four replications was used. For each treatment, 40 cuttings were planted in a medium of two parts river sand and one part compost. None of the hormone treatments had better root emergence than the control. However, Rhizopon AA (indole-butyric acid or IBA) had more roots per cutting, and longer and more fibrous roots than the control and other treatments (Table 2). Several hormone treatment, including several with IBA, showed improvement in average root length over control (Nikiema and De Fraiture 1989).

Table 2. Effect of hormone treatments on rooting of cuttings of *Faidherbia albida,* CNSF, Burkina Faso, 1989.

Treatment	Percent rooting	Rooting index[2]	Mean length of roots (cm)
Rhizopon A			
0.5%	45	2.2	3.9
1.0%	45	2.5	6.0
50 ppm	20	2.0	4.0
100 ppm	13	3.8	5.5
Rhizopon AA			
0.5%	10	4.8	4.8
1.0%	28	4.0	1.3
2.0%	8	4.7	2.6
50 ppm	18	3.6	0.9
100 ppm	8	4.0	1.5
Rhizopon B			
0.1%	28	2.3	3.9
0.2	50	2.5	5.9
25 ppm	10	3.0	3.7
50 ppm	15	3.0	3.8
Control	43	2.1	3.6

1. Rhizopon A is 3-indole acetic acid (IAA); Rhizopon AA is 3-indoie butyric acid (IBA); Rhizopon B is Naphtylacetic acid (NAA). Doses expressed in (%) are in powder form; those in (ppm) are in liquid form.
2. Rooting index of 1 = 1 root produced; 2 = 2 roots; 3 = 3-4 roots: 4 = 5-7 roots; 5 = 8 roots.

Nursery Requirements

Temperature Requirements

Nikiema and De Fraiture (1989) demonstrated that favorable temperatures for rooting ranged from 15-30°G In order to control temperature, CNSF utilizes 'Norten' shade screen which reduce sunlight exposure by 40%. We found that thatch made of reed mats can lower temperature by 2-5°C.

Humidify

Cuttings must remain turgid from the time of collection to planting. Humidity control throughout this period is critical. Besides the double-enclosed mini-greenhouses described earlier, we mist the environment 2-4 times a day to keep both the substrate and air saturated. We use the presence or absence of water droplets on the mini-greenhouse panels to determine if more mist is needed.

Phytosanitary Problems

Fungus attacks on cuttings are a common problem. Soaking cuttings in Benlate® (0.5 g L^{-1}) before planting and irrigating the rooting medium with the same mixture is effective. Before planting, cuttings should be stripped of leaves to prevent them from rotting. Two weeks after planting, cuttings are sprayed with Benlate® solution on a weekly basis.

Hardening

Rooting rates and root development from different material can vary greatly. Rooting of branch cuttings from adult trees occurs after about 2-3 months and much earlier for cuttings from young growth. Sudden outplantings of cuttings results in stress and mortality. A method by which cuttings can be slowly and gradually hardened is needed.

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Session 4
Site Effects, Silviculture, and Symbiosis

Cover photo: Agronomic studies of the 'albida effect' have been confined to traditional cereal and leguminous crop species. Agronomic trials at ICRISAT Sahelian Center are assessing the possibility of introducing higher value crops in the favorable microclimate under the tree canopies. Cotton and sorghum are seen growing here in Sadore, Niger, an area traditionally cropped only with millet and cowpea. (Photo: J.W.Williams.)

Site Effects of *Acacia albida* Del.

P.N. Sall[1]

Abstract

The effects of Acacia albida *on microclimatic factors, soil properties—especially organic matter and biological activity—and crop yields are briefly outlined. Much is still unknown about the site effects of this species, and further research, with a multidisciplinary approach, is essential to an understanding of its potential in agroforestry.*

Introduction

The following notes presented on the site effects of *Acacia albida* do not represent an exhaustive review of all that has been done in this area. Other references-- for example, the monograph published by the Centre technique forestier tropical (CTFT 1988)— serve as reference tools. Papers presented during this seminar will certainly supplement the previous work and outline the new paths to be explored.

Effect on Climatic Factors

Several microclimatic factors favorable to crops grown under *A. albida* have been previously studied (Dancette 1966; Schoch 1966; Dancette 1968; Giffard 1971). These include relative humidity, differences in rainfall distribution, and influences of temperature and sunlight. However, several other factors, considered favorable in reducing evapotranspiration under tree shade, have not been sufficiently addressed.

If it can be established that the presence of trees reduces the potential evapotranspiration and thus provides a better environment for crops (therefore an increase in yields), then the case for *A. albida* can be strengthened. However, even with a positive microclimatic balance, factors may still exist that are detrimental to crop growth, such as interception of sporadic rains at the onset of the rainy season, which gives rise to root competition.

The climatic buffering role of *A. albida* is enhanced by foliar transpiration during soil water deficit periods in the growing season. The combined phenomena of rising humidity under the canopy and diminishing atmospheric evaporation result in decreased potential evapotranspiration (PE) for crops.

Fields with tree cover of foliated stands of *A. albida* in the foliated state during winter have 50% less PE than fields without tree cover (Schoch 1966). With defoliation in the rainy season, this reduction drops to 10%. This component of the energy balance is poorly understood, but it no doubt moderates the influence of *A. albida* on the microclimate. Any economy of water caused by the presence of *A. albida* on crop sites, however small it is, may make the difference between successful crop establishment and failure during the critical periods of the beginning or end of the rainy season (Dancette 1966).

Influence on Soil Fertility

A number of soil studies carried out in West Africa (Charreau and Vidal 1965; Jung 1970; Poulain 1984) have allowed the following conclusions to be drawn.

Influence on Physical Properties

Past studies have focused on the amounts of clay and silt, which are not influenced by trees, and on the very

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slight differences in porosity, bulk density, and soil cohesion. The absence of tillage in these studies explained poorer porosity and the lack of litter incorporation into the soil. Studies on farming practices would supplement this study.

Influence on Organic and Biological Characteristics

The presence of *A. albida* strongly influences soil organic matter status. Beneath the tree, there is a larger percentage of total carbon and nitrogen, averaging 40-100%, and two to five times as much biological activity (Poulain 1984). To obtain this level of nitrogen and carbon, quantities of organic matter and nitrogen not normally available to the Sahelian farmer would have to be applied. Such contributions to the soil, however, would pose risks of raising the rate of mineralization and possibly leaching.

Influence on Chemical Characteristics

The impact of tree cover on chemical characteristics of soil is important (Jung 1970). The pH is consistently higher and the cation exchange capacity increases notably beneath *A. albida.* Calcium and magnesium, which represent 95% of the sum of exchangeable cations, increase considerably.

Influence on Crop Yields

Several trials have shown the positive effect of *A. albida* on crops. Litter drop combined with high microbiological activity in the soil (especially during the rainy season) apparently constitute the main soil-improving effect of *A. albida.* Trials set up by the Institut de recherches pour les huiles et oleagineux (IRHO) in 1966 in Senegal have demonstrated the beneficial effect of *A. albida* on groundnut. These effects were not obtained, however, with mineral fertilizers applied at levels equivalent to those provided by tree litter. In addition, fertilizer supplements do not considerably increase crop yields in plots already improved by *A. albida* (Giffard 1972).

The influence of *A. alhida* on millet yields is both quantitatively and qualitatively remarkable. Other trials on maize and sorghum in Ethiopia (Poschen 1986) and on wheat in Sudan (Blair 1963 as cited by Wickens 1969) showed the positive cover effect of *A. albida.* Methods of determining different production variations as a function of distance from the base of the tree have been proposed in Senegal, but they have never been effectively demonstrated on millet or groundnuts (Louppe 1989).

Determination of Fertilization Effects

The contribution of mineral elements to the soil nutrient cycle is similar for many tree species. Under *A. albida,* the quantity of litter was estimated at 4.2 t ha^{-1} (Jung 1970), a figure comparable to stands of trees in subhumid tropical zones. Other trials carried out under different conditions, however, have given somewhat lower results (Dunham 1989).

The deep-rooting capabilities of the trees play a particularly important role in enriching surface soil horizons by drawing up mineral elements from lower horizons. The reverse phenology of *A. albida* contributes much to crop fertilization, since its litter fall occurs in the rainy season. Other beneficial effects of *A. albida,* such as nodulation and the attraction it holds for cattle—resulting in manuring of the site—are important as well.

Conclusion and Prospects

Giffard (1964) raised a critical point in stating, 'when...the synthesis of information pooled on *A. albida* was processed, we were led to state that one was unaware of almost everything periodically presented on this tree...that could revolutionize agriculture in tropical regions having a long dry season.' Apparently, this lack of knowledge no longer exists; many professionals—including agronomists, soil scientists, foresters, and geographers—have realized the importance of A. *alhida* and are expanding research in this field.

Much is still unknown about *A. albida.* In order to tap its potentials, further understanding of the site effects of *A. alhida* is of utmost importance. In cooperation with the Sahara and Sahel Observatory, the ORSTOM microbiology team in Dakar has set up a study project with other research institutions that will focus on this. The project is using a multidisciplinary approach that includes botany, population genetics, vegetative propagation, and microbiology.

The enormous human resources available should be judiciously used to better understand the potentials of this species in order to significantly advance in agroforestry.

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Variations in Root Morphology of *Faidherbia albida* in Relation to Soil and Agronomic Effects

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Abstract

A preliminary study of Faidherbia albida *root systems in two regions of Burkina Faso revealed morphological variation of root systems on different soils. On sandy soils, the taproot penetrated deeply into the soil while root systems in compacted clay soils remained in the upper horizons.*

It appears that this species plays its celebrated agronomic role under conditions which favor taproot development. It is hypothesized that the beneficial effects of this species on associated crops is linked to water uptake of F. albida *from lower soil horizons.*

Introduction

As part of a research program focusing on the dynamics and the performance of agroforestry systems in Burkina Faso, root systems of *Faidherbia albida,* as well as those of other tree species, were studied at two sites. The first was the village of Watinoma, located approximately 100 km north of Ouagadougou, Burkina Faso. The second site was situated in the classified forest of Nazinon in Sissili province, 100 km south of Ouagadougou. The program began in Dec 1990. Initially, the study was limited to root systems of short bushy trees resulting from annual lopping of natural regeneration from old stumps.

The Watinoma Village Site

Watinoma is a Mossi village with a high population density and a pronounced topography susceptible to erosion and soil degradation. Existing vegetation types differ greatly due to variable soil conditions and the influence of the Sudano-Sahelian climate. In Watinoma, *F. albida* is restricted to a plain, characterized by deep sandy soils and a high water table. There are few trees between the juvenile and mature age classes (Ouedraogo and Alexandre 1991).

Several root systems were studied in the three distinct zones of the village. The first zone is poorly-drained. Perennial vegetation including *Mitragyna inermis, Piliostigma* sp and *Combretum paniculatum,* mature trees, and an abundance of small shrubby *F. albida* are present. The root systems of two of these small trees were first examined. Both possessed multiple stems resulting from incessant cutting by local farmers. The stems averaged 30 cm in height and originated from a root found at a depth of 17 cm. The taproot abruptly terminated at a depth of 126 cm and secondary roots branched out laterally. Fine roots, indicative of water uptake, were not evident. However, on closer inspection the fleshy portion of the taproot had latent secondary roots appearing as lenticels on the root bark.

The second zone was also poorly drained, and included a drainage depression. Shrubby *F. albida* were few and the stand was composed of numerous trees of diverse ages. One individual, 96 cm tall and 1.2 cm in basal diameter, was excavated (Fig. 1). Its taproot branched out at a depth of 120 cm to form secondary roots which attained a depth of 470 cm to a mottled, seasonally anaerobic horizon. At this depth, roots grew horizontally and abruptly changed direction (sometimes 90°) several times. No roots devel-

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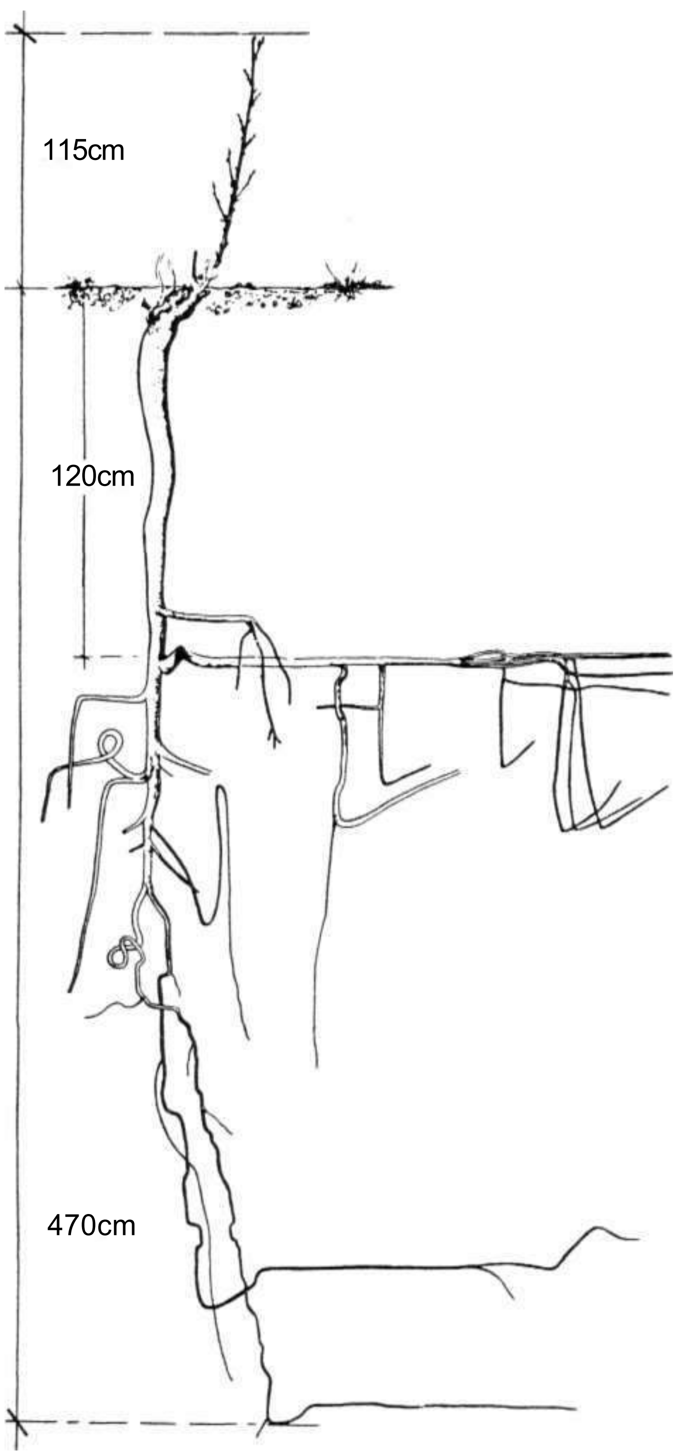

Figure 1. *Faidherbia albida* root system from Watinoma, Burkina Faso.

oped laterally towards the drainage depression. Lateral roots began to appear at a depth of 113 cm.

The third zone studied in Watinoma was a transition between the sandy bottomlands and a degraded clayey hill. Here, although individuals were abundant, no adult *F. albida* were observed. Five multistemmed individuals averaging about 1 m in height were excavated to a depth of 50 cm. All emerged from a large, flat base to form multistemmed shoots over 1 m in height. There were large lateral roots and an axillary taproot.

Ring counts were done on taproot sections cut 25 cm below the root collar. Twenty-three rings were counted on one root 3.7 cm in diameter (0.80 mm per ring), and 50 rings were counted on another 7.8 cm in diameter (0.78 mm per ring).

Sissili Province Sites

Sissili province receives more rainfall than the Watinoma area, but is much less populated because of extremely poor soils. Two principal ethnic groups, the Mossi in the east and the Gurunsi in the west, inhabit this area.

Only village lands of the Gurunsi possess significant *F. albida* parks, which contain a number of huge and very old individuals. In Looru village, the circumference of one adult *F. albida* was 5.6 m. The crown of another had an average diameter of 35 m. The sandy soils, rich in organic matter at the surface, were clayey (reddish) and compact at a depth of 1 m. *F. albida* trees were affected by drought. The water level in local wells was 32 m.

These old trees were often surrounded by numerous drought-stressed, shrubby F. *albida.* In the Rakaye Yarse village, shrubby *F. albida* formed numerous thickets which were frequently cut back. Shoot heights averaged over 2 m, and sometimes grew from stumps exceeding 1 m in diameter. Root systems did not surpass 32 cm in depth. At Bum village, a large, recently windthrown *F. albida* exhibited a shallow root system with no trace of a taproot.

These shrubby thickets are very old, and village elders have always known them to exist. There has been a relentless struggle between the rural population which cuts back the regrowth, and the trees, which resprout. Farmers who were interviewed complained that *F. albida* "takes up space" and that the species "is not wind-resistant".

In the Ku village, an old, large-diameter *F. albida* tree overlooked the landscape. The owner of this tree claimed to have high crop yields under it. One excavated bushy tree downhill from there had a taproot which penetrated the yellowish and very compacted upper horizon. Sixty rings were counted on a cross section of one root 2.8 cm in diameter (0.2 mm per ring, four times less than the ratio found in Watinoma).

Most of the trees we excavated were in Rakaye Yarse. Twenty of these rooted only to a shallow depth, but three others rooted to 210 cm. Figure 2 is typical of the peculiar morphology of *F. albida* existing in this village. Stems emerged from a large hori-

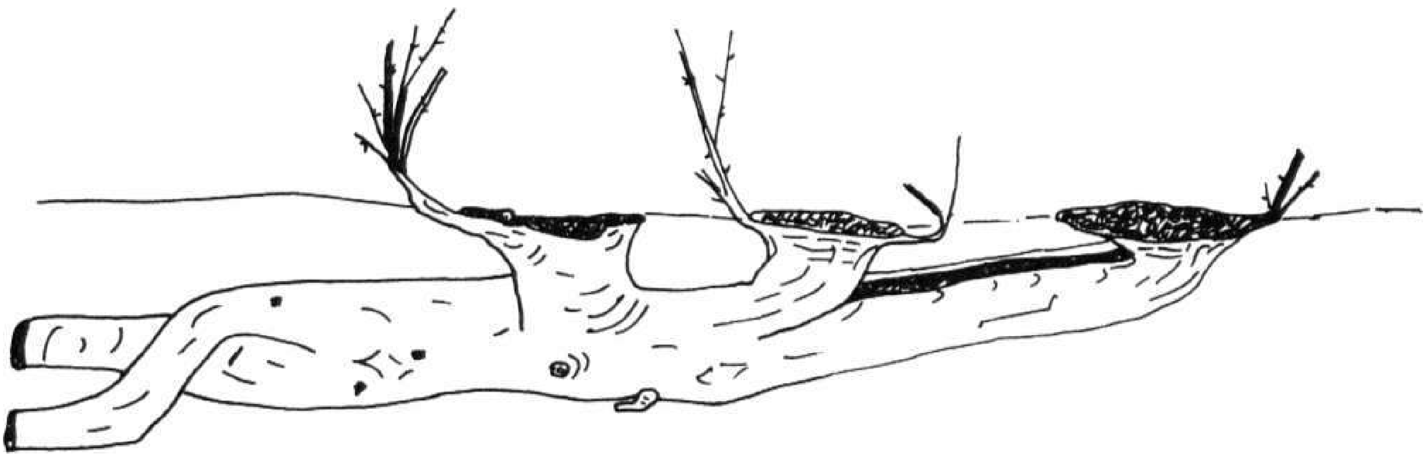

Figure 2. ***Faidherbia albida*** **root section observed in Rakaye Yarse on sandy soils becoming rapidly clayey and compact with depth. The roots developed horizontally and remained in the upper horizons of the soil.**

zontal root which had secondary roots at one end; these were atrophied on the upper side. At the other end, there was a partially decayed stump which had shoots growing along its periphery. The specimen we excavated had shoots growing from three stumps. Such horizontal roots and their associated stumps grew close together and could be confused with a root sucker system.

Some roots successfully penetrated the clayey horizon. Their pathways were erratic, veering both horizontally and vertically in an apparently random manner. At 210 cm, a small root (3 cm in diameter) was uncovered which probably continued to greater depths.

Conclusion

These initial observations revealed the morphological plasticity of *F. albida* taproot development under different soil conditions. In Watinoma, a taproot hit an indiscernable barrier at a depth of 126 cm. In Bum, as in Rakaye Yarse, the root systems were restricted to the upper soil horizons. In Ku, roots penetrated compact soils but with much difficulty.

The presence of latent lateral roots reflect the great environmental flexibility of *F. albida. F. albida* takes up water from great depths and can also send out shallow lateral roots if moisture conditions in the upper horizons are favorable.

The presence of *F. albida* has been frequently linked to the history of the farmer's use of the land. It would be interesting to know whether the abundance of *F. albida* in the Gurunsi villages indicates a more positive attitude of the local people towards the species vis-a-vis the Mossi or whether this is due to the existence of better soils.

F. albida has two habitats (Wickens 1969): a 'natural' one in hydromorphic lowlands, where the species is characteristically shallow-rooted, and the other is linked to the activities of farmers on sandy soils overlying accessible but deeper water tables. Only in the second habitat has *F. albida* been associated with its celebrated effects on crop yield. It is possible that *F. albida* could benefit associated crops by taking up otherwise inaccessible water from a great depth and making it available to crops by releasing it from its taproot (Alexandre 1990). Measurements by Dancette and Poulain (1968) in Senegal showed that soil moisture at 1.2-4 m beneath *F. albida* was much higher than away from the tree at the end of the dry season. If this hypothesis is true, *F. albida* would have little or no positive impact on growth of associated crops on soils where taproot development is inhibited or delayed.

Although these observations are preliminary, they should indicate the limitation of *F. albida's* extension. Its establishment where soil conditions do not favor taproot development may not result in beneficial effects.

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Faidherbia albida Parks and their Influence on Soils and Crops at Watinoma, Burkina Faso

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Abstract

The floral, dendrological, and soil characteristics of four Faidherbia albida *parks in the area of Watinoma, Burkina Faso, were inventoried. Soil analyses of samples from two bottomland parks and two less fertile upland parks demonstrated that the species improves soil. Organic matter content, organic carbon, and organic nitrogen, available phosphorus, and excltangeable bases were higher in soils beneath* F. albida. *Significant differences were found between various crop production parameters for sorghum beneath* F. albida *cover and away from the tree's influence.*

Introduction

As part of a collaborative program between the Institut de recherche en biologie et ecologie tropicale (IRBET) and the Programme special de conservation des eaux et du sol/Agroforesterie (CES/AGF), research activities were initiated at Watinoma in Burkina Faso. Four *Faidherbia albida* parks were inventoried and the effect of this species on sorghum soils and crops were presented.

Watinoma Village

Watinoma, a Mossi village, has a population of 1500. Located in the north of the Central Plateau of Burkina Faso, it consists of two bottomland areas and their drainages. The village has practiced most of its agriculture in these bottomlands over the past 30 years. Lately, the last fallow lands were cleared and cropped because of population pressure (130 persons km^{-2}).

Watinoma is in the Sudano-Sahelian zone and experiences great variation in annual rainfall. Between 1982-90, rainfall was 30-50% below the long-term average of 609 mm. This was accompanied by irregular rainfall distribution during the wet season, another major constraint for agriculture. In 1990, for example, the discontinuous and poor rains (547 mm in 37 days) affected all upland and plateau crops.

Location of Parks

The four parks studied were among the densest *F. albida* stands at Watinoma. Parks 1 (1.7 ha) and 2 (0.6 ha) were located on sloping piedmonts below a water-impermeable plateau. These parks are located on ravine-free topographical highs, and are therefore important to the village. Park 3 (4 ha) was located in a bottomland area prone to flooding. Park 4 (2.2 ha) was situated on the fringe of a bottomland area. Parks 3 and 4 made up part of the farmed bushlands, and were located further from the village than Parks 1 and 2.

Results of an inventory (Table 1), revealed two park Vegetative types, i.e., monospecific and multispecific. Parks 2 and 4, classed as monospecific, were largely composed of *F. albida.* The densest had an average of 55 trees ha^{-1} of which 45 were *F. albida.* In Parks 1 and 3 (multispecific), F. *albida* made up only one-third of the trees, and tree densities were low. Nearly 20 species were noted in Parks 1 and 3—*Adansonia digitata. Acacia Senegal, Sclerocarya birrea, Azadirachta indica,* and *Balanites aegyptiaca* in

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Table 1. Site and tree characteristics of *Faidherbia albida* in four parks of Watinoma, Burkina Faso, 1990.

Parameter	Park 1	Park 2	Park 3	Park 4
Total area (ha)	1.7	0.6	4.0	2.2
Tree density (stem ha^{-1})				
All trees	38	55	21	24
F. albida	14	45	7	19
Ratio *F. albida/*all trees	37	82	33	78
Average canopy size (m^2)	43	15.5	140.5	88.5
Range of canopy sizes (m^2)	3-239	2-80	9-417	1-599
Ground cover by *F. albida* (%)	6.4	7.0	9.8	16.5
Height distribution (%)				
2-7 m	25	41	3	15
7-12 m	35	59	11	58
12-17 m	35	0	75	12
17-21 m	5	0	11	15
Diameter distribution (%)				
5-30 cm	24	67	14	50
30-60 cm	56	33	18	25
60-90 cm	20	0	64	10
90-140 cm	0	0	4	15

Park 1; *Butyrospermum parkii, Gardenia ternifolia, Ficus gnaphalocarpa,* and *Piliostigma reticulatum* in Park 3.

The percentage of ground cover of F. *albida* (area shaded by the canopies) was low in Parks 1 and 2 due to the small average size of the trees. It was higher in Parks 3 and 4, where individual trees were much larger.

Throughout the entire area, natural regeneration of *F. albida* from stump sprouts and root suckers were frequently cut back by farmers at the end of the dry season. Densities of these shoots and other regeneration were 22 ha^{-1} for Park 1,27 ha^{-1} for Park 2,4 ha^{-1} for Park 3, and 29 ha^{-1} for Park 4. Although all were constantly exposed to cutting back and browsing, abundant regeneration existed in Parks 1, 2, and 4.

Height and diameter distributions reflected the ages and dynamics of these parks. Park 1 was dominated by adult trees, but there was also a significant number of young and old trees. In Park 2, the youngest and densest stand, two-thirds of the *F. albida* trees had small diameters. Park 3, a very old stand, was marked by few trees per hectare and a very uneven diameter class distribution. Here, there were few small-diameter trees or natural regeneration. Park 4 was generally young, with an even distribution of large-diameter classes.

An attempt to establish allometric correlations of tree parameters between parks (Janodet 1990) yielded no significant differences between the stands for the height and circumference (at diameter breast height (dbh), or 1.30 m) comparison. For crown surface area as a function of height, there was a significant difference between parks. Regression coefficients were very close, despite heavy pruning of the smallest trees, particularly in Parks 2 and 4, (i.e., stands containing higher numbers of young F. *albida).*

An evaluation of pods and seeds collected from 10 trees in each park (Table 2) showed that values for pods and seeds of bottomland parks were 50-100% greater for all parameters measured. Further, seeds from bottomland trees were much less susceptible to insect attack.

Farming Practices

Soils of upland Parks 1 and 2 were cultivated with the hoe, and donkey-drawn plows were predominantly used in the bottomlands. Parks 1 and 2 were fertilized only with manure whereas farmers applied modest levels of chemical fertilizers in Parks 3 and 4, which were also manured in the dry season.

Sorghum, sometimes intercropped with beans in Parks 1 and 2, is the major crop throughout the area. Long-duration sorghum is planted at 80 x 40 cm in the bottomlands. Short-duration sorghum is grown on

Table 2. Pod variation between the four parks, Watinoma, Burkina Faso, 1990. (Samples were collected from 10 trees per park.)

Parameter	Park 1	Park 2	Park 3	Park 4
Color	Gold	Gold	Orange	Orange
Relative thickness	Flat	Flat	Pulpy	Pulpy
Relative length	Short	Short	Long	Long
100 pod mass (g, ±SE)	252 ± 11	220 ± 9	347 ±11	345±11
No. of seeds per 100 pods	534	508	1034	907
100-pod seed mass (all seeds, g)	31	34	59	76
Insect-infested seeds (%)	51	51	70	82
Mass of 100 insect-free seeds (g)	5.1	5.8	5.6	7.9

Table 3. Chemical characteristics of soils from two horizons under[1] and away[2] from *F. albida* canopies, Watinoma, Burkina Faso, 1990.

	Park 1		Park 2		Park 3		Park 4	
Soil parameter	Under	Away	Under	Away	Under	Away	Under	Away
0-20 cm								
Organic matter (%)	1.4	0.9	1.6	0.9	2.7	2.4	1.6	1.6
Organic carbon (%)	0.8	0.5	1.0	0.5	1.6	1.4	1.0	0.7
Organic nitrogen (%)	0.9	0.8	1.3	0.6	1.8	1.3	1.2	0.9
C/N ratio	8.6	6.7	7.6	8.3	8.7	11.1	8.1	7.9
Phosphorus (ppm)	36.1	30.2	29.4	24.9	14.0	10.6	8.3	6.1
Calcium (meq 100 g^{-1})	4.3	4.2	3.7	2.5	10.0	8.9	5.2	4.6
Magnesium (meq 100 g^{-1})	1.0	1.0	1.1	0.8	3.9	3.9	2.3	2.3
Potassium (meq 100 g^{-1})	0.8	0.5	0.5	0.3	0.7	0.4	0.6	0.3
CEC	5.8	5.2	5.0	3.4	14.9	13.7	8.1	7.1
pH (water)	7.8	7.7	7.1	6.7	5.9	5.8	6.1	6.0
pH (KCl)	7.0	6.9	6.5	5.7	5.2	4.9	5.3	5.0
20-40 cm								
Organic matter (%)	-	-	0.8	0.6	2.2	2.2	1.2	0.9
Organic carbon (%)	-	-	0.5	0.3	1.3	1.3	0.7	0.5
Organic nitrogen (%)	-	-	0.8	0.5	1.2	1.2	0.9	0.7
C/N ratio	-	-	6.0	6.8	11.2	10.3	7.7	7.2
Phosphorus (ppm)	-	-	9.1	10.6	10.6	6.6	5.8	6.3
Calcium (meq 100 g^{-1})	-	-	3.1	3.7	11.3	10.2	4.9	4.6
Magnesium (meq 100 g^{-1})	-	-	1.0	0.8	4.2	4.5	2.3	2.0
Potassium (meq 100 g^{-1})	-	-	0.8	0.3	0.4	0.3	0.6	0.6
CEC	-	-	4.5	4.7	16.0	15.2	7.7	7.4
pH (water)	-	-	7.0	7.4	5.9	5.8	6.2	6.4
pH (KCl)	-	-	6.4	7.0	5.0	4.9	5.2	5.7

1. Samples under *F. albida* consisted of bulked subsamples collected from east, west, north, and south of the trunks of three trees/park.
2. Samples away from *F. albida* consisted of two bulked subsamples, each located 15 m from each tree.

the gravelly soils of Parks 1 and 2, and is usually planted with a spacing of about 65 x 35 cm.

Soil Characteristics

Soils samples were taken at depths of 20 cm in each park and at depths of 20-40 cm in Parks 2,3, and 4. In each Park, 4 samples were taken under each of three adult *F. albida* (1.5 m from the bole) and 2 samples 15 m away from each tree. Results of the analyses, presented in Table 3, clearly demonstrated differences between not only bottomland and upland park soils, but also between soils beneath *F. albida* cover and those outside the cover of the species.

Upslope soils, characterized by sandy-clay texture and gravel, contained less organic matter, carbon, nitrogen, and exchangeable bases than bottomland soils. Only available phosphorus content was higher in upslope soils. We speculate that the higher values for bottomland (Park 3) and border-bottomland (Park 4) soils were derived from soil and organic matter additions washed down from surrounding slopes. These clayey sands or loams had a lower pH than upslope soils (pH = 7.0).

A comparative analysis of soils under and outside the cover of *F. albida* showed that the presence of the tree improved soils in all cases (Table 3). Organic matter increased 45% and organic carbon content 85% under *F. albida* cover in Parks 1 and 3. Organic nitrogen content was 15% higher in soils beneath trees in Park 1,107% higher in Park 2,43% higher in Park 3, and 29% higher in Park 4. Similarly, there was 20% more available phosphorus under the trees in Park 1,18% more in Park 2,32% more in Park 3, and 36% in Park 4. The trend was similar for exchangeable potassium.

Agronomic Effects

In each of the four parks studied, 10 circular plots measuring 20 m^2 (excluding the area of the trunk) were laid out beneath adult *F. albida* 60-90 cm in dbh. The midpoint of each circle was the center of the tree trunk. Similarly, ten 33.2 m^2 circular control plots, were randomly placed 15 m from adult *F. albida* under topographical conditions similar to those under tree canopies.

Results and Discussion

Table 4 presents the average crop yields obtained for each park under and outside the influence of *F. albida.* As in the case of the soil analysis, differences occurred according to topography and influence of *F. albida.*

Differences in average numbers of sorghum stems ha^{-1} and heads ha^{-1} produced under and outside the

Table 4. Yield components of sorghum grown under and away from *F. albida* canopies, Watinoma, Burkina Faso, 1990.

	Park 1		Park 3		Park 4	
Soil parameter	Away	Under	Away	Under	Away	Under
No. stalks ('000 ha^{-1})	14.3	20.9	19.1	20.3	20.7	18.5
SE ±	4.7	7.1	4.3	4.6	6.3	4.9
No. heads ('000 ha^{-1})	6.4	11.9	16.2	16.2	15.7	14.5
SE ±	2.0	2.9	4.2	3.5	2.8	3.3
Total mass (t ha^{-1})	2.1	3.4	3.5	* 5.9	3.4	* 6.7
SE ±	0.5	1.0	1.0	1.3	0.4	1.6
Stalk mass t ha^{-1}	1.5	2.6	2.7	* 3.9	2.2	* 4.4
SE ±	0.5	1.0	0.8	0.4	0.4	1.4
Head mass (t ha^{-1})	0.5	0.7	0.8	* 2.1	1.2	* 2.4
SE ±	0.2	0.2	0.2	1.0	0.4	0.7
Grain mass t ha^{-1}	0.2	* 0.5	0.7	* 1.6	0.9	* 1.8
SE ±	0.1	0.2	0.2	0.8	0.4	0.7
100-seed mass (g)	15.3	15.3	24.5	24.5	24.0	24.2
SE ±	0.6	0.6	0.9	0.9	0.1	0.4
Seed mass per head (g)	30.6	43.6	42.1	* 110.4	58.4	* 134.8
SE ±	13.8	4.7	7.7	72.4	25.1	69.3
Threshing percent (%)	45	70	82	82	76	75
SE ±	3	9	4	12	12	9

1. * indicates significant difference between mean pairs in a given park at $P < 0.05$.

influence of *F. albida* in Parks 3 and 4 were insignificant. In Park 1, however, average values were much higher beneath *F. albida.* Average total biomass and mass of seeds, stems, and heads were significantly higher in plots under *F. albida* in Parks 3 and 4. The effect was particularly notable in Park 3, where seed mass values of plots beneath *F. albida* were 149% higher than control plots. In Park 1, only grain yield (0.5 t ha^{-1} vs 0.2 t ha^{-1}) under *F. albida* cover reflected the beneficial effect of the species. In Parks 3 and 4, average seed mass per stem and head beneath *F. albida* were higher than those outside the canopy.

Although there was little or no difference in 1000-seed mass or percent yield at the time of threshing between the two types of plots in the parks, differences were evident between bottomland and upland parks. A significant correlation existed between increases in grain yield under *F. albida* and diameter size in bottomland parks.

Conclusion

Results on the effect of *F. albida* on sorghum crops in Watinoma confirmed those obtained under comparable conditions (Charreau and Vidal 1965; Dancette and Poulain 1968, Louppe 1989). However, the differences noted between the two plot types in this study are much larger than those that have been described up to present. In the Yatenga (CTFT 1965), increases in millet yields beneath *F. albida* (relative to yields outside *F. albida* cover) decreased from 78% on upland laterite to 64% downslope, to 18% in the bottomlands. In the province of Bazega, Maiga (1987) there was 75% more millet and 45% more sorghum beneath *F. albida.*

Differences in results may be attributed to the proximity of the plots to the trunk. Louppe (1989) found that average grain yield decreased as a function of distance from the trunk to the periphery of the crown and a few meters beyond. In this study, crop yield gains expressed in terms of yield per total crown surface area were 11% for Park 1,14% for Park 3, and 17% for Park 4.

Park 3 showed the best crop yield gain in terms of yield/density of *F. albida.* This Park had the most large-diameter individuals per unit of surface area which correlated strongly with yields. Also, Park 3 was the least affected by pruning which, by reducing crown sizes and therefore their beneficial effect, has a negative impact on crops (Louppe 1990).

Water stress resulting from lack of rainfall in 1990 apparently increased the difference in yields obtained beneath and outside the influence of *F. albida.* The crowns created microenvironments with higher relative humidity, a lower evapotranspjration potential, reduced maximum temperature, increased soil humidity, and greater rain interception (Dancette and Poulain 1968). Bottomland parks gave higher yields than upland parks.

These first results clearly justify the silviculture of *F. albida* parks for better crop yields. Specific strategies and techniques for multipurpose management (agriculture, forestry, fodder production) remain to be investigated.

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The Effect of *Faidherbia albida* on Soil Properties in a Semi-Arid Environment in Morogoro, Tanzania

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Abstract

An ongoing 6-year old experiment on the effects of Faidherbia albida *trees on soil properties in a semi-arid environment in Morogoro, Tanzania is discussed. The experiment was a split-plot design in randomized complete blocks with four replications. The main plots were food crops (maize or beans with fertilizer) and clean weeding; the subplots were without any tree, or with trees spaced at 4x4,5x5, and 6x6 m. Plots with* F. albida *trees had significantly higher levels of soil pH, organic carbon, total nitrogen, and calcium. No significant differences existed in the levels of soil phosphorus, potassium, magnesium, and sodium between areas with and without the trees. Plots intercropped with either beans or maize had significantly higher levels of calcium, phosphorus, total nitrogen, and organic carbon but lower soil pH. There were no significant interaction effects between tree density and intercropping, indicating that these effects acted independently in influencing residual levels of soil nutrients. Despite the high levels of certain soil nutrients in areas with trees, there were no significant differences in crop yields between areas with and without the trees.*

Introduction

Although the great benefits of *Faidherbia albida* to farmers in the Sudano-Sahelian zone of Africa is well known, very little information exists in the eastern African region regarding the performance of *F. albida* on crop lands. This paper presents results from a semi-arid environment in Tanzania where relatively young *F. albida* trees were assessed for their effects on soil nutrients when grown in association with maize and beans or as a monocrop.

Materials and Methods

Site Description

The experimental site is at Mafiga, Morogoro (37°38'E and 6°50'S) which is 520 m above sea level. The area lies on a flood plain and is almost flat, with a slope of less than 5%. The soils are sandy loams, with pH (water) of 6.5, organic carbon content of 0.7%, total nitrogen content of 0.04%, available phosphorus content of 8.8 ppm, and exchangeable bases of 10.5 meq 100 g^{-1} (Kesseba et al. 1972). The mean annual rainfall is about 860 mm, falling between December and May. Monthly mean temperatures vary between 19 and 34°C, while mean monthly relative humidity varies from 40% to 70% (FAO 1984).

Experimental Design

Container-grown seedlings of *F. albida* were planted in Feb 1980 in a plowed and harrowed field that had been fallow for several years (Maghembe and Redhead 1982). The design was a split plot, replicated 4 times, with food crops (maize or beans) and a non crop control forming the three main plots. The 4 subplot treatments were without trees or with trees spaced at 4 x 4, 5 x 5, and 6 x 6 m. The subplots

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measured 30 x 30 m and contained 0, 56, 36, or 25 trees. Maize (*Zea mays,* Ilonga composite) and beans *(Phaseolus vulgaris,* Canadian Wonder) were planted for seven consecutive seasons. Fertilizer was applied each season at a rate of 400 kg ha^{-1} ammonium sulfate and 200 kg ha^{-1} triple superphosphate for maize and 200 kg ha^{-1} ammonium sulfate and 200 kg ha^{-1} triple superphosphate for beans. All plots were clean weeded by harrowing using a tractor and supplemented by hand hoeing.

Soil Samples

Soil samples were collected using a soil auger from five sampling points in each of the subplots without trees and from the subplots with trees spaced at 5 x 5 m (400 trees ha^{-1}) of each replication. At each sampling point, soil samples were taken at three soil depths (0-15, 15-30, and 30-60 cm). Samples were bulked for each subplot, and then subsampled.

Chemical analyses were carried out to determine total nitrogen (Bremmer 1965), available phosphorus (Bray and Kurtz 1945), exchangeable potassium, calcium, magnesium, and sodium. In addition, soil pH (1:2 soil to water paste) and organic carbon (Allison 1965) were determined.

Statistical Analysis of Data

Analysis of variance for the split-plot design was performed on the nutrient content of the soil to test differences between the treatments. Duncan's multiple range test was used to separate significant means.

Results and Discussion

Soil pH and the concentrations of organic carbon, total nitrogen, phosphorus, and potassium decreased down the soil profile, while those of magnesium and sodium increased (Table 1). The concentration of calcium remained relatively constant throughout the soil profile. Intercropping with beans or maize significantly increased the levels of soil calcium, phosphorus, total nitrogen, and organic carbon but lowered soil pH. It did not seem to affect the levels of potassium, magnesium, and sodium. Plots with *F. albida* trees had significantly higher soil pH, organic carbon, total nitrogen, and calcium, but phosphorus, potassium, magnesium, and sodium were not affected in these plots. There were no significant interaction effects between the presence or absence of trees and intercropping, indicating no link between the two on the soil chemical differences.

Table 1. The concentration of soil elements in areas with and without *Faidherbia albida* trees under an agroforestry program at Mafiga, Morogoro, Tanzania.

Treatment	PH	Organic carbon (g 100 g^{-1})	Total nitrogen (g 100 g^{-1})	P (mq kg^{-1})	K	Ca	Mg	Na
					(meq 100^{-1})			
				Main plots				
No crop control	6.2	0.62	0.05	24.5	0.42	3.58	1.15	0.03
Bean intercrop	5.9	0.68	0.06	33.6	0.46	3.80	1.13	0.03
Maize intercrop	6.0	0.70	0.06	30.5	0.43	3.89	1.23	0.03
SE±	0.04	0.03	0.002	2.4	0.03	0.12	0.05	0.003
				Subplots				
No trees	6.0	0.64	0.05	27.8	0.43	3.56	1.15	0.03
400 trees ha	6.1	0.70	0.06	31.4	0.44	3.95	1.19	0.03
SE±	0.03	0.02	0.002	1.9	0.02	0.10	0.04	0.002
				Soil horizon				
0- 15 cm	6.1	0.80	0.07	38.5	0.59	3.82	1.13	0.03
15-30 cm	6.0	0.70	0.06	28.3	0.44	3.83	1.13	0.03
30-60 cm	6.0	0.50	0.05	21.9	0.27	3.61	1.26	0.04
SE±	0.04	0.03	0.002	2.4	0.03	0.12	0.05	0.003

The high levels of phosphorus and nitrogen in the intercropped areas were probably due to the residual effects of the fertilizers that had been applied to these plots. The increase in organic carbon and calcium could also be indirectly related to the application of fertilizers. The slightly higher but statistically significant levels of soil pH, organic carbon, total nitrogen, and calcium in areas with *F. albida* trees agree with findings elsewhere in Nigeria (Alexander 1989), Malawi (Saka and Bunderson 1989) and in the Sudano-Sahelian zone, (Charreau and Vidal 1965; Dancette and Poulain 1969).

However, at the Kenyan Coast, Jama and Getahun (in press) reported no significant differences in the levels of soil nutrients between experimental areas with trees and without trees. They ascribed this to a possible 'lock-up' of these nutrients in the tree biomass in high density stands.

The absence of any significant influence of *F. albida* trees on soil at the Kenyan Coast could be attributed to the young age of the trees (4 years). Most of the other studies cited involved mature trees. This could explain why in this study involving 6-year old trees, most soil elements that are usually reported as significantly higher in the presence of *F. albida* trees were not. It could also be the reason why the yields of maize and beans that had been intercropped with the trees were not significantly different from those in areas without the trees (Okorio and Maghembe 1991).

Poschen (1986) estimates that *F. albida* trees need 20-40 years to grow to a size when they can influence the soil nutrients and hence significantly improve yields of underplanted crops. If so, this means that the present trial needs to be maintained and monitored for some time to come before any firm conclusions and recommendations can be made. The next assessment on the influence of the trees on the soil nutrients should also include all the tree densities in the trial (278, 400, and 625 trees ha^{-1}) because the present assessment only considered medium tree density stands (400 trees ha^{-1}). It is possible that a different picture could have emerged if the other tree density stands had also been assessed.

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Preexisting Soil Fertility and the Variable Growth *of Faidherbia albida*

S.C. Geiger[1], R.J. Vandenbeldt[2], and A. Manu[1]

Abstract

A study at the ICRISAT Sahelian Center on the association between the variability in soil properties and growth of young (3-year old) Faidherbia albida *trees indicated that the variability in* F. albida *growth is caused, in large part, by variability in soil properties over relatively short distances. Good growth areas had higher clay contents and base saturations, and lower aluminium saturation percentages than poor growth areas within the site. Seedlings planted on sheet-eroded sites caused by runoff from micro-topographically high areas performed poorly. The proximity to abandoned termite mounds and other fertile micro-high areas determined the rate of tree growth. Variability in* F. albida *growth in plantations within Niger is hypothesized to be due, in part, to preexisting soil parameters. Results also suggest that the 'albida effect' might be partially caused by these preexisting islands of fertility. This site-determined variable growth of* F. albida *could be exploited with proper seedling placement strategies, e.g., selecting micro-high areas and abandoned termite mounds for seedling outplanting and avoiding sheet-eroded areas and other undesirable microsites.*

Introduction

Faidherbia albida is renowned for the so-called 'albida effect', i.e., crops growing under *F. albida* trees have higher yields than crops growing away from the tree canopy. Proposed explanations for this yield increase are: (1) light shading early in the cropping season, which results in a decrease in soil surface temperatures (ICRISAT 1991); (2) nutrient cycling, where nitrogen (N) fixed by the tree and nutrients assimilated through the roots are returned to the soil surface through litter fall (CTFT 1988); and (3) feces and urine deposition by cattle seeking shade and fodder during the dry season.

There have been many attempts to plant *F. albida* in farmers' fields to increase total system productivity and therefore crop yield, but these have given mixed results. This is due to erratic tree establishment and subsequent variable growth. The variable growth pattern has been attributed to genetic heterogeneity (Felker 1978), but it is similar in appearance to variable millet growth caused by spatial variability in soil physical and chemical properties (Manu et al. 1990). These can vary widely within short distances (10 to 15 m) creating 'islands of fertility' within a field. The productive sites are generally characterized by micro-topographically high positions (micro-highs), lower percent Al saturation, higher percent base saturation, and a thicker A horizon.

Several of the soil parameters found under *F. albida,* especially the 52% increase in clay content reported by Jung (1966), cannot be explained by the nutrient pump or any other currently proposed hypothesis. Quantitative experiments have not been done to determine whether higher soil productivity precedes or is created by the trees (Sanchez 1987). If the growth of *F. albida* to maturity is influenced by seedling placement on more productive microsites, then it could be logically argued that such fertility would remain later in the life of the tree and influence the increased crop growth underneath it.

The objectives of the present study were to determine if spatial variability in soil chemical and physical properties was a causal factor in the variable

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Gelger, S.C., Vandenbeldt, R.J., and Manu, A. 1992. Preexisting soil fertility and the variable growth of *Faidherbia albida.* Pages 121-125 *in Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt. R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry,

growth of young *F. albida* trees. The results of this study will be used to develop a methodology for seedling outplanting and to propose a more comprehensive model explaining the increased levels of fertility found under mature *F. albida* trees.

Materials and Methods

Site Description

The experiment was located at the ICRISAT Sahelian Center (ISC), Sadore, Niger, 45 km south of Niamey at 13°N 2°E. The site is situated within the sand plain geomorphological unit, which consists of gentle sloping terraces of eolian sand underlain by an indurated laterite layer. At this particular site, the laterite layer was found at a depth of approximately 5 m. The soil at this site is part of the Labucheri series and is classified in the US Soil Taxonomy as a sandy, siliceous, isohyperthermic Psammentic Paleustalf (West et al. 1984). Total yearly rainfall averages approximately 540 mm. Depth to the water table is approximately 30 m.

The trial was planted in Aug 1987, using 3-month-old potted seedlings raised from a collection of seeds bulked from 20 trees near Sadore. Seedlings were transplanted in a 2 x 2 m grid pattern that covered an area of 5305 m^2, with a final population of 1258 trees.

Field Methodology

Soil topographic differences throughout the field were measured on a 4 x 4 m grid, with each data point located in the center of each tree quartet. *F. albida* growth was estimated in Mar 1990 by averaging the height of the four trees in each quartet surrounding grid point measurements. These data have been previously reported (Geiger et al., in press).

In order to statistically correlate differences in soil properties with differences in *F. albida* growth, a series of ten sites were sampled, five in areas of poor tree growth and five in areas with good tree growth. Soils were sampled to a depth of 150 cm in 10-cm increments at each site. As with the topographical survey, sampling sites were located between four adjacent trees, the heights of which were averaged to compare with each soil sample.

Soil Analyses

All soil samples were air-dried and ground to pass through a 2 mm sieve prior to analysis. Particle-size fractionation was determined by the pipette method (Gee and Bauder 1986). Soil pH was measured in 2:1 soil:H_2O and M KCl. Exchangeable acidity and Al were determined by titration after extraction in M KCl as described by McLean (1982). Exchangeable bases were displaced with M NH_4OAc (pH 7.0) (Thomas 1982). Calcium (Ca) and magnesium (Mg) were analyzed by atomic absorption spectrophotometry and potassium (K) and sodium (Na) by flame photometry. Available P was determined using the Bray 1 extractant, and P in solution was analyzed spectrometrically using the molybdate blue method (Olsen and Sommers 1982).

Table 1. *Faidherbia albida* tree height (m) compared with surface elevation (cm) on good and poor growth sites at Sadore, Niger, 1990. (Tree age =5 2.0 years.)

Area type	Tree height (m)	CV (%)	Surface elevation[1] (cm)
Good	147±19(n=20)	12.3	76 ±23
Poor	80±9(n=20)	12.3	53 ±36
Field average	108 ±28 (n=1258)	26.0	-

1. Surface elevation is relative and is based on whole-field topography.

Results

There was no significant correlation between tree height and microtopography over the entire field site. However, well-defined areas of good growth were observed within the site (Table 1). While tree height differed significantly among the 10 sites selected for their growth characteristics, surface topography was barely significant. Differences in tree height ranged between 0.44 and 2.09 m. The CV among the trees located in the 5 good growth positions was identical to that of the 5 poor growth positions (12.3%) and lower than that of the field average (26%). These data indicate that factors other than site topography and genetic heterogeneity of *F. albida* were primarily responsible for the variable growth.

Effect of Soil Characteristics on Tree Growth

Differences in average clay content between the good and poor growth sites were greatest below a depth of

20-30 cm (Fig. 1a). The general trend clearly indicated a higher clay content with depth in the good growth areas.

Total exchangeable bases were significantly different below the 20 cm depth, following the clay distribution (Fig. 1b). Notably, exchangeable acidity, which has been linked to the variability in millet growth in this part of the Sahel (Scott-Wendt et al. 1986) followed a reverse trend; it was greatest at the poor growth sites (Fig. 1c). Values of available P, although significantly different between good and poor sites, were too close numerically to draw definitive conclusions (Fig. 1d).

Microsites Affecting Tree Growth

In studies concerned with the variable growth of millet, the productive and nonproductive areas within farmer's fields can often be deduced from surface characteristics of the soil (Geiger and Manu 1991). These microsites included microtopographic high areas (productive) and erosional surfaces (nonproductive). While there was no correlation between microtopography and tree growth over the entire field, three abandoned termite mounds (T1, T2, and T3) and two micro-high areas relative to the surrounding soil (MI and M2) were identified with these 'islands' of good growth (Table 2). Trees on these microsites were among the tallest 25% found in the trial. The highest elevational point was located in the center of the field, and associated with the T2 eroded termite mound which had ' melted' to a 2-3 m diameter crusted surface 3-4 cm above the soil surface. The poorest growth in the field was associated with sheet-eroded surfaces (E1 and E2). These trees were among the smallest 50% found within the site.

Table 2. *Faidherbia albida* height (cm) at different microsite positions identified by soil surface characteristics, Sadore, Niger, 1990. (Tree age = 2 years.)

Microsite	Location symbol	Number of trees in the microsite	Tree height (cm)
Termite mound	TI	16	152±14
	T2	16	143 ±29
	T3	16	161 ± 9
Microhigh	MI	6	176 ± 7
	M2	6	138 ± 8
Sheet-erosion	E1	81	80 ±15
	E2	35	69 ±12

Discussion

Soil parameters to a depth of 150 cm affected the fertility status and differed significantly between the good and poor growth areas. The most striking differences were in clay content and exchangeable acidity, which have been shown to effectively control the status of other fertility parameters affecting plant growth in these poorly buffered soils (Manu et al. 1990).

An association between abandoned termite mounds and increased growth of crop plants has been observed in the Sahel (Lal 1987). In the termite mounds within the field site, this effect could be attributed to: (1) water harvesting from the surface of the mound, where rain falling on the crusted surface runs off and is concentrated in the surrounding soil; and (2) increased fertility of the soils beneath the mound due to an enrichment in clay. It is likely that the increased clay content in the good growth sites, which was significantly different from the poor sites below a depth of 20-30 cm, was due to the action of termites redistributing clay from deep within the profile and concentrating it in the surface 1.5 m. To take this one step further, the existence of topographic relief differences supporting good tree growth may be due to very old termite mounds that are no longer visible at the soil surface. A detailed study of the effect of past termite activity on the growth of *F. albida* is presented elsewhere in these proceedings (Brouwer et al. 1992).

Previous studies coorelating soil variability with pearl millet growth variability have shown a clear relationship with microtopographic position (Pfordresher et al. 1989; Geiger and Manu 1991). Differences in soil physical and chemical parameters were greatest in the surfaces of those soils, and relatively similar with depth. This type of variability has been associated with deposition and deflation of eolian materials and is different from the variability described in our study.

Qualitative observations over a wide range of geomorphic and climatic zones in Niger indicate that many farmers take advantage of fertile microsites, such as those near abandoned termite mounds and micro-high areas, to plant crops such as sorghum that normally would not grow to maturity in the surrounding soils. This would suggest that soil fertility parameters and/or water relations are better in these sites. The outplanting of *F. albida* seedlings on these microsites would no doubt improve chances of their survival and growth.

If one assumes that, in the real world, *F. albida* seed is randomly dispersed in fields through animal

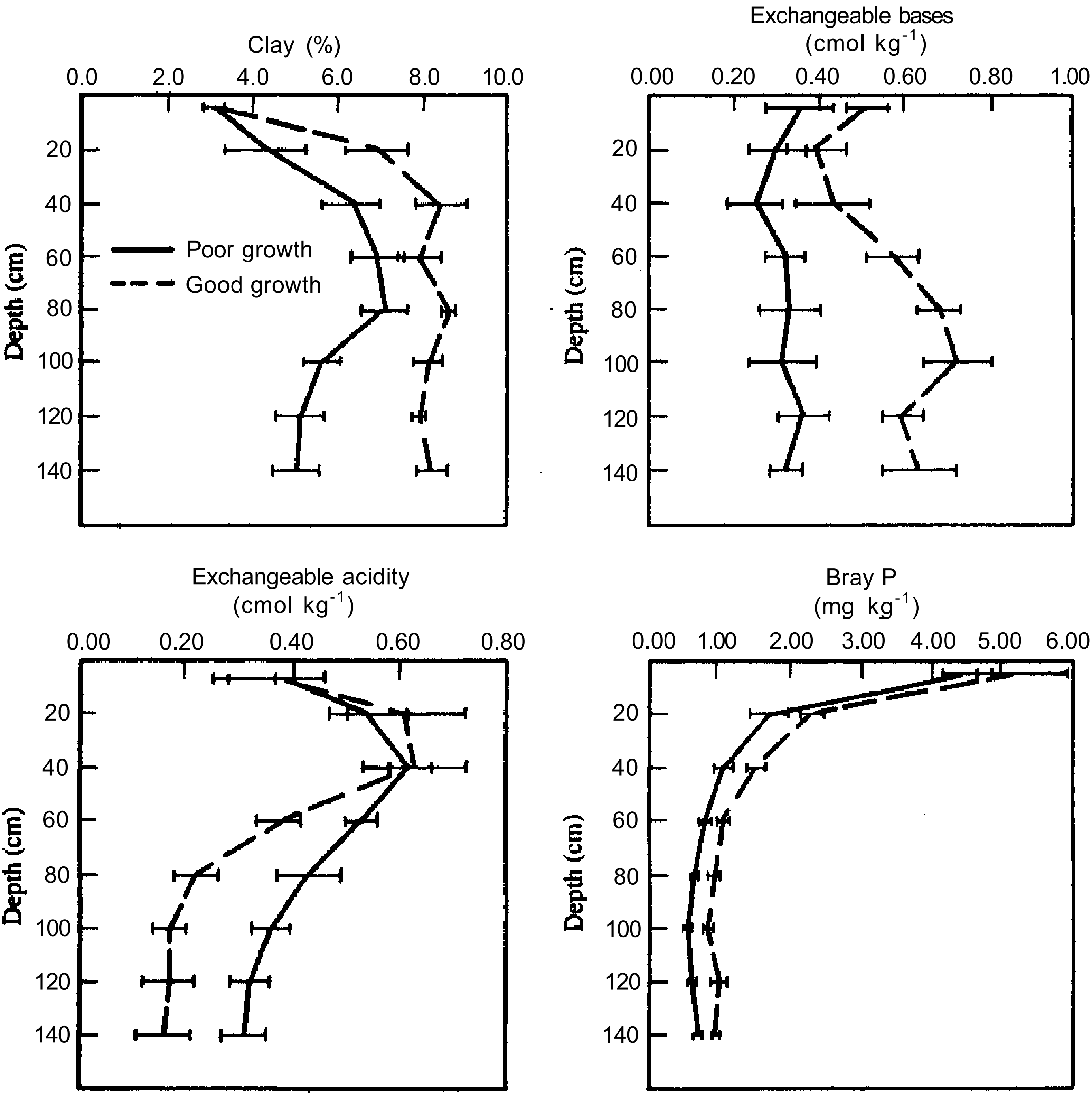

Figure 1. Depth distribution of soil properties associated with good and poor growth sites at ISC, Sadore, Niger, 1990. Horizontal bars represent one standard deviation.

manure, then it follows that the fastest growth and highest survival will be by those seeds landing on the most fertile microsites on the landscape. We believe that the growth variability found in *F. albida* plantations in Niger is caused by similar factors. If tree planting were restricted to termite mounds, microhighs, and other "islands of fertility' as indicated by good millet growth, tree survival and productivity of both the tree and the crops grown beneath its canopy would be ensured. The fertility of these microsites would be sustained and even improved through other factors integrated into the 'albida effect'.

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The Agroecological Significance of *Faidherbia albida*

J.H. Williams[1]

Abstract

Pearl millet (Pennisetum glaucum) *and* Faidherbia albida *generally co-exist in some of the world's harshest cropping environments. The tolerance of millet to high temperatures, soil acidity, and low soil fertility allows it to dominate over other more productive and valuable crops in these regions. However,* F. albida *is associated with many environmental changes at the micro-environment level that results, in effect, in a more favorable agroecological environment and provides the opportunity for increased diversity of cropping with the traditional millet-growing regions of Africa. We have begun a major research effort to determine limits to new species introduction within the 'albida' agroecological environment.*

Introduction

One of the major problems facing farmers of the Sahel is the lack of cropping diversity. They are restricted by the rigors of the environment—which other crop species are unable to tolerate—to growing millet, for which there is a very limited market. Despite considerable investment in technology, very little has changed at the farm level, because of the lack of trade in the primary agricultural commodities. Development of the region requires more valuable crops to help reverse the decline in farmers' income.

This paper reviews the major determinants of adaptation of crops, shows how *F. albida* modifies these factors and the direction in which it does so, and finally points to the opportunity to exploit this 'albida effect'.

The Major Determinants of Crop Adaptation

The major determinants of crop adaptation are temperature and soil factors. The seasonal variations in water supply are perhaps less significant in determining cropping options than is generally believed.

Temperature and Crop Adaptation

The most important single factor determining crop growth in Sahelian Africa is temperature. There is first the general temperature effect on the biological processes of plant growth and development over short periods but at critical phases of crop growth. It is well established that crops have definite temperatures below (T_{base}) and above (T_{max}) which they do not grow (Ong and Monteith 1984). Wheat, for instance (T_{base} = 0°C, T_{max} = 35°C) only succeeds in sub-Saharan Africa in the cooler high- altitude environment or during the winters. Yields are greater where the mean temperatures during the growing season are 20-25°C.

In the first weeks after sowing, cereal plants are too small to shade the soil surface, which may reach temperatures exceeding 60° C a few days after a rain. This results in death or greatly reduced growth of the plants. In a recent experiment at Sadore we examined the effect of different amounts of shading on soil temperature and the related growth of a number of species. Where we shaded the soil for nearly half the day we were able to grow maize in the middle of May. Millet also clearly responded to manipulation of the soil surface temperature (Fig. 1). Legume species in contrast locally control the soil surface temperature

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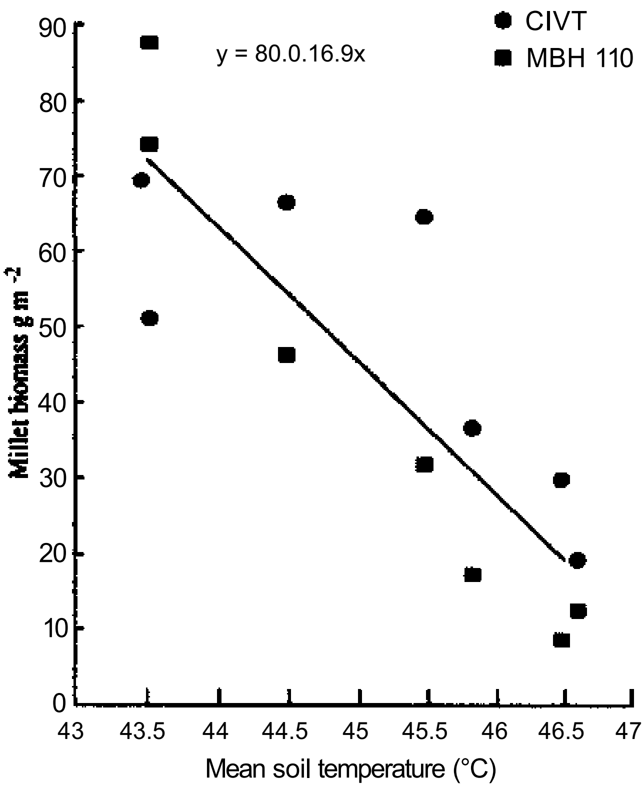

Figure 1. Biomass of pearl millet at 6 weeks after sowing as influenced by cultivar and duration of shade, ICRISAT Sahelian Center, Sadore, Niger, 1990. (Source: Vandenbeldt and Williams, in press.)

by rapidly shading the soil around the stem, and are thus much less prone to damage by the effects of a large radiation load on soil temperature.

Another circumstance where tolerance to high temperatures determines the relative success of a crop species is in the event of drought. The temperature of a leaf depends on its energy balance. When transpirational cooling can no longer occur because of stomatal resistance, the temperatures of leaves exposed to full sunlight may rise to 10°C above the ambient air temperature instead of remaining a few degrees below it. In such conditions, maize leaves quickly pass the T_{max} of that species, but millet leaves would still be able to survive; this probably explains why millet is less drought-susceptible than maize and sorghum.

Soil Fertility and Crop Adaptation

Soil chemistry and physical properties are also a major basis for adaptation differences between crops. Maize generally requires higher fertilizer levels than sorghum, which in turn has higher soil fertility levels than millet. In West Africa, the soil pH is also a major determinant of soil nutrient availability. Many soils have a low pH, which results in toxic levels of aluminium and manganese in the soil solution. Again, however, millet will grow in soils where low pH prevents successful cultivation of sorghum or maize.

Soil physical properties are also a factor in determining the relative success of a species. Where there is a higher clay content, there is usually more nutrients available and soil pH is better buffered and generally higher. Also, the presence of finer particles results in a better water-holding capacity and therefore in less drought-induced temperature stress.

F. albida Agroecological Shift

Dancette and Poulain (1969), quantifying the effect of *F. albida* on air temperature, found that maximum temperature under the tree was about 3°C lower than that outside the tree's influence. This small reduction is to be expected because of advective air movement within the relatively small area influenced by a tree. One would not expect this to affect crop growth.

Soil temperature during the seedling establishment phase is an important factor limiting crop selection in the Sahel. Temperatures at this phase of crop establishment can be limiting to the growth of staple crops like millet. Vandenbeldt and Williams (in press) have shown that the partial shading of the soil surface can reduce the temperatures considerably and keep them within limits that dramatically expand the range of crop species available to the farmer.

Similarly, in the event of drought, the reduced radiation load in the partially shaded area around the tree could be important in preventing thermal damage to leaves. The soils in the vicinity of the *F. albida* have many of the attributes needed to expand the range of crops possible. They have higher N, P, K, pH, clay content, and the associated better cation exchange capacities (Geiger et al, in press) and water holding contents.

While we do not yet have evidence to show that these changes are sufficient to allow new species to succeed in the Sahel, there is enough evidence to show that an agroecological shift is a very real possibility. We have begun experiments at Sadore to evaluate this. Farmers should be shown that new marketable crops can be cultivated. Foci of more intensive cropping can be developed around the trees that can then support purchase of inputs known to increase productivity outside the influence of the trees. When trees are perceived by farmers to result in greater prosperity, there will in due course be more trees.

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Variability in the Growth of *Faidherbia albida:* a Termite Connection?

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Abstract

Termite activity can have a positive effect on soil fertility. In a Faidherbia albida *plantation near Niamey, Niger, we compared the soil profiles at a poor, a good, and a very good growth site* (*edge of termite mound*). *The poor growth site had low subsoil termite activity as well as low physical and chemical fertility; the very good growth site had high termite activity and relatively high fertility; the good growth site was intermediate between the other two infertility as well as termite activity. Data taken from a trench through the trial showed positive correlation between the growth of F.* albida *and level of termite activity, pH, and bulk density at 0.5-1.0 m depth. Soil tillage has been shown to decrease termite activity, and may therefore in the long term detrimentally affect soil fertility, growth of F.* albida, *and sustainable yield of agroforestry systems. This should be kept in mind when evaluating the economic benefits of agricultural production systems that incorporate both* F. albida *and soil tillage.*

Introduction

Spatial variability in the growth rate of crops and trees over distances of only 5-20 m is widespread in the Sahelian zone of West Africa. This effect is largely due to preexisting variability in soil chemical and physical properties (Scott-Wendt et al. 1989; Manu et al. 1990; Geiger and Manu 1991). The so-called 'albida effect', where soils under the canopy of *Faidherbia albida* trees have been found to be more fertile than soils in the adjacent open field is probably due to a considerable degree to such preexisting soil differences.

Geiger et al. (in press) have shown that *F. albida* growth is particularly good around abandoned termite mounds, but that there were other areas of good growth as well. Improvement of soil fertility by termites is well-documented (Lal 1987, Lee and Wood 1971, Miedema and Van Vuuren 1977).

Carrying on from that work, we investigated whether the other areas of good growth in the plantation might in fact be associated with higher levels of previous termite activity, not evident from surface conditions but nevertheless increasing soil fertility and *F. albida* growth.

Materials and Methods

The field trial was located at the ICRISAT Sahelian Center, near Niamey, Niger (13°N 2°E), on a slightly undulating eolian sand plain. Annual rainfall in Niamey has averaged 562 mm over the past 80 years (Sivakumar 1986). The rainy season is from May to September. The soil is a deep (4.2-5.1 m) reddish sand. *F. albida* seedlings were planted in Aug 1987, at 2 x 2 m spacing, as part of a preplanting amendment field trial.

In Oct 1990 three pits were dug down to laterite (4-5 m)—one each in a poor, a good, and a very good site. The 'very good growth' site was located along the edge of an abandoned termite mound, probably constructed by a *Macrotermes* species. In addition, a trench 30 m in length and 1.5 m in depth was dug

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from the poor to the good growth area. A second 15-m long trench was dug parallel and 25 m away from the first, leading from the center of the abandoned termite mound to a second poor growth area.

In the three pits, full profile descriptions were made (FAO 1977) and all horizons (8-10 per profile) were sampled for physical, chemical, and micro-morphological analysis. Evidence of biological activity was mapped to scale on graph paper, down to a depth of 3.5-4.0 m using a 1 x 1 m metal frame which was divided into 10 x 10 cm squares and hung against the pit face. From these maps, the relative areas of various types of biological activity (roots, termite activity, and activity by other fauna) were estimated. Similar biological activity maps and calculations were made along the full length of the two trenches.

Depths to horizon boundaries were determined, and samples were taken at 9 depths every meter (second trench) or every two meters (first trench) for determination of pH (in water), texture and bulk density. Around all pits and trenches tree height or length of the longest branch and diameter at 10 cm were measured.

Table 1. Average diameter and height of living *F. albida* trees around three soil pits in areas of poor, good, and very good growth, Sadore, Niger, 1990-91.

	Site description		
Growth parameter	Pbor	Good	Very good
Core trees[1]			
Number of dead trees	3	0	1
Height (cm)	80	241	107
SE		±84	±58
Diameter (cm)	3.0	6.0	2.4
SE		± 2.0	± 0.9
Surrounding trees[1]			
Number of dead trees	4	5	1
Height (cm)	122	205	237
SE	±61	±53	±94
Diameter (cm)	2.8	4.7	5.3
SE	± 1.4	± 1.6	± 2.2

1. Core trees are those forming a square immediately bordering the pit. The 12 surrounding trees are those forming a square around the 4 core trees.

Results and Discussion

Height and diameter for the four trees immediately surrounding the termite mound are low (Table 1). This is because the growth conditions at such sites are often unfavorable due to high bulk density and low infiltration capacity (Lal 1987). Areas around recently abandoned mounds are often favorable to growth, because of runoff from the degraded mound as well as increased fertility. This is reflected in the growth figures for the 12 trees immediately around the mounds.

Except for the surface crust, there was a relatively high organic carbon content to a depth of 3 m under the termite mound. The poor growth area had low organic carbon and the good growth area was intermediate. Bray-1 P showed the same trend, as did total N (weakly) and free Fe. The pH (H_2O) also followed this pattern, except for a completely worked zone immediately under the old mound (to a depth of 1.9 m), which was very acid (Fig. 1).

Similarly, clay contents are highest under the old mound, and lowest under the poor growth (Fig. 2). All these trends more or less coincide with termite activity (mostly back-filled tunnels), particularly in the top 1.5 m of the soil (Fig. 3).

The high level of termite activity at 2 to 3 m depth under the good growth area may have had a major effect on tree growth because the tunnels were old and their beneficial effects could be in decline. In support of this, tunnels higher up in the profile were leached and already disappearing. Alternatively, the tunnels might have been buried under more recent eolian deposits. It is also possible that tunnels under this site were made by a different less beneficial termite species.

Trenches

At the time of writing only data from the trench leading away from the abandoned termite mound were available. The properties of the top half-meter of soil had no major effect on growth of F. *albida.* This is not surprising, as the seedlings were put into plant holes 40 cm deep and would have very quickly developed a taproot going straight down.

We found good correlations, however, between tree height and the relative presence at 50-100 cm of backfilled termite tunnels (r = 0.66, Fig. 4). There were also strong correlations between percentages of backfilled tunnels at 50-100 cm or 100-150 cm, and pH in water at depths of 50 m (r = 0.60), 70 m (0.86), 90 m (0.88), 110 m (0.73), 130 m (0.75), and 150 m

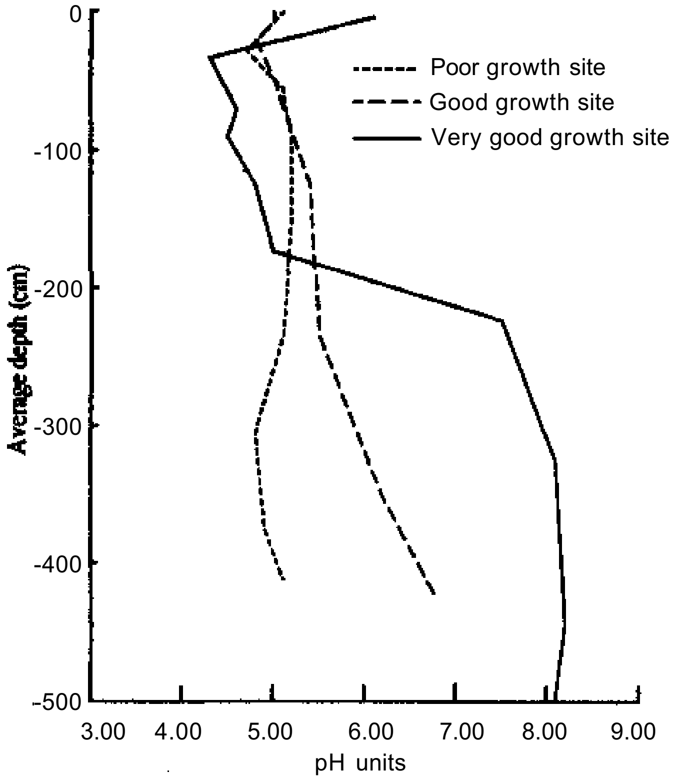

Figure 1. Soil pH (H_2O) of soil at sites with poor, good, and very good *Faidherbia albida* growth, ICRISAT Sahelian Center, Sadore, Niger, 1991.

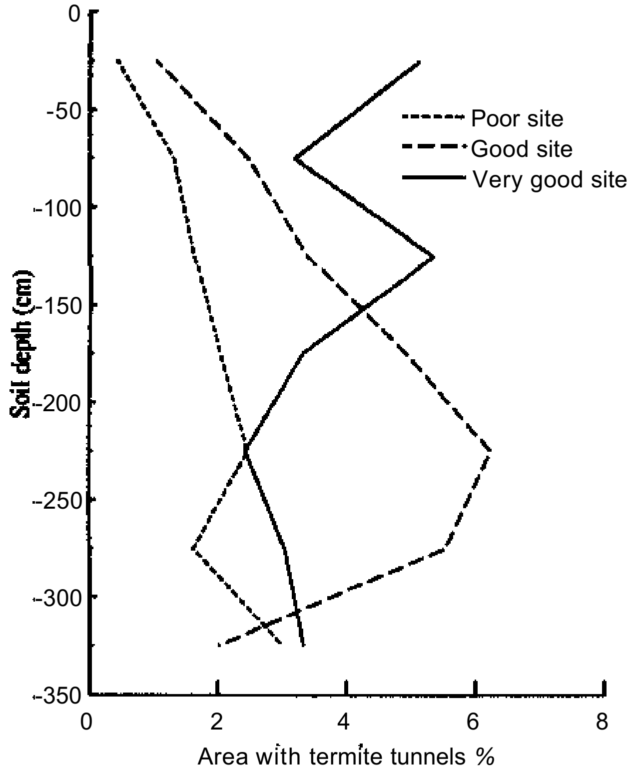

Figure 3. Area of termite tunnels (% of total cross sectional area) of soil profiles at sites with poor, good, and very good *Faidherbia albida* growth, ICRISAT Saheiian Center, Sadoré, Niger, 1991.

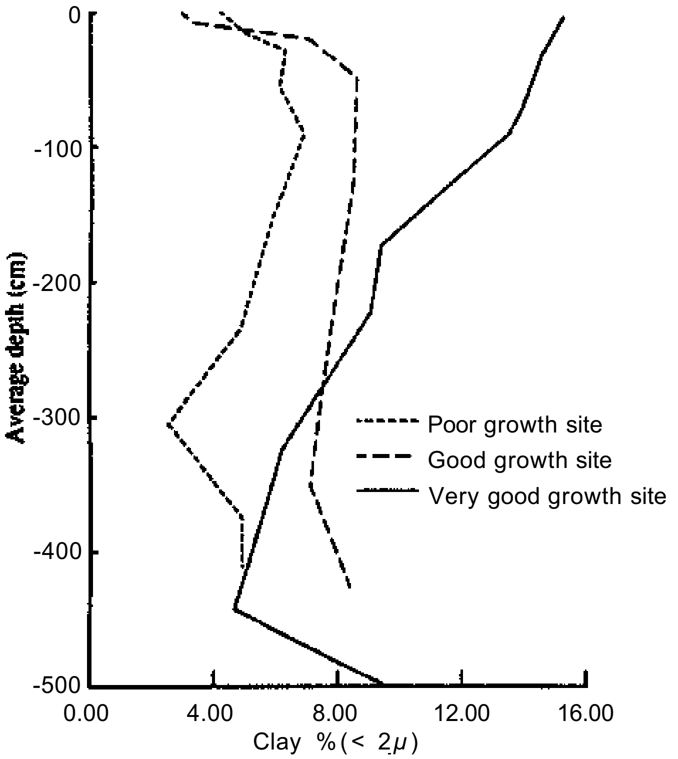

Figure 2. Fraction of soil particles *Faidherbia albida* growth, ICRISAT Saheiian Center, Sadore, Niger, 1991.

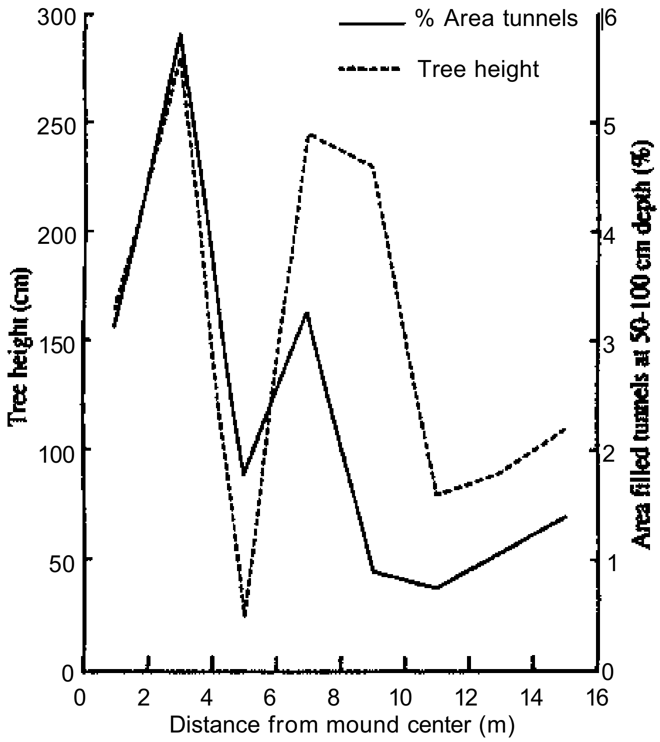

Figure 4. Relationship between area of termite tunnels (% of total cross-sectional area) of soil profiles and height of *Faidherbia albida* growth, ICRISAT Saheiian Center, Sadore, Niger, 1991.

(r = 0.81). Termite activity and bulk density were correlated only at 50 and 70 cm depth (r = 0.57-0.82). The positive correlation between bulk density at 50 cm depth and tree growth probably has no functional basis; we can conclude only that bulk density was not limiting growth. But bulk densities found in the old mound itself, mostly over 1.60 g cm^{-3} in the top meter, probably did limit growth.

Conclusion

These data correspond well with findings by other authors that termites can have a positive influence on soil fertility by increasing soil organic matter and clay contents. It might be argued that termites may have a preference for sites that already have better fertility characteristics, e.g., sites that are less leached and have a higher pH. If this was the case at our field site, we would argue that the termites there had made a relatively good site even better.

The data also support the conclusions of Geiger et al. (1992), that preexisting-soil fertility affects the growth of *F. albida* and that the so-called 'albida effect' is, to a considerable degree, due to fertility differences that precede the growth of the tree.

It appears that, at least in the situation studied, the two findings can be combined by saying that certain termite species can positively affect the growth of *F. albida* by improving soil physical and chemical fertility. Perhaps their effects on soil biological fertility and soil organisms (bacteria, mycorrhiza, nematodes) should be studied as well. As termites can have a beneficial effect on soil fertility, their well-being should be kept in mind when evaluating agricultural production systems. Tillage has been shown to reduce termite activity (Pierri 1989; Kooyman and Onck 1987); frequent broad acre soil tillage, by affecting termite activity, may in the long term detrimentally affect soil fertility and thus growth of *F. albida* as well as profitability of agroforestry systems in which *F. albida* plays a part.

Acknowledgment. The trenches were dug by local laborers under the supervision of Mahamadou Djibeye, who also measured the trees. The chemical analyses of the samples from the pits were performed by staff of the Department of Soil Science and Geology, Agricultural University, Wageningen, managed by T. van Mensvoort. Diafarou Amadou diligently analyzed all the pH samples. Ousmane Youm discussed termite identification with us. To all these people, our sincere thanks.

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Direct Seeding Experiments with *Faidherbia albida* in an Arid Environment

P. Beckman[1]

Abstract

In 1990, a field experiment was carried out to determine the best way to establish Faidherbia albida *by direct seeding. Five different seed treatments and two sowing depths were tested. Best results were obtained with scarified seed (26% germination at 15 mm sowing depth). Poorer results were obtained when seeds were sown at 10 mm depth. The total rainfall was 172 mm with a 1-month drought period 1 week after sowing. Almost all the seedlings that survived until the end of September still had green leaves at the end of December. Many of these seedlings are expected to survive until the next rainy season.*

Introduction

Faidherbia albida can be found around Tanout, Niger, near the Eden field station in East Niger, both beside riverbeds and on plateaus. Average annual rainfall in Tanout was 201 mm during 1971-80 and 177 mm 1981-90. The chief goal of the research presented in this paper was to determine how to establish *F. albida* by direct seeding.

Materials and Methods

Seed for the experiment was gathered in Feb 1990 from trees around Tanout. Laboratory tests showed 100% viability. Seeds were scarified by:

- Nicking with a nail clippers;
- Cutting with a sharp knife;
- Abrasion with a grindstone;
- Covering 10:1 by volume with boiling water, cooling, and then soaking for 12 h.

Seeds sown without any treatment were used as a control. The soil at the site was a mixture of a fine red sand with an overlay of coarse pale yellow sand of varying depth. The seeds were sown at two different sowing depths, 10 mm and 15 mm, on 1 and 2 Aug 1990, in the middle of the rainy season.

Plots consisted of 9 holes each, with 10 seeds per hole and 4 replicated plots of each treatment combination (scarification + sowing depth), for a total of 360 seeds for each treatment combination. The plots were arranged in a completely randomized design among plots of other perennial species undergoing similar tests. Seedlings were weeded twice during the rainy season.

Results and Discussions

Generally, the physical scarification techniques gave better results than the control and the hot water treatment (Table 1). The 15-mm sowing depth gave significantly better results than the 10-mm treatment, due partially to less predation by mice and ants.

Total rainfall was 172 mm for 1990 at the field station; of this, 92 mm fell before sowing. The remaining 80 mm fell in a few erratically spaced showers after sowing. Only 4 mm of rain fell during a drought period of 1 month which started a week after sowing. It was therefore quite remarkable that so

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many seedlings survived. Almost all the seedlings that remained after thinning (one seedling per hole, done after counting in September) still had green leaves at the end of Dec 1990. Based on results of earlier preliminary studies, we expect many of the *F. albida* seedlings to survive until the following rainy season.

Table 1. Total number of germinating seeds (out of 90 sown) at two sowing depths and four scarification treatments, Eden Foundation, Tanout, Niger, 1990.

	Seeding depth				
Treatment	10 mm		15 mm		Mean
Control	0.3[1]	(0.25)	1.3	(0.75)	(0.50)
Nicking	10.8	(3.10)	23.8	(4.83)	(3.96)
Cutting	1.8	(0.86)	16.3	(3.43)	(2.15)
Abrasion	4.5	(2.00)	16.8	(3.96)	(2.98)
Hot water	2.8	(1.36)	1.0	(0.68)	(1.02)
Mean	4.0	(1.52)	15.8	(2.73)	
SE (Depth)		±0.28			
SE (Treat.)		±0.44			
CV (%)		59			

1. Values in parentheses are derived from square root transformations of plot counts. Standard errors for depth and scarification treatments should be applied against transformed values for comparison.

Regeneration of *Acacia albida* with Direct Seeding

S.A.N. Samba[1]

Abstract

A trial conducted at Thienaba, Senegal by Cazet (1987) compared direct seeding and outplanting of potted seedlings. Results showed that direct seeding can give better survival rates than outplanted potted seedlings. As a regeneration technique, direct seeding is cost efficient and labor extensive.

Introduction

Throughout the northwestern part of the Groundnut Basin, Senegal, *Acacia albida* parks consist predominantly of mature trees. However, natural regeneration beneath them is virtually non-existent. In 1986, the DRPF/ISRA, Senegal, established a direct seeding study to determine if this inexpensive method could be used to regenerate this regionally important species (Cazet 1987).

Site Description

Thienaba, the site chosen for the regeneration trial was located in the Sahelian zone of Senegal characterized by a 9-month dry season and a 3-month rainy season. Annual precipitation ranges between 400 and 500 mm. The soils were sandy (90-94%) and dominated by fine sands (54-62%). The clay plus silt fraction was less than 5%. Organic matter content of the soil was estimated at 0.2% and available soil water was approximately 4%.

Materials and Methods

Seeds used in the trial were collected in a region with similar ecological conditions as those of Thienaba. Seeds used in the nursery were pretreated with concentrated sulfuric acid for 30 minutes. Following pregermination in an incubator (95% germination), seeds were then sown in pots on 28 Apr 1986. Seeds used for direct seeding were also pretreated with sulfuric acid.

In preparation for planting and seeding, 50 x 50 x 60 cm holes were dug on the site, treated with dieldren, then backfilled. Outplanting was done on 11 Jul 1986 following a rain of 22 mm. At the time of planting, the bottoms of pots were cut to remove the coiled roots of the 11-week old plants. A 21-day drought period followed the planting date, requiring resowing of direct seeding plots on 5 Aug because of high mortality.

The design was a randomized complete block design. Each of the 4 blocks of 2 treatments (direct seeding or potted seedlings) formed plots of 24 (6 x 4) plants. Potted seedlings were planted at 4 x 4 m whereas seed pockets (each seeded with 3 pregerminated seeds) were spaced at 2 x 4 m. Plots were weeded in August, September, and October.

Survival rate, plant height, diameter at the root collar, dry shoot mass, taproot length, maximum diameter of the taproot, total length of roots, and dry root mass were recorded. Samples for weighing were dried at 105°C to constant weight.

Results

On 29 Nov, 49% of the hills had 3 seedlings, 33% had 2 seedlings, and 15% had 1 seedling. Only 3% of the hills had no emergence. Thus, the survival rate of the total number of seeds planted was 76% at 3.8 months.

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No mortality was observed afterwards. Survival of seedlings grown in pots decreased from 79% at 3 months to 66% at 6.5 months. Comparison of juvenile growth parameters between the two techniques are shown in Table 1.

Table 1. Comparison of juvenile growth differences in *Faidherbia albida* as a function of planting method, Thienaba, Senegal, 1986. (Source: Cazet 1987.)

Growth parameter	Direct seeding	Pots	Ratio Direct seeding: pots
Height (cm)	42.3[1]	21.7	1.9
Diameter (mm)	6.4	2.6	2.5
Dry shoot mass (g)	8.7	0.5	17.7
Taproot length (cm)	273	149	1.8
Taproot diameter (mm)	8.5	1.3	6.5
Cumulative root length (cm)	520	173	3.0
Dry root mass (g)	34.5	1.4	24.5

1. All mean pairs comparing direct seeding versus pots are significantly different at $P < 0.05$.

Recommendations

For all the parameters studied, direct seeding gave the best results. Favorable conditions at the time of seeding, however, were critical for the success of this technique. Besides the clear superiority of direct seeding over potted seedlings in terms of growth (Table 1), survival rates of direct-seeded plants were much higher. At month 6, direct seeding of three pregerminated seeds per hill had a 48% higher survival rate than potted seedlings raised 2.5 months in the nursery.

Based on these results, direct seeding can be recommended provided that seeding is done when the soil is moist to a depth of over 50 cm. Weeds must be suppressed and the site must be adequately preparated to encourage rapid taproot development.

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Growth of *Faidherbia albida* in Nurseries: Standard Production Techniques or Air Pruning?

D. Louppe and N'Klo Ouattara[1]

Abstract

Root coiling in the nursery is a problem with Faidherbia albida. *The standard practice is to cut off the root coil at the bottom of the pot before outplanting, but this can hinder plant development. Root coiling and/or roots growing out of the bottoms of the pots occurs in the nursery as early as 18 days after sowing and requires pruning of or pot transfer.*

Three nursery methods were studied—standard polyethylene pots with and without coil pruning, and rigid tubes that allowed air pruning of roots. Air-pruned plants were generally less developed than potted seedlings. However, they had 50% more secondary roots and 28% more nodules than potted plants with pruned root coils, and suffered less transplant shock.

After outplanting, there was no difference in plant development with the three treatments. Coil-pruned potted plants developed a new, effective taproot at the site of the pruning wound. Air-pruned tubed seedlings developed taproots from lateral roots. More work should be done with this method. Also, this study should be repeated in a more drought-stressed environment.

Introduction

Nursery production techniques for *Faidherbia albida* have yet to be optimized. Cazet (1987) demonstrated that root systems of *F. albida* grown in pots are inferior to those of direct seeded plants 6 months after sowing. Under 334 mm of rainfall, direct seeded plants had 14 times more root biomass than those of potted plants which had also stayed for 6 months in the field after 3 months in the nursery. Individuals established by direct seeding had large-diameter taproots whereas potted seedlings had taproots less than 1 cm in diameter.

The difference was explained by root pruning of potted seedlings at the time of outplanting. After 3 months in the nursery, *F. albida* seedlings form a coiled root at the bottom of the pot which can limit root development of outplanted seedlings. In Cazet's study (1987), development of new roots following pruning of the coiled taproot was poor. Reduced uptake of water and nutrients resulted in marked growth differences between the two treatments after 2 years.

Two trials were carried out to determine if production time in the nursery could be reduced in order to avoid formation of coiled roots, and if sufficiently well-formed seedlings could be obtained through air-pruning techniques.

Production Time in the Nursery

The first trial was done in the nursery to study growth of *F. albida* seedlings raised in perforated plastic pots 16 cm high and 9 cm in diameter. Results demonstrated that 20-cm tall seedlings suitable for planting could be produced in the nursey in less than 2 months. Seedlings were naturally inoculated and the nodules were active. It appears to be unnecessary and perhaps undesirable to keep the plants longer in the nursery for two reasons. Firstly, our results showed that young root-pruned *F. albida* seedlings regenerate their taproots better than older root-pruned seedlings. Secondly, frequent and numerous measurements of root systems showed that after day 52, fine roots on

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the upper part of taproots appeared to decrease in number to the point where their activity no longer seemed functional. Nodules in this root zone declined at the same time, and by day 60 had blackened. These superficial fine roots and nodules survive for a shorter period than previously thought.

Nursery Production Techniques

Although direct seeding of *F. albida* can result in higher quality seedlings than standard nursery techniques (Cazet 1987), climatic hazards limit the success of this method. For this reason, production of *F. albida* in the nursery remains necessary to ensure high rates of survival in the field.

Growth of *F. albida* in the nursery is very rapid and, ideally, seedlings can be outplanted after 2 months. However, due to many constraints, planting operations are often delayed and time in the nursery must be extended. In order to maintain superior root structure, pots must be shifted frequently, sometimes every 15 days in the later stages of nursery operations. This, however, is labor-intensive and expensive. Ways to limit the number of shiftings should be studied.

It was necessary to find out whether air pruning, which is increasingly being used in industrial nurseries, could be applied to *F. albida.* A trial was run to determine whether this technique results in well-formed *F. albida* seedlings which successfully redevelop taproots after planting.

Materials and Methods

Nursery Techniques

Two treatments were used, the first was raising seedlings in 9 x 16 cm polyethylene pots. Root pruning was done every 15 days in accordance with standard nursery practices. For the second treatment, seedlings were produced in bottomless tubes of uniform dimension which were placed on medium-size wire mesh suspended 30 cm above the ground. Root apices emerging from the base of the tube were exposed to air and died back, thus resulting in limited root elongation.

The trial consisted of 4 replications and 25 pots or tubes per plot. Two scarified seeds per tube or pot were sown on 20 Jul 1990.

Since the only available balance measured to the nearest 0.1 g, biomass measurements were feasible only after several months of growth. In month 7,16 plants per treatment were randomly selected from the 4 replications and were destroyed for analyses. The potting medium was removed by a fine water jet, and the roots and nodules were carefully removed with tweezers. In the laboratory, a final cleaning preceded nodule counts and weighings. Because of the lack of accurate equipment, only fresh and dry weights (after 24 hours at 100°C) were measured. Nodule weights were too small to be accurately recorded.

Field Techniques

At month 4, a sub-trial was installed to study the impact of plant production techniques in the nursery on growth in plantations. Seedlings were planted in an 80-cm deep tub filled with sand to facilitate later destructive sampling. To simulate real plantation conditions, seedlings were watered on a weekly basis corresponding to 60 mm of rainfall per week. In 3 months, the plants received 780 mm, which represents Sudano-Guinean conditions. The trial was laid out in blocks of 4 repetitions, similar to the first trial. Five containers per treatment were planted. Because there was no thinning of the pots, this resulted in a range of 32-40 plants per treatment. Three planting methods were used: (1) potted seedlings planted after removing the plastic bag; (2) potted seedlings planted after cutting the base of the pot 2 cm from the bottom to eliminate the coiled roots; and (3) tubed seedlings planted by removing the plastic without disturbing the roots.

Results

Growth in the Nursery

At month 4, tubed plants averaged 23 cm in total height whereas potted plants averaged 27.8 cm. At month 7, the average above-ground biomass of tubed seedlings was 1,86 g; potted seedlings weighed 2.85 g on the average. Although these differences were not significant, the respective values were logical. After the two root prunings, potted plants developed temporary root systems that filled the available growing space and enhanced access to soil nutrients to an appreciable degree. Root pruning, although done frequently in the nursery, did not hinder initial plant development in the field.

When one potted and one tubed seedling were destroyed for measurement at the outplanting stage, it was noted that the potted plant formed a coil which represented more than 50% of the root system (dry weight). It should be noted that 15% of seedlings had rooted through the drainage hole of the pot and therefore formed no coil. Taproots of the air-pruned seedlings stopped at the base of the tube. There was no taproot malformation, but some fine roots did develop in a circular pattern along the insides of the tube.

A difference in the spatial distribution of secondary roots was noted. For the air pruned, tubed seedlings, roots were homogeneously distributed throughout the tube. In the pots, however, they were concentrated at the base.

On the whole, plants raised in tubes were less developed compared with the potted plants. However, potted seedlings lost 38% of their root systems when coiled roots were cut off. It is probable that we underestimated measurements of root systems in the root-pruned pots. In one plant, a part of the root system grew upwards from the base of the pot to the top and could not be distinguished from the coiled roots before or after trimming them for planting.

At the time of outplanting, tubed seedlings had 15% less dry root mass and 31% less taproot mass than potted plants. However, tubed seedlings had 51% more secondary and fine root mass and 28% more nodules than potted plants. This represents a decisive advantage over plants raised using classical nursery techniques. There were no significant differences in seedling development at the time of planting or 3 months later (Table 1). The only statistically significant differences existing between treatments were numbers of coiled roots observed after planting and angle of insertion of the new roots (Table 2).

Contrary to observations by Cazet (1987), normal regrowth of taproots was observed after they were trimmed from potted seedlings. This may be due to the absence of moisture constraints in this trial, as opposed to that carried out in Senegal where annual rainfall was 334 mm.

Some air-pruned seedlings produced new taproots from lateral roots while still in the tubes. These lateral roots sometimes coiled upward in the tube at later stages of development. This problem could be minimized by using wider tubes with vertical ridges along the inner walls to limit root coiling and result in a well-formed root system.

Table 1. Average heights (cm) of outplanted *Faidherbia albida* seedlings at 4 and 7 months, Korgoho, Cote d'Ivoire, 1990.

Production Technique	Height at Month 4 (Outpianting) (cm)	Height at Month 7 (3 Months in Field) (cm)
Air Pruning	22.9	39.5
Potted, Base Cut	29.0	44.8
Potted, Base Uncut	26.6	43.0

Table 2. Development characteristics of *Faidherbia albida* seedlings 3 months after planting. Korgoho, Cote d'Ivoire, 1990.

Seedling parameter	Air pruned	Potted pruned	Potted unpruned
Root collar diameter (mm)	3.7	3.7	3.7
Diameter 10 cm below ground (mm)	5.1	5.2	5.0
Presence of root coils (%)	34	9	59[1]
Number of new taproots	1.5	1.7	2.0
Diameter of new taproots 10 cm below container (mm)	1.8	2.4	2.1
Insertion angle of new taproots (*)	102	135	107[1]
Dry shoot mass (g)	3.4	3.4	4.3
Root mass at planting (g)	2.1	2.1	2.7
Root mass 3 months after planting (g)	2.2	2.5	2.4

1. These were the only two parameters with significant differences between treatments (*P* <0.01).

Conclusion

Air pruning of *F. albida* seedlings, induced by desiccation of root meristems emerging at the base of containers, was successfully achieved in the nursery. This is better than standard nursery techniques for three reasons. First, seedling root systems have more secondary and fine roots and nodules at the time of outplanting. Second, the root system remains undisturbed and is therefore fully functional after outplanting. Finally, this technique requires less labor both in the nursery and during outplanting. One disadvantage, however, was noted. Since root development was limited because of the small size of the tube, lateral roots coiled upwards. Use of larger tubes should be investigated.

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Presence of *Bradyrhizobia* under *Acacia albida*

N. Dupuy and B. Dreyfus[1]

Abstract

Soil samples taken beneath adult Acacia albida *in Senegal revealed that large populations of* Bradyrhizobium *exist at depths of 30-35 m i.e., at the water table level. Sixty-seven strains of* Bradyrhizobium *were isolated from both shallow and deep soils. A study of their symbiotic capability showed that several strains isolated from deep soils can actively fix nitrogen in association with* Acacia albida.

Introduction

It is thought that soil improvement beneath *Acacia albida* is linked to its nitrogen-fixing ability. Abundant nodulation on roots of *A. albida* trees growing in rice fields of Casamance, Senegal (annual rainfall 1000 mm) has been observed. However, no nodules have been found on roots of adult trees in the Sahelian zone (annual rainfall <1000 mm). Thus, there is a question whether *A. albida* does indeed fix nitrogen in arid zones.

In order to answer this, two approaches were considered. The first consisted of determining the presence of nodules on root systems as well as the existence of specific *Rhizobium* populations in the rhizosphere. The second approach involves measuring nitrogen fixed by tree-host associations using the isotope labelling method. Studies using the first approach are presented here.

Two holes were drilled beneath adult *A. albida* in order to sample the distribution of specific *Rhizobium* populations throughout the soil profile. Subsequently, *Rhizobium* strains from upper and lower horizons were collected and their nitrogen-fixing capability determined.

Materials and Methods

Sampling Method

Borings were done using a light, hand-operated auger to which 1.5-m long aluminum shafts (Dormer's Engineering, South Murwillumbah, NSW 2484, Australia) were attached as the hole deepened. One shaft sunk in Louga (200 km north of Dakar), located 8 m from the trunk of an isolated *A. albida,* reached the water table at of 34 m depth. A second shaft, dug in the Groundnut Basin near Bambey, was located between two *A. albida* trees spaced 5 m apart. Here, the water table was reached at 16.5 m. Soil samples were taken at various depths (Table 1), chilled, and analyzed in the laboratory for rhizobia capable of nodulating A. *albida.*

Rhizobium Densities in Soil Samples

Rhizobium densities of the soil samples were estimated using the most probable number method (Brockwell 1980). *A. albida* seeds were sterilized in concentrated sulfuric acid for 1 h, then washed several

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Table 1. Nitrogen-fixng capability of *Rhizobium* strains isolated from soil samples taken at different depths at two sites in Senegal, 1990.

Origin	Depth (m)	Nitrogen-fixing ability[1] E	VG	G	P	Total number of isolate groups
Louga	0.5	1	3	2	2	8
	2.5	0	3	1	0	4
	5.0	0	0	1	1	2
	17.5	0	2	1	1	4
	24.0	0	1	0	1	2
	27.5	1	0	0	0	1
	28.5	0	0	1	1	2
	30.0	0	0	2	0	2
	32.0	1	0	0	1	2
	33.5	0	0	2	0	2
	34.0	0	0	2	0	2
	Total	2	9	12	7	31
Diokoul	0.5	0	1	0	0	
	2.5	0	0	1	0	
	4.0	0	0	1	0	
	11.5	0	0	1	0	
	14.0	0	0	2	0	2
	Total	0	1	5	0	6
Casamance	Surface	0	8	5	3	16
N. Senegal	Surface	1	4	8	1	14

1. Distribution of rhizobium groups as a function of nitrogen-fixing ability. E = excellent, >9 µmoles hr^{-1}; VG = very good, 6-9 µmoles hr^{-1}; G = good, 3-6 µmoles hr^{-1}; P = poor, <3 µmoles hr^{-1}.

times in sterile water and finally germinated in petri dishes on agar-agar water (0.8%) for 48 h. Roots of the germinated seedlings were placed in test tubes containing Jensen medium; the shoots remained exposed to air. The seedlings were placed in a culture chamber and inoculated after 5 days with 1 mL of a suspended soil dilution. For each dilution, tubes showing nodulation after 4 weeks were counted. Non-inoculated controls did not nodulate.

Isolation of *Rhizobium* Strains

Nodules from inoculated tubes were sterilized in a 0.1% $HgCl_2$ solution for 3 min, washed in distilled water 6-7 times, then ground in a drop of water with a sterile glass rod. Strains of *Rhizobium* were isolated on a YMA medium following the procedure of Vincent (1970).

Evaluation of Nitrogen-Fixing Capability

After removing the aerial parts, the liquid culture medium was discarded and the tubes were closed with stoppers. Acetylene was injected (10% of tube volume) into the tube, and acetylene reduction was measured by chromatography in the gaseous phase using the method of Hardy et al. (1968) after a 30-min incubation period at 28°C. *Rhizobium* activity remained linear for 90 min. The strains were divided into four classes according to the acetylene reduction assay results (Table 1).

Results

Rhizobium Distribution as a Function of Depth

Contrary to expectation, *Rhizobium* population densities were highest (Table 2) at the greatest depth measured (Louga). Also, certain intermediary zones (7-14

Table 2. Distribution of *Rhizobium* density (no. soil g^{-1}) associated with *Acacia albida* in two soil profiles in Senegal, 1990.

Louga Depth (m)	*Rhizobium* density	Diokoul Depth (m)	*Rhizobium* density
Surface	68	Surface	<1
0.50	1271	0.50	22
2.55	91	2.50	22
5.05	159	4.00	51
7.55	<1	6.00	<1
11.05	<1	8.00	<1
14.05	<1	10.00	<1
17.65	91	11.50	27
21.05	<1	14.00	76
24.05	37	16.50	27
27.55	12	Water table	
28.65	119		
30.05	22		
32.05	24		
33.55	344		
34.00	1323		
Water table			

m at Louga, 6-10 m at Diokoul) contained less than 1 rhizobia per gram of soil throughout the profiles studied. *Rhizohium* populations were less numerous at the Diokoul site than the Louga site. This is probably due to differences in soil texture—the Diokoul soil is much more clayey and therefore probably not as favorable to *Rhizobium* multiplication and development as are the sandy dune soils of Louga.

Characteristics of *Rhizobium* Strains

Of the 67 strains isolated, all except two (ORS167, ORS173) demonstrated slow growth on the YMA medium and were thus considered as *Bradyrhizobium.* Eleven of the 31 Louga strains were classed as very good or excellent in terms of nitrogen-fixing capability. Two of the excellent strains (ORS130 and ORS136) were isolated at depths of 27.5 and 32 m. At Diokoul, however, no strains classed as very good or excellent were isolated below 0.5 m.

Discussion

Until now, it has been believed that *Rhizobium* populations reside only in the upper horizons of the soil; i.e., at depths not exceeding 1-2 m (Alexander 1977). Before this experiment, only the research team led by Virginia et al. (1986), following the work of Felker and Clark (1982), studied *Rhizobium* distribution in the soil. Their results showed that *Rhizobium* populations beneath *Prosopis glandulosa* in California could attain densities of 10×10^3 g^{-1} of soil, at depths reaching 4-6 m. The present study has demonstrated that *Rhizobium* can heavily populate soils (up to 1.3×10^3 per g of soil) beneath *A. albida* at depths never previously thought to have been inhabited by this bacterium.

Jenkins et al. (1987) showed that two distinct *Rhizobium* populations existed under *P. glandulosa,* according to depth. In the upper horizons, *Rhizobium* predominates, whereas deeper in the soil, *Bradyrhizobiiim* prevails. With the exception of two strains, all of the *Rhizohium* strains isolated in this experiment exhibited traits similar to those of *Bradyrhizobium* (Jordan 1984).

It is possible that the lower-horizon strains and those of the upper horizons form two distinct subgroups. Since environmental conditions at greater depths are relatively constant, the lower-horizon *Bradyrhizobium* may differ from upper-horizon strains which are better adapted to wide environmental fluctuations. A taxonomic study based on the comparison of total protein profiles and of nutritional traits is under way to verify this hypothesis.

The presence of nodules on shallow roots of naturally occurring *A. albida* in the Sahelian zone is rare. This absence of nodules may result from the inhibitive effect of limiting factors of the environment, notably drought, and not genetic determinants linked to the plant. *A. albida* nodulates abundantly on continually moist soil, as in the rice fields at Casamance. The absence of large *Rhizobium* populations at greater depths at Casamance may have been due to a lack of oxygen or the difficulty of observing roots. Isotopic tracing may prove useful in determining whether *A. albida* fixes nitrogen in the Sahelian zone. Lower-horizon strains which proved to be very effective nitrogen-fixers could be used to colonize deep root systems of A. *albida.*

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Acacia albida: Nodulation by Fast- and Slow-Growing Rhizobia

M. Gueye[1]

Abstract

Up to now, Acacia albida was known to nodulate only with slow-growing *Rhizobium* strains which are common in most tropical soils. This paper reports for the first time the isolation of three fast-growing strains of *Rhizobium* isolated from A. *albida* nodules.

Introduction

Because of its well-known economic benefits, *Acacia albida* is a valuable nitrogen-fixing tree growing in the Sahelian savanna from Senegal to Sudan. Up to now, *A. albida* has been thought to nodulate promiscuously with slow-growing *Bradyrhizobium* (like that associated with *Vigna unguiculata*), which are common in tropical soils. This paper reports for the first time the isolation of three fast-growing strains of *Rhizobium* isolated from *A. albida* nodules.

Materials and Methods

Isolation of *Rhizobium* Strains

Seeds of *A. albida* were sterilized with concentrated H_2SO_4 for 1 h and germinated in petri dishes containing sterile 3% water agar for 3 days. Seedlings were then transplanted into pots (one seed per pot) containing 2 kg of a soil sample (0-20 cm layer) collected from nine sites in the central region of Senegal. Before transplanting, the soil samples were sieved (1 mm mesh). The pH of the soils ranged from 5.9 to 7.4.

Forty days after germination, one well-developed, firm, pink nodule was sampled from each plant. The *Rhizobium* strains were isolated and grown on YEM agar according to standard procedures (Vincent 1970).

Study of Acacia Species Nodulation

Seed of four acacia species (*A. albida, A. raddiana, A. Senegal, A. seyal*) were germinated as described above and transplanted into Gibson's tubes (Gibson 1963). After 3 days, the seedlings were inoculated with 1 mL of a *Rhizobium* suspension containing 10^9 cells mL^{-1}.

After 40 days of growth, the nodulation index (NI) of the four acacia species was recorded using the method of Gueye and Bordeleau (1988). The index integrates information on the number (N), internal color (C), and size (S) of the nodules as follows:

$$NI = N \times C \times S$$

Nodule number is rated on a scale from 0 (no nodule) to 3 (many nodules), nodule internal color from 0 (white) to 1 (red), and nodule size from 1 (small nodules) to 2 (large nodules).

Results and Discussion

Twenty-five *Rhizobium* strains were isolated from A. *albida* nodules. They were listed in the MAO (West Africa MIRCEN) culture collection as MAO 210 through MAO 232, MAO 234, and MAO 236. All the strains were slow-growing except three (MAO 223,

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MAO 225, and MAO 226), which had a generation time of 3-5 h.

Table 1 shows the nodulation index of the four acacia species inoculated with the fast-growing rhizobia. All strains were infective on *A. albida.* Strains MAO 223 and MAO 226 had high indices; strain MAO 225 had a lower index value. On *A. seyal,* one small nodule was associated with strain MAO 223 and only two nodules with MAO 225. The three fast-growing strains did not nodulate *A. raddiana* or *A. Senegal,* contrary to reports by Dreyfus and Dommergues (1981) that these species do nodulate with fast-growing strains of *Rhizobium.*

Table 1. Nodulation index[1] of four *Acacia* species inoculated with three fast-growing *Rhizobium* strains isolated from *Acacia albida,* Bambey, Senegal, 1990.

Acacia species	Control	*Rhizobium* strain MAO 223	MAO 225	MAO 226
A. albida	0	6	4	6
A. raddiana	0	0	0	0
A. Senegal	0	0	0	0
A. seyal	0	1	1	0

1. Nodulation Index (NI) = number of nodules (N) x internal color (C) x nodule size (S). N rated on scale of 0-3 (none to many); C, 0, or 1 (white or red); S, 1, or 2 (small or large).

Since it is known that some *Bradyrhizobium* strains may be fast-growing, we can assume that strains isolated from *A. albida* belong to this group of *Bradyrhizobium,* which would explain why they did not nodulate *A. radiana* and *A. Senegal* (NI = 0).

A. albida is reputedly a promiscuous legume tree that nodulates with a large array of typical slow-growing *Bradyrhizobium* strains, like those infecting *V. unguiculata.* Our study clearly shows that in addition to the typical slow-growing *Bradyrhizobium* strains, the fast-growing strains MAO 223, MAO 225, and MAO 226 can nodulate *A. albida* as well.

Inoculants made of fast-growing strains are easier to produce, provided their effectiveness is high. This opens up new possibilites for their utilization in management of *A. albida.* Investigations are under way in our laboratory to evaluate the effectiveness of our fast-growing strains.

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Endomycorrhiza Infection in Young *Faidherbia albida:* Influence on Growth and Development

M. Ducousso[1] and J.P. Colonna[2]

Abstract

The effects of inoculation by Glomus mosseae *on nodulation and plant growth, and the development of the endomycorrhizal infection were studied on* Faidherbia albida *seedlings. The seedlings were cultured in either polyethylene bags (vol = 1 L), or 25-L, 50-L, and 75-L PVC (polyvinyl chloride) tubes containing nonsterilized soils.*

Compared with the noninoculated control, inoculation with Glomus mosseae *enhanced height (34% increase in bags and 68% in PVC tubes); above-ground biomass production (82% and 112%); root biomass production (44% and 57%); and nodulation (30% and 263%). Endomycorrhizal inoculation did not appear to have any impact, either positive or negative, on taproot elongation.*

Observations revealed that only the upper part of the plant root system was infected and that the inoculum did not penetrate deeply into the soil. Thus, it is likely that endomycorrhizal inoculation of young F. albida *will probably not have a lasting positive impact in the field.*

Introduction

Faidherbia albida, like most of the Acaceae, is capable of simultaneously forming nitrogen-fixing nodules and vesicular arbuscular endomycorrhizae (VAM) on its roots (Ducousso 1990). These infections have been shown to improve seedling development, and have been the focus of studies under controlled conditions in the laboratory and the nursery. Efforts to successfully extend these beneficial effects to transplanted seedlings have failed. Outplantings of *Acacia holosericea, Acacia Senegal,* and *Acacia raddiana* in Senegal demonstrated that beneficial effects of endomycorrhizal inoculation diminished after 1 or 2 years.

Interest in *F. albida* as an element of Sahelian agroforestry systems (CTFT 1988) has stimulated research on mycorrhizal infection on this species in the field and its effect on growth. Two experiments were simultaneously carried out on nonsterilized soil representative of *F. albida* park zones in Senegal.

In the first experiment, we monitored the effects of seedling inoculation in polyethylene bags (vol = 1 L), using standard nursery techniques. In the second experiment, seedlings were cultivated in PVC tubes (25 cm in diameter) of various lengths. This experiment represented an intermediate step between the nursery conditions (i.e., bags) and field conditions by allowing observation of root systems and mycorrhizal development on plants growing in a larger volume of soil.

Materials and Methods

F. albida seeds (provenance 90/2709, DRPF/ISRA, Dakar, Senegal) were pretreated with concentrated sulfuric acid for 1 h, rinsed well with tap water and then germinated for 48 h on moist sand. After germination, seed coats were removed and the seedlings were planted in the nursery in either polyethylene

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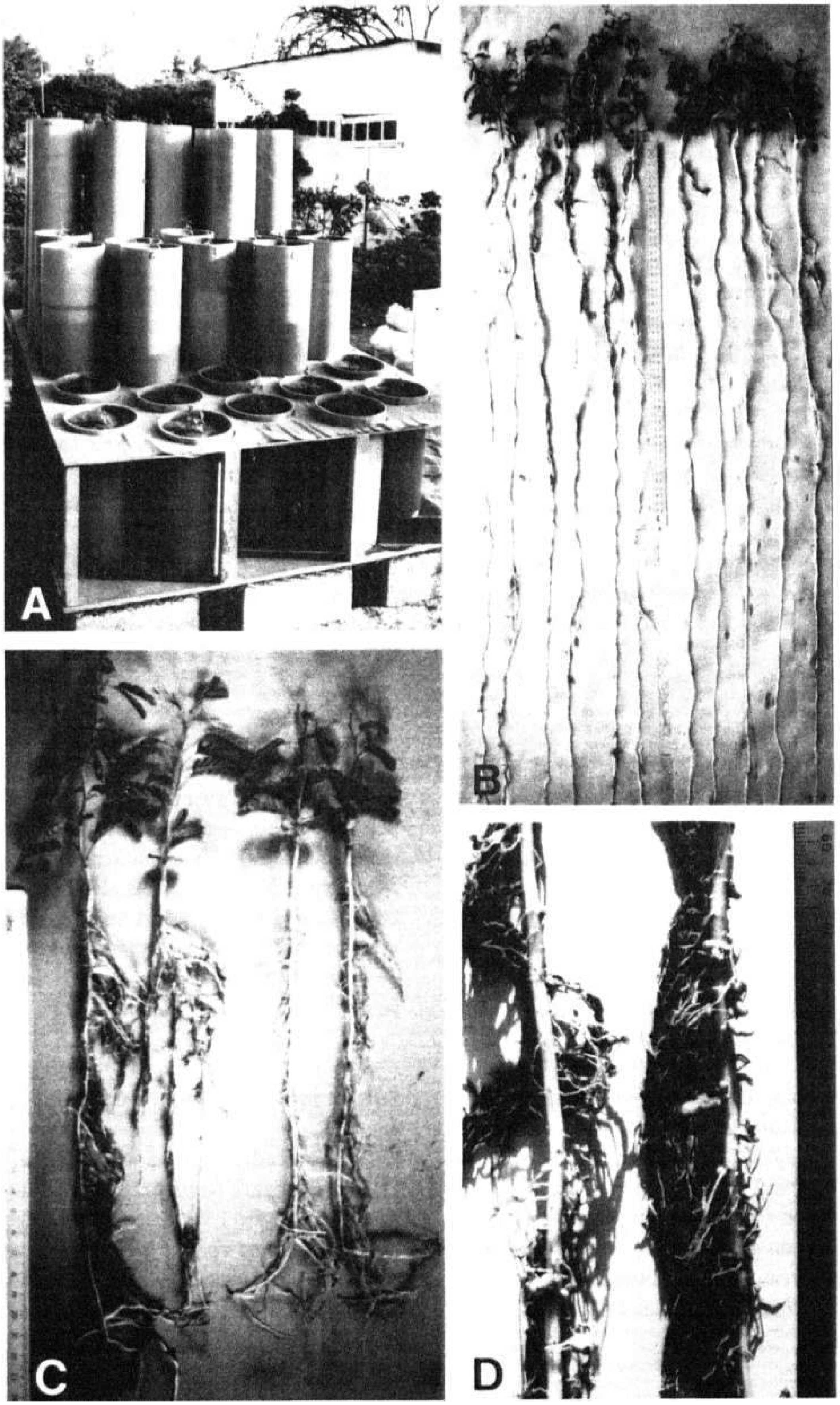

Figure 1. A. Experimental set up showing PVC tubes of various lengths 6 weeks after sowing. B. Root growth in 1.0-m PVC tubes 9 weeks after sowing. Five noninoculated plants (right) and five inoculated plants (left). C. Mycorrhizal infection in 8-week-old plants grown in 1-L bags. (Note root coiling.) On the second plant to the left, taproot branching caused early infection. D. Nodules on roots.

bags (vol = 1 L) or in 0.5-m (vol = 25 L), 1.0-m (vol = 50 L), or 1.5-m (vol = 75 L) PVC tubes (25 cm in diameter) (Fig. 1). All pots were filled with sifted Deck soil (Table 1). Plants were watered daily throughout the duration of the experiments.

Table 1. Principal physico-chemical characteristics of Deck soil, Bambey, Senegal, 1990.

Soil parameter	Value
Total carbon (ppm)	5100
Total nitrogen (ppm)	380
Mineral nitrogen (ppm)	103
Total phosphorus (ppm)	75
Available phosphorus (ppm) (Olsen)	4.4
Clay content (%)	6.4
Silt content (%)	7.3
Sand content (%)	86.3
pH (KCl)	7.0
pH (H_2O)	7.8

Individuals were inoculated during potting with 1 g of finely cut *Vigna unguiculata* roots which were thoroughly infected by the endomycorrhizal fungus *Glomus mosseae.* The inoculum was placed 2-3 cm deep in the planting hole.

Experimental Design

The first experiment had two factors—inoculation (a noninoculated control, C, and inoculation with *Glomus mosseae,* G), and sampling date (1, 2, 3, 4, 6, 8, 10, and 12 weeks). Each treatment was replicated three times in a completely randomized design.

The second experiment involved the same factors, but sampling commenced when the first roots appeared at the bottom of each of the three tube sizes (0.5, 1.0, and 1.5 m in length). There were five replications of each treatment in a completely randomized design.

Main stem height, dry above-ground biomass, root length, and number of nodules were measured for both experiments. The percentage of roots infected with endomycorrhiza was estimated with a 10x microscope after staining with Trypan blue in lactophenol (Phillips and Hayman 1970). In the first experiment, this was done using 100 pieces of root fragments, each 1 cm long, chosen randomly from the root system of each plant. For very young seedlings, samples were taken from the bulked root systems of all sampled plants.

In the second experiment, all roots present at the following depths were observed:

- For 0.5-m PVC tubes: 0-10 cm, 20-30 cm, and 40-50 cm.
- For 1.0-m PVC tubes: 0-10 cm, 20-30 cm, 45-55 cm, 70-80 cm, and 90-100 cm.
- For 1.5-m PVC tubes: 0-10 cm, 20-30 cm, 45-55 cm, 70-80 cm, 95-105 cm, 120-130 cm, and 140-150 cm.

Plants were harvested after 7 weeks for the 0.5-m PVC tubes, 9 weeks for the 1.0-m PVC tubes, and 12 weeks for the 1.5-m PVC tubes.

Results and Discussion

Inoculation by *Glomus mosseae* had a clear positive impact on plant height. After 12 weeks, this effect was even more noticeable on plants grown in PVC tubes (68% height increase over the control) than on plants grown in polyethylene bags (34%, Fig. 2). Likewise, above-ground biomass of inoculated plants grown in polyethylene bags exceeded the control by 82%. Plants grown in PVC tubes produced 112% more

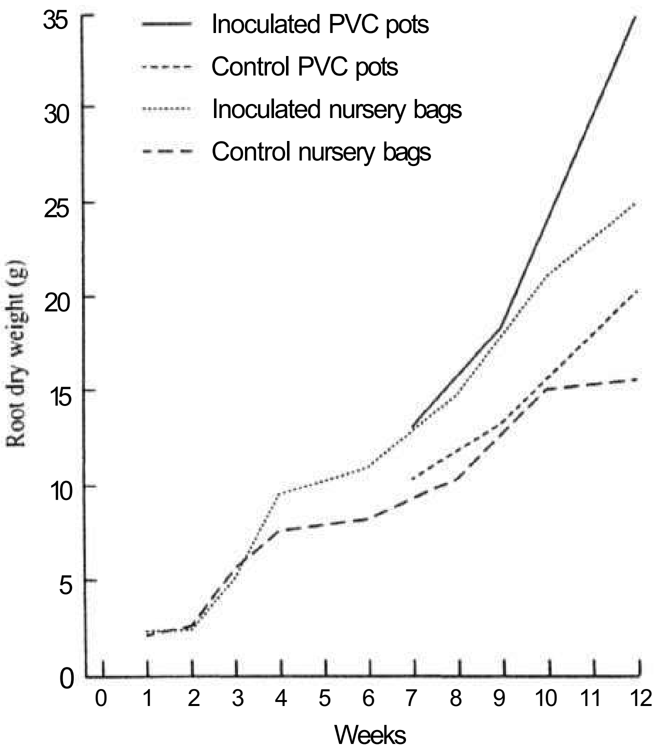

Figure 2. Height of the principal stem of *Faidherbia albida* as a function of age, inoculation by *Glomus mosseae,* and culture conditions.

above-ground biomass than the noninoculated control grown in bags. This is because the limited volume of the bags suppressed root growth after the 8th week, whereas the larger PVC tubes allowed unrestricted root development up to the 12th week.

Besides evidence of a slight depressive effect on 1-week-old plants, inoculation by *Glomus mosseae* had no effect on taproot elongation. Root length in polyethylene bags averaged 32 cm at 12 weeks. At this time, limited growing space caused the roots to coil up at the bottom. In the PVC tubes, where taproot growth was unhindered, root lengths averaged 47 cm in 7 weeks, 95 cm in 9 weeks, and 143 cm in 12 weeks. Inoculated plants in polyethylene bags produced 44% more root biomass than the control, whereas those in PVC tubes yielded 57% more root biomass than the control (Fig. 3). This difference is strongly linked to the large increase in fibrous roots observed on the inoculated plants. This increase evidently resulted in increased mineral absorption capacity which led to growth variations among the treatments. With the exception of plant height, other growth parameters measured were greater than those recorded by Gupta et al. (1973) at equivalent ages. This could be due to differences in growth conditions, growth period, and/or genotype.

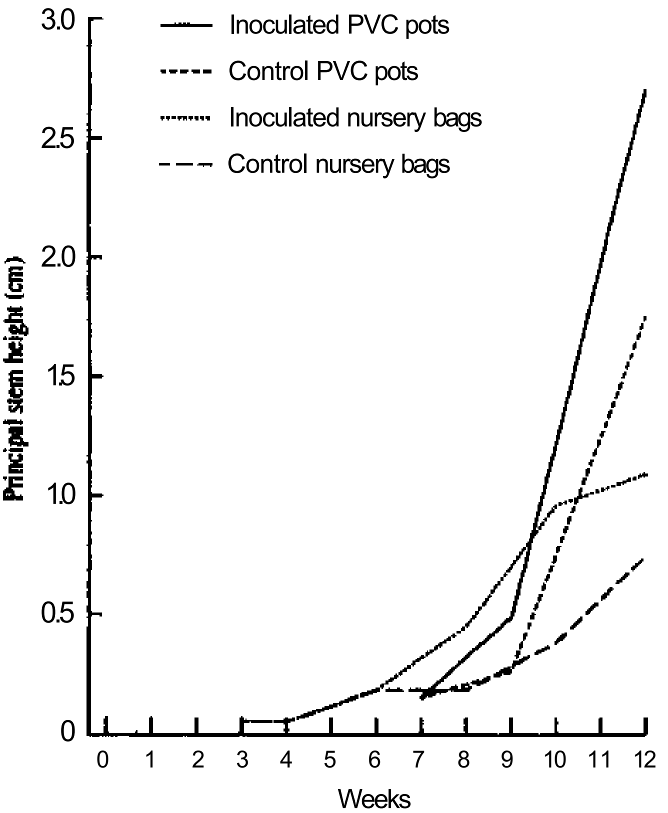

Figure 3. Dry root mass of *Faidherbia albida* as a function of age, inoculation by *Glomus mosseae*, and culture conditions.

Inoculation at the time of outplanting caused necrosis of the taproot on 20% of the plants. Plants thus affected developed 2-6 secondary roots. Inoculating the plants 2-3 weeks after outplanting may have two advantages, i.e., a well-developed root system would ensure a good infection, and the well-formed taproot would not be injured.

Twelve weeks is the minimum time required in the nursery for F. *albida.* These data show that, in this time, the average seedling grown in 1-L pots would have a 32-cm taproot and a root biomass of 0.75 g for the noninoculated control or 1.08 g for inoculated plants. To reduce or eliminate production time in the nursery and to take advantage of the growth potentials demonstrated by these experiments, use of larger containers, or even direct seeding, is a preferable alternative.

Nodule counts were taken after the second week, and correlated positively with root development. Inoculation by *Glomus mosseae* greatly enhanced spontaneous nodulation by *Bradyrhizobium* (Dreyfus and Dommergues 1981) already present in the soil. Colonna et al. (1990a and 1990b) and Ducousso (1990) suggested that this effect is due to better phosphorous nutrition resulting from infection with endomycorrhiza.

Soil volume had a positive effect on plant development, but the degree of development depended on whether the plants were inoculated. For inoculated plants, the quantity of available phosphorus and *Bradyrhizohium* already in the soil (which would increase with increasing soil volumes), affected the degree of nodulation in the larger PVC tubes. On noninoculated plants, however, seedlings grown in larger volumes of soil had fewer nodules than plants grown in 1-L bags. This could be because nitrogen availability was sufficient in the PVC tubes but limited in the bags.

For the noninoculated plants produced in bags, the rate of contamination by local endomycorrhizal fungi varied with plant age, i.e., 0% for individuals at 1, 2, 3, and 4 weeks, and 40% (maximum) for 12-week-old plants. No endomycorrhiza was observed on noninoculated plants grown in PVC tubes. Since the soil used was not sterilized at the beginning of the experiment, the appearance of endomycorrhizal contaminants would be expected. The absence of infection of plants raised in PVC tubes remains unexplained.

After 6 weeks, 90% of plants raised in bags showed signs of endomycorrhizal infection. One week after inoculation, the first appressoria and intraroot hyphae were noticeable. The first arbuscules were visible in the second week of culture. The rate of infection increased steadily until the 6th week of culture, and then stabilized between 79-90%.

In the PVC tubes, infection rate decreased with depth. No endomycorrhiza was observed below 70-80 cm. Endomycorrhizal infection was profuse at 0-10 cm where it was 76% at week 7, 82% at week 9, and 95% at week 12. At 20-30 cm, a more moderate endomycorrhizal development occurred—6% at week 7,12% at week 9, and 41% at week 12. Virtually all of the roots infected by *Glomus mosseae* were located in the upper part of the plant root system.

It is quite possible that this temperate variety of *Glomus mosseae* would not endure extreme variations in surface soil temperature typical in the Sahelian dry season. If an introduced strain happens to survive, its ability to infect new roots at depth would diminish as the root system continued to develop at depth. These results explain, at least in part, the poor results of the inoculation trials carried out in Senegal with *Glomus mosseae* (Cornet 1982, Cornet et al. 1982, Jaques 1986).

Conclusion

Results of the effects of endomycorrhizal inoculation on growth of *F. albida* seedlings illustrate the importance of infection in improving the silviculture of this species. Positive effects on growth parameters emerged following inoculation by *Glomus mosseae* and were enhanced when larger containers were used. We believe that successful manipulation of mycorrhizal infection in *F. albida* in the field could lead to spectacular results.

The failure of endomycorrhizal fungi to develop at greater depths, even under optimal moisture conditions, requires further investigation. As in the case of the inoculation trials undertaken in Senegal, utilization of temperate strains of *Glomus mosseae* may explain the limited benefits demonstrated here. In future, research should not be limited to the surface horizons only , as is often the case, but also cover the mycorrhizal infection at greater depths. Roots of *F. albida* in Senegal have been found at depths attaining 34 m (Dupuy and Dreyfus, these proceedings).

Collection and conservation of endomycorrhizal fungi of *F. albida* is important. Also, improved methods for producing sufficient quantities of inoculum for nurseries is essential. Inoculation techniques should emphasize development of controlled infection at depths using selected strains which can successfully compete with wild types already in the soil.

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Session 5
Social and Development Issues

Cover photo: *Faidherbia albida* growing in Malawi. Although cropping under *Faidherbia albida* parks is predominately found in West Africa, it has also been used in traditional farming systems in many eastern African countries. (Photo: C.W. Fagg.)

Extension *of Acacia albida:* Recapitalization of the Natural Resource Base

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Abstract

Acacia albida *parks, despite their well-known usefulness to agriculture and livestock, are becoming less numerous in many areas with deteriorating environmental and economic conditions. Realizing that there is no single technological fix, a small but growing number of smallholders are trying a wide array of relatively low-input practices to increase soil, forest, and range productivity. The establishment of A.* albida *trees is among these options, but the diffusion of the tree is localized. If the tree is to contribute to the long-term recapitalization of the soil's productive capacity, it should be part of a broader strategy that includes short- as well as long-term benefits and builds on lessons learned from past experience.*

Introduction

Acacia albida is a tree that is well known to most workers involved in agricultural development in the Sahel. The traditions of the region include many stories and proverbs about the tree, and its impact on soil productivity and animal nutrition has been the topic of serious research (Felker 1978). But relatively little is known about its extension except that its establishment is probably on the decline.

It is the premise of this paper that *A. alhida,* because of its long-term impacts on soil and livestock productivity, be seriously considered for any plan focusing on sustainable agricultural development. The purposes of this paper are (1) to support this premise by examining the role of this tree in traditional production systems, (2) to examine past experience in its extension, both traditional and assisted, and (3) to consider options for future extension.

The Closing of the Frontier

At some point during the last 20 or 25 years, something happened to a group of Sahelian farmers that fundamentally changed the way they farmed—the frontier closed. The 'frontier' in this context is the new land (or the old fallowed land) normally available to farmers as the land under cultivation is degraded. A management option upon which our illustrative group depended was no longer available. While the above group is illustrative, we can be sure that it existed. It was not the first group to have dealt with this new reality. Porteres (1954a, 1954b) writes of fallow periods being short or nonexistent in parts of the Groundnut Basin of Senegal in the early 1950s, Nor is it the last—there are still relatively large frontier areas in the Sahel and Sudanian zones, such as the lands freed from onchocercosis. But this disappearance of the frontier started to accelerate during the drought of the early 1970s, as more and more farmers, herders, and woodcutters were forced to move on to increasingly marginal lands.

Given the increasing rate of degradation, one can see the day, possibly in the lifetime of a current generation, when 'new lands' are a thing of the past in the Sahelian and woody Savanna Zones of West Africa. At that time, will the productive capacity of all lands be so marginalized that it will be able to support only a small proportion of the present population, or will there be more intensive, but sustainable and economically viable, management systems?

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To prepare for that day, better and long-range stewardship of the natural resource base must begin now, and, as this paper illustrates, *A. albida* has a major role to play. But the establishment of the tree depends upon the willingness of today's farmers to participate in an activity from which they can expect few tangible returns within the next 10 years. Consequently, wider diffusion of *A. albida* should be seen as an element within a strategy that has short-term as well as long-term impacts; that ensures that smallholders have long-term security over the products of better management; and, that strengthens the capacity of local villages to manage village lands.

Coping in the Face of New Realities

As the new realities are better appreciated, one sees discernible, if localized, changes in the way smallholders manage the natural resource base.

Agroforestry technologies, including renewed interest in the establishment of *A. albida,* are among the natural resource management practices being adopted. It is the premise of this paper that ignoring the lessons learned from these types of experience will lead to repeating old mistakes based on the notion that economic growth depends primarily on the development of new technologies.

On the contrary, assessments of dozens of resource management case studies tell us that we do not need to wait for technological breakthroughs to make substantial progress toward achieving sustainable rural economic growth. Rather, we need to better appreciate the constraints to the wider diffusion of existing technologies and understand, this would enable wider diffusion of a whole range of technologies, including the 'old' A.*albida* system.

Risks and Benefits

Whether to invest in the extension of *A. albida* is, above all, an economic question. The success or failure of the extension effort depends upon balancing costs and benefits. At the household level, the focus is necessarily on the short-term risks, while the national government must balance the costs of doing nothing about long-term productive capacity against the delayed benefits from long-term investments.

Constraints and Risks

Farm-level Economic Risk. There are indeed risks to establishing *A. albida;* for instance,

- While smallholders may have to invest time and effort in protecting young trees, they cannot expect to receive benefits for at least 7-9 years, and more likely substantial benefits probably cannot be expected for 15-20 years. This is a risk for many smallholders living on the margin of survival.
- Establishing trees in agricultural fields is a potential problem for animal or machine cultivation. One must remember that trees planted today will have a long-term impact on those considerations.
- The tree can become a nuisance because of its thorns and its tendency to attract granivorous birds.
- Finally, there is the question of who owns the rights to use the products of the trees (fruit, leaves, wood, etc) or the ground upon which it stands can become a source of contention.

Institutional Constraints. Despite excellent and detailed research work in the 1960's, *A. albida* has been ignored by many agronomists. Charreau, according to Pelissier (1966), expressed astonishment that, during 40 years of agronomic work in the Groundnut Basin of Senegal, European researchers (and we can now add American) had given little serious consideration to the agronomic potential of *A. albida.* As a tree it was considered as an obstruction to agricultural development, and the primary research was to determine how much mineral fertilizer was required to replace the amount lost after the removal of the tree.

It should be noted that Charreau (1974) was one of the first agricultural researchers to give serious consideration to the agronomic aspects of *A. albida.* In his wake followed a number of other French and Senegalese researchers who contributed substantially to our knowledge of the tree. Dancette and Saar (1985) noted that most of this research occurred before 1968 and went on to write that *this interest, alas, did not continue.' But the studies up to 1968 were intensive and covered the impact of the tree on millet and sorghum yields, on soil organic matter, on microbiological properties, and on agroclimatology. From the late 1960s through the mid-1970s, agricultural research was guided by the notion that the problems of increased pressure on land resources and reduced fallow periods could be met by addition of mineral fertilizer (Dancette and Saar 1985). However, this orientation changed as it became evident that mineral fertilizer and improved varieties were not, in themselves, sufficient to sustain increased productivity.

Dancette and Saar (1985) further wrote that this narrow orientation against rational use of all sorts of naturally produced soil amendments greatly influenced the degradation process in the Groundnut Basin. To correct the faults of these past orientations-and given the vagaries of the world's petroleum market-these authors suggested promoting better use of the natural forms of soil amendments, including revitalizing interest in the A. *albida* system.

Traditional Husbandry of A. *albida*

Looking at traditional systems is one way to capture hard-earned knowledge; in many dry regions of Africa, *A. albida* plays major roles in these systems. For example, numerous sources report the role of the species in various agrosilvipastoral systems in Africa. In Niger, old established stands are not an accident. The Sultan of Zinder, over 100 years ago, is reported to have made cutting an *A. albida* a capital offense (Wentling 1983) and the legend, real or not, appears to reflect a respect for the usefulness of the tree as manifest in the thick stands of the tree in regions around Zinder. Others report mature stands to be widespread in parts of Mali, Burkina Faso, Malawi, Sudan, Chad, and Zimbabwe, and in Senegal, where it was the foundation of production system of the Groundnut Basin.

The Agrosilvipastoral System of the Senegal Groundnut Basin

Pelissier (1966) reported on the role and extension of *A. albida* in the Serere systems in Senegal. He noted that the quasi-permanent production system of the Serere depended upon *A. albida* parks and allowed pastoral sedentarization, which in turn, helped stabilize the production system by contributing large quantities of manure.

The establishment and maintenance of these parks depended upon a proactive and systematic husbandry by farmers, who tended and pruned young trees and controlled how limbs were lopped. The phrase for tending young trees in the local language was very similar to that used for raising a child.

Degradation of Natural Stands

Despite the obvious benefits of the tree, its density is on decline in many places. Dancette and Saar (1985) report on the disappearance in the Groundnut Basin of many *A. albida* parks over the last 20 years and link the reduced productivity of these areas to this disappearance. In visiting the Groundnut Basin today, one is struck by the old, overmature stands of *A. albida.* the trees have been harshly pruned and crowns that once enriched hundreds of square meters of soil now cover only a small area. But a more telling measure of the decline of these old parks is the lack of young seedlings. One can imagine that the next drought will kill off many of the existing trees leaving a barren, unprotected and, much less productive landscape.

The Groundnut Basin is not the only area where A. *albida* parks are in a state of degradation. In the Mopti region of Mali, the tree is well established, but the stand consists primarily of very mature trees with few young trees. The demise of these mature trees will have the same consequences as in Senegal. In response to the condition around Mopti, a senior Malian forester suggest a policy change to allow farmers to harvest a couple of trees per year per hectare without a fine if they protect five young trees for every tree harvested.

Recent Initiatives in Agroforestry Extension

Farmer-Managed Extension

During natural resource management assessments over the last few years, farmers have often been found protecting young *A. albida* trees and practicing other forms of agroforestry. While these cases do not represent an adequate groundswell of action to address the magnitude of the problem, they do provide insights into the conditions contributing to actions being taken.

There has been a resurgence of interest in reestablishing the *A. albida* in the Senegal Groundnut Basin (J. Seyler, 1990, Michigan State University, personal communication). This is due to several reasons. First, there is a growing realization on the part of many farmers, that intensification of some kind is needed, but that mineral fertilizer alone is not sufficient. Second, in the Groundnut Basin there is a decline in use of mineral fertilizer since the withdrawal of subsidy support. The plausibility of the link between lower fertilizer subsidies and higher interest in agroforestry will have to wait for more analysis, but is intriguing.

Donor-Supported Extension

A. albida has been extended through a number of projects, including Peace Corps/Niger Gao Project, the United Nations Sudano-Sahel Organization (UNSO) Project in the Department of Dosso (Niger), the United States Agency for International Development (USAID)/Senegal Reforestation Project and the CARE/Chad *A. albida* Project. This section will also review a project that encourages natural regeneration of any trees-not just A. *albida.*

Peace Corps/Niger Gao Project. In 1973, U.S. Peace Corps volunteers initiated a project to establish *A. albida* trees in a number of villages. The major inputs included fencing materials, plastic pots, and food-for-work. The results varied from excellent (near Maradi) to poor, the reasons for the impact varying with the site, the interest of the village, and, doubtless, the volunteer. These sites should be revisited to determine the impact of these trees and to correlate the impacts to the characteristics of each site.

UNSO Gao Project. This project, located in Dosso, Niger, and visited during this workshop, has gone through several changes in policy. The sites have varying survival and growth rates. The policy of sharing the cost of establishing the trees by paying money to farmers on a survival-rate basis was easier to control and administer than food-for-work.

USAID/Senegal Reforestation Project. This project is only about 2 years old and impacts are starting to be assessed. The project encourages reforestation through cost sharing by reimbursing farmers for half their costs. As in UNSO/GAO project, the farmers receive funds only after the first year and only after a certain survival rate has been verified.

CARE-Chad *A. albida* Project. In 197S, CARE-Chad initiated the A. *albida* Extension Project aimed at establishing the tree on 3500 ha of farmland over 3 years, in the region from Bongor to Massaguet. Although the target had been achieved by 1978, the survival rates were highly variable.

The rationale for the project was that much of the farmland in this area had only been open to agriculture during the last generation and did not have A. *albida* trees to provide cover. Consequently, as the lands were cleared for millet and sorghum (and for cotton in the south), nearly all permanent vegetation was removed; as noted above, this could only lead to the eventual loss of the productivity of large areas of land once the topsoil was leached and eroded.

The project worked with farmers to stake the land, to plant the trees out, and to protect them from livestock and fire. For each of these steps, the farmers received food rations. Most farmers planted out 200 trees on 2 ha. In the Bongor area, where the tree was widely spread and constituted an integral part of the farming system, protection of natural regeneration was used with impressive success. In 1985,1 returned to the project area and estimated that 600 to 800 ha had 25 ha^{-1} or more surviving trees, a sufficient density to provide a sustainable impact in terms of crop and forage yields. Because the visit occurred in September, it was possible to see the effects on crops and other grasses under the 8- to 10-year old trees. Given the upright habit of young *A, albida* trees, the area covered by the crown was small; nevertheless, some of the trees had begun to produce fruit. The possible reasons for the variation in survival rate include the following:

- **Seedling size.** It is possible that the larger seedlings survived better; 3-4 months' growth in the nursery seemed ideal. One or two root prunings did not appear to have any negative effects on the survival or growth of the seedlings. The survival rate of the seedlings grown in the larger (30 cm) pots was higher. In April of both 1976 and 1977, the road to the project area was closed for 2 weeks by political disturbances. Consequently, the fuel supplies for two nurseries ran out and thousands of seedlings died. We resowed the pots, but the seedlings sown in the April and May heat were extremely small-the survival rates from these planting was very poor.
- **Rainfall distribution.** The earlier and more even the rains, the better is the survival rate. We planted out as early in the season as possible, primarily because it became too difficult to find the planting sites once the grain crops reached knee height in the field to be planted.
- **Supervision.** With better supervision of the planting, the survival rate is better. In some areas, fields were grouped together, supervision was very good, and survival was high; in other areas, fields were more isolated, and the quality of the work depended upon the participating individuals.
- **Food-for-work.** Given the logistics of moving large amounts of food, using food as an incentive was often disruptive to forestry operations.
- **Initial number of farmers.** Because of the 4-year time-frame of the project, which was considerably

compressed by the war, there was pressure to work with as many farmers as possible in the first year before many of the logistic and technical service approaches had been adequately tested.

Recapitalizing the Natural Resource Base

Conceptual Premise

The future of the rural economy of the Sahel depends upon recapitalizing the productive capacity of the natural resource base in the short, medium, and long terms. Short-term elements such as improved varieties and mineral fertilizers have important roles, but are not in themselves sufficient (Charreau 1974). Wider diffusion of A. *albida* and other agroforestry systems is among the conditions for the future productivity of the Sahel.

The recapitalization should take place in the context of a strategy that builds on the new partnership emerging between village-level organizations and governments. At the base of this new relationship is a sharing of both the responsibility of protecting the natural resource base and the benefits from that stewardship. The following strategy is based on field experience and contains few, if any, untried elements.

Operational Elements

Economic Analysis. Before there is a commitment by host governments or donors, an economic analysis should be conducted in order to establish the value of benefits and the cost of doing nothing. Scenarios with and without long-term investments such as A. *albida* should be considered. This analysis should be conducted by a team including both donors and host-government officials and cover a 20-year period. This type of analysis was conducted in Mali under the USAID Natural Resource Management Project.

Land-Use Plans. Village-level land-use plans should be developed to give security over use rights, these plans should contain long-range measures. Personnel from the various technical services, in collaboration with village representatives, should develop a village lands development plan that addresses management of soil, range, and forest resources in the short, medium, and long terms. This step requires a strengthening and reorientation of technical services. In particular, the roles of Forestry Service personnel would be reoriented from regulatory to outreach and additional training may be required. The plan should specify the rights of the village to the products of better management as well as the villagers' responsibility for long-range measures, including establishing A. *albida* parks. The plan should identify assistance to be provided to villages that adopt the long-term measures.

Assistance. Assistance should be provided on a priority basis to those villages implementing long-term measures and should be aimed at increasing the productive capacity of the village lands. Illustrative types of assistance include the following:

- **The right to harvest living trees.** If the farm has a uniform stand of large A. *albida* trees, the farmer whould be allowed to harvest one large tree for every five trees established.
- **Assistance for short-term investments.** For smallholders who establish A. *albida* stands, assistance should be provided for recapitalization measures that have short- as well as medium- and long-term impacts. For example, stabilizing the soil through contour dikes may require the transport of stones or cutting of grasses such as andropogon or vetiver. Provision of rock phosphate to those establishing A. *albida* is an option that could be justified because of its capacity to 'kick-start' the recapitalizing process. Farmers should also be provided with appropriate technical assistance.
- **Strengthening the organizational capacity of village-level organizations.** As a growing number of villages are discovering, the village-level capacity to manage enterprises and negotiate with outside groups is a very powerful tool. Making the establishment of a land-use management plan a condition for providing assistance to strengthening village-level organizations would be an incentive.
- **Assistance in gaining first-hand knowledge.** Assisting smallholders to make informed decisions about which practices to adopt is critical to the strategy. In the case of establishing the A. *albida,* for example, smallholders have the option of natural regeneration or potted stock. They should see examples of both option.

Choice of Sites. It is essential to start small and build on success. The first sites should be chosen for their potential for success and should form the foundation for future diffusion. It is critical in the initial years to develop a core of successful sites and to use these as examples for other villages to make informed decisions about the benefits and costs of participating in the strategy. These sites would also be used to strengthen the capacity of host governments to provide services and formulate policies that increase the incentives for long-term investments at the village level

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Faidherbia albida: A Witness of Agrarian Transformation

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Abstract

The utilization of Faidherhia albida *by Sudanian and southern Sahelian agrarian societies is a very old practice and is largely unstudied by scientists. The species is ubiquitous, yet is underutilized or unused in many agricultural systems in the region. Since the turn of the century, the practice of intensive agriculture in* F. albida *parks of Africa has been largely abandoned by most peoples who have turned to an essentially extensive agriculture.*

Isolated groups, independently and with no outside intervention, are once again practicing the former intensive agricultural techniques under F. albida *parks. This deserves investigation. Also, the involvement by rural development programs in this movement merits discussion.*

Introduction

An excerpt from a conversation held with Tengsoba of Niaogho, Burkina Faso (Hervouet 1978) is given below:

"When the Bissa arrived in this region, they found no one. There was nothing but bush which was opened for clearings. In the beginning, their homesteads were surrounded by *Parkia africana;* but since the Bissa had many cattle and the *Parkia africana* does not prefer manured soil, they were gradually replaced by *Faidherhia albida.*

F. albida demarcated field borders and the Bissa no longer needed to farm in the bush. All the village children learned to raise-in the sense of raising a child-F. *albida* by pruning it. After the white man's arrival, land had to be cultivated longer and agricultural lands expanded. Then the *F. alhida* began to perish, and it was cut down to make mortars and pestles, for the white man was prohibiting the cutting of *Khaya senegalensis* and we didn't have money to pay for permits.

At this time, many people left, and if they all came back today, the country would not have the resources to support them, even with all the fields that have been cleared in the bush."

Two years have passed since the study team visited the land and farmers of Niaogho. Tengsoba's description of land use as it existed when he was young was as a prelude to an in-depth description of *F. albida*-its ecology and its contribution to the soils and to agricultural and animal production.

Reality Ignored by Science

Despite their importance, numbers, diversity, and vastness in range, descriptions of *F.albida* parks are scarce in scientific literature. Before Pelissier (1953), agronomic and geographic references to the intensive agrarian system generally associated with *F. albida* parks were rare, A few years after Pelissier, Savonnet (1959) also described 'a perfected farming system practiced by the Bwaba-Bobo-Oule of the Hounde region'. He did not extend those observations to the numerous other agropastoral people of this Sudanian zone. Following that, studies done in Bambey, Senegal focused on the impact of *F. albida* on soil and crop yields (Charreau and Vidal 1965; Pelissier 1966).

Despite the ubiquity of *F. albida* in western Africa, available geographic and agricultural literature

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Hervouet, J.P. 1992. *Faidherbia albida:* A witness of agrarian transformation. Pages 165-169 *in Faidherbia albida* in the West African semi-arid tropics: proceedings of a workshop, 22-26 Apr 1991, Niamey, Niger (Vandenbeldt, R.J., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics; and Nairobi, Kenya: International Centre for Research in Agroforestry.

gives the impression that the adoption of *F. albida* by the rural population is a rare phenomenon in Sudanian and southern Sahelian Africa. Rather, it would seen that the norm consists of extensive farming systems where most crop production is carried out in temporary fields cleared in the bush. One cannot count the number of publications on village lands, even in villages where it predominates, in which authors ignored this species. Careful examination of rural land use contradicts the idea of ignorance or disinterest in *F. albida* on the part of farmers. Most village lands in Burkina Faso are occupied by at least a few *F. albida.*

Abandonment of *F. albida* Parks

When the Niaogho chief was speaking of *F. albida* and its benefits, decades had already passed since parks on Bissa land were tended. The system was in a state of decline. Except for one dense grove and a few isolated trees, no *F. albida* remained

The abandonment of *F. albida* parks in Burkina Faso occurred over the past 20 years between the White and Red Volta Rivers (now called the Nakambe and Nazinon), on Birifor and Dagari lands, on Bwaba lands to the west and to the north of Bobo Dioulasso, on Senoufou lands between Mali and the Cote d'Ivoire, on Sissala lands neighboring Ghana, and on Samo lands bordering the Sourou River (Fig. 1).

The Samo abundonment occurred with particular suddenness. In 1975, Samo fields were grouped around the villages, shaded by a dense *F. albida* park manured by Fulani cattle and located near a natural wood and wildlife reserve almost untouched by farming. A neighboring Mossi region, where bush-based agriculture played an essential role in the production system, contrasted with the Samo system. The following year, the Samo Cleared fields in the bush following the example of the neighboring Mossi, and parklands were practically abandoned. The trees were lopped heavily, a sign of their impending doom.

All such transitions have not occurred with this suddenness, and it is not uncommon to see parks abandoned by farmers for 2-3 years, and then recultivated. This occurred in a Sissala region of Burkina Faso between 1978 and 1980, and in the Bwaba area between Boromo and Bobo Dioulasso. These actions

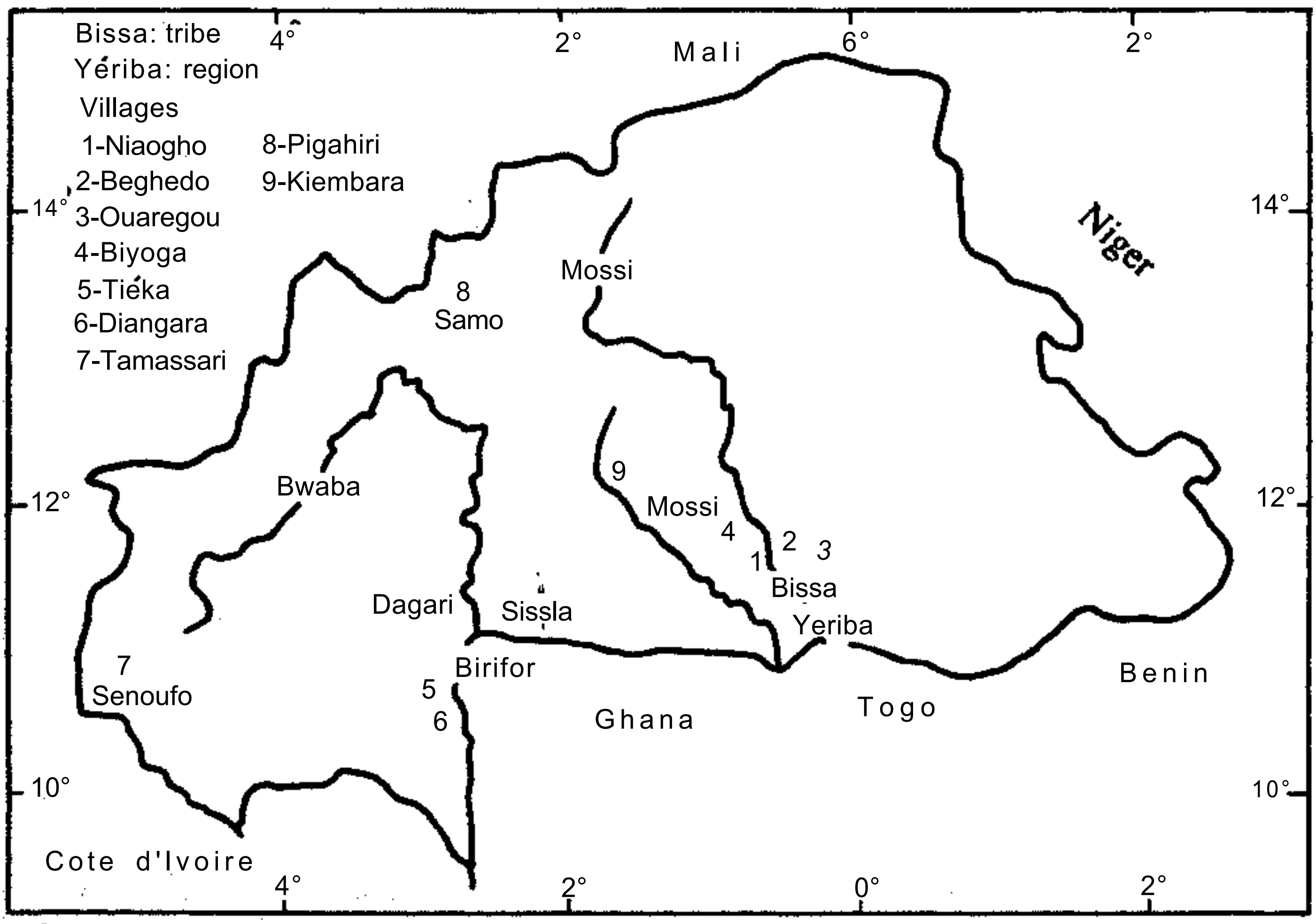

Figure 1. Map of Burkina Faso showing location of villages and ethnic groups.

may have resulted from crop pest invasions, and should not be confused with true abandonment of parks and practices which lead to the decline, or even disappearance, of the trees.

A Tree of Old Villages

With few exceptions, regardless of the ethnic group or population density, F. *albida* parks do not exist in new villages or recent settlements. One exception was noted by Benoit (1973) who noted that recent homesteads in the village of Daboura, Burkina Faso were built on an F. *albida* park, whereas the oldest parts of the village existed outside the park. This was because the village had taken part in a 1916 revolt and was relocated outside the park after its defeat. Similarly parks are sometimes found where old but now abandoned villages exist. However, they are never found on more recent village sites. For example near Yeriba, along the White Volta, 25 Bissa villages were settled during from 1900-40 (Hervouet 1978). Although F. *albida* does not occur in these village lands, it was an integral part of the agricultural practices in the original villages the settlers emigrated from.

Thus, a long time has passed since F. *albida* parks were cropped, established or regenerated. It is also apparent that, because of the diverse ethnic groups involved, this move toward extensive agricultural techniques did not happen simultaneously.

The Adoption of *F. albida*

Whenever African agriculture is described, it is often argued that intensive systems are the outcome of outside constraints, whether due to insecurity or demographic pressure.

F. albida parks are found in both highly populated (60 to up to 150 persons km^{-2}) and sparsely populated areas in Burkina Faso. As previously mentioned, farmlands of Niaogho were once surrounded by a vast, forested 'no man's land'. Towards the west, the tree savanna stretches over 30 km to the first Mossi village in the canton of Manga. The same contrast between the bush and densely populated settlements is found among a number of other peoples including the Samo, Birifor, Dagari, Senoufo, and Bwaba. These examples refute the argument that demographic pressure forces intensification of cropping systems.

Among all these ethnic groups, there are numerous villages which include sizeable forested areas that cannot support dense populations. People in such areas tend F. *albida* parks. In the village of Tieka, for example the area of permanent agriculture under park cover is higher than that in the bush. The same is true in Diangara, a neighboring village where the demographic pressure is much greater and F. *albida* is rare (Savonnet 1976). This village is established on a embarkment slope, and only a few F. *albida* trees exist. Young trees are intentionally destroyed, whereas at Tieka, a large stand of F. *albida* about 12 years old is well-tended (Hervouet, personal observation 1979). Thus, demographic pressure alone cannot fully account for the establishment of F. *albida* parks.

The husbandry of F. *alhida* is a choice of the population and stems from a peoples' perception of the land and their relationship with it. In Mossi country, for example, it is striking that only lands first settled by the Nioniosse still retain F. *albida* parks, whereas areas occupied by administrative and warrior aristocracy, the Nakomse, are shaded by *Butyrospermum* sp and P. *africana.*

The Diversity of *F. albida* parks

F. albida parks still encountered in western Africa are abundant but are far from homogeneous. Depending on location and the groups that use them, their form and function are extremely diverse. Three general types of F. *albida* parks occur: homogeneous parks characterized by a relatively even-aged structure; random stands that show great variability in age and form; and lastly, scattered individuals, often old and of little agronomic use.

The dissimilarity of these park types reflects the diversity of the roles assigned to this tree by rural societies in their socioeconomic and farming systems. The dense homogeneous parks are usually tended by societies having a profound vision of their long term production. Young F *albida* parks do not serve those who decide to tend them—their descendants will benefit.

Inventories and descriptive stratification of different F. *albida* park types could help elucidate relationships existing between agrarian societies and the species. Since some societies have incorporated F. *albida* into their production and sociopolitical systems, the reasons why others have practically deserted this species deserves attention.

From *F. albida* to the Bush

At the time of colonial conquest, the land area used by the Bissa of Niaogho did not exceed 1000 ha despite the fact that the population density in this period equalled that of 1970, Since 1920, existing *F. albida* parks have been added to the cultivated lands which once were dominated by *P. africana.* This also occurred on Serer land in Senegal (Pelissier 1966), Bwaba territory (Capron 1965), and Dagari land (Pradeau 1970), among others. Although at first glance this might be attributed to demographic pressure, population densities in Bwaba and Bissa lands were actually low as a result of the quelled 1916 revolt, and remained so long afterwards. The population of Bissa inhabiting the canton of Niaogho decreased from 7635 to 5545 (27% drop) from 1923 to 1931. This occurred due to fiats imposed by the colonial administration in 1923 which attempted, among other things, to double the area cultivated and to introduce cotton production.

These actions gave rise to large *Parkia africana* populations. A second change, sometimes occurring with the first, was the clearing of fields in the bush accompanied by the establishment of settlements on cleared areas (Hervouet 1978). With the exception of Senoufo areas, the trees left on the newly settled lands were *Butyrospermum parkii* rather than *Parkia qfricana.*

During the 1950s, the abandonment of parks and the decline of intensive agriculture associated with it accelerated. The parks were deserted and largely destroyed by felling and unsustainable lopping. Young seedlings and root suckers were eliminated rather than tended. This period was marked by a movement to the bush. In Niaogho, for example, areas put under agriculture (fields plus fallow land) grew from 4600 ha in 1956 to 8400 ha in 1972, and then to 17800 ha in 1978. At the same time, the population grew from 5400 to 7800, and then to 8500. During this period, the people of Beghedo crossed the White Volta to cultivate the lands of Niaogho. Population density in the settlement was 120 persons km^{-2} in 1956 and no higher than 60 persons knr^{2} 20 years later. The permanent and semi-permanent fields of the village represented no more than 5% of the space cultivated in 1978.

Similarly, in the case of Tamassari, a Senoufo village, fields located in the bush represented 22% of the area cultivated in 1946, 27% in 1957, and 41% in 1971. Between 1957 and 1971, the areas under cultivation were multiplied by two despite the fact that the population only increased by 18%. Thus, this period was characterized by a change from a space-saving (intensive farming under F. *albida* parks) to a time-saving (extensive farming) practice.

These changes certainly reflect the changing objectives of rural societies. The dispersion of populations following abandonment of park areas is a result of the adjustment by rural folk to alternate production systems imposed by changes in the administrative and political environment.

The Bissa have long since abandoned intensive farming practices under *F. albida* parks and have adopted a system requiring greater spatial distribution to meet short-term economic needs. The Senoufou (around 1940), the Bwaba (1960) as well as the Sissala, and the Samo (1970s) have followed suit. The role of the rural Mossi immigrants, by their practice of extensive agriculture with a strong commercial base, can also be included in this change.

This non-synchronous change towards a monetary economy over a long period of time shows that reactions of populations differ by region. Lineages and socio-religious values of villages associated with agricultural systems are presently decaying. Collective discipline is declining as the individual search for immediate monetary gain only grows. The considerable weakening of the elders' power, which is spiritual, political, and economic, has deprived societies of a vision for long-term production. The tendency towards extensive cultivation that yields more production per unit of input, requires greater and greater areas over time whereas former practices were characterized by less space but more labor (often collective) per unit of surface area.

Rapid improvements of human development by increasing and diversifying food crops may justify extensive practices; however, this will only remain possible as long as there exists available lands to clear and exploit. In order to resolve declining production and land degradation in zones previously dominated by an agrarian system which rationally managed *F. albida* parks in agrarian systems, it is essential to study the evolution of the relationship existing between this species and the societies associated with them.

Conclusion

The presence of *F. albida* on agricultural lands has never been a mere coincidence. On the contrary, it is one of the principal indicators of past relationships between societies and their environment. Before World War II, Africa was being changed to respond to production norms defined by the colonizing countries rather than by preexisting agrarian structures. If ethnological and anthropoligical studied had been carried out in the course of this period, they would have discovered the void underlying the agrarian structures and systems of production.

Despite the general abandonment of intensive agricultural practices under *F. albida* parks, groups of farmers, unrelated to one another and without any outside intervention, have been recently regenerating the parks. Their actions are not linked. Rather they are apparently a convergence of progressive stages of isolated societies confronted with the same production problems, i.e., erosion and declining of soil fertility.

Parks were re-established in the Mossi region near the Red Volta 25 years ago when land was still abundant. Reestablishment of regeneration of former parks can also be seen on Dagari, Birifor, and Senoufo lands, as well as in other areas. These actions are evolving gradually without any apparent reason, and are spreading in a dispersed manner.

These attempts at regenerating past agrarian systems are arising from the very bases of African civilizations. It is not clear why some groups reactivate such practices and others do not. These new practices seem to indicate that many Sudanian farmers were pracitising intensive before farming before shifting, under various constraints, to extensive farming.

To possess such knowledge would certainly aid agricultural development projects in reincorporating former rational systems into current practices. An effort should be made to direct rural farmers towards intensive farming by trying, at best, to teach them to utilize the *F. albida* tended by their ancestors.

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Precolonial Agroforestry and its Implications for the Present: the Case of the Sultanate of Damagaram, Niger

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Abstract

This case study presents a precolonial system of agroforestry based on the protection of a certain number of useful species of which Acacia albida (gao *in Haousa*) *was the most important. The sultanate of Damagaram in the 19th century covered the central and western parts of the present Department of Zinder in Niger. It profited from religious and economical upheaval, particularly under the reign of sultan Tanimoune, to enlarge its domain. The control of the* Talakawa, *its subjects, was carried out through an administration which became more and more bureaucratic. One of its famous laws concerns tree protection and states that "whoever cuts down a* [*protected*] *tree cuts off his own head". The calculated application of the law, together with the distribution of* gao *seeds prompted the widespread establishment of agroforestry parklands with* A. albida *as the dominant species. Although this repressive rule disappeared during the colonial period, numerous examples of these parks persist and continue to be rejuvenated. When drawing conclusions from this historic example, it seems that while repression is not a crucial element for the spreading* of gao *trees, centralized authority and organization, especially as the scale of activity increases, may be indispensable.*

Introduction

The hinterlands of Zinder, in eastern Niger, bear witness to surprisingly frequent and dense stands of trees in agricultural fields. The composition of these stands, generally dominated by *Acacia albida* (or *gao),* is noteworthy in that most species in them are known for their usefulness. The historical span of this agroforestry association is reflected in the varying ages of these *gao* trees. In the light of current difficulties with tree planting, the presence of these stands, dating from the precolonial era, merits study. What inducements succeeded in establishing these customary practices? To what degree and in what form did these practices survive the profound transitions associated with colonial and post-colonial rule? What lessons can be learned from this historical evolution?

This case study is part of a larger examination of the relationship between land and tree tenure in Niger. This paper aims to describe different ecological zones and planting, maintenance and usufruct practices for trees and their by-products among the different cultural traditions. The study employed a rapid rural reconnaissance methodology that combined a literature review with directed field surveys. The particular form of land/tree tenure raised by the Damagaram sultanate case inspired us to continue our investigations at the court of the present Sultan as well as into the surrounding villages.

The information thus collected confirms the remark made by Bonfils (1987) that "a certain sultan let the hand be cut off of anyone who cut down a *gao* and signals the nature of a precolonial system that, while effective, was also centralized and repressive/' From these observations it is tempting to formulate the somewhat heretical hypothesis that "to make agroforestry succeed, local participation does not necessarily imply individual liberalization nor a de-

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volution of central authority." To what extent is this hypothesis true? Can it be applied more generally in the current political and ecological contexts?

Protection of the environment for rational and efficient management is not a recent phenomenon in the agricultural landscape of Niger. Conservation practices were integrated into the traditional organization at the village level which gave rise to the concept of land management (*gestion des terroirs*). It is certain that colonialism and the introduction of a new logic of territorial administration have precipitated a spatial reorganization and a transformation of agrosilvipastoral interests. However, neither the traditional practices, nor the traditional logic have disappeared completely, and a legislative patchwork *(bricolage juridique,* Le Roy 1991) characterizes this inheritance so far as land and tree tenure issues are concerned. In Zinder, farmers still refer to the "trees of the Sultan". It is an appropriate moment to contribute to the ongoing discussion of agroforestry practices and constraints and consider once again the role of the State in the initiation and the application of natural resource policies, programs, and of natural resource management projects. With regard to the agroforestry of *A. albida,* Nigerien experiments so far have shown that inducement to plant and to protect young trees remains ambiguous.

Historical Context

Although the situation in Zinder is relatively specific, it was not exceptional. In certain regions, e.g. in Gaya in southwestern Niger, a chief traditionally dealt with village issues. At the same time there was *le Tchangakoye,* who concentrated his efforts on protection of the environment and its resources, on cultivated land, woodlands, and grazing land and who, as such, exercised a power acknowledged by all. They surrounded themselves with certain myths and virtues and were feared by the people, as they were believed to be in contact with the spirits and wild animals of the forests. A system of control and forestry resource management was thus established that was very effective at the time.

In Zinder, it was under the reign of Tanimoune (1854-84) that the management of natural resources underwent an unprecedented expansion still bearing fruit today. Understanding the system of tree ownership and use, and of the land tenure situation in this sultanate is directly related to an understanding of the region's history and the way state control in Damagaram developed.

At the beginning of the 19th century, Damagaram consisted only of a small group of six villages, which paid tribute to the Bornu empire. The group of villages was often victim of raids by Tuaregs from the north, or was threatened by their immediate neighbors (Dunbar 1970). Damagaram and its capital city, Zinder, benefitted indirectly from the upheavals which characterized the central Sudanian zone at the time. The Jihad of the Fulbe in the heart of the Sokoto caliphate served at the same time to distract Bornu's attention, thus making the expansion of Damagaram possible. When Tanimoune overthrew his brother Ibrahim and took over in 1854, "Damagaram had become the most powerful state north of Kano and also the best situated to pursue commerce and military campaigns" (Collion 1982).

The wealth of Damagaram depended on three related sources-on taxes and income from the caravan trade, the capture and the exchange of slaves, and internal taxes. In all manuscripts related to the sultanate of Damagaram it is confirmed that the empire reached its peak with the reign of Tanimoune (Salifou 1971). It was indeed under Tanimoune that the sultanate became independent from the Bornu suzerain kingdom. His achievements included the fortification of Zinder, development of trade with *la Tripolitaine* and the forming of an army. This fearsome army, equipped with modern weapons, conquered surrounding peoples in the region, thus extending the borders of the sultanate to the gates of Kano in the south, to Aderbissannat in the north, to Maradi towards the west and to the Komadougou towards the east.

As he expanded his power, Tanimoune established an administration with a direct representative of the sultan in each locality, whose responsibility it was to strictly control the reigning dynasty in that locality. Dunbar (1970) traces this growing administrative evolution, detailing the spreading of various appointed representatives throughout the state. This "bureaucratization" had an effect in the area of natural resources particularly through the reinforcement by the State of the role of the *Sarkin Dawa,* or master of the bush.

The Agroforestry System of Damagaram

In view of the abundance of arable land at the time, it is surprising that management of forestry resources was of such special importance. Why was this so? The various European explorers who visited the sultanate in 1851 were struck by how little of the total area was under cultivation. The practice of leaving land fallow for six years was still in practice all the way through the first half of the 20th century.

The establishment of the empire was accompanied by the introduction of a land tenure system based on total appropriation of the land conquered by the sultan. The citizens who were free but without title (the *Talakawa*), were little more than serfs who were obliged to pay tithes at the end of each harvest. It can therefore be speculated that restrictions on cutting down trees were instituted for political reasons, as a means of control by the central level of a dispersed population, rather than, in the first instance, to carry out a better ecological land management. The present state of research does not allow us to confirm nor invalidate this hypothesis. But the question deserves further investigation.

Nevertheless, due to the peace that was reestablished throughout the sultanate, sedentarization and its corollaries-the extension of land under cultivation-increased and was certainly accompanied by locally excessive clearing of land that had been left uncultivated until then. Faced with this fact, the sultan and his counsellors took stock of the damage inflicted and found no better solution than to take draconian measures to ensure protection of the environment.

It is in this context that the 'law' on protection of the environment was adopted at the sultan's court. Revolutionary for its time, this law effectively stipulated that "whoever cuts down a tree, cuts off his own head." In other words, the life of a tree was worth as much as the life of a man. This law also named a certain number of protected species. Whether used as a pretext or reflecting far-sightedness, the law was effective.

The Protected Species

The species protected by the sultan in the traditional agricultural systems, later called 'trees of the sultan' were *gao* (*A. albida*), *adouwa* (*Balanites aegyptiaca*), *kouna* or *magaria* (*Ziziphus mauritania*), *madachi dirmi* (*Khaya senegalensis*), *magge* and *gamji* (*Ficus* spp.). The *gao* was the most protected tree. This was no coincidence, for its role and its multiple virtues were understood at a very early stage by the farmers and the reigning class of the sultanate.

Intuitively, people were aware that the *gao* concentrated and fixed nitrogen, which was useful for restoration and maintenance of soil fertility. They also noticed an improvement of the physical and chemical quality of the soil. The demand for pods and leaves that form a source for fodder for animals, especially for the sheep and goats, is also of particular importance during the transitional season (April, May, June), when herbaceous pasture is scarce, and the leaves and pods of the *gao* therefore form a desirable aerial pasture. This regulating role of the *gao* was understood at a very early stage by the farmers of Damagaram.

Aspects of Awareness of the Protection of the Environment

The application of this law was made easier by certain factors. First, it was a revolutionary law, as trees had until then always been considered as gifts from the gods, hence not to be owned by anyone. At the same time, the sultan was paying particular attention to trees. This was possible because the *Talakawa* considered the sultan as a representative of the gods to whom unconditional respect had to be paid. The saying that "the life of a tree is worth as much as the life of a man" produced victims, as some recalcitrant farmers were executed to set an example for others. This news spread through the whole sultanate and from these acts people's behavior towards trees began to change.

Secondly, the application of this law was aided by an intelligence gathering system of formidable effectiveness and organization that was feared by the people and even by the closest collaborators of the sultan. Some became victims of their own zeal and dishonesty.

Thus, to assure protection of the environment, informants were recruited in every village, without their chiefs knowledge, sometimes from the most deprived classes of the fringe of society. Each reporter was to give true information, describing in the greatest detail the offender's appearance, the place as well as the circumstances of the damage. Lies were not tolerated, for the informant could then become victim of his own trickery. Also, he had to be discreet and capable of transmitting the information rapidly (without being suspected) and without any intermediary, directly to the sultan's court. The only exception to these draconian measures was cutting green wood for funerals. Dead wood could be gathered with the village chief's permission but any excess could be punished.

This information system involved a kind of self-control and formed the very base of respect for the law as decreed by the sultan. For every *Talakawa*, wherever he was and at any moment, felt he was being watched and not free to do whatever he liked with the trees. The appropriation of all land by the sultan was also reinforced by means of this effective control of trees. The particular case of the Sultanate of Damagaram represents a transfer of awareness of tree protection (the most important one being *A. albida)* from the reigning dynasty (the political class) to the rest of the population.

From a dynamic perspective, this awareness grew, became real, and guided Damagaram's citizens' behavior towards trees. The consequences of this now seem to be deeply anchored. Soon, the ambiguous and ambivalent belief that the tree belonged to the spirits of the bush, according to the non-Islamized, or to Allah for those for whom Islamization had been accelerated under Tanimoune, was replaced by the belief that "the tree belongs to the sultan". They still talk in this way in the oldest rural districts of Damagaram. This idea was reinforced all the more since the sultan and later his successors proceeded to plant trees, *"gao"* trees in particular, and dispersed the seeds throughout the whole empire. The villagers were made to work and, since they lacked idle time, they were thus more pliant and less likely to challenge or disobey the sultan's authority.

Colonial and Post-Colonial Transformations

After the elimination of Adamou Kuuren Daaga in 1899, the conquest by the French and their assumption of power became undeniable, despite the fact that a young legitimate heir was installed as new sultan. The logic of the new political economy progressively transformed the pillars of the precolonial sultanate: decline of the trans-Saharan trade, progressive elimination of slavery, and new forms of taxation with a redirection of fiscal revenues towards a distant colonial power indifferent to local interests (Baier 1980). The ban on cutting trees did not end with the arrival of the French, but its application became less severe under the reign of Sultan Moustapha, and later Oumarou Sanda. In the protection of the environment, the colonial administrators, impressed by the system already in place and in an effort to get the local administration on its side, tried to collaborate with the sultan's court, but this was an illusion-later French laws regulated the appropriation of trees and land to the disadvantage of the local authorities. Has this been a factor affecting people's attitude towards trees? Was colonization in fact a demotivating factor in preserving trees?

The colonial economy set in motion space-consuming processes which made protection of agroforestry trees both more difficult and more important. Now that there was no more income from the trans-Saharan trade, the colonial state initiated other measures to provide income, e.g. taxation of the villagers and their herds. Groundnut cultivation from the 1930s onwards eventually led to the imposition of a policy of group fields (Sutter 1982). This practice was not appreciated by the local population, and ignored the traditional land tenure system, contributed to further land clearing and relegated to the background traditional agroforestry practices. The environment was threatened by population pressure much before the droughts of recent decades. For instance, faced with the disappearance of the bush during the fifties, the *Service des Eaux et Forets* in the Kantche Canton imposed a 15-year moratorium on the expansion of cultivated areas in order to protect forests. This showed a transfer of ownership: the "sultan's trees" had become "governor's trees", and sparked protests by the local farmers (Nicolas 1962) who felt their land was being sacrificed in favor of pastoral groups which had been given the right of access. Due to local pressures the decision to establish these forests was reversed. This demonstrated that the State's capacity to intervene had decreased relative to the sultan's former authority.

In spite of the inefficiency of the official forestry control measures, regeneration of the *"gao"* trees between villages continued from the colonial period until today. The *"gao"* parklands show variation in age, however "sometimes, stands are relatively even-aged, contrary to a dynamic management" (Helmsteter 1990). In other areas one finds a diversity where both young and old trees are well represented. This geographic variation demands supplementary research to distinguish the causes related to historical, or socio-economical factors, to developmental actions or the ecological base of a given area.

Conclusion

An analysis of the factors which favor natural and dynamic regeneration of agroforestry associations dominated by *"gao"* will allow researchers to better orient his investigations and will help development workers to better define the appropriate methods of action. Such analysis will help formulatmg necessary reforms of land tenure and forestry legislation. This paper outlines the first steps in that direction. It has been shown that the sociopolitical organization of the sultanate of Damagaram, with its specific behavior towards trees, played an important role in the genesis of the present rural landscape, notably characterized by a dominance of A. *albida.*

An important conclusion that can be drawn from this example is the fact that every situation merits careful consideration. In each case it is necessary to separate the variables determin ing the relationships between man and environment and to consider to what extent it is possible to apply experience gained elsewhere. As far as the sultanate of Damagaram is concerned, the autocratic and repressive nature of its administration makes adaption in a modern context of its law regarding protection of trees most unlikely. It is a case where traditional repressive but effective laws were replaced by repressive but ineffective laws. It is clear that an evolution is necessary, but to new forms have still to be worked out. On the other hand, in other situations, traditional codes and institutions could be revitalized and serve as models, e.g. the cases of the Tchangakoye of Gaya or of the Dina of the interior delta of the Niger.

At a time when the winds of change sweep across the Sahel, there is talk of decentralization, of a transfer of power to local people, and of the need to rethink and change the role of the State. The case of Damagaram demonstrates a fact that is often forgotten: the local institutions have never been either egalitarian or autonomous. It would be desirable to abandon the repressive nature of outside control, but at times central or top-down authority is necessary to pursue development and avoid chaos. This is particularly true where projects of large scope are concerned, such as the windbreaks of the Maggia Valley. The moment has come to define a new equilibrium between central authority and local autonomy.

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Faidherbia albida on Mine Spoils in the Tin Mining Region of the Jos Plateau, Nigeria

A.D. Kidd[1], M.J. Alexander[2] and K.D. Phillips-Howard[3]

Abstract

A pilot study on the potential utility of Faidherbia albida *for the improvement of mine-spoils suggested that the tree had a beneficial effect on spoil under the canopy and therefore could be used as an alternative to* Eucalyptus *spp. In a follow-up multidisciplinary study,* F. albida *showed much more variable effects on mine spoil and less obvious benefits. Farmer preference studies suggested that although the tree is regarded as useful by farmers, its use as an alternative for mine-spoil improvement would not be viable. This is because* F. albida *is not regarded as an "economic" tree by farmers and is ranked low in comparison with other trees in terms of its utility. Therefore its use in mineland reclamation is unlikely to be supported by these farmers.*

Introduction

Tin mining on the Jos Plateau has produced an extensive disturbed landscape. Reclamation programs have filled the mining paddocks, levelled spoil, and planted *Eucalyptus* spp. However, only some 2-3 km^2 of the 316 km^2 damaged by mining has been formally reclaimed. *Faidherbia albida* grows extensively by natural colonization throughout the tin fields. The possible utilization of this tree on mineland by the Jos Plateau Environmental Resource Development Program (JPERDP) is the focus of this paper.

Soil Relations and *F. albida*

Research in Phase 1 of the Program (1982-86) gathered information on many different aspects of the environmental and human resources, settlements, and problems of the tin-mining region (Phillips-Howard 1989).

A strategy based on "level and fill" and planting with *Eucalyptus* spp was expected to improve the soil sufficiency for the land to be returned to productive agriculture (Wimbush 1963). The variable results of this eucalyptus planting meant that the JPERDP began to look for alternatives/This and encouraging work from elsewhere on the effect of *F. albida on* soil nutrient status (Charreau and Vidal 1965) led to a pilot study on a single tree in 1983.

Alexander (1989) reported that the tree significantly increased the pH, nitrogen, organic carbon, exchangeable base content, and percent base saturation in topsoil under the canopy. He concluded that *F. albida* had a beneficial effect on both the nutrient status and physical condition of the soils lying beneath its canopy.

Field and Laboratory Methods

To test this initial hypothesis four areas of mineland were chosen to examine the effect of F. *albida* on the soil. In each of these sites two *F. albida* trees were chosen for study. Diameter breast height (DBH) of the 8 trees ranged from 27-64 cm; canopy diameter ranged from 6-12 m. Two small sampling pits were dug near each tree. One pit was dug under the canopy about 1 m away from the trunk and the second was outside the canopy, at a distance of at least twice the diameter of the canopy from the trunk. Pits were located approximately southeast of the tree trunk, in the

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direction of prevailing winds during the time of leaf fall. Presumably, this reduced the chances of the site outside the canopy being affected by litter deposits.

Bulk soil samples were collected in Dec 1990 (midway through the dry season) from each pit at 0-5 cm and 5-20 cm depths; This corresponded to the sampling depths of the pilot study (Alexander 1989). There was no evidence of cultivation on any of the sites. Soil analyses were carried out using standard methods (Alexander 1989; Hesse 1971).

Results and Discussion

Vegetation growing immediately beneath *F. albida,* had about the same species composition as that growing outside the canopy, but was usually much thicker and taller. It also tended to have a greater ground cover (90-95%) compared with cover found outside the influence of the canopy (50-60%).

Of all the soil properties measured, pH appeared to show least variation between sites (average = 5.9). Organic carbon, total nitrogen and available phosphorus were all greater in the topsoil (0-5 cm) beneath the canopy as compared to soil outside the canopy. This was reversed for subsoil values (5-20 cm). None of these differences were statistically significant.

Exchangeable calcium, magnesium, and sodium were lower but statistically similar, in both the topsoil and subsoil beneath the canopy. Only exchangeable potassium was significantly higher ($P < 0.01$) in the topsoil beneath the canopy as compared to topsoil outside the canopy. A similar, but not significant, trend was found in the subsoil samples for cation-exchange capacity (CEC) and base saturation.

The impact of *F. albida* on mine-spoil soil fertility is variable and not as obviously beneficial as suggested by Alexander's (1989) pilot study. Only improvement in topsoil potassium was noted. However, Plateau soils tend to have sufficient potassium for crop growth.

Social Issues and *F. albida*

Field Methods

Studies involved a combination of individual semi-structured interviews, group discussions, and preference ranking with both male and female farmers in the areas where the soil samples were taken. Preference ranking involved 1) asking which trees grow in and around their farms, and 2) pairwise comparison of each tree species. Farmers were asked which of each pair they preferred and why. Subsequently a ranking was found and the reasons for preferences were listed (Table 1).

Table 1. Farmers' order of preference for trees found on farms in Du village, Jos, Plateau State, Nigeria, 1990.

Species name			
Botanical name	Berom name	Times preferred[1]	Reasons for preference
Canarium schweinfurthii	*Pwat*	11	Food and oil
Butyrospermum sp[2]	*Jol*	9	Food and oil
Mangifera indica	*Mangoro*	9	Fruit
Psidium guajava	*Gweba*	8	Fruit
-[2]	*Baruwa*	7	Leaf and seeds for food, drink, and medicine
Bomssus flabellifer	*Jolgo*	7	Food and weapons
Ficus sp[2]	*Buring*	4	Fruit
Ficus sp[2]	*Baye*	4	Fruit
Ficus platyuphylla	*Vwangan*	2	Fruit
Ficus thonningii	*Kumua*	2	Fruit
Eucalyptus camaldulensis	*Lulel*	0	-
Faidherbia albida	*Sina rogo*	0	-

1. Number of times a tree was preferred over another by interviewed farmers in pair-wise preferences.
2. Species name not identified.

Results and Discussion

Known as *gao* in Haousa and *sina rogo* in Berom (the predominant tribe in the tin-mining region), F. *albida* is locally regarded as useful as a raw material for firewood, fencing, making mortars, medicine, fodder (both pods and leaves) and as a source of shade in the dry-season. Moreover the tree "produces fertility" *(taki* in Haousa) and "makes the soil soft" *(laushe* in Haousa).

Grasses are observed by farmers to grow well under *gao.* This led one group of farmers to cultivate yams under and around the tree on old tin workings, believing that the presence of grasses indicated sufficient soil fertility for yams production. Planting was initially on a small scale, as an experiment *(gwada* in Haousa), which, if successful, would lead to expanded cultivation, or, if not, other crops will be tried.

One dry-season farmer said he was very pleased with growth of tomatoes around a *gao* which he attributed to the *taki* that the tree puts into the soil. He had lopped all the branches at head height (later used for firewood) to avoid getting thorns in his foot and to reduce shade on his crops. Many farmers, however, associated luxuriant vegetative growth under *gao* with poor production of *Digitaria exilis,* or hungry rice (known locally as *findi,* or *fonio),* and tomatoes. Other farmers noted that the trees' roots can make cultivation difficult.

F. *albida* is not regarded as an "economic" tree by local farmers. Rather, it is seen as a liability on their farms. Farmers do not plant the species or protect it. Some trees are felled, despite fear of sanctions from the State Forestry Department. Dry-season farmers probably gain little beneficial effects of leaf fall that occurs early in the rainy season. Instead, they are troubled by shade effects.

F. albida is perceived as having the best impact on soil fertility and *E. camaldulensis* as having the worst. Farmers say that crops always do badly adjacent to *E. camadulensis* and vegetative cover there is always very poor. However, one farmer stated that, although *F. albida* gave the most *taki* and that £. *camaldulensis* was detrimental to the soil, he preferred the five tree species found on or near his farm in the following order: mango, guava, *E. camaldulensis, F. albida,* and *E. torelliana.* Mango and guava were ranked top because they produce fruit. *E. camaldulensis* was preferred over *F. albida* because of its ability to produce more firewood. *E. torelliana* was least preferred as it was seen as a poor producer of firewood without the redeeming features of *F. albida* with respect to production of fodder and medicine.

The two species consistently ranked last were *F. albida* and *E. camaldulensis.* The main reason for preference of other species was that they provide human food. The most preferred species were those that produce edible oil. It seems reasonable to infer that a reclamation strategy using *F. albida* would probably not receive much support from fanners.

Conclusion

Following the pilot study, investigations were carried out to clarify the potential utility of *F. albida* for the improvement of mine-spoil soils. The study took a human ecological approach included both natural and social scientific perspectives. Soil studies found more variable effects of *F. albida* on mine-spoil than the pilot study had inferred and less obvious benefits, except for significant improvement in topsoil potassium levels.

Benefits associated with greater efficiency of water use in crop/tree systems in semi-arid areas are probably not so applicable on the Jos Plateau. The climate of the Jos Plateau is less harsh than that of the Sahel. This means that the region is more conducive to growth of a wider range of economic plants.

Consequently, the comparative advantage of *F. albida* are not so apparent. Further, *F. albida* is not regarded as an "economic" tree by farmers and its utility is ranked low in comparison to other trees. Therefore its use in mineland reclamation is unlikely to be supported by these farmers. It is important to search for other alternatives for soil improvement on mineland that fit in better with farmers* resource priorities.

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Faidherhia albida in Zimbabwe

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Abstract

Faidherhia albida *has a limited distribution in Zimbabwe, occurring along riverbanks in remote, sparsely populated zones of the country. It is an important source of fodder for both wild and domestic animals and is retained infields. Trials started in 1985 have shown that eastern and southern African provenances have larger seed, greater nodulation at the seedling stage, and faster growth up to 43 months in comparison with western African provenances, Performance of even the best provenances has been poor in comparison to rates achieved on favorable sites elsewhere in Africa. Further testing on more suitable sites is required in order to assess its potential outside its natural range. Within its range, opportunities for protection and further planting should be assessed. In the rest of the country, farmers consider acacia species to he weeds and always remove them from fields. There are several valuable indigenous tree species in Zimbabwe that are more widely known than* F. albida *and these should be given priority in forestry trials.*

Natural Distribution and Ecology

In Zimbabwe, *Faidherhia albida* is a riparian species found along the Zambezi River and its tributaries in the north, and along the Limpopo River and its tributaries in the south. It is confined to recently deposited alluvial soils at an altitude of 900 m and below (Guy 1977). *F. albida* is a primary colonizer of sandy river banks, where it is able to withstand prolonged waterlogging. This has been attributed to its characteristic leaf shedding and dormancy in the wet season (Dunham 1989b). Where alluvial terraces exist, the species forms a high open woodland, at a density that results in approximately 25% canopy cover (Dunham 1989a).

As a result of its limited distribution, *F. albida* is currently only of limited importance on a national scale. In its natural range the species plays an important role both in communal areas and in National Parks.

More effort is needed to protect existing stands, encourage natural regeneration, and plant more seedlings of *F. albida* in areas where it occurs naturally. It is already known and appreciated by traditional occupants of the land, the Tonga people, who grind and eat the seeds as porridge in times of severe drought (Scudder 1971). A survey of Tonga farmers in southern Zambia revealed many were interested in planting more *F. albida* seedlings in their fields (Sturmheit 1988). Awareness about the role and importance of the species among new settlers should be assessed and further promoted.

In National Parks, the species is protected from cutting, but not from elephants. Although elephants inflict a lot of damage mature trees do not usually die. In the 1960s there was concern that many old trees at Mana Pools appeared to be dying without regeneration. A subsequent study revealed that while there is no regeneration under mature stands, new sandbanks close to the rivers are continually being colonized by seedlings (Dunham 1989b).

The potential for promoting the species outside its existing range is less promising than in areas where it

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is already well known and appreciated In the higher rainfall areas of the country, farmers generally dislike acacias, and *F.albida* is likely to fall into this category. In Shurugwi, a medium-potential cropping area, farmers consider acacias to be weeds and are not interested in planting more of them (McGregor 1990). In Zvishavane district, indigenous acacias are considered by farmers to have a negative effect on crops and are always removed from fields (Wilson 1987). In the low-potential areas of the country, where cropping is. marginal, acacia species make an important contribution to livestock nutrition and are appreciated for this. There is likely to be potential for encouraging planting of *F. albida* as a fodder species in these areas.

Provenance Trials

Trials to test the potential of the species outside its natural range in Zimbabwe have been initiated (Sniezko and Stewart 1989) but their results are disappointing. So far, despite intensive management, performance of even the best provenances on the best trial site has been mediocre. It may be necessary to further test the best provenances from these trials on a much wider range of sites, taking care to select those that meet the species' requirements. If the species is found to perform adequately in such trials, it should then be introduced and tested in small-scale farming areas, particularly those in low rainfall areas.

Because of its restricted range in Zimbabwe, *F. albida* is therefore not known or appreciated across most of the country. Bthnobotanical studies have identified a number of valuable indigenous tree species that are deliberately retained in croplands and protected by farmers (Wilson 1987; McGregor 1990). As these species are already well known and play an important role in farming systems, they should be given priority in species selection and breeding trials.

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Faidherbia albida in Nigeria

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Abstract

Despite local acceptance of Faidherbia albida *in most of the semi-arid areas cf Nigeria, little research has been done to enhance its cultivation. Evaluations have revealed that* F. albida *is genetically variable. Seed handling and silviculture of the species are also well understood, through small-scale field trials and natural forest management in Kano and the northeast of Nigeria* (*Borno State*). *However, a concerned effort to generate data from these old and new plantings by state forestry departments and universities within this area is needed to enhance its utilization and further exploitation.*

With the development of a viable means of vegetative propagation, developed at the Forestry Research Institute of Nigeria (*FRIN*), *clonal selection is viable and genetic improvement possible.*

The benefit that can accrue from a regional effort with this species that cuts across both Anglophone and Francophone West Africa cannot be overemphasized.

Introduction

In Nigeria, *Faidherbia albida* is a traditionally popular local species, widely used and associated with riddles and folk tales relating especially to its unique reverse leaf phenology or its association with animal husbandry and improvement of crops grown under its canopy. Despite its popularity in local customs and traditional land use systems, this species has not received adequate attention. There are no large-scale plantations within its native semi-arid areas of Nigeria as with *Acacia nilotica* and *Acacia Senegal,* which are major sources of tannin and gum arabic. Between 1920 and 1928 in the northeastern area of Nigeria, K.R. MacDonald, a forest officer, took a bold step to protect natural stands and to plant *F. albida* on farms because of its supposed land fertilizing influences.

This effort with the support of the Emirs of Kano and Sokoto was the first effort in *F. albida* extension. However despite this, there is today very little quantitative data or information on the silviculture and role of *F. albida* in the local farming and animal production systems.

Distribution of *F. albida* in Nigeria

F. albida occurs naturally in the Nigerian savanna, which is characterized by a short rainy season alternating with a long dry and hot season. Savanna vegetation dominated by acacias covers about 75% of Nigeria's total landmass. F. *albida* is distributed from Nigeria's border with Niger Republic (14°N) south to the edge of the Guinea Savanna zone (19°N), or within the 400-1000 mm isohyets. It occurs in a wide range of habitats from riparian vegetation to open savanna and cultivated land and on all soil types from alluvium to sandy-clays.

Although the species withstands drought as well as moderate amount of flooding, its best development is on well-drained, coarse-textured soils with 650-700

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mm annual rainfall. Where groundwater is easily accessible, *F. albida* is independent of rainfall as in the northeast corner of Nigeria near Lake Chad which has less than 400 mm mean annual rainfall. The species is seldom found in natural woodland or unexploitcd climax vegetation because it is intolerant of shade while young. It often occurs in association with *Acacia nilotica* in Sokoto, Katsina and Kano (Kura et al. 1990).

Research in Nigeria has verified findings elsewhere that soils under *F. albida* have more organic material, higher water-retention capacity, and higher cation exchange capacity than soils way from tree (Verinumbe 1989).

Role of *F. albida* in traditional Nigerian Farming Systems

Planting of *F. albida* on fields is no longer a significant activity in the traditional crop and animal production systems in the Nigerian savanna, although historically farmers have experience with its use in dryland farming and grazing (Kerr 1942; White 1941). Only when rainfall and groundwater permit its growth is it particularly favored, and once its positive effect on production is recognized in an area, it is allowed to establish in densities much higher than that of any other tree species growing in fields. The prized pods are gathered by children and marketed for livestock feed. The branches are lopped for foliage.

F. albida bark and roots are used in local medicinal preparation. A survey of the ethnobotany of nonwood resources of the Nigeria savanna by E. Igboanugo of the Nigeria Forest Research Institute describing this work will soon be published.

The species is found in almost pure continuous stands (20 trees ha^{-1}) on deep sandy loams used for millet and sorghum cultivation a few kilometers southeast of Maiduguri (11°53'N, 13°17'E). Less dense stands (8-10 trees ha^{-1}) occur on farmlands surrounding Kano, Sokoto, Katsina, Bauchi, and Jos. At present, the species is being planted in state-sponsored desertification control programs in Kano and Katsina States. The Afforestation Programme Coordinating Unit (APCU) of the Federal Department of Forestry Abuja is also promoting *F. albida* for desert control and agroforestry. Unfortunately, these plantings are based on wild, unimproved stocks.

The farmed parkland southeast of Maiduguri is old, dating back to the early 1900s when the species was planted and protected on farmlands. During that time, felling of the species was prohibited. To enhance the spread of planting, the forestry officer (K.R. MacDonald) personally distributed seedlings to farmers and visited the farms regularly.

Conservation of *F. albida* Genetic Resources

Land clearing for crop production outside reserves has resulted in substantial loss of *F. albida* genetic resources. In the northern states of Nigeria, where this species abounds, over 30% of the older trees have been lost, substantial for an outbreeding and genetically variable species. No significant effort is presently being made to ensure the security of this gene resource. Only 33 accessions of this species is in exsitu storage at the FRIN West African Hardwoods Improvement Project (WAHIP) in Ibadan.

Scientists at WAHIP have successfully rooted juvenile stem cuttings and then enhanced their root form with the use of hormones. Application of 200 mg kg^{-1} of napthyl acetic acid yielded good root form while indole butyric acid and gibberelic acid at 50, 100, and 200 mg kg^{-1} did not. Roots produced under mist without hormone treatment were short and established dominance 2 months after initiation. The need for good root form, and particularly good root growth, is important to clonal success in the field.

Conclusion

In general, the utilization of *F. albida* in the Nigeria savanna is haphazard and exploitative. Entire stands are often decimated for feed, particularly during drought years or by indiscriminate land clearing.

There is need for research on physiology, growth and genetic variability, and germplasm collections throughout the Nigerian savanna. Progeny and provenance studies should be done. The utilization of vegetative multiplication methods will allow clonal evaluation in genetic improvement programs.

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Working Group Recommendations

Working Group Recommendations

Recommendations by the various Working Groups follow.

Working Group on Genetic Improvement

Introduction

Knowledge on the genetic variation of *Faidherbia albida* is lacking, and although several related studies are being carried out, a lot remains to be done. The Working Group identified several factors that need to be either reemphasized or addressed before improvement programs in the region can be successfully implemented. These include:

- Future collection efforts of *Faidherbia albida* should continue to be coordinated with existing regional institutions-CILSS in West Africa, SADCC in southern Africa, and IGAPC (Inter-Government Agency for Project Control) in East Africa. Global coordination should be done by FAO.
- National programs lack trained staff who are qualified to undertake independent studies. Training and collaboration are necessary in this field.
- Initiating an improvement program requires a long-term commitment from donors and regional institutions. This should be borne in mind as the work proceeds.

Breeding Objectives

Three criteria were identified to guide collection efforts. These include:

- phenology and yield parameters reflecting the needs of user groups;
- improved juvenile growth; and
- improved quality and quantity of forage and fodder.

Prospection, Collection, and Storage

The ultimate aim of germplasm collection is to serve improvement programs.Therefore, collections should be made keeping breeding objectives and, ultimately, the needs of end users in mind. The following criteria should be considered:

- Critical zones of in situ conservation and ex situ collection and storage need to be identified. The Group recommends that Sudan and Ethiopia should be named as priority areas.
- Standard methodologies for prospection, collection, and storage of germplasm should be worked out and universally adopted.
- Methods and procedures for gene transfer between sites by pollen should be studied.

Trials and Methodology

- Gene frequency and flow need to be studied with the use of enzyme electrophoresis.
- Methodologies for in vitro culture techniques need to be simplified, standardized, and extended.
- Existing progeny and provenance studies should be inventoried and results of these should be compared.
- Standard methodologies need to be developed for phenological studies.
- Progeny trials should be conducted simultaneously with clonal comparisons of mother trees to determine correlations between juvenile and mature trees, and between mother trees and progeny. Effort should be made to separate genetic and phenotypic effects.
- Progeny trials of full-sib, controlled crosses need to be performed.
- Studies on reproductive biology, gametogenesis, pollination agents, and self incompatibility are necessary.

Information and Seed Exchange

- Information in French and English on the species should be centralized at the subregional level, and made available.
- Inventories of locations of previous germplasm collections need to be made and disseminated.
- Procedures for exchange of germplasm needs to be simplified in the subregions.

Working Group on Rhizosphere, Site Effects, and Silviculture

The three topics covered are interrelated, and were discussed by the Working Group as a whole. Minutes for each component were recorded separately and are presented below:

Rhizosphere

Two types of micro-organisms exist in the rhizosphere—the bacterium *Rhizobium* that forms nitrogen-fixing nodules on the roots, and endo-mycorrhizal fungi that improve absorption of phosphorus and other mineral elements. At present, nitrogen-fixing nodules have been found either on the roots of young plants or on adult trees in areas with shallow water tables. Endo-mycorrhizal fungi are present on the roots of both young and adult trees. The following research priorities were identified:

- The synergistic effect of inoculation with both improved *Rhizobium* and mycorrhizal strains should be studied.
- *Rhizobium* and mycorrhizal strains should be collected. These studies should focus on the selection of the most efficient local strains found in different Sahelian soils, and in particular acid soils. A network of exchange of strains and information should be developed.
- The study of symbionts should include the migration of the micro-organisms to depth during the extension of the root system, and should use local strains of *Rhizobium* and mychorrizae isolated at depths.
- Inoculation techniques suitable for Sahelian conditions must be developed, with emphasis on resistance to high temperatures.
- The genetics of the variability in plant/symbiont relationships should be investigated. Studies utilizing N_{15} should be initiated to examine the real effect of nitrogen fixation on the improvement of soils under *F. albida.*
- A comparative study of root systems under inundated or dry conditions should determine if nitrogen fixation is a genetic or a biological factor.

Site Effects

The subgroup on site effects recommend further studies to better define the 'albida effect' and associated effects connected with the microsite in which individual trees are found. Priorities for the following five categories of research are:

Effect of the Site on the Tree

Specific effects of the site on the tree were described during the workshop with examples from Cameroon and Niger. Areas for further studies are:

- The effect of pre-existing soil variability on the growth of *F. albida,*
- The selection of fertile microsites for seedling placement and an easy method to delineate such microsites.
- The effect of pre-existing soil fertility on the 'albida effect'.

Effect of the Tree on the Site

Improved soil parameters under the tree have been adequately described, but cause-and-effect analyses are lacking. Work should be continued on a site-selective basis and should routinely include analyses of subsoils. Important research priorities include:

- The agro-ecological shift in microclimate and its effect on the efficiency of nutrient use in agronomic systems and on risk to farmers during years of good and poor rainfall distributions.
- The risk of reducing soil water level in the crop zone with high populations of trees.
- Possible disequilibrium in nutrient balances over time due to increases in organic matter and nitrogen in soils under mature trees.

Effect of Tree on Agronomic Systems

Although the general 'albida effect' has been adequately elucidated, further study of the most efficient use of microsite under the canopy for enhanced crop growth will be necessary. Specific studies in this area include:

- Response of different crop species to the 'albida effect'.
- Effect of crop planting density.
- Effect of supplemental additions of fertilizer or crop residues.
- Use of local versus improved crop varieties.

- Determining the age or size of the tree at which the 'albida effect' is first evident under particular environmental conditions.

Livestock Interactions with the Tree

The overall role of the tree in livestock nutrition is not well understood. Evidence presented at this workshop indicated that a diet consisting solely of pods is detrimental. It is not clear exactly what role deposits of livestock manure play in the dynamics of the 'albida effect'. Specific studies recommended include:

- The overall role of the species in livestock nutrition.
- Nutritional importance of pods versus leaves.
- Importance of livestock in the recycling of nutrients by manure deposition, relative to the direct recycling of leaves to the soil.

Socio-economic Studies for Different Silviculturai Treatments

Little is known about the effects of delimbing and off-site utilization of tree products as opposed to the on-site benefits from intact trees. Studies in this area were recommended.

Silviculture

Further studies to confirm previous experimental results are needed. New questions also need to be answered. Research priorities include:

Artificial Regeneration

- Effective methods of storage of seeds in rural areas must be developed.
- Improved nursery methods to produce uniform, healthy seedlings must be developed.
- The need to prune roots of potted seedlings at the time of outplanting should be studied.
- Comparison of direct seedling and outplanting seedlings at different times of the rainy season are needed for the entire range of sites where *F. albida* grows. These studies should continue for two growing seasons and include root development.

Natural Regeneration

- The effect of animal exelosures and soil amendments to increase the production of parklands should be studied.
- Studies of enrichment of plantings in parklands by direct seeding or outplanting seedlings should be done.

Population Management

- Monitoring and inventory methodologies to determine the effects of management techniques must be developed and utilized.
- The effect of frequency, intensity, and timing of pruning on pod, leaf, and branch growth must be studied.
- Predictive models of pod production as a function of dendrological and soil parameters need to be developed.

Certain other points were raised in this section. Although these were not research topics per se, they still have an important bearing on further use and extension of F. *albida.* The question of the need to maintain or introduce tree species diversity in F. *albida* parklands is important. Questions on land tenure need to be addressed, including that of amending forestry laws to enable better management of the trees. Finally, it is necessary to work towards greater understanding of the mechanisms responsible for the inverse phenology.

Working Group on Development Issues

Introduction

The Working Group noted with satisfaction the relatively wide range of technical disciplines represented at the workshop and the trend for closer collaboration between agronomists, foresters, soil scientists, and geneticists. While an important start has been made, there is still much that can be done to strengthen this collaboration and further broaden the number of disciplines involved.

The Working Group recommends that the socio-economic aspects and broader human ecological context of agroforestry and silvipastoral production systems should be given more attention. This is essential to help orient biophysical research into useful directions.

The Group recommends that *Faidherbia albida* should be seen by both researchers and developers in the broader context of multipurpose trees and production strategies used by farmers and herders in the semi-arid tropics. Systems studies are better than sectoral studies, so that the broader development context is fully taken into account

From Research to Development: Utilization of Research Results

Utilization

- The group recommends increased attention by development projects should be given to existing mature and overmature trees.

Rhizosphere, Site Effects, and Silviculture

- Greater use should be made of direct seeding, given the encouraging results presented in the workshop.
- The Group encouraged further study on the option of planting higher value crops under the canopies of mature trees.
- Greater attention must be paid by development projects to effective nursery management and seedling production.

Genetics and Tree Improvement

- Anticipating major improvement in quality and quantity of seed for planting purposes, the Group recommends that planting projects should proceed slowly. Where planting is necessary, only seed of superior local trees should be used.
- Greater use of other trees should be made in areas where *F. albida* is not a priority species for farmer and pastoralists.

Development Projects

- Development projects need much closer interaction with research efforts and should use already acquired knowledge. The research/development project linkage must be a two-way flow of ideas and information.
- Relative investments in research and development need to be reviewed. Research must have long-term funding and national support.

From Development to Research: Research Priorities based on Development Experience

Biophysical Research

Utilization

- A methodology to quantify production and products of *F. albida* is needed.
- More research on lopping of mature trees is necessary. This should include the development of an appropriate research methodology.
- Increased attention to nutritional analysis and feeding value of foliage and pods is necessary.

Site Effects

- Drought response and identification of drought-resistant provenances is a priority.
- Further study of the effect of soil microvariability on growth is needed.
- Studies of phenology vis-a-vis the interrelationships with different crop associations are necessary.

Silviculture

- Investigations of natural regeneration mechanisms of the species in fallow and cropped land situations should be done.
- Identification of silvicultural rules and treatments to improve yield and productivity of *F. albida* is necessary. The species' response to different management options must be quantified.
- Studies of the most suitable tree/crop associations involving F. *albida* and the effect of tree management on crop production are necessary.

Genetics

- A major priority should be reduction of maturity period so farmers can benefit early from pod production.
- Productivity increases (fruits, fodder, seeds, fuelwood, etc.) as defined by the various user groups should be a major objective of tree improvement programs.

The Neglected Dimension: Socio-Economics

- The legal and tenure issues affecting tree utilization must be addressed.
- The economic contribution of F. *alhida* in local farming systems must be investigated. Local markets dealing with products of the species should be studied.
- The history and evolution of F. *albida* use and management by farmers and herders should be studied extensively. Current farmer strategies concerning tree/crop associations should be carried out, and the scope/needs for further development of such mixtures considered.

The Research/Development Linkage: Recommendations for Follow-up

This workshop has been an important initiative in joining development workers and researchers in a common forum. Meetings of this type should continue to be organized periodically as constructive critique of research work by development institutions and vice-versa will assist in accelerating progress and avoiding dead ends by both groups.

The Group recommends that the regional and inter-regional organizations involved in supporting agroforestry research in the semi-arid tropics (ICRISAT, ICRAF, CILSS, CTFT, etc.) pay particular attention to the research/development linkage and to the farmers' perspective. The launching of the regional tree seed/improvement program is welcomed. It is recommended that the initiative be widely advertised so that development groups are aware of the resource.

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Acronyms and Abbreviations

AFRENA	Agroforestry Research Networks for Africa (Uganda)
BFP	British Forestry Project (UK)
CGIAR	Consultative Group on International Agricultural Research (USA)
CILSS	Comite permanent inter-Etats de lutte contre la secheresse dans le Sahel (Mali)
CNRA	Centre national de recherche agronomique (Senegal)
CNSF	Centre national des semences forestieres (Burkina Faso)
CRED	Center for Research on Economic Development (USA)
CRF	Centre des recherches forestieres (Cameroon)
CRZ	Centre des recherches zootechniques (Mali)
CTFT	Centre technique forestier tropical (France)
DBH	Diameter breast height
DM	Dry matter
DRFH	Direction de recherche forestiere et hydrobiologique (Mali)
DRPF	Direction des recherches sur les productions forestieres (Senegal)
DRZ	Division des recherches zootechniques (Mali)
EEC	European Economic Community
ENGREF	Ecole nationale du genie rural des eaux et des forets (France)
FAB	Forestry Association of Botswana (Botswana)
FAO	Food and Agriculture Organization of the United Nations (Italy)
FRC	Forestry Research Centre (Zimbabwe and Ethiopia)
FRIM	Forestry Research Institute of Malawi (Malawi)
FRIN	Forestry Research Institute of Nigeria (Nigeria)
ICRAF	International Centre for Research in Agroforestry (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
IDRC	International Development Research Centre (Canada)
IER	Institut d'economie rurale (Mali)
IITA	International Institute for Tropical Agriculture (Nigeria)
ILCA	International Livestock Centre for Africa (Ethiopia)
INRAN	Institut national de recherches agronomiques du Niger (Niger)
IRA	Institut de la recherche agronomique (Cameroon)
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrieres (France)
IRBET	Institut de recherche en biologie et ecologie tropicale (Burkina Faso)
IRHO	Institut de recherches pour les huiles et oleagineux (France)
ISC	ICRISAT Sahelian Center (Niger)
ISRA	Institut senegalais de recherches agricoles (Senegal)
IUFRO	International Union of Forestry Research Organization
KEFRI	Kenya Forestry Research Institute (Kenya)
MIRCEN	Microbial Resources Centre (UK)
NFTA	Nitrogen Fixing Tree Association (USA)
NORAD	Norwegian Agency for International Development (Norway)
NRA	National Range Authority (Somalia)
OAU	Organization of African Unity (Ethiopia)
OCCGE	Organisation de coordination et de concertation pour la lutte contre les grandes endemies (Burkina Faso)
ODA	Overseas Development Administration (UK)
OFI	Oxford Forestry Institute (UK)
ORSTOM	Institut francais de recherche scientifique pour le developpement en cooperation (France)
PDAAT	Projet de developpement agroforestier et d'amenagement des terroirs (Niger)

PE	Potential evapotranspiration
PPDAF	Projet pilote de developpement agroforestier (Niger)
SADCC	Southern African Development Coordination Conference (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Nigeria)
SPRP	Soil Productivity Research Program (Zambia)
TAFORI	Tanzania Forest Research Institute (Tanzania)
UNSO	United Nations Soudano-Sahelian Office (USA)
USAID	United States Agency for International Development (USA)
WAHIP	West African Hardwoods Improvement Project (Nigeria)

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