STATE OF THE ART: ACACIA ALBIDA

AS A COMPLEMENTARY PERMANENT INTERCROP WITH ANNUAL CROPS

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"State of the Art: *Acacia albida* as a complementary permanent intercrop with annual crops"

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Peter Felker
Moisture Utilization in Semi-Arid Tropics:
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FOREWORD

Documents reviewed for "Acacia albida: State of the Art" were obtained in numerous ways. A few useful citations on Acacia albida and on Acacia were obtained from computer searches on the following six data bases using facilities provided by the University of California, Riverside (UCR) library.

(1) Biosis Previews (Biological Abstracts and Biological Research Index)

(2) National Technical Information Service

(3) CAIN - U.S. National Agricultural Library

(4) Smithsonian Science Information Exchange, Inc.

(5) SCISEARCH - Science Citation Index

(6) CAB Abstracts - Commonwealth Agricultural Bureau

The holdings of the Moisture Utilization in Semi-arid Tropics (MUSAT: sra) special collection at UCR provided several references. Many useful documents were examined and photocopied at the Centre Techniques Forestier Tropicale (CTFT) and Institute Recherche Agronomique Tropicale (IRAT) in Nogent-sur-Marne, France. Additional materials were located in ORSTOM holdings in Bondy, France and various other locations in Paris. At the following organizations in Senegal, West Africa resource personnel were contacted and/or bibliographic holdings were examined: ORSTOM - Bel Air Dakar; ORSTOM-HANN, Dakar; Laboratoire d'Elevage, Dakar; CNRF, Dakar; Eaux et Foret, Dakar; IFAN, Dakar; FAO, Dakar; ICRISAT, Dakar; SODEVA, Dakar and Thies; and CNRA, Bambey. The most complete Acacia albida bibliographic holdings were found at the Centre Nationale Recherche Forestier (CNRF) in Dakar. A copy of all A. albida documents and publications examined has been deposited in the MUSAT:sra holdings in the University of California, Riverside (UCR) library.

This reviewer, having a good reading knowledge of agronomically related French examined all the listed articles in their original language. No doubt some passages have not been comprehended as fully as possible but tables and graphs "speak for themselves", so there is little chance for significant errors in overall interpretation.

The review of the Acacia albida literature follows the format requested in the contract. Papers pertaining to Acacia albida reporting measured observations are listed alphabetically in the first section. Papers or reviews pertaining to Acacia albida but containing no original data are listed in a second section. A third section contains a listing of papers with valuable analagous data on other Acacias but with no specific mention of Acacia albida and any other references that may have been cited in this document.

Papers reporting original measured observations are dealt with in four subheadings as requested: (a) reports on the principal and supporting hypothesis, and states results and conclusions; (b) discusses methods used to conduct the experiments; (c) makes analytical judgements of the reliability of the work, and (d) states the net contribution of Acacia albida to soil fertility or other benefits to be derived from Acacia albida.

"Condensed Summary of Agriculturally Related _Acacia albida_ Literature"

INTRODUCTION

At present the available literature does not allow a completely accurate objective analysis of _Acacia albida_ capabilities and potential capabilities. Nevertheless this reviewer having closely followed the literature on leguminous trees for 5 years and having worked with the leguminous tree _Prosopis_ in native stands, in the greenhouse, and in University of California, Riverside field station studies, believes the following condensed _Acacia albida_ summary to be a fair, conservative, and defensible representation of _Acacia albida_'s agro-sylvo-pastoral capabilities.

CONDENSED SUMMARY

Directly under _Acacia albida_ foliage cover yields of millet and peanuts increased on infertile soils from 500 ± 200 kg/ha to 900 ± 200 kg/ha. Approximately 45 large trees per hectare were required to achieve complete soil cover.

In addition to yield increases under _A. albida_, a 50 to 100% increase in soil organic matter and nitrogen content, a marked increase in soil microbiological activity, and an increase in water holding capacity beneath the trees has been found.

Acacia albida has been demonstrated to nodulate and fix nitrogen in pot studies. How, when, and where *A. albida* fixes nitrogen in the field was unclear, but an analysis of the nitrogen cycle suggested that *A. albida* nitrogen fixation was probably the cause for increased soil fertility beneath *A. albida* canopies.

Average annual *A. albida* height growth for 8 trees was 92 cm, with a range of 50 to 160 cm. Annual diameter growth ranged from 0.6 to 2.9 cm, and this 4.8-fold diameter growth range represents a 23-fold range in volume growth, because volume is proportional to diameter squared.

A. albida flowered at seven years of age and produced first pods at about eight years of age, but did not bear well until about thirty years of age. *A. albida* tree pod yield has been reported to range from 6 kg/tree to 135 kg/tree which has been extrapolated to yields ranging from 105 kg/ha to 5400 kg/ha.

The pods were a much used source of livestock feed in West Africa. The protein content of the pods was 10-15%, the seed protein content was 26-28%, and the carbohydrate content was about 50%. Feeding trials on *A. albida* pods have not been carried out.

It has been suggested, through not proven, that *A. albida* has increased the land carrying capacity from about 10-20 persons/km^2 to 25-40 persons/km^2 and that *A. albida* has made it unnecessary to clear and fallow land permitting sedentary, permanent agricultural settlements. *A. albida* has been an important part of West African culture and in some areas sacrifices of millet and chickens have been made to *A. albida*.

Acacia albida has substantially increased the well-being of small farmers in Sahelian regions by increasing soil fertility and crop yield and by providing pods for animal food. While this is indeed remarkable, there is much room for improvement. Acacia albida has never been the subject of genetic or horticultural studies designed to improve its beneficial characteristics. Acacia albida strains in Senegal are land races and might be compared in productivity to maize and wheat in the U.S.A. in the 1800's. There is little doubt that cultural, selection, and propagation techniques, plant pathology studies, pruning and spacing studies, and development of devices for protection from animals could profoundly improve A. albida's beneficial qualities and the quality of life for Sahelian farmers.

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LIST OF ACRONYMS AND ABBREVIATIONS

AID - Agency for International Development (Washington, D.C.)

CARE - Cooperative for American Relief Everywhere (New York, U.S.A.)

CNRA - Centre National de Recherche Agronomique (Bambey, Senegal)

CNRF - Centre National Recherche Forestier (Dakar, Senegal)

CTFT - Centre Technique Forestier Tropical (Ouagadougou, Upper Volta)

ENCR - Ecole National Centre Rurale (Bambey, Senegal)

FAO - Food and Agricultural Organization of the United Nations (Rome, Italy)

IDRC - International Development Research Centre (Ottawa, Canada)

IEMVT - Institut d'Elevage et de Medecine Veterinaire des Pays Tropicaux (Maisons - Alfort, France)

IFAN - Institut Fondamental d'Afrique Noire (Dakar, Senegal)

ILCA - International Livestock Center for Africa (Addis Ababa. Ethiopia)

IRAT - Institut de Recherche Agronomique Tropical (Paris, France)

IRHO - Institut de Recherche pour les Huiles et Oleagineux (Paris, France)

MAB - Matiere azote brute

MUSAT:sra- Moisture Utilization in Semi-Arid Tropics: summer rainfall agriculture (Riverside, California)

NASA - National Aeronautics and Space Administration (Washington, D.C.)

ORSTOM - Office de la Recherche Scientifique et Technique d'Outre Mer (Paris, France)

SODEVA - Societe de developpement et de vulgarisation agricole (Dakar, Senegal)

UCR - University of California, Riverside (U.S.A.)

I. Review of *Acacia albida* Literature

A. Analysis of published and unpublished literature reporting original measured observations on *Acacia albida*

1.

Author: Aloni, R. (1972)

Title: New site of *Acacia albida* Del in the Sharon coastal plain of Israel

Source: Israel J. of Botany 21, 39-41

This paper only reports on the presence of a new *Acacia albida* site in Israel and does not involve agronomic issues.

2.

Author: Anon (1966)

Title: *Acacia albida*: etude de la croissance

Source: Centre Technique Forestier Tropical. 14 pages

a) The first part of this report discusses Mariaux's (1966) work :h has been critiqued independently and will not be further discussed :. A second part of this paper deals with the use of dendrometer to l-continuously measure increases in tree diameter over a two-year period.

From data presented in the text it is possible to assign units to the graphs and tables, and to calculate average circumference growth for two trees at Bambey, Diourbel, and Hann to be 35, 11 and 1.9 cm/season, respectively. *A. albida* circumference measurements showed rapid growth from April until the end of July, no growth from August until November, and rapid growth from November on.

The third part of this study involved height and circumference measurement of A. albida trees which had either arisen from cut stumps or had been transplanted from polyethylene bags. For a 10-month period, eight - 32 month old seedlings had an average height increase of 92 cm with a 50 to 160 cm range and a stem diameter increase ranging from 0.31 to 2.9 cm. Eight year old sprouted plants in a ten-month period had diameter increases ranging from .63 to 2.54 cm with an average increase of 1.6 cm. In a different study with 2 year old naturally occurring plants the diameter increase had a range of .16 to 1.27 cm in 10 months with an average increase of .69 cm.

b,c) As outlined in discussion of the Mariaux (1966) paper, the methodology and procedure is straightforward with little chance for error.

d) Once again it becomes obvious that there are very large unexplained differences in growth rate which could be attributed to heterozygosity of the seedlings. Due to this large variation there is little else that can be drawn from these studies except for a very approximate idea of height and diameter growth of A. albida seedlings.

3.

Author: Anon (1968)

Title: Report on two consignments of Haraz Acacia albida from the Republic of Sudan

Source: Ministry of Technology, Forest Products Research Laboratory Report on Overseas Timbers No. 10. FPRL consignments Nos. 1305 and 1373, 8 pages.

This document reports data on the properties of two lots of Acacia albida timbers which were harvested in the Sudan. An evaluation of this research is beyond the capabilities of this reviewer and therefore only a summary of their experiments and conclusions will follow.

Following a general description of the wood, analyses were made of: shrinking and movement during seasoning; mechanical properties, natural durability; preservation treatment; and working properties.

The reports summarizes ". . .the timber was not particularly attractive in appearance and was very susceptible to damage by powder-post beetles and by staining and wood rotting fungi. It dried fairly quickly and without splitting but distorted badly because of the wild grain.

Except for hardness and resistance to shock it was below the average in strength properties. It sawed easily without blunting, planed to a fine finish, and was easily impregnated with preservatives. Selected material from mature trees of this species would be suitable for buildings but would need to be treated if used in exposed positions. Similar material not quite so carefully selected would be useful for carpentry and shuttering."

4.

Author: Anon (1971)

Title: Recherche sur Acacia albida: Reponse a l'engrais

Publ: Centre Technique Forestier Tropical - Dakar, Senegal
Rapport Activite 1971 (appeared 1972), 5 pages.

a) The study was begun in 1969 to study the response of Acacia albida seedlings to fertilizer. The study concluded that fertilizing in general increased the growth of the seedlings and conclusions were made regarding the efficacy of various types and amounts of fertilizers.

b) Ten fertilizer treatments and one control were established with 68 plants per treatment. The seedlings were raised in polyethylene bags and the area was sub-soiled before planting. Weeding was carried out several times after planting.

c) The experimental design seems reasonable enough if possible genetic heterogeneity is not taken into account. The coefficient of variation within the treatments ranged from a low of 31% to a high of 68%.

This reviewer visited the site in Bambey and noticed two adjacent trees of remarkably different heights. As the accompanying CNRF personnel had the plot plan it was possible to determine the initial fertilizer doses. A comparison of fertilizer doses with tree height measurements obtained with an expandable 6 m measuring device revealed that a tree 154 cm tall received 150 g of $(NH_4)_2SO_4$, while a 580 cm tree approximately 3 meters away received 100 g of $(NH_4)_2SO_4$. Since the trees were only 3 meters apart on level ground this reviewer doubts that soil differences were the cause for the difference and suggests that the differences are in part genetic, due to outcrossing as occurs with other leguminous trees such as Prosopis (Simpson, 1977).

d) The importance of this experiment is that it demonstrates that uniform genetic material must be obtained before other kinds of experiments are attempted.

5.

Author: Boudet, G. and R. Riviere (1968)

Title: Emploi pratique des analyses fourrageres pour l'appreciation des paturages tropicaux

Source: Rev. Elev. Med. Vet. Pays. Trop. 21,2 (227-266).

a) The central hypothesis is that it is possible to approximate the feeding value of native African savannah plants from chemical analyses of their edible parts. Results are given for 500 plants including the pods of Acacia albida which are stated to have 77% of the available energy of an equivalent weight of barley.

b,c) None of the procedures used for chemical analysis are listed or referenced. The term M.A.B. (matiere azote brute) is used which can be translated as crude nitrogen percentage but this value is very close to what one would expect for crude protein (Kjeldahl nitrogen x 6.25). A major source of error is that these authors use the protein digestability coefficient for alfalfa hay to arrive at digestability for Acacia albida pod protein. It is somewhat understandable that the authors use this coefficient as they were attempting to screen over 500 savannah plants for nutritional quality. Nevertheless A. albida pods have very hard coated seeds which pass undigested through the rumen of some animals (Wickens, 1969) and it does not seem reasonable to use the same nitrogen digestability coefficient for both alfalfa hay and A. albida pods.

c) It is impossible to determine the true feeding value of A. albida pods from this paper. One would expect from the proximate analyses of Prosopis (mesquite) pods (12% protein and up to 30% sucrose) that they would be excellent sources of cattle feed. Yet if cattle are fed Prosopis pods exclusively a small percentage of cattle may die with a ball of undigested pods in their rumen (Dollahite, 1964). While both A. albida and Prosopis are leguminous trees, A. albida pods may bear no resemblance in feeding value to Prosopis pods.

If it is desirable to know the true feeding value of A. albida pods in order to optimize their use as cattle feed, actual feeding trials will have to be carried out.

6.

Author: Brunck, F. (1972)

Title: Entomologie et pathologie forestieres (Premiere etude sur le deperissement des Gaos dans les arrondissements de Magaria et de Matameye

Source: Centre Technique Forestier Tropical - Compte rendu d'un deplacement au Niger, 10 pages.

a) The purpose of this report is to examine possible plant pathological and entomological reasons for the disappearance of many Acacia albida trees during the 1970 drought in Niger. The author concluded that caterpillars of the Noctuides had a large part to play in the disappearance of Acacia albida in Niger. Brunck also pointed out that because of the drought the water table in some wells was lowered by 4 meters and this might have caused disappearance of Acacia albida.

b) The research method involved: examining sites where A. albida disappeared; questioning inhabitants of the area; collection of diseased plant material for examination in the laboratory; and raising and identification of insects collected from the diseases plants.

c) This reviewer is not familiar with insect taxonomy and pathology and is not competent to judge that aspect of the work. Apparently only several field trips were made into the area where A. albida trees were disappearing so that Brunck rightfully hedges on his conclusions. Since a drought was present when the trees began to disappear it is possible that a combination of the following three factors caused the death of A. albida trees: 1) lowering of the water table which stressed the trees and made it more susceptible to insect attack, 2) presence of foliage chewing insects which defoliated some A. albida trees, 3) greatly reduced herbaceous ground cover caused by the drought and overgrazing, which may have caused chewing insects to seek a new source of food in A. albida.

d) It is clear from this study that insect problems on A. albida can be quite severe. While Brunck has made several suggestions for control of insects on A. albida these suggestions are based on experience with other plants and not on actual research with A. albida. In view of the importance of A. albida a plant pathologist/entomologist should be assigned full time to examine the phytotoxicity of various insecticides and to develop either chemical or biological control methods of A. albida major insect pests.

7.

Author: Charreau, C. and P. Vidal (1965)

Title: Influence de l'Acacia albida Del sur le sol, nutrition minerale et rendements des mils Pennisetum au Senegal.

Source; Agron. Trop. 6-7 pp 660-626

a) The purpose of this paper was to study the effects of A. albida .

on the yield of millet and on the fertility of the soil on which the millet was growing. The results showed the yield of millet was approximately 2-1/2 greater under the A. albida canopy than away from the tree, and that the yield of protein in millet seeds was 3.4 times greater under the tree than away from the tree. The soil under the A. albida tree was twice as rich in organic matter and nitrogen, and had a 50% higher cation exchange capacity than away from the tree. Foliar analyses of the millet leaves under the tree showed an increase in all plant nutrients.

1(b) The research method is based on differences of yield and soil fertility under the foliage cover and away from the foliage cover of A. albida trees. The experimental design used two sets of two A. albida trees with overlapping canopies. Soil samples were taken next to the trunk, just at the boundary of the limit of foliage cover, and completely outside the limit of foliage cover. The soil analyses at each of these points was subjected to statistical analyses by the authors, although it is not possible to check these calculations as the raw data and number of replications per sample have been omitted from the methods. Soil analyses of total carbon and nitrogen (sulfuric-chromic acid digestion and Kjeldahl analysis respectively) are by standard procedures subject to little error.

2(b) Near each soil sampling site three to five hills of millet containing a total of about 20 heads were collected for yield determinations. For each of the 3-5 hills sampled, the weight of millet seed per head, the number of heads per hill, and the total weight of millet and seed per hill was determined to allow calculation of an average millet yield per hill at the soil sampling site. Seven such determinations were averaged for each of the three categories: millet under the tree, millet at the proximity of tree coverage, and millet outside the tree coverage. The results were then expressed in kg/ha assuming a planting density of 10,000 hills/ha.

2c) A multiple range test run at the University of California, Riverside, on the 7 yields under A. albida, the 6 yields in the proximity of coverage, and the 7 yields away from the tree indicated that yields under and away from the tree were significantly different at the 1% level. The yields just under the edge of the foliage were not significantly different from either yields away from the tree or under the tree at the 1% level. These statistical analyses assume the sampling was done either in a representative or random manner but this was not stated in the paper.

3b) The yield of peanuts was also measured under and away from an Acacia albida on 100 m^2 sized plots. The results were the pod yield of peanuts decreased under A. albida (from 2,813 kg/ha to 1,839 kg/ha) while the straw yield of the peanut increased (from 2,587 to 2,761 kg/ha) under A. albida.

3c) The yields of peanuts in these experiments are rather high (1,839 and 2,813 kg/ha) both away and under the A. albida compared to normal pod yields of peanuts in Senegal (600-800 kg/ha). Because of the high yields of vegetative matter in this experiment and the fact that high N levels can depress the yield of reproductive structure in plants, it appears as if a very high level of fertility under the A. albida was the cause of this low yield.[1]

d) There are many facets to this paper but the two main inescapable ones are: 1) under A albida there is a two fold statistically significant increase of soil nitrogen and organic matter[2] which has probably caused the observed increases in cation exchange capacity and water holding capacity, 2) under A. albida there is a 2.5 fold statistically significant increase in millet yields.[3] Since cattle had been excluded from this region for many years, it is unlikely that the increased fertility is due to preferential deposition of fecal material around the trees.

The fact that A. albida lowered the yield of peanuts is probably due to a depressing effect of high fertility on pod yield, caused by a long absence of cultivation beneath the trees. It is important to realize that the depressed peanut yield (1800 kg/ha) is in this instance double or triple what Senegalese farmers normally obtain.

[1] Dr. Charreau has informed this reviewer that since the publication of this paper he has discovered that peanut yield depression is quite uncommon under A. albida.

[2] Please note that Charreau uses the notation $^{0}/00$ which is parts per thousand not per hundred.

[3] Dr. Charreau has suggested to this reviewer that not all trees appear to have this remarkable fertilizing effect and that a population study of trees having beneficial effects on yields might be of value. (For further discussion of this point see Sarlin, 1963, and Dancette and Poulain, 1969.)

8.

Author: Corby, H. D. L. (1974)

Title: Systematic implications of nodulation among Rhodesian legumes.

Source: Kirkia, 9, 300-329

In a survey of 439 Rhodesian species of legumes Acacia albida was reported to be nodulated. In most cases in this study woody plants were grown from seed and examined for nodulation as seedlings. If this test was negative, the species were regrown with inocula provided by either rhizosphere soil from three flourishing native plants, or from cultures of rhizobia from near relatives.

9.

Author: Dancette, C. and J. F. Poulain (1969)

Title: Influence of Acacia albida on pedoclimatic factors and crop yields

Source: African Soils 14, 1-2, 143-184

a) The object of this study was to evaluate the effect of A. albida in a long established traditional Senegalese farming setting on: chemical and physical properties of soils; microclimate of crops; responses of crops to normal fertilizer addition; and yield of crops. The major statistically significant results of the effects of the Acacia albida were: the relative humidity under the Acacia albida is higher than away from the tree; there is a reduction in the absolute maximum temperature and an increase in the absolute minimum temperature under the A. albida; the soil humidity is greater under the tree for the first 120 cm of soil and less for deeper soil layers (than soils beyond A. albida foliage cover); the quantity of rain intercepted by the soil under the A. albida is greater for rains of intensity greater than 16mm/hr and less for rainfall of less than 16mm/hr than soil without A. albida; there is a 40% increase in soil carbon and a 33% increase in soil nitrogen under the A. albida; and there is an increase in yield of 300 kg/ha of peanuts (37% increase) and an increase of 480 kg/ha of sorghum (105% increase).

b) One of the most important assets of the experimental design of this paper was the inclusion of a large number of trees (12) in a traditional Senegalese setting which had been farmed for many years. Five 3.6 x 9 m plots were made with each tree. Two of the plots (with and without added fertilizer) were located under the cover of the tree and three of the plots (no fertilizer and two levels of fertilizer) were located outside the cover of the tree. For yield determinations the center line of each plot consisting of 9 hills of sorghum were harvested. The sorghum heights were also measured as a function of time and developmental stage. The soil analysis was carried out by techniques which have been reviewed in other papers, e.g., Charreau and Vidal (1966) and Radwanski and Wickens (1969).

The following microclimatological experiments were conducted on a single tree at the limits of the Centre National de Recherche Agronomique (CNRA), Bambey. The humidity analysis was done with sheltered psychrometers during the month of July at various times of the day with paired psychrometers 2 and 15 meters away from the tree trunk. The temperature measurements were made using maximum and minimum thermometers over a three week period at the start of the dry season (late October) at two distances (one near the trunk and the other outside the foliage limit). The soil moisture measurements were made gravimetrically after sampling with an auger at three distances in four directions from the tree before the rainy season began and 9 days after the end of the rainy season.

The rainfall was measured using vessels buried to one third of their height in 8 directions at 5 distances from the the _Acacia albida_ tree.. This rainfall data was correlated with data taken at the meteorological station (both the studied tree and the meterological station were on the grounds of the CNRA, Bambey) on rainfall intensity and wind direction.

c) Due to the extensive experimental replication employed by these authors they were able to obtain a good statistical evaluation of their experiments so that the results they report are valid. Their use of what appears to be a random sample of 12 trees in a heavily farmed area yields results which are more generally applicable than those of other authors using single trees.

d) The major results of this paper are that in a population of _A. albida_ trees, the yields of peanuts increased by a rate of 300 kg/ha and the yields of sorghum increased by a rate of 475 kg/ha. This rate of increase occurs only under the _A. albida_ tree and it would be necessary to have complete canopy cover in order to achieve these increases over a hectare.

10.

Author: Delwaulle, J. C. and Mialhe, P. (1974)

Title: Observations sur la foliation d'<u>Acacia albida</u>

Source: Centre Technique Forestier Tropicale - Niger, Haute Volta. Mimeo, 7 pages.

a) Due to the controversy in the literature regarding the mechanism for <u>A. albida</u> defoliation in the rainy sason Delwaulle observed the foliage of 15 <u>A. albida</u> trees near Niamey, Niger from 11 May 1973 to 28 February 1974. On 11 May, the date of first measurement he found 3 of the 15 trees defoliated even though by that time only 2.5 mm of rain had fallen. By the 15th of June only 25 mm of rain had fallen but 7 of the 15 trees had defoliated. On 21 July some of the trees which were defoliated in May began to sprout new leaves. The foliage patterns of some of the above mentioned trees were very different from each other since during the May observation a tree, only 50 m from a completely defoliated tree was in full leaf. Furthermore, while some trees defoliated in May and resprouted 21 July, other trees did not lose their foliage completely till September.

The length of the period without foliage varied a great deal since one tree was without foliage for only one month while another tree was without foliage from May till November. Delwaulle made the observation that trees which resprouted first were also the first to have ripe pods. Delwaulle and Mialhe stated that the variability among trees made it extremely difficult to determine a relationship between flowering and rainfall. In conclusion Delwaulle and Mialhe do not believe <u>A. albida</u>

defoliation is very tightly coupled to water availability and they believe defoliation in A. albida is related to the intertropical front which carries the rain.

b,c) The research method in attempting to develop a correlation between foliage patterns in Acacia albida as a function of rainfall is rather naive for mature trees in the field. If the roots of A. albida did respond to water by defoliating then one would have to know the moisture profile all the way down to 20 meters. The moisture profile down to 20 meters under trees is likely to be variable depending on 1) the duration of foliage cover the previous season (i.e., the amount of water lost by transpiration), 2) the amount of rainfall received, 3) the slope of the ground on which the tree grows, 4) the hydraulic conductivity of the soil from surface to site of absorption, and 5) the amount of deep water drainage and lateral movement.

Aside from all of the above parameters this reviewer believes as outlined in reviews of other papers (Mariaux, 1966 and Anon, 1971) that as a result of outcrossing A. albida is very heterozygous. If such is the case, even if all moisture patterns were the same one would expect A. albida to behave differently.

d) The reason for A. albida defoliation in the rainy season is not resolved in this paper. This reviewer would suggest study of A. albida foliage patterns in the greenhouse or growth chamber under controlled environmental parameters and with controlled moisture stress.

11.

Author: Dugain, F. (1960)

Title: Rapport de Mission au Niger

Source: Centre de Pedologie de HANN-Dakar. Mimeo, 22 pages.

a) The main purpose of this document was to report methods for erosion control in Niger. An appendix is attached on the effect of Acacia albida on soil chemical and physical parameters. The soils under A. albida were found to be increased in organic matter by 269% and in nitrogen by 231% as opposed to areas not under Acacia albida cover. The soil water holding capacity was higher under the Acacia albida as well as the plant nutrients, calcium, magnesium, potassium and phosphorus.

b) Dugain's (1960) method employed five Acacia albida trees. Twenty five, 100 g soil samples (0-10 cm) were taken from a site under each Acacia albida and from a site about 10 meters away from the limit of coverage. It was not stated what method was used for soil analysis, but commonly used simple soil analyses methods such as these are little prone to error. The results of the assay are similar to that of Charreau and Vidal (1966) and Dancette and Poulain (1969).

c) Statistical analysis of the data from the five trees was not carried out since in no case was the nitrogen, organic matter, cation exchange capacity, potassium, calcium and magnesium in any of the soils away from the Acacia albida greater than the levels under the Acacia albida. The average values for the preceding chemical analyses under the tree were several fold higher than found away from the tree.

d) While yield measurements under the tree were not carried out it would indeed be surprising if soils under the five Acacia albida trees with several fold higher contents of plant nutrients than away from the tree would not have several fold higher yields.

12.

Author: Giffard, P. L. (1964)

Title: Les possibilites de reboisement en Acacia albida au Senegal

Source: Bois et forets des tropiques 95, 21-23

a) This article reviews the uses of Acacia albida and its potential for agriculture in Senegal. As this article is a review, much of the material covered by Giffard is evaluated for the Acacia albida state of the art elsewhere.

Giffard stresses the importance of Acacia albida in earlier times in West Africa. Giffard notes that A. albida occurs today around Zinder Niger in vast stands of nearly touching canopies because of the following edict promulgated by the Sultans of Zinder, "If one mutilates a branch of an Acacia albida without reason, his arm will be cut off, and if one cuts down an Acacia albida without authorization, his head will be cut off."

Giffard discusses results of several earlier attempted large scale A. albida plantings which met with failure. In one attempted planting, holes were poked in the ground with sticks, a seed placed in the hole and the hole covered up. Supposedly, hundreds of hectares were planted in this manner but none of the A. albida seedlings came up.

A second experiment used sulfuric acid to weaken the cuticle followed by directly planting after the first rain. The initial germination was 90%, but one by one the plants died in the dry season, so that in 1953 on the 1,000 hectares planted there were no living Acacia albida.

A third experiment raised A. albida seedlings in sheet-iron pots. Unfortunately the seedlings were transplanted later than November in dry soil and again no seedlings survived.

A method which finally proved to be successful involved: harvesting the pods in April; immediately removing the seeds and plunging them into boiling water; and 48 hours later transplanting the seeds in polyethylene bags 30 cm deep. The seedlings were transplanted in August when the seedlings were several centimeters tall and the roots were all the way to the bottom of the container. These experiments had a 90% success rate at the end of the dry season and a 75% success rate 15 months later.

The major lesson to be learned from these tree planting failures is the need for back-up support in the form of research on simple cultural practices to avoid large scale failures.

Data cited by Giffard on the yields of millet going from 370 to 2900 kg/ha are indeed deceptive. From numerous replications in the cited experiment, Giffard has chosen to cite the lowest yield value for millet away from A. albida and the highest yield value under an A. albida rather than the 2-1/2 fold average yield increase reported by Charreau and Vidal (1965). One wonders if other data in the paper are "stretched" a little as well.

13

Author: Gwynne, M. D. (1969)

Title: The nutritive values of *Acacia* pods in relation to *Acacia* seed distribution by ungulates

Source: E. Afr. Wildl. J. 7:176-178.

a) The seeds and pods of many *Acacia* species constitute an important source of food for many wild ungulates in native African savannahs. Research was conducted to evaluate the degree of selection of *Acacia* pods and to evaluate the role of this browse as a source of feed. In the dry season when grass availability was low, *Acacia* pods provided up to 47% of the food on a frequency basis and up to 65% on a dry weight basis. Proximate analyses of *A. albida* pods showed the pods plus seeds to have between 10 and 13.5% protein, the seeds to have between 26 and 28% crude protein, and the entire pods to have between 43 and 59% nitrogen free extract (carbohydrates).

b,c) Methods for proximate analyses are not listed but are quite standard and little subject to error. Determination of the frequency of plants browsed was conducted using oesaphageal-fistulated cattle which were sampled on a monthly basis. These experiments are straightforward and there is little doubt that the data presented is correct. There are only two collections made of *A. albida* for the chemical analyses but the values are in agreement with values reported by Wickens (1969).

d) The major result of this paper are *A. albida* proximate analyses, showing the pods to contain about 12% crude protein and about 50% carbohydrate.

14.

Author: Habish, H. A. and Sh. M. Khairi (1968)

Title: Nodulation of legumes in the Sudan: Cross inoculation groups and the associated rhizobium strains

Source: Expl. Agric. 4,227-234.

a) This paper reports on cross-inoculation experiments between native rhizobium strains of commonly found legumes in the arid tropical Sudanese climate. From among rhizobia strains isolated from 21 legume species only the rhizobia from A. albida produced effective nodules on A. albida. Rhizobia isolated from cowpeas (Vigna sinensis) did produce ineffective nodules on A. albida. For an average of three pot culture experiments, inoculated A. albida seedlings produced 70% more nitrogen than the non-inoculated control. Measurements of the effects of temperature on rhizobial growth rates were performed but not for rhizobia isolated from A. albida.

b) The rhizobia were isolated from red nodules of wild and cultivated legumes by a method described by O. N. Allen. The plants were provided with a nitrogen free nutrient solution to induce nodulation and were grown in sterile sand bottle jar assemblies. Each experiment was repeated three times but statistical analyses of the data is not given. Microbiological characterization was done using the Manual of Microbiological Methods published by the American Society for Microbiologists.

c) The procedures used in this paper follow procedures described either by outstanding nodule bacteriologists, e.g., O. N. Allen of the University of Wisconsin, or by standard procedures published by the American Society of Bacteriology. There is little doubt that the methods, used are reliable. There was a sizeable variation in growth rates of plants being supplied by nitrogen fixation and it is unfortunate that standard deviations are not listed for plant nitrogen content, with and without inoculation.

d) The experiments demonstrate that nodule formation can occur in _A. albida_ seedlings, that the bacteria are specific for _A. albida_ among other legumes, and that there can be an increase in total pot nitrogen over a non-rhizobium inoculated control seedling.

15.

Author: Habish, H. A. (1970)

Title: Effect of certain soil conditions on nodulation of _Acacia spp._

Source: Plant and Soil 33, 1-6.

a) Five _Acacia spp._ including _A. albida_ were compared for growth, nodulation, and nitrogen fixation at the ranges of 7.5 - 30% soil moisture, 30-45^{o}C soil temperatures and soil pH 4.5 - 10.0.

When _Acacia_ seedlings were grown at 7.5% soil moisture content rather than 15% soil moisture content the total nodule number, the total plant dry weight, and the total nitrogen content were reduced by 60%, 65%, and 73%, respectively.

When _Acacias_ were grown in pH buffered pots sixty five percent fewer nodules were observed in the pH range 8.5 to 9.0 than in the pH range 6.5 - 7.0 and no nodules were observed at pH 5.5 or at lower values. Surprisingly the total dry plant weight was the same at pH 5.5 where there were no nodules as it was at pH 6.5 - 7.0 where there were abundant nodules. The mean nitrogen content of the nodulated plants grown at pH 6.5 - 7.0 is 56% higher than plants grown at pH 5.5 without nodules, but this difference is not significant at P = .05, probably due to the low replication number (4).

In a study of three soil temperatures (30, 35 and 40°C) on growth and nitrogen fixation it was found that growth, nodulation and nitrogen accumulation were generally greater at 35°C than 30°C than 40°C. For example, 65% more nodules were formed at 35°C than at 30°C and no nodules were formed at 40°C. The total plant dry weight was statistically greater at 35°C than at 30°C but surprisingly the total nitrogen content of the plant was statistically lower at 35°C than at 30°C. The total dry weight of <u>Acacia</u> grown at 40°C was almost 6 fold lower than plants grown at 35°C.

b) For the experiments on the effect of soil moisture content on growth and nodulation a set of pots were weighed daily and either distilled water or nutrient solution was added to compensate for water loss. The experiments on the effects of various temperatures on growth and nodulation were carried out by immersing the pots in constant temperature water baths at temperatures of 30, 35 and 40°C. The pots were irrigated daily with distilled water to correct for water loss. For the experiment in which soils were maintained at various pH's the soils were adjusted initially to the desired pH with either NaOH or H_2SO_4, and were watered either with distilled water or nutrient solution adjusted to the same pH with NaOH or H_2SO_4. The treatments were replicated 4 times and grown in a cooled greenhouse provided with supplemental lighting. In order to separate soil temperature, pH, and moisture effects on plant growth in general, from effects specific to nitrogen fixation, a control with supplied nitrogen was included in all experiments. As a rule the plants with adequate supplied nitrogen were larger and had more nitrogen than those in which nitrogen was being supplied by nitrogen fixation.

c) In general the experiments seem to have been conducted quite well. Inclusion of more replications in the study of soil pH on nitrogen fixation would have been desirable to determine the statistical significance of differences in nitrogen accumulation by the plant.

In the study of pH on nodulation and plant growth it would have been advisable to use a series of buffers without biological activity as sulfuric acid and sodium hydroxide have no buffering capacity from pH 3.8 to 9.0. Without any buffering, small amounts of acid or base produced by the plant or bacteria could create large pH changes.

All the experiments reported here were conducted on A. mellifera which from initial tests appeared to behave the same as the other four Acacias.

d) A useful comparison can be drawn between the soil humidity data of Dancette and Poulain (1969) and the moisture requirements for Acacia growth and nodulation in this paper. In the middle of the rainy season Dancette and Poulain (1969) found the highest percent soil moisture in the top 20 cm in field of A. albida was 6.7% while the same soil had 4.05% moisture nine days after the end of the rainy season and 0.3% soil moisture at the end of the dry season. In these studies the soil permanent wilting point (-15 bars) occurs at 1.4% soil moisture content. As the author for this paper (Habish, 1970) reported a 40% decrease in nodule number going from 15% soil moisture to 7% soil moisture it is probable that in the dry season when A. albida grows, soil moisture conditions in the top 20 cm of Senegalese soils would severely reduce maximum nodule numbers.

Charreau and Nicou (1971) have reported maximum soil temperatures of 55 to 60 °C (absolute max 65) for bare soils and 38-41 °C for vegetatively covered soils (absolute max 43.5) in Senegal. A. albida seedlings occurring from natural regeneration on bare soils in millet fields would experience these extreme dry season soil temperatures during their growth period. As no nodules were observed at soil temperatures of 40 C in this present study there is little doubt that dry season soil temperatures would inhibit nodulation of A. albida seedlings.

When comparing the soil moisture and temperature conditions for nodulation described in this paper with soil humidity and temperatures which occur naturally during A. albida's growing season (the dry season), there is little wonder that various authors (Jung, 1967) have been unable to find A. albida seedlings nodulated under natural conditions.

16.

Author: Habish, H. A. and Sh. M. Khairi (1970)

Title: Nodulation of legumes in the Sudan II. Rhizobium strains and cross inoculations of Acacia spp.

Source: Expl. Agric. 6, 171-176.

a) The purpose of this paper was to study cross inoculation among 10 <u>Acacia</u> rhizobia strains and 1 cowpea rhizobium strain (since cowpea rhizobia are reported to be quite promiscuous) and for each rhizobial strain to provide data on optimal temperature, pH, and growth conditions in liquid media.

For rhizobia species isolated from 10 <u>Acacia spp</u>. and <u>Vigna sinensis</u> only rhizobia isolated from <u>A</u>. <u>albida</u> produce effective nodules on <u>A</u>. <u>albida</u>. Every other <u>Acacia</u> tested produced effective nodules with rhizobia from at least 4 different <u>Acacia</u> species. After 10 weeks growth <u>A</u>. <u>albida</u> rhizobia inoculated seedlings had a 60% increase in dry matter and a 34% increase in nitrogen content over the non-inoculated controls.

The rhizobial liquid culture temperature optimum for all <u>Acacia</u> rhizobia tested was between 30 and 35^{o}C. Growth of <u>Acacia</u> rhizobia at 40 and 45^{o}C was found to be markedly reduced. The growth rate for <u>A</u>. <u>albida</u> rhizobia in liquid culture was high between pH 5.5 and 7.0, but dropped markedly outside that range. In contrast <u>Acacia</u> <u>senegal</u>, <u>A</u>. <u>polycantha</u> and <u>Vigna</u> <u>sinensis</u> growth rates dropped only slightly at pH 8.0. Rhizobia microbiological characterization of serum production zone, gelatin liquefaction, and acid or base production, from 12 sugars were also noted. Some of the rhizobia resisted heating at 80^{o}C for 10 minutes, and had considerably higher optimal temperature growth rates (30-50^{o}C) than temperature legumes, which suggested to the authors that <u>Acacia</u> rhizobia are adapted to hot, dry climates.

b) The methods used in this article are almost identical to those described for a previous paper (Habish and Khairi, 1968).

c) There appears to be no major procedural errors in the article. There is a misprint in Table 1 in which the average dry plant weights are listed in mg. Since it would have been impossible to weigh a plant of 0.11 mg without an electrobalance, and since units for a similar table in the previous publication are listed in grams, it can be safely assumed the units in the third and fourth columns of Table 1 should be in grams.

d) The agronomic significance of this article is the demonstration of nitrogen fixation by A. albida and the delineation of soil temperatures and pH in which A. albida rhizobia would survive in the soil. Rhizobia might not be able to survive in the upper bare soil layers which can reach 60°C in Senegal.

17.

Author: Hughes, J. F. (1957)

Title: A summary of the information available on the utilisation of Acacia albida

Source: Utilisation Division, Forest Department. Moshi, Tanganyika Mimeo. 6 p.

This is a summary of information pertaining to the wood properties and uses of Acacia albida. The following timber properties are discussed: 1) physical, 2) mechanical, 3) milling, 4) seasoning, 5) natural durability and preservation, and 6) woodworking properties. Since the subject of this article is outside the scope of this reviewer's competence, Hughes conclusion will follow.

"Although its (A. albida) strength properties are appreciably lower than those of softwood timbers (Scots pine) on which building specifications are based, building construction is the most obvious and suitable use for it. When used for this purpose designs should be used that have an adequate strength safety factor and when in doubt timbers should be cut 1/4" oversize up to 3" dimension and 1/2" oversize from 3" to 6" dimensions. It should also be suitable for cheap joinery."

18.

Author: I.R.H.O. Senegal (1966) (probably Gatreau)

Title: Essais sous kads

Source: IRHO Senegal rapport annual memeo. Station de Bambey, 19-29.

a) As Acacia albida was reputed to increase yields of peanuts, the Senegalese government commissioned a research program to study the effect of Acacia albida on the yield of peanuts. In 3 cases out of 5 Acacia albida increased the peanut yield on the test plots an average of 590 kg/ha but in two cases a small decrease in yield (60 kg/ha) was observed under the Acacia albida. The study concluded (in translation) "the effect of the Acacia albida cover was beneficial for peanuts. It is not possible to obtain the soil fertility level provided by Acacia albida with mineral fertilizer."

b) The research method used 5 sites in which the yield of peanuts was measured under the trees and outside of the foliage cover. Two of the sites located near Patar were 1 km apart, and each contained two trees with overlapping foliage. Each of these sites had 28, 5.8 m^2 plots marked out in perpendicular directions. Sixteen of these small plots were under the cover of the foliage and 12 plots were exterior to the foliage cover.

Near Marnane three more trees were chosen for study. Two of the trees had 5 or 6 small plots under the tree and 8 small plots exterior to the foliage cover. Under the third tree near Marnane the top 2 cm of soil was removed from a series of plots beneath the foliage cover and placed on plots just at the limit of the foliage cover to examine the relationship between soil fertility and yield under A. albida.

On all 5 experimental sites fertilizer additions were made to determine if mineral fetilizers could replace yield increases produced by A. albida.

c) It is difficult to evaluate these experiments for several reasons. First, it is difficult to gain an idea of an average effect of A. albida trees as three of the five Acacia albida plots produced yield increases of 590 kg/ha while 2 of the plots depressed yield by 60 kg/ha.

Second, no statistical calculations were carried out to evaluate the validity of yield increases even though as many as 13 subplots were used for yield determinations. Third, the significance of the experiment in which soils were moved from sites close to the tree to areas near limit of foliage cover is clouded by the fact that 2 out of 5 Acacia albida sites depressed yield. It would seem that until A. albida yield increases were demonstrated in all cases it would not be appropriate to study causal mechanisms for the yield increase.

Fourth, soils of high fertility have been known to increase plant vegetative growth at the expense of reproductive structures, e.g., pods or grain. If A. albida's natural capability to increase soil fertility were combined with a fertility restoring long fallow, the soil under A. albida could have a sufficiently high fertility to depress peanut pod yields. In the absence of any description of past farming practices on the involved sites, it would not be possible to know what general fertility level could have been expected under the trees, and thus whether yield depressions were caused by overfertility. The rather high pod yields obtained (1300 kg/ha) indicate the soils were far from infertile (Gillier, 1960).

d) Although the experiments are far from perfect, two useful facts emerge. (1) while A. albida increased the average peanut yield for all trees, in some cases there was an actual yield depression; (2) peanut yield depressions are associated with A. albida on sites where peanut yields are high (approximately 1300 kg/ha) and yield depressions if statistically significant are much smaller (60 kg/ha) than yield increases (590 kg/ha) associated with A. albida on poor sites.

19.

Author: Jung, G. (1966)

Title: Etude d l'influence de l'Acacia albida (Del.) sur les processus microbiologiques dans le sol et sur leurs variations saisonnieres.

Source: Centre ORSTOM-Dakar Senegal. Mimeo, 49 pages.

a) This document compares soil microbiological characteristics under, at the limit of, and exterior to Acacia albida foliage cover. In addition to the microbiological studies, measurements were also made on the physical, inorganic, organic, and biochemical (enzymatic) changes occurring under Acacia albida.

For the physical properties under the tree there was a 52% increase in clay and a 51% increase in water holding capacity, both statistically significant at the 1% level. For the chemical properties there was a 120% increase in the cation exchange capacity, a 91% increase in total soil carbon, and a 110% increase in total soil nitrogen, all significant at the 1% level.

For the microbiological properties under the A. albida cover there was a clear increase of invertase, dehydrogenase, asparaginase and respiratory CO_2. Carbon dioxide released upon soil moistening was also increased by 54% (significant at 1%). These increases are taken as a measure of a generally higher microbiological activity under the A. albida.

The bacteria counts did not significantly increase under the A. albida, but the levels of fungi and actinomycetes did increase. These latter organisms are the major decomposers of lignin, cellulose and organic matter, and their increased population implies faster organic matter decomposition, nitrification, and nutrient availability. This view is supported by a doubled cellulose-stimulated CO_2 release under the A. albida.

In an evaluation of the nitrogen cycle Jung found ammonium and nitrate nitrogen were doubled under the tree as opposed to the control. The conversion rate of organic matter nitrogen to mineral nitrogen measured over a 28 day period was 110% greater under the A. albida. The ability to convert urea nitrogen to ammonium also increased 233% under the tree. The _percent_ soil nitrogen potentially convertible to nitrate is the same under and away from the tree, but the total quantity of this nitrogen is twice as great under the tree, and therefore the total amount of nitrogen convertible to nitrate (nitrifiable N) is also twice as great under the tree. None of the normal, free living nitrogen fixers, e.g., Azotobacter or Beijerinckia, were found under the tree but a _Bacillus circulans_ was found to fix nitrogen and to have a 20 fold higher population under the _Acacia albida_.

There were no significant differences in the iron or sulfur cycle under the tree. Experiments initiated but not completed in the reporting period for this document will be discussed in connection with Jung (1967).

b) For this study six trees were chosen on the grounds of the Centre de Recherches Agronomiques de Bambey. The soil under the trees had been in fallow and protected from cattle incursions for 10 years. The tree ages were estimated at 80 years old for 5 trees, and 30 years old for one tree. Three zones were distinguished under each tree: a zone under the foliage cover (I); a zone at the proximity of the foliage cover (II); and a zone completely exterior to the foliage cover (III). A sample site from each of the three zones was selected directly south from the trunk. At each place the soil was excavated from a 70 cm wide square 10 cm deep, screened to pass a 2 mm sieve, and then replaced at the site in a 0.5 mm mesh nylon netting and covered with litter. These bags were sampled every two months in the dry season and every two weeks in the rainy season.

The bacteria, actinomycetes, and fungi counts were obtained by plating out the organisms and counting colonies on several referenced media. The CO_2 release was measured 7 days after moistening 50 g of soil. Invertase was measured by monitoring an increase in reducing sugars. Dehydrogenase activity was measured by following triphenyltetrazolium chloride reduction. Asparaginase activity was measured 24 hours after soil incubation with a buffered asparagine solution by following ammonia release. Upon analysis of glucose remaining 24 hours after addition of 100 mg glucose, the glucose utilization was determined. Cellulose degradating ability was measured by cellulose stimulated CO_2 release. Total nitrogen was determined by Kjeldahl and nitrate was determined colorimetrically using a phenolic acid-sulfuric acid mixture. Conductivity, salinity, pH, and humidity were measured by standard procedures discussed in critiques of other papers.

c) The use of 6 trees, all sampled in the same direction, allowed a statistical evaluation of the data which was carried out by the author. The author is careful to state which effects were statistically significant and which were not.

This reviewer is not qualified to judge the soundness of the microbiological assays and growth media. There does not appear to be any obvious biochemical errors. It is to be noted that the French soil microbiologists have been making significant contributions on soil nitrogen transformation since Winogradsky's earlier papers in 1878. The method of removing, homogenizing, sieving the soil samples and then returning them to the original soil position does seem a bid odd. There is no doubt that the soil sample would be more homogeneous after this treatment, but would it be more representative? Possible errors in any of the enzymatic or microbiological assays should cancel since a control away from A. albida was used. With the use of a control any large changes observed in soil microbiology should become obvious.

d) The results of the chemical analyses in this paper show that the Acacia albida trees over their respective lifetimes have contributed carbon and nitrogen to the soil beneath their foliage cover at rates of 5.85 T/ha and .736 T/ha respectively. However, supplies of lime, magnesium and phosphorus were not greatly increased.

Large increases were seen in the general population and activity of soil micro-organisms beneath A. albida trees, as well as the ability of those micro-organisms to degrade organic matter to release plant nutrients.

20.

Author: Jung, G. (1967)

Title: Influence de l'Acacia albida (Del.) sur la biologie des soils dior

Source: Centre ORSTOM-Dakar, Senegal. Mimeo, 66 p.

a) This is the concluding half of a report (Jung, 1966) initiated to study the effect of Acacia albida on the microbiology and the effects of possible microbial changes on soil fertility in Senegalese soils. There are many facets to this report so that for each major facet the results and conclusions (a) will be immediately followed by an analysis of research method and procedures (b) and an analytical judgement of validity and reliability (c). A common summary of the effect of *Acacia albida* on soil fertility will appear at the end (d).

1(a) Effect of *A. albida* on physical, chemical, organic and soil microbiological properties

For the entire year the average pH of the soil was 0.3 pH units higher under *A. albida* than under the controls. Under the *Acacia albida* the soil carbon and nitrogen percentages were twice as high as under the control. The C/N ratio under the *A. albida* is lower than the control but this is expected since the C/N ratio of *A. albida* leaves are 17 and gramineae leaves are approximately 80. The soil organic matter profile under the *A. albida* had .25% C to a depth of 40 cm, while away from the tree the soil was .29% C at only 10 cm depth.

Statistically significant increases for 16 microbiologically related parameters including asparaginase activity, dehydrogenase activity, respiratory CO release, etc. were found under *A. albida* as opposed to a control zone with no *A. albida*. While the numbers of bacteria were not significantly greater under the *A. albida*, statistically significant increases in the fungi and actinomycete population were found year round under *A. albida*. The density of cellulytic bacteria and bacteria capable of transforming ammonium to nitrate increased 63% and 390% respectively under the tree. (This is important since plants take up nitrate and not ammonium.) This is not surprising since Jung found the nitrifying bacteria population (which converts ammonium to nitrate) is 10 fold higher under *A. albida*.

From a year round survey of activities Jung has shown that the respiratory CO_2 levels, the dehydrogenase activity, the invertase activity, and the glucose utilizing ability are all characterized by a maximum at the end of the dry season, and at a minimum in the rainy season. In contrast, the asparaginase activity, and microflora density have a maximum in the rainy season and a minimum in the dry season. The ammonia and nitrate levels have a maximum at the end of the dry season and decrease quickly with the first heavy rain.

In an examination of the interactions between site (under or away from the tree) and season, the author found large differences in amplitude of biological activity. They attributed these differences to a lower soil organic matter content away from the tree which attentuated the amplitude of the seasonal biological changes.

1(b) The research methods used in this document are very similar to the procedures described for soil sampling and measurement of biological activity in a previous document by the same author (Jung, 1966). The major differences are the experiments reported here were carried out for the duration of an entire year to observe seasonal patterns.

1(d) The author noted that after the leaf fall in the second year there was an increase in the C/N ratio (which means less nitrogen contribution to soil) and Jung felt this might be due to the inability of organic litter to penetrate the semi-permanently emplaced soil sample bags. As the method used in this section of the document are the same as those used in the previous Jung (1966) document, the same comments on the soil sample bags would apply.

2(a) This part of the document deals with a study to compare litter nutrient release from a leguminous tree (Acacia albida) and a non-leguminous tree (Guiera senegalensis) with soil levels of carbon, nitrogen and other nutrients. A comparison of leaf proximate analysis revealed that A. albida and G. senegalensis had 3.25% N - 53.8% C, and 1.26% N 55.5% C respectively. Thus leaf C/N ratios for A. albida and G. senegalensis are 16.5 and 44 respectively. Analyses of the soil nitrogen and carbon content showed that under A. albida the soil was 3 times higher in carbon and 2 times greater in nitrogen than under G. senegalensis. Both the mineral and nitrifiable nitrogen were also 3 times greater under the A. albida as under the G. senegalensis. The following activities were greater under A. albida by the specified percentages: cellulytic activity (60%); CO_2 releasing activity (300%); dehydrogenase activity (300%) and assimilable phosphate (300%). Leaching experiments on A. albida and G. senegalensis litter in Erlenmeyer flasks revealed the leaching rates were approximately the same and that total leached materials reached a plateau in one day. Also included in this section was a comparison of A. albida, G. senegalensis and Andropogon (a grass) proximate analyses.

2(b) The leaf samples chosen for this study were harvested in the fresh state from green plants, air dried, and cut into squares. Five grams of the leaves were then placed in 300 mls of glass distilled water with one ml of a "fresh soil suspension." At 1, 2, 4, 8, 16, 32 and 64 days three replicates were taken for analyses of soluble substances, soluble N, conductivity, pH, reducing ability and percentage dry weight in liquid. One set of 3 replications was done aerobically and one set anaerobically.

2(c) The chemical analyses were done by standard techniques already discussed (Jung, 1966). The leaching experiments in Erlenmeyers would seem to have doubtful relevance to litter decomposition in the soil, since the soil would be expected to contain large amounts of cell wall degrading bacteria and fungi which might not be capable of growing in distilled water. Jung makes the interesting comment that proximate analyses should be conducted on green leaves still on the tree as the nitrogen content decreases by 45% after the leaves have fallen.

3(a) This section of the document is devoted to analyses of the weight of litter fall, and a chemical analyses of the litter fall to assess the flow of plant nutrients through the Acacia albida soil system. A five tree average showed the following components and weights in kg/tree: leaves and flowers 97.4 kg; wood and bark 45.5 kg; and pods 125 kg. The author used the average surface area of the trees (231 m^2) and assumed complete cover for a hectare to give a pod yield of 5,400 kg/ha. Such a continuous cover would correspond to 43 trees/ha at a 15 m spacing center to center. This pod production has a rather high harvest index of 46%. From litter elemental composition Jung estimated A. albida returns 4.3 kg N, 0.089 kg P, 1.74 K, 5.12 kg Ca, and 0.89 kg Mg per tree annually. The above based per tree returns were calculated to yield the following amounts per hectare assuming 43 trees of 231 m^2/tree: N 186 kg/ha, P 3.9 kg/ha, K 76 kg/ha, Ca 222 kg/ha, and Mg 39 kg/ha. A theoretical analysis was also developed which estimated the annual rate of litter decomposition.

3(b) To quantify the litter fall two, 2 m^2 metallic mosquito nets were suspended off the ground under each of 5 A. albida trees and were harvested eleven times between 17 May 1966 and 17 May 1967. The A. albida trees ranged in estimated age from 30 to 80 years and the ground surface area covered by foliage ranged from 98 to 312 m^2.

3(c) In order to assess the validity of this experiment it would be helpful to know the position of the collecting nets, i.e., were they near the trunk of the tree, near the edge of the foliage, etc. It is especially critical to know the position of these collecting nets since on the average they cover less than 2% of the surface area under the tree. The use of litter density per area of foliage cover beneath the trees yields somewhat misleading results. It would be necessary to have 43 trees of 8.6 m radius foliage cover, spaced 15 m center to center in order to achieve 10,000 m^2 of cover in a 100 x 100 m plot (one hectare). Such a tree density is the maximum likely to occur in the most closely spaced stands. One half of the 43 tree density, i.e., 21 trees, would be a more realistic density and would correspond to a pod production of 2,625 kg/ha and a nitrogen return to the soil of 93 kg/ha annually. These pod production and nitrogen returns to the soil are still very substantial, being several fold higher than is commonly expected of other legumes in the same area, i.e., cowpeas or peanuts.

A. albida pod yields cannot be considered firm for any tree density in this study until more complete information is available on the reliability of using these small collecting nets to determine pod yield/tree.

The reference quoted as first using these nets gives no satisfactory foundation for using them to determine pod yield/tree under A. albida.

4(a) The last section of this document deals with experiments to elucidate the mechanisms for A. albida's ability to increase the soil nitrogen content. In the first experiment when soil inocula from under A. albida was cultured on nitrogen-free media, suitable for growing free living nitrogen fixers, the total nitrogen content of the culture increased. Azotobacter or Beijerinckia could not be isolated from the media, but a nitrogen-fixing Bacillus circulans was isolated.

The author very seldom noticed nodules on A. albida in the field, but because nodules were frequently observed in pot culture, and because of the increased growth of nodulated potted plants he assumed the nodules were effective.

An experiment in which total nitrogen was measured in pots containing Dior soil A. albida showed that the nitrogen in the A. albida pots was significantly higher than the pots without seedlings after 4 months but not after 9 months. Since the soil in the control lost nitrogen they concluded that soil denitrification complicated the analyses.

A further experiment using washed sand, plant nutrients lacking nitrogen, and surface sterilized seeds was conducted with and without rhizobial inoculation to determine the importance of nitrogen fixation to the seedlings. After 3 months all inoculated seedlings had nodules, were non-chlorotic, and were significantly taller than non-inoculated chlorotic controls. The slight increase in nitrogen content of the inoculated seedlings over the controls was not statistically significant.

The author concludes that since he has not observed nodules in the field, A. albida must be removing nitrogen from the water table instead of fixing nitrogen by symbiotic nitrogen fixation. As a general rule Jung feels A. albida takes N from the external media rather than fixing it.

4(b,c) This reviewer feels that Jung's work is technically correct. However, he appears to not fully appreciate the complexity of the factors which play a role in governing nitrogen fixation by the rhizobial-plant system. For example if in the presence of rhizobia, nitrogen is supplied to a legume in either nitrate or ammonium form, nodules will not form on the plant and nitrogen will not be fixed. This is because nitrogen fixation is very energetically costly to the plant so that if nitrogen is present the plant will repress nodule formation and stop nitrogen fixation. Due to the high energy demands for nitrogen fixation the plant must be in strong light to create enough photosynthate to supply nitrogen fixation. For example soybeans in a greenhouse in Michigan during the winter will not nodulate unless they have supplemental lighting. The failure to observe higher pot nitrogen contents when A. albida seedlings were grown without nitrogen in either the potting soil or applied nutrient solution could be attributable to low light intensity if the plants were grown indoors or various other problems such as absence of molybdenum or sulfate, or incorrect soil moisture, temperature or pH (Habish, 1970).

The failure to observe nodules on mature A. albida is reminiscent of A. mollissima which has abundant nodules on young trees but as the nitrogen content of the soil becomes higher (over a period of 15-20 years) fewer and fewer nodules are observed (Orchard and Darb, 1956). Thus the high soil nitrogen created by the nodules eventually represses their own formation. There is a logical explanation for the failure to observe nodules in the field on young seedlings since nodule formation can be severely limited by both heat and water stress. A young seedling with roots not long enough to reach moisture would probably be too drought stressed to form nodules and fix nitrogen.

The author's viewpoint that A. albida obtains its nitrogen from the water table is inconsistent with an analysis of the nitrogen cycle for the following reasons. Nitrogen does not occur in any parent material or bedrock that can be weathered to produce nitrogen. Nitrogen is not produced in animal manure or dung, merely transformed from the pre-existing plant form. Nitrogen can only be fixed by lightning in very small amounts (3-5 kg/ha). Since nitrogen is being exported in large amounts in crops and animals it must be entering the cycle at some point. If it is not purchased and applied to the soil, nitrogen must be fixed either by free living or symbiotic organisms. How and where nitrogen fixation occurs is unclear, but the fact that nitrogen is being fixed in the ecosystem is inescapable. The fact that the increased nitrogen is not associated with non-leguminous shrubs like Guiera senegalensis or Balanites aegyptica (Wickens, 1966) but is associated with A. albida leads this reviewer to believe that at some point in time, at some season of the year and at some depth in its soil profile *A. albida* fixes nitrogen.

4(d) This document lists many *Acacia albida* contributions to soil fertility. All microbial activities are higher under the tree including those for degrading cellulose and for converting ammonium to nitrate. The larger seasonal amplitude changes of microbiological activity under *A. albida* are attributed to a higher soil organic matter content under the tree.

Leaf litter analysis of *A. albida*, the predominant shrub *Guiera senegalensis*, and the predominant grass, *Andropogon*, showed their respective C/N ratios to be 16, 44 and 80. Low C/N ratios promote rapid decomposition and mineralization of organic matter so that *A. albida* leaf litter would be expected to provide nitrogen to the soil more quickly than either the predominant shrub or grass. It is not surprising to find the soil carbon content beneath *A. albida* to be 3 times greater than under *Guiera senegalensis*.

From pods collected under 5 trees in two 2 m^2 litter baskets per tree, the average *A. albida* pod yield was estimated to be 125 kg/tree. Assuming a moderate density of 21 trees/ha or a high density of 43 trees/ha *A. albida* would yield 2600 or 5300 kg/ha of pods annually. The nitrogen content of the *A. albida* litter estimated with the above described litter baskets was found to be 4.3 kg/tree annually, which would be 90 kg N per hectare at a modest stand of 21 trees/ha or 185 kg N per hectare at a dense stand of 43 trees/ha. Such levels of nitrogen return to the soil are comparable to levels of nitrogen fixed by many temperate crops (Date, 1973).

Lastly, the document demonstrated that 4 month old *A. albida* seedlings nodulated and increased total nitrogen content of seedlings and soil in pots. Few nodules were observed in natural field settings where the soil nitrogen content was high.

21.

Author: Jung, G. (1969)

Title: Cycles biogeochimiques dans un ecosysteme de region tropicale seche Acacia albida (Del) sol ferrugineux tropical peu lessive (DIOR)

Source: Oecol Plant IV 195-210

Much of the material in this paper has been reviewed for the State of the Art in earlier works (Jung, 1966 and Jung, 1967). Only material not discussed in previous works will be discussed here.

(a,b) A six year old A. albida was excavated, dried, divided into above and below ground parts, and chemical analysis done to determine mineral nutrients stored above and below ground. The root mass was found to contain 41% of the entire tree mass. The author extrapolates the results from this single tree to obtain a total standing biomass of 140 T/ha and the mineral content of the standing biomass.

The author (Jung, 1969) found no differences in the mineral content of rainwater below A. albida foliage cover and in the zone removed from the A. albida foliage cover. This is not surprising because of the low rainfall where A. albida grows and because A. albida does not have leaves in the rainy season. The author cites references as showing very substantial foliar mineral nutrient leaching in tropical humid regions.

(c) The method of extrapolation used by the author to obtain the standing biomass/hectare from biomass of a single six year old tree is not discussed. Using the tree density normally employed by the author (43/ha) Jung's six year old average tree would have had to have a mass of 3255 kg but from other work (Mariaux, 1966) this would be impossible to obtain in six years. A further complication is the author reveals that in the region of study the average tree density is 10 so that Jung's estimates of litter production based on 43 trees/ha are considerably higher than usually occurs.

(d) The annual nitrogen return to the soil of 186 kg/ha assumes 43 trees/ha. As the average density in the region of study is 10 trees/ha the nitrogen return would be 43 kg/ha. To obtain values applicable to the naturally occurring density the yield of pods, litter, etc. would be reduced to 23% of Jung's stated value. Perhaps tree densities could be managed to achieve the levels described above since naturally occurring _A_. _albida_ densities in the Sudan reach 40 trees/ha (Wickens, 1966). As pointed out in the critique of Jung (1967) the subsampling techniques used to obtain litter mass/tree could lead to serious errors.

22.

Author: Jung, G. (1970)

Title: Variations saisonnieres des caracteristiques microbiologiques d'un sol ferrugineux tropical peu lessive (Dior) soumis ou non a l'influence d' _Acacia_ _albida_ Del.

Source: Oecol. Plant V 113-136

The work reported here can also be found in unpublished form in Jung (1967) where it was analyzed for the State of the Art. In published form the table and graph legends are more clearly marked and the text is more concise than in unpublished form.

23.

Author: Karschon, R. (1961)

Title: Acacia albida Del. in Israel and the near East

Source: La - Ya'aran 11:4-7

This short article describes A. albida as occurring naturally in the following areas and/or conditions:

(1) Mediterranean and Irano-Turanian territories, (2) in an altitudinal range from minus 270 to plus 300 m sea level, (3) in climatic regions with rainfall from 300 to 550 mm, and (4) growth on a wide range of soils including dune sand, basalt soil, and heavy alluvial soil. The article notes that in Irael A. albida is leafless in the rainy season and in full leaf in the dry season. Karschon notes that A. albida coppices freely and produces prolific suckering. No agronomic studies were referenced in Israel.

24.

Author: Lebrun, J. (1968)

Title: A propos du rythme vegetatif de l'Acacia albida Del.

Source: Collectanean Botanica V. 7, Fasic 22, No. 33, 625-635

Lebrun reviews various hypotheses why Acacia albida might defoliate in the wet season. Lebrun believes that the rising water table in the rainy season causes root asphyxiation which in turn causes the leaves to fall. In support for this hypothesis he notes that along the river Lufira flooding does not always coincide with the rainy season, but Acacia albida loses its leaves during innundation and sprouts new leaves as it dries out again.

Lebrun's hypothesis and conclusions while interesting, are experimentally unsubstantiated.

25.

Author: Lematire, C. (1954)

Title: Le Faidherbia albida

Source: These presentee au concours de principalat de 1954 pour Ingenieur de Iere classe des Services de l'Agriculture de la France d'Outre Mer, 62 pages.

Lemaitre's thesis appears to be derived from his own experiences in Niger. There is little quantitative data in this thesis useful in an agronomic sense (except for the experiments on enhancing seed germination) but it contains original observations on: the economics and extent of Acacia albida utilization in Niger; A. albida's effect on human and livestock population density; and comments on the anthropological problems posed by A. albida. For that reason, the following brief review of Lemaitre's 50-page the is will be given although it is not possible to assess the accuracy of his observations.

Lemaitre begins with a general description of Acacia albida's morphology, soil and temperature requirements and tree density around Zinder, Niger.

Lemaitre notes that where there are 80 A. albida trees/ha it is possible to cut one tree every year. From a single tree 5 to 6 cubic meters of firewood can be obtained which in 1954 was in high demand and sold for 1,000 CFA/m^3 in Zinder, Niger.

According to Lemaitre there can be excessive lopping of A. albida branches for cattle food which results in lower pod yields, lower soil fertility and increased tree mortality. Because nomadic cattle herders do not live continuously on the same land, they do not have the same respect for the soil fertility and pod yield as do sedentary farmers. For these reasons Lemaitre believes the nomadic cattle herders are responsible for the majority of the A. albida lopping.

Pod production begins when the A. albida trunk is 20 cm in diameter, is maximum when the crown is large, and over a period of years there seems to be significant differences in average pod production by some individual trees. Lemaitre states that average pod yields for twenty 30-year old trees are 6 to 8 kg, but an exceptional tree may produce 40 kg. Evidently assuming 100 trees/ha, Lemaitre states that 30-year old A. albida trees would produce 600-800 kg/ha/yr. The A. albida tree pod yields of 6-8 kg are much less than values of 125 kg/tree and 135 kg/tree reported by Jung (1967) and by Wickens (1969).

Lemaitre gives an interesting comparison of two villages near the same isohyet. One of the villages has a high A. albida density while the other has no A. albida trees. The village without A. albida has 4 people/km^2, 2 cow equivalents/km^2, and few wells. The farmers in the village without A. albida are often clearing new land to plant crops. In the village with many A. albida, there are 30 people/km^2, 10 cow equivalents/km^2, abundant well water but no fallowing or clearing of new land takes place. These villages constitute an interesting comparison, but as discussed in the accompanying trip report to Paris and Senegal, A. albida could only be expected to lower the water table. As there was more water available in the village with more A. albida it is not possible to tell whether the increased population is due to more water, to the presence of A. albida, or both. To strengthen his contention that A. albida can increase the human carrying capacity of the land, Lemaitre cites 5 villages with many A. albida which have population densities of 25 to 40 people/km^2 and notes that areas without A. albida have only 10 to 20 people/km^2. Moreover, these high population densities occur in areas where the land is not being left to fallow and where new land is not being cleared to improve crop yields. Tremendous social consequences stem from the permanent sedentary agricultural settlements made possible by Acacia albida's ability to eliminate fallowing and clearing of new land.

A criticism sometimes made of A. albida is that it does not improve the yields of peanuts nearly as much as it does the yields of millet. Lemaitre notes in Niger people eat millet and sell peanuts and as a result of the farmer's main concern to have something to eat only 110,000 ha of peanuts were planted in Niger in 1954 versus 1,800,000 hectares for millet and sorghum. The point that A. albida does not increase the yields of peanuts as much as millet is of little concern in Niger. Lemaitre states that there are 800,000 ha in Niger capable of being planted with A. albida.

With regard to cultural practices, Lemaitre reports that caterpillars often eat *A. albida* leaves and may be a problem. If increasing the soil fertility is the major reason for planting *A. albida*, Lemaitre suggests planting 120, 140, or 160 trees/ha.

In a short experimental section of the thesis Lemaitre compares scarification treatments and sowing dates on the germination rate.

Lemaitre used the following seed treatments replicated 8 times with 100 seeds per replication: (1) seeds placed in the ground with no preparation, (2) seeds soaked 24 hours in pure water, (3) seeds soaked in water 24 hours then placed in cow dung, (4) seeds placed in sulfuric acid for 5 minutes (concentration unknown as is expressed in nonstandard units), (5) seeds placed 15 minutes in sulfuric acid diluted in 4 volumes of water, (6) seeds placed 15 minutes in a 1 to 4 dilution of sulfuric acid and then in cow dung, (7) seeds placed 15 minutes in hydrochloric acid diluted 4 times, and (8) seeds placed 15 minutes in 4-fold diluted hydrochloric acid followed by soaking 24 hours in cow dung. The 5-minute sulfuric acid treatment was better than all other treatments tested at the 0.1% level. The germination percentages obtained with sulfuric acid (77.5%) are less than the germination percentage reported by Wickens (1966) for seeds which were surgically nicked. Abrasive-lined mechanical shaking devices have successfully been used to scarify other seeds and might be the safest and fastest method for obtaining high *A. albida* germination rates.

In a comparison of the seedling dates 28 July, 7 August, 17 August, and 27 August, Lemaitre found the 7 August date to have the highest survival (significant at 0.1%). The higher survival on 7 August is probably due to ideal rainfall and soil moisture conditions. As the rainfall distribution is different most years, the ideal A. albida seeding date would be expected to differ each year from 7 August.

In conclusion, this reviewer believes Lemaitre's most intriguing hypothesis is that A. albida doubles human carrying capacity of the land to a maximum of 25 to 40 persons/km^2. Pelissier (1967) has come to similar conclusions. It is not possible from Lemaitre's thesis to determine the validity of this statement, but the problem is straightforward and could be solved by either demographers or agricultural economists.

26.

Author: Mariaux, A. (1966)

Title: Rapport d'etude - Croissance du Kad (Acacia albida)

Source: Centre Technique Forestier Tropicale - Division d'Anatomie. Mimeo, 23 pages.

a) The growth of Acacia albida in Senegal was evaluated where it is used to "fix" sand dunes, and where it grows in farmers fields. The diameter growth rate was found to vary from 6.1 to 29 mm/year. The fastest growing trees were found associated with crops near Thies and Diourbel, while the slowest growing trees were found on sand dunes near Bao.

b) The growth rate of Acacia albida logs originating from several areas were estimated from the distance between growth rings. After the cut surface of the log was finely sanded, six rays were chosen 60 degrees apart. With the aid of a 10X dissecting microscope the number of rings along each ray and the distance along each ray were measured. Growth rate was calculated by dividing distance by the number of rings.

c) There are two major assumptions here. The first being that the number of growth rings equals the number of years. In a frost free climate one would expect a growth ring to result from a wet-dry cycle. Errors in relating growth rings to years have arisen because of more than one growth cycle per year. Therefore, errors in relating growth rings to years would result in an over-estimate of the age and an under-estimate of the annual growth rate. The values for annual growth rate derived here are similar enough to that of Wickens (1966) to largely rule out the possibility of errors from more than one growth cycle per year.

The other complicating assumption is that all trees in an area have approximately the same growth rate but as shown in the CTFT 1971 annual report there is a three or four-fold growth rate difference among seedlings.

d) This survey illustrates the range of plant growth to be expected from seedlings.

27.

Author: Nongonierma, A. (1976)

Title: Contribution a l'etude biosystematique du genre Acacia Miller en Afrique occidentale.

Source: Bulletin l'Institute Fondamental d'Afrique Noire. Tome 38 ser A, No. 3, 487-642.

This is a classical botanical study on Acacias of west Africa. The information presented in this paper pertains very little to agronomic uses of A. albida. The study places Acacia albida back in the old classification Faidherbia albida and distinguishes 2 subspecies of Faidherbia albida.

Dr. Nongonierma reported that A. albida grown on the University of Dakar premises first flowered at 7 years of age and had pods at 8 years of age.[1]

28.

Author: Pageard, R. (1971)

Title: Note sur l'Acacia albida (-Faidherbia albida) en Haute-Volta

Source: Notes et documents Voltaiques 4(4) 50-59.

This paper reports original anthropological observations of Acacia albida in Upper Volta. The author describes sacrifices of chickens and millet being made to A. albida trees, and "divine rules" promulgated by priests to protect A. albida. It is obvious from this work that a project in Upper Volta designed to protect and increase the number of A. albida trees would be favorably looked upon.

[1] In a conversation with this reviewer Dr. Nongonierma indicated that he had no information relating to flower-self incompatability, outcrossing, or genetics of Acacia albida.

29.

Author: Pelissier, P. (1967)

Title: Les paysans du Senegal - Les civilisations agraires du Cayor a la Casamance.

Source: (Book) Imp. Fabregues, Saint Yrieux (Haut Vienne) p. 265-274.

This chapter by the much-respected French geographer and anthropologist, Paul Pelissier, does not report new data of agronomic significance on A. albida but develops fundamental and seldom recognized relationships between farmers of Senegal and A. albida trees. For these reasons his paper is briefly reviewed here.

Pelissier stresses that A. albida does not occur in native stands in Senegal or West Africa and has never been reported as part of a forest climax vegetation. A. albida's failure to occur in wild stands, or to spread naturally, Pelissier suggests, is because of a combination of an impermeable seed coat which germinates with great difficulty and a high mortality of the germinated seedlings which leaf out and grow in the dry season with perhaps only a very shallow root system. Among the A. albida seedlings which do sprout in farming areas of Sine Senegal, farmers choose seedlings they wish to retain based upon their present A. albida tree density and upon the vigor of the particular seedlings. For the seedlings they desire to keep, Pelissier notes that farmers prune them, make them straight, and protect them from grazing animals until they are tall enough to be safe. In view of the natural tendency of A. albida to have bushy rather than "tree-like form" Pelissier suggests the appearance of large stands of straight trees represents a concerted initiative by man.

Pelissier reports the phrase in serer language "yaram-sas" which means to raise an A. albida, is used in the same general context as "yaram o ndiay" which means to raise a child.

Lastly Pelissier points out that the soil-enriching properties of A. albida has negated use of fallowing and clearing of new farm land to allow a permanent sedentary agriculture.

30.

Author: Radwanski, S. A. and G. E. Wickens (1969)

Title: The ecology of Acacia albida on mantle soils in Zalingei, Jebel Marra, Sudan

Source: J. Appl. Ecol. 4, 569-579

a. This paper gives a general description of Acacia albida site characteristics in the Sudan. Much of the work reported here was previously described in a mimeo (Wickens, 1966). Only observations not found in preceding papers will be discussed here.

The new contribution of agronomic significance is the inclusion of soil analysis on similar slopes with and without A. albida. The major result is that the soil under A. albida had twice the organic carbon percent and six times as much total nitrogen as the soil without A. albida.

b. Two approximately equal slopes were chosen for analysis. The main vegetation on one slope was the non-leguminous tree Balanites aegyptiaca, while the predominant vegetation on the other slope was Acacia albida. The techniques used for the soil carbon and nitrogen analyses are identical to that used by Charreau and Vidal (1965), that is a sulfuric acid-chromic acid wet digestion for carbon, and Kjeldahl analysis for total nitrogen. These soil analysis methods are reliable standard, time-tested methods.

c. While neither the number of replications or standard deviations are given for the soil analyses, the higher soil nitrogen and carbon contents under _A. albida_ are probably statistically significant for the following reasons: (1) the ranges for soil carbon content only barely overlap between soils under _A. albida_ and the control, while the range of nitrogen percentages do not overlap; (2) the means for soil carbon and nitrogen content are respectively 2- and 6-fold greater under _A. albida_ than under the control.

The nitrogen (.43%) and organic matter (1.33%) contents of the soil with _A. albida_ are much higher than values of 0.067% and 0.5% observed in Senegal by Charreau and Vidal (1965). The Sudanese soils have much more silt plus clay (30-40%) than Senegalese soils (6-7%), and perhaps this retards organic matter leaching. The exceedingly low C/N ratio of 2.4, in the Sudanese soils under _A. albida_, is a very unusual phenomenon for which the authors have no explanation.

d. The benefits of 6-fold increased soil nitrogen and 2-fold increased soil carbon caused by _A. albida_ would probably produce millet and/or sorghum yield increases comparable to that found by Dancette and Poulain (1969) or Charreau and Vidal (1965), i.e., about 500 kg/ha. It is important to note that the non-leguminous control tree, _Balanites aegyptica_, induced no such increase in soil fertility.

31.

Author: Ross, J. H. (1966)

Title: Acacia albida Del. in Africa

Source: Sociedade Broteriana (coimbra) Boletin 40:187-205

This is a taxomonic work on Acacia albida with no information pertaining to its agronomic potential.

32.

Author: Sarlin (1963)

Title: Le Faidherbia albida (Acacia albida Del) a Ouahigouya

Source: Mimeo: Centre Technique Forestier Tropical, 36 pages.

a. This research examined the effect of Acacia albida on millet yields and on soil fertility on numerous sites near Ouahigouya. For an average of 29 sites on various topographies (crests of hills, slopes, and low-lying areas) Acacia albida increased the unthreshed millet head yields from 820 to 1,250 kg/ha.

b. Twenty-nine sites were established close to roads leaving Ouahigouya in all directions. The sites were chosen to represent crests of hills, slopes, and low-lying areas. Measurements were made of Acacia albida's trunk diameter, crown diameter and distance to the nearest Acacia albida. The following soil parameters were also measured: pH; organic matter; nitrogen content; carbon content; exchangeable calcium, magnesium and potassium; and total and assimilable phosphate.

The soil was sampled by staking out a square 10 meters on a side. Each corner and each side were sampled once and the middle of the square was sampled twice. Each of the above places was subsampled 10 times for a total of 100 samplings per square. The yield of millet was also measured in the above described squares. For each square under an Acacia albida there was a control outside the Acacia albida cover. Correlations were attempted between most of the tree and soil parameters. An equation was derived to relate Acacia albida seedling death to number and frequency of cattle steps.

c. The effort used to derive equations relating frequency of cattle steps to A. albida seedling mortality and thus mature stand density would have been better spent designing animal-proof protection devices. Plots of the attempted correlations between tree parameters and soil parameters have a great deal of scatter and in view of the absence of a statistical asessment of their reliability, they are of questionable value.

The extensive number and replication of soil samples taken should be sufficient to find any real differences between the control soil and the soil under Acacia albida. As the type of soil analyses are quite standard and as they were carried out at the CTFT lab near Paris one would imagine they are reliable. Nevertheless, the data for the tree on the crest looks suspicious since the millet yield under A. albida went from 300 kg/ha to 1,125 kg/ha, while the soil organic matter and nitrogen content under A. albida went down when all other soil parameters remained the same. Similarly, in parcel 3 the yield under A. albida went down by 900 kg/ha when soil analyses showed all soil parameters under the tree to be more favorable. These strong inverse correlations between yield and soil nutrient status are in conflict with data obtained by Dancette and Poulain (1969) and Charreau and Vidal (1965). This reviewer would tend to support the conclusions of the latter workers. It is this reviewer's opinion that the results from the data in this document are overextended.

d. Acacia albida increased the yield in 22 out of 29 cases, it had no effect in 2 cases, and in 5 cases it decreased the yield. While A. albida does not always increase the millet yield there was an average millet yield increase for all 29 trees of 430 kg/ha. Research is needed to determine why the yield is depressed in some cases and what will be required for A. albida to increase the yield in all cases.

33.

Author: Schoch, P. G. (1966)

Title: Influence sur l'evaporation potentielle d'une strate arboree au Senegal et consequences agronomiques

Source: L'Agron. Trop. Nov. 1283-1290

a. Schoch's hypothesis is that as opposed to large areas where all the trees have been removed, a density of 25 to 30, 3 to 5-meter tall Acacia albida trees/ha will reduce the potential evapotranspiration in crop fields. From calculations derived from Piche evaporimeter data, Schoch concludes there is a reduction of potential evapotranspiration in cultivated fields with A. albida trees as compared to fields with no trees.

b. The research method involved placing sheltered Piche evaporimeters in the five following widely differing sites: (1) fields of at least 100 hectares in which trees are entirely removed; (2) a traditional farming field with 25 to 30 A. albida trees per hectare; (3) the Botanic Garden which is a clearing of about 10 ha surrounded by natural windbreaks; (4) a piece of land on which are located 3 to 4-meter tall Acacia albida parallel windbreaks spaced 30 meters apart and directed at right angles to prevailing winds, and; (5) a 600 m^2 site surrounded by a screen of trees and buildings 4 to 5 meters tall. In all cases the sheltered Piche evaporimeter was placed in approximately the center of the study area.

c. The formula used by Schoch to calculate potential evapotranspiration from Piche evaporimeter data is an empirical one developed by Bouchet (1965). Even if the values reported by Schoch are not the same as potential evapotranspiration, measured with a class A pan, his sheltered Piche evaporimeter readings should be proportional to potential evapotranspiration and it should at least be possible to distinguish sites of low and high evapotranspiration. The data could have been strengthened with the use of several sheltered evaporimeters at each site to evaluate the statistical significance of the data. The credibility of Schoch's data is enhanced since the ranking of potential evapotranspiration at the five sites remains the same for 21 sampling periods.

d. At the beginning of the growing season Schoch reports a 50% decrease in potential evapotranspiration in the field with Acacia albida vs. the field without trees, but he does not report tangible effects on crop yield. He suggests that reduced evapotranspiration would allow stomates to remain open longer and thus increase crop yield by allowing more photosynthesis. Schoch believes a lowered water stress resulting from decreased potential evapotranspiration would decrease the mortality of freshly sprouted crops by allowing them to survive until the next rain. A further advantage of reduced evapotranspiration and soil water loss would be a reduction in soil hardness which would facilitate the digging of peanuts at later stages of plant maturity. While all of the above-mentioned advantages of lowered evapotranspiration are possible, Schoch presents no evidence that any of them are in fact occurring.

34.

Author: Trochain, J. L. (1969)

Title: Le rythme phenologique aberrant de Faidherbia albida (Del.) A. Chev. (Mimosaceae)

Source: Annales Scientifique de l'Universite de Besancon Botanique 3 serie, fasic. 6, pages 7-13.

Acacia albida's unusual foliage pattern losing its leaves in the rainy season and sprouting them in the dry season is the subject of this paper. Trochain cites examples in which the rainy season occurs from November through April in both northern and southern hemispheres and notes that A. albida leafs out in the dry season in both cases. Therefore, it seems as if A. albida leaf formation is regulated not by photoperiod (which would be different in northern and southern hemispheres), but by the soil moisture. (To further support this notion, A. albida leafs out in the dry season in the Sahel from November to May.)

Trochain also reports that millet yields increase from 370 kg/ha to 2,900 kg/ha, progressing from areas outside of A. albida foliage cover to areas under A. albida foliage cover. While the yield data is not cited, the numbers appear to be those reported by Charreau and Vidal (1965) for extrapolated yields of the highest yielding plot of millet under A. albida and the lowest yield millet plot away from A. albida. If these numbers are taken from Charreau and Vidal (1965), the yields reflect extreme cases and not the average yield increase caused by A. albida. In any case without a citation or description of the method used to measure the yields, the yield data reported by Trochain is meaningless.

35.

Author: Wickens, G. E. (1966)

Title: Acacia albida Del - A general survey (with special reference to observations made in the U.N.S.F. Jebel Marra Project). 67 pages.

1(a) This document reviews the Acacia albida literature and reports Acacia albida silviculture techniques and a steer feeding study with Acacia albida seeds.

1(b) Effect of A. albida on the water table. The depth to the water table was measured directly under an A. albida tree and in a nearby Agricultural Department Garden well over a period of one year. It is not stated how the water table under the tree was measured, but a measurement of that sort is difficult to do incorrectly.

1(c) Although the experiment is not described as thoroughly as it could be, the data is probably reliable. The results of this experiment appear quite reasonable since the water table comes closer to the surface during the rainy season when A. albida does not transpire and then becomes deeper during the dry season when A. albida leafs out.

1(d) At the end of the rainy season the A. albida and the garden are about the same depth to the water table, but at the end of the dry season the water table under A. albida is 2 m lower than the garden. Total transpiration is proportional to total leaf area and therefore a grove of A. albida trees would be expected to lower the water table even more than a single tree. The significance of the possibility of lowering the water table in wells over large areas does not need elaboration.

2(b) Proximate analyses for A. albida pods from various sources are listed in the document. While the methods for proximate analysis have not been listed, these analyses are straightforward and errors are not likely to be great.

2(c) The sampling error is probably larger than the error from chemical analysis. The listed proximate analysis values are in agreement with Gwynne (1969) for A. albida pods.

2(d) The crude protein levels in A. albida pods (10-15%) are significantly higher than most cereals, but unfortunately their digestability has not been studied.

3(b) An uncited statement in the text compares wheat height, number of heads per plant, and number of grains per head on wheat grown under and away from A. albida foliage cover.

3(c) Neither the number of plants measured or any statistical analyses were given to judge the validity of the data.

3(d) The wheat under A. albida was 60 cm tall, had 8 heads per plant with 32 grains per head, while the wheat away from A. albida was 30 cm tall and had only 3 heads per plant with 22 grains per head. The data seems reasonable when compared to the results of Charreau and Vidal, but there is no objective way to judge the validity of the data.

4(b)(c)(d) A trench 60 m long was dug between two A. albida trees to examine differences in soils under and away from the trees but no statistically significant differences were found. The normal A. albida stand in the area provides complete canopy cover and perhaps the site of the trench was previously occupied by an A. albida. No conclusions can be drawn from this experiment.

5(b) A two year old stall-fed steer at the University of Khartoum was fed a single alfalfa meal with 3,280 A. albida seeds to determine seed digestability. The feces were collected daily and examined for undigested seeds. On the 5th and 6th days after feeding, 66% of the seeds appeared unbroken.

5(c) The experiment appears sound with no obvious errors.

5(d) The data is quite useful in assessing the feedling value of the pods since on a weight basis the seeds contain more protein than the pods.

6(b)(c)(d) A comparison of the quantity of forage obtained from an A. albida tree with a yield of unshelled groundnuts at about 300 kg/acre (749 kg/ha) is made using A. albida; pod yield per tree, seed to pod ratio, percent digested seeds, and crude seed protein. The result is that 5 Acacia albida trees have the same amount of digestible protein as an acre of groundnuts.

The weak point in the calculation is that the method of determining the 135 kg of pods per tree is not specified. If the average Acacia albida tree can yield 135 kg there is little doubt the forage value of A. albida pods will be equivalent to groundnuts. However, only 5 trees per acre (12 trees/ha) were used in the calculation and as many as 35 trees/acre (86 trees/ha) were reported in this area A. albida might provide 4 or 5-fold more forage value per acre than peanuts.[1]

7(b)(c)(d) The diameter of 29 A. albida trees was measured in 1958 and 7 years later again in 1965. The mean annual diameter growth increment was 15.9 mm with a standard deviation of 5.9 mm. These values compare favorably with values of 6.1 and 29.2 mm per year found respectively on sand dunes and in cultivated areas in Senegal by Mariaux (1966). If the Sudanese trees were more mature, as well as larger in diameter than the Senegalese trees, a slower diameter growth rate might have been expected. The average annual rainfall in Wicken's study is slightly over 600 mm and is comparable to the 665 mm average annual rainfall recorded at CNRA, Bambey, Senegal (Dancette and Poulain, 1969) where Mariaux's (1966) fastest growing A. albida trees were measured. The methods used to obtain this data are simple enough that the data must surely be correct. The data will be useful in predicting growth rate and fuel yield from A. albida plantings.

8(b)(c)(d) The seed to pod weight percentage was determined by

[1] The belief that A. albida pods can provide substantially higher yield of forage than the grass beneath it, is held by Dr. Charreau.

weighing the pods, dissecting the seeds, and reweighing the seeds. Nine pods were found to have an average seed to pod weight ratio of 1 to 4.4. The pod to seed weight ratio is used to convert pod yield per tree to seed yield per tree, which after correction for cattle seed digestability yields available seed protein per tree.

As the range of seed to pod weight was from 1:2.6 to 1:7.7, there would be an opportunity to select tree cultivars with either high or low protein pods by merely selecting for seed/pod ratio. The method of seed to pod weight ratio determination used here is accurate, but the sample size is not sufficiently large to allow it to be used widely. The seed/pod weight ratio derived in this study is useful in estimating the forage value for the tree reported here.

9(b)(c)(d) A series of experiments was carried out to determine the most effective manner of breaking A. albida seed dormancy. One hundred seeds were used in each experiment. After each treatment the seeds were kept on moist paper and the date of germination noted. The treatments involved nicking the seed coat with a sharp knife and placing seeds in boiling water for 0, 1/2, 1 1/2, 2, 2 1/2 and 3 minutes. Between 87 and 97 percent germination was obtained in 10 days if seeds had their testas nicked. None of the boiling water treatments were significantly different from the control and took 85 days to obtain 90 percent germination. Due to the poor germination of boiled seeds and the fastidious nature of nicking seeds, Wickens suggested the use of acid. This reviewer would like to point out that abrasive-lined "paint shakers" have been calibrated to mass produce nicked seeds of other hard coated species. The simple experimental setup and interpretation leave little room for error and are undoubtedly reliable.

10(b)(c)(d) One hundred pods were dissected to determine the extent of seed insect damage. In the 100 pods, 1,092 damaged seeds and 1,077 undamaged seeds were counted for a 50% damage frequency. A sample this large must be statistically significant and is valuable information. The seed damage with other legumes such as mesquite increases with the length of time the pods lay on the ground and therefore it would have been interesting to know how long the A. albida pods were on the ground. This heavy insect damage also raises the issue of the nutritional value of pods in which the seeds are destroyed by insects.

11. Other minor comments such as sparcity of nodules will be dealt with in connection with other major papers on nodulation.

36.

Author: Wickens, G. E. (1969)

Title: A study of Acacia albida Del (Mimosoideae)

Source: Kew Bulletin, Vol. 23, no. 2, p. 181-202

This paper provides an especially good review of the more botanical aspects of A. albida such as taxonomy, cytology, anatomy, pollen structure and geographical distribution. Wicken's earlier work on Acacia albida pertaining to agricultural issues can be found in other papers (Wickens, 1966 and Radwanski and Wickens, 1967) which have been reviewed for the State of the Art.

I. B. Acacia albida articles which do not report original measured observations:

Author: Anon (1967)

Title: Acacia albida (Kakabu)

Source: Timbers of Tanganyika, utilisation section, Forest Division, Moshi, 3 pages.

Application: This work is a condensed version of an earlier work (Hughes, 1957) already reviewed for the State of the Art.

Author: Anon. (1974)

Title: Tree planting practices in African savannas

Source: FAO-Forestry Development Paper #19, Rome, Italy, p. 42 and 72

Author: Catinot, R. (1974)

Title: Contribution du forestier a la lutte contre la desertification en zones seches

Source: Bois et Forets des Tropiques 155, 3-13

Application: Briefly discusses use of A. albida for runoff control and other more general features.

Author: Curasson, M. G. (1953)

Title: Etudes sur les paturages tropicaux et subtropicaux

Source: Rev. Elev. Med. Vet. Pays Trop. 6:243-266
Rev. Elev. Med. Vet. Pays Trop. 7:37-48
Rev. Elev. Med. Vet. Pays Trop. 7:103-120
Rev. Elev. Med. Vet. Pays Trop. 177-180

Application: The preceding four articles comprise a list of where plants grow and there is little agronomically useful information contained therein.

Author: Curasson, M. C. (1958)

Title: Etudes sur les paturages et les aliments du detail dans les pays tropicaux et subtropicaux

Source: Rev. Elev. Med. Vet. Pays Trop. 14:41-75

Application: This is a review of plants found in tropical pastures. No original data is contained in the paper and there is only a short sentence, p. 45, describing the importance of A. albida pods in the dry season. (Giffard, 1964 cited this article as saying A. albida pods and leaves are among best livestock feeds.)

Author: Charreau, C. (1974)

Title: Soils of tropical dry and dry wet climatic areas of west Africa and their use and management

Source: Lecture series Cornell Univ. AID supported mimeo. 211-217.

Author: Dancette, C. (1968)

Title: Note on the advantages of a planned utilization of the Acacia albida (Faidherbia, Kad, Sas) in Senegal

Source: Institut de Recherches Agronomiques Tropicales et des cultures vivrieres. CNRA, Bambey, Senegal. 4 pages.

Application: This is probably the best and shortest review of Acacia albida in Senegal.

Author: Delwaulle, J. C. (1973)

Title: Desertification de l'Afrique au sud du Sahara

Source: Bois et Forets des Tropiques 149, 3-30

Application: Very little information on Acacia albida.

Author: Delwaulle, J. C. (1975)

Title: Le role du forestier dans l'amenagement du sahel

Source: Bois et Forets des Tropiques 160, 3-22

Application: Minor mention of use of Acacia albida in reforestation.

Author: Elamin, H. M. (1975)

Title: Germination and seedling development of the Sudan Acacias

Source: Sudan Silva 3(20) 23-33

Application: Elamin used leaf morphology of young seedlings in a taxonomic study of Acacia seedlings. In this study he places A. albida in a class by itself. There is no information in this article concerning agronomic or economic uses of A. albida.

Author: Giffard, P. L. (1966)

Title: Utilisation de l'Acacia albida dans la regeneration des sols en zones tropicales arides

Source: Sexto Congreso Forestal Mundial Madrid, 8 pages

Application: This article is a condensed version of an earlier paper (Giffard, 1964), already reviewed for the State of the Art.

Author: Giffard, P. L. (1971)

Title: Recherches complementaires sur Acacia albida (Del)

Source: Bois et forets des tropiques 135, 3-20

Application: This work reviews research on Acacia albida commissioned by the Senegalese government and carried out by ORSTOM, IRAT, IRHO, and CTFT. Each of the individual works carried out by these organizations is separately reviewed for the *A. albida* state of the art. In many cases Giffard fairly reviews the literature but in some cases his review is biased in reporting the most favorable conditions created by *A. albida*. For example, Giffard reports values for *A. albida* pod yield and nitrogen fixation of 5,400 kg/ha and 186 kg/ha respectively, but does not mention these values assume the highest tree density (43 trees/ha) postulated by Jung (1967).

Author: Giffard, P. L. (1974)

Title: Les essences de reboisement au Senegal LeKad: *Acacia albida* Del (*Faiderbia albida* cleo)

Source: Centre Technique Forestier Tropical. Dakar - Mimeo, 35 pages.

Application: This article is a good review but contains no original data that is not discussed in original papers.

Author: Giffard, P. L. (1974)

Title: L'arbe dans le paysage Senegalais, 154-156; 245-291-304

Source: Central Technique Forestier Tropical, Dakar, Senegal

Application: This is a useful review but no original data is presented.

Author: Griffith, A. L. (1961)

Title: *Acacia* and *Prosopis* in the dry forests of the tropics

Source: FAO Rome, Italy, Mimeo, 149 pages.

Author: Grondard, A. (1964)

Title: La vegetation forestiere au Tchad

Source: Bois et Forets des Tropiques 93, 15-34

Application: Lists various forest tree species in order of their area of distribution.

Author: Kaul, R. N. (1970)

Title: Afforestation in arid zones

Source: DR. W. Junk N. Ve Publishers, the Hague, p. 66, 69, 75, 141.

Author: Michon, P. (1973)

Title: Le Sahara avance-t-il vers le sud

Source: Bois et Forets des Tropiques 150, 3-14.

Author: Pardy, A. A. (1953)

Title: Notes on indigenous trees and shrubs of southern Rhodesia

Source: Rhodesian Agricultural Journal, Vol. 50, 325

Application: Notes that in times of famine people ate _A. albida_ boiled seeds.

Author: Pelissier, P. (1977)

Title: Competition and the integration of agriculture and cattle raising in Sahelian and Soudano-Sahelian Africa

Source: An International Symposium on Rainfed Agriculture in Semi-Arid Regions, April 17-22, 1977, Riverside, CA.

Author: Porteres, R. (1948)

Title: Les plantes indicatrices du niveau de fertilite du complex cultural edapho-climatique en Afrique tropicale.

Source: Conference Africaine des sols Gome (Congo Belge) 8-16 November, 1948, #15, 735-748.

Author: Porteres, R. (1952)

Title: Linear cultural sequences in primitive systems of agriculture in Africa and their significance

Source: Sols Africains v. 2 1, p. 14-29

Application: Slight mention but no measured observations on A. albida.

Author: Porteres, R. (1953)

Title: Amenagement de l'economie agricole et rurale au Senegal

Source: Gourvernment General d l'Afrique Occidentale Francais. Territoire du Senegal. Mimeo. p. 145 Fasc II

Application: Contains map of A. albida density in Senegal in 1952.

Author: Porteres, R. (1954)

Title: Scheme for the improvement of the agricultural economy of Senegal (Guilloteau, J. Ed.)

Source: African Soils III 184-235

Application: Gives livestock carrying capacity of land under Acacia albida but no measured observations.

Author: Robertson, J. K. (1954)

Title: Acacia spp. as shade trees for coffee

Source: E. African Agricultural Journal, Vol. 19, p. 272.

Application: *Acacia albida* is successfully used as a coffee shade tree in certain parts of Southern Highlands Province (Tanganika) having annual rainfall of 50 to 60 inches

Author: Sarlin, P. (1963)

Title: L'eau et le sol

Source: Bois et Forets des Tropiques 89:11-29.

I. C. Articles without reference to *A. albida* but with valuable analagous data or otherwise cited in the text.

Author: Beadle, N. C. W. (1964)

Title: Nitrogen economy in arid and semi-arid plant communities III the symbiotic nitrogen fixing organisms

Source: Proc. Linnean Society of New South Wales 89, 2, 273-286

Application: This paper does not specifically discuss *Acacia albida*, however it does give nodule characteristics for 21 species of *Acacia* found in Australia. Also discussed are reasons why nodules are not observed in the field on *Acacias* which do nodulate and fix nitrogen.

Author: Beale, I. F. (1973)

Title: Tree density effects on yields of herbage and tree components in southwest queensland Mulga (*Acacia aneura* F. Muell) scrub

Source: Tropical Grasslands 7(1), 135-142.

Application: The effects of tree density on yields of tree foliage and on yields of herbage foliage were studied.

Author: Birot, Y. and J. Galabert (1972)

Title: Bioclimatologie et dynamique de l'eau dans une plantation d'eucalyptus

Source: Centre Technique Forestier Tropical No. 1, Niger - Haute Volta, 51 pages.

Application: Water balance studies on eucalyptus may help evaluate water balance studies for *A. albida*.

Author: Bouchet, R. J. (1965)

Title: L'eau et la production vegetale

Source: Cah. Ing. Agron. 199, 5-17

Application: Correlation of Piche evaporimeter data to potential evapotranspiration.

Author: Bowen, G. D. and M. M. Kennedy (1959)

Title: Effect of high soil temperatures on Rhizobium spp.

Source: Qd. J. Agric. Sci. 16:177-195

Application: 87 strains of Rhizobium were found to have maximum growth from 31°C to 42°C. High soil temperatures were shown to have killed enough Rhizobium to prevent nodulation in some annual species.

Author: Charreau, C. (1974)

Title: Soils of tropical dry and dry wet climatic areas of west Africa and their use and management

Source: Lecture Series Cornell University, AID supported mimeo, p. 204

Application: Discusses hydrologic balance for large forest watersheds before and after clearing.

Author: Charreau, C. and R. Nicou (1971)

Title: L'amelioration du profil cultural dans les sols sableux et sablo-argileux de la zone tropicale seche Ouest Africaine et ses incidences agronomiques

Source: L'Agron. Trop. XXVI 5, 565-631

Author: Charney, J. G. (1975)

Title: Dynamics of deserts and drought in the Sahel

Source: Quart. J. R. Met. Soc. 101, 193-202

Application: NASA's weather model indicates a change in albedo from 0.35 (desert) to 0.14 (vegetation) would increase rainfall in Sahel.

Author: Conner, D. J., Tunstall, B. R., and R. van den Driessche (1971)

Title: An analysis of photosynthetic response in a Brigalow Forest

Source: Photosynthetica 5(3):218-255

Application: In an Acacia harpophylla Australian forest with 560 mm annual rainfall, incident radiation, ambient temperature, and plant water potential were measured 25 times over a period of 2-1/2 years, and an attempt was made to predict photosynthesis over the entire forest canopy.

Author: Cunningham, G. M. and P. J. Walker (1973)

Title: Growth and survival of Mulga (Acacia aneura F. Muell ex. Benth) in Western New South Wales

Source: Tropical Grasslands 7, 1, 69-77.

Application: Growth and survival of an Acacia (indigenous to 150 to 400 mm rainfall area) under grazing and rainfall stress were measured.

Author: Date, R. A. (1973)

Title: Nitrogen, a major limitation in the productivity of natural communities, crops and pastures in the Pacific area.

Source: Soil. Biol. Biochem. 5, 5-18

Application: Gives rates of nitrogen fixation by annual crops and discussion of nitrogen cycle.

Author: Dollahite, J. W. (1964)

Title: Management of the disease produced in cattle on an unbalanced diet of mesquite bean.

Source: Southwestern Vet. 17:293-296

Application: Feeding excessive quantities of tree legume pods can be deleterious to cattle.

Author: Dommergues, Y. (1963)

Title: Les cycles Biogeochimiques des elements mineraux dans les formations tropicales

Source: Bois et Forets des Tropiques 87, 9-25

Application: Reviews mineral nutrient cycling and primary productivity in tropical forest ecosystems.

Author: Gartner, R. J. W. and I. S. Hurwood (1976)

Title: The tannin and oxalic acid content of Acacia aneura (Mulga) and their possible effects on sulphur and calcium availability

Source: Australian Veterinary Journal 52, 194-195

Application: Possible relationship of feeding value of Acacia albida leaves.

Author: Gillier, P. (1960)

Title: La reconstitution et le maintien de la fertilite des sols du Senegal et le probleme des jacheres

Source: Oleagineux 15^e^, 8-9, 637-704

Application: This paper identifies the peanut yield changes which occur in continuous cultivation without Acacia albida.

Author: Hanover, J. W., E. Young, W. A. Lemmien and M. van Slooten (1976)

Title: Accelerated optimal growth: A new concept in tree production

Source: Res. Rpt. 317 Mich. State Univ. Agric. Exp. Sta. 16 pages.

Application: Reports use of continuous lighting techniques to reduce the time to flowering in trees by several fold.

Author: Johnson, C. R. and S. Michelini (1974)

Title: Effect of mycorrhizae on container grown Acacia

Source: Florida State Hort. Soc. Proc. 87, 520-522

Application: Mycorrhizae has a small positive effect on Acacia seedlings in nursery.

Author: Linderman, R. G. and C. A. Call (1977)

Title: Enhanced rooting of woody plant cuttings by mycorrhizal fungi.

Source: J. Amer. Soc. Hort. Sci. 102(5): 629-632

Application: Mycorrhizae stimulates rooting of hard wood cuttings.

Author: Moore, A. W., Russell, J. S., and J. E. Coaldrake (1967)

Title: Dry matter and nutrient content of a subtropical semiarid forest of Acacia harpophylla F. Muell (Brigalow)

Source: Aust. J. Bot. 15, 11-24

Application: The dry matter production and nutrient flow in this Australian Acacia helps to understand leaf fall in relation to fertility in Acacia albida.

Author: Obeid, M. and A. S. E. Din (1971)

Title: Effect of simulated rainfall distribution a' different isohyets on the regeneration of Acacia senegal (L.) Willd. on clay and sandy soils.

Source: J. Appl. Ecol. 8, 203-209

Application: Studies effect of rainfall frequency and distribution on germination of Acacia senegal. Also notes that germination is higher on sandy soils than clay soils at the same rainfall amount.

Author: Orchard, E. R., and G. D. Darb (1956)

Title: Fertility changes under continued wattle culture with special reference to nitrogen fixation and base status of the soil.

Source: Sixth Int. Cong. of Soil Science Paris IV 45, 305-310

Aplication: Reports nitrogen fixation rates of 200 $\pm$ 45 kg/ha/yr under Acacia mollissima and correlates increasing soil nitrogen content with decreasing nodule frequency.

Author: Paul, E. A., R. J. K. Myers, and W. A. Rice (1971)

Title: Nitrogen fixation in grasslands

Source: In "Biological nitrogen fixation in natural and agricultural habitats, Plant and Soil Special Volume, 495-507

Application: Gives values for non-symbiotic nitrogen fixation.

Author: Poupon, H. (1976)

Title: La biomasse et l'evolution de sa repartition au cours de la croissance d'Acacia senegal dans une savane saheliene (Senegal)

Source: Bois et Forets des Tropiques 166, 23-38

Application: The biomass accumulation is studied as a function of age of Acacia senegal in northern Senegal.

Author: Pressland, A. J. (1973)

Title: Rainfall partitioning by an arid woodland (Acacia aneura F. Muell) in southwestern Queensland.

Source: Aust. J. Bot. 21, 235-245

Application: This paper is helpful in that it allows comparison of rainfall partitioning reported by Dancette and Poulain (1969) on A. albida.

Author: Pressland, A. J. (1976)

Title: Effect of stand density on water use by Mulga (Acacia aneura F. Muell) woodlands in southwestern Queensland

Source: Aust. J. Bot. 24, 177-191

Application: This study would be of use in designing research to study the effect of stand density of A. albida on transpiration, water use, and the water table.

Author: Pressland, A. J. (1976)

Title: Soil moisture redistribution as affected by throughfall and stemflow in an arid zone shrub community.

Source: Aust. J. Bot. 24, 641-649

Application: Soil water infiltration rates in a semi-arid climate were shown to be 2.7 times greater under an Acacia aneura tree than in the open cover.

Author: Salinas, H. E., and S. C. Sanchez (1971)

Title: Estudio del tamarugo como productor de alimento del ganado lanar en la pampa del tamarugal

Source: Instituto Forestal Departamento Forestal Seccion Silvicultura, Informe tecnico No. 38

Application: Pod and leaf production for the leguminous tree Prosopis tamarugo was 12,000 kg/ha at 26 years of age in stands receiving no rainfall which were 6 m from the water table of 1 g/liter salinity.

Author: Simpson, B. B. (1977)

Title: Prosopis flowers as a resource

Source: In "Mesquite: Its biology in two desert ecosystems;" Beryl Simpson, Ed., Dowden Hutchinson, Stroudsburg, Pa. p. 96.

Application: Reports flower incompatability and outcrossing in a leguminous tree.

Author: Skolmen, R. G. and M. O. Mapes (1976)

Title: Acacia koa Gray plantlets from somatic callus tissue

Source: J. Heredity 67, 114-115

Application: If it is desirable to propagate A. albida vegetatively through tissue culture the method reported here on another Acacia would appear promising.

Author: Slatyer, R. O. (1961)

Title: Methodology of a water balance study conducted on a desert woodland (Acacia aneura F. Muell) community in central Australia

Source: Arid Zone Res. 16, 15-26

Application: This article may prove useful in designing hydrologic balance studies for A. albida.

Author: Slatyer, R. O. (1965)

Title: Measurements of precipitation interception by an arid zone plant community (Acacia aneura F. Muell)

Source: Arid Zone Res. 25, 181-192.

Application: Data presented here can be compared with Dancette and Poulain's (1969) data on rain interception by A. albida.

Author: Tadaki, Y. (1968)

Title: The primary productivity and the stand density control in Acacia mollissima stand

Source: Bulletin 216 (of the Imperial Forestry Experiment Station, Megano, Tokyo) 99-125

Application: Reports net production of 33.5 metric tons/ha/yr for Acacia molissima growing in Japan, and therefore there is no inherent reason why tree legume production must be low.

Author: van den Driessche, R., Connor, D. J. and B. R. Tunstall (1971)

Title: Photosynthetic response of Brigalow to irradiance, temperature and water potential

Source: Photosynthetica 5(3):210-217

Application: A laboratory study was conducted on Acacia harpophylla, an Acacia from semi-arid regions of Australia to determine the effects of irradiance, temperature and water potential on photosynthesis.

Author: Walters, G. A. (1974)

Title: Styroblocks: new techniques for raising and planting seedlings in Hawaii

Source: Tree Planters Notes 25(4) 16-18

Application: Hawaiian Acacia species were successfully started in modular, molded polystyrene blocks from which they were easily and successfully extracted and transplanted to the field.

Author: Weller, M. C. (1974)

Title: Mulga as a drought feed for cattle

Source: Queensland Agric. J. 100:530-538

Application: Acacia aneura (Mulga) grows on 150 million hectares in Australia in regions receiving from 250-500 mm annual rainfall where it supplies fodder in times of drought.

Author: Wilkins, J. (1967)

Title: The effects of high temperature on certain root nodule bacteria

Source: Aust. J. Agric. Res. 18, 299-304

Application: Research on the viability of rhizobia from Acacia aneura to high temperature stress is reported.

I. D. Acacia albida projects

US AID Project number 683-170-I-A in Niger.

Acacia albida expansion project - Republic of Chad. U. S. government memo dated 25 July 1975.

United Nations Environmental Programme Project Document.

Title: Integrated ecological pilot project in arid grazing lands to promote rehabilitation and management.

Project Number: FP/1101-75-05 (896) (Phase II)

FAO Dune fixation project, Kebemer, Senegal. (Peter Felker, personal observation November 1977)

II. SUMMARY

A. Effect of *Acacia albida* on crop yields

There are four original papers in which the effect of *A. albida* on crop yield was studied (Sarlin, 1963, Charreau and Vidal, 1965; IRHO, 1966; and Dancette and Poulain, 1969). In all four cases there was a valid average yield increase reported, but in cases where a large number of trees were included there were a few *A. albida* trees under which crop yields decreased. Sarlin (1963) reported an average millet increase of 430 kg/ha, Charreau and Vidal (1965) reported a 1,008 kg/ha increase for millet, Dancette and Poulain (1969) reported yield increases of 480 kg/ha for sorghum and 300 kg/ha for peanuts, and IRHO (1966) reported an average 330 kg/ha yield increase for peanuts. For the single case where Charreau and Vidal (1965) measured peanut yields, they found a 974 kg/ha decrease. (Charreau has informed this reviewer that very seldom is such the case in Senegal.) The peanut yields were depressed by the *Acacia albida* trees to 1300 kg/ha in the IRHO (1966) study and to 1800 kg/ha in the Charreau and Vidal (1965) study, and these "depressed yields" are much higher than typical Senegalese peanut yields. For instance, Gillier (1960) lists the following yields for different soil categories: (a) 320 kg/ha for a completely infertile soil; (b) 620 kg/ha for the soil listed above after three years of fallow and (c) 1535 kg/ha for a soil thoroughly enriched in inorganic and organic nutrients. An example of an average peanut yield would be the 810 kg/ha yield observed by Dancette and Poulain (1969) outside the foliage cover of *A. albida* trees.

The peanut yield depressions reported by Charreau and Vidal (1965) and IRHO (1966) are most readily explained if one considers that excessive soil fertility can cause excessive vegetative growth at the expense of reproductive growth (grain or pods). In the Charreau and Vidal (1965) study, the peanut vegetative growth under _A. albida_ was higher than away from _A. albida_ even though the grain yields were not. Since the fields in the Charreau and Vidal study had not been in cultivation for many years, it seems probable that the fertility was excessively high under the peanuts. As the past farming history of the IRHO (1966) study was not discussed, it is not possible to ascertain whether a high fertility level there might also have caused a yield decrease.

Yield decreases induced by high fertility are very unlikely to occur on most Senegalese soils because they are farmed continuously without fallow. For example, well-fertilized peanut fields with yields of 1200 kg/ha when placed under continuous peanut culture, without fertilization, have been reported by Gillier (1960) to yield 600 kg/ha three years later. It seems reasonable that land which had been under continuous cultivation for many years would have a low fertility level and its yields would be stimulated by _A. albida_. Dancette and Poulain's (1969) study which was conducted in a natural farming setting that had been under continuous cultivation for many years supports this point of view. This reviewer would choose the Dancette and Poulain study as the work which was both most representative of typical farming situations and most thorough.

As an average figure, _A. albida_ will increase peanut yields when grown under continuous cultivation by approximately 300 kg/ha but, if peanut yields approach 1200 kg/ha, A. albida may have a slight yield-depressing effect. Yield depressing effects of A. albida on cereals could also occur by increasing the soil fertility, but this is less likely to occur because millet, unlike peanuts, has no capacity to fix nitrogen. Again, Dancette and Poulain's data for millet yield increases (480 kg/ha) are probably the most accurate and representative of a typical farming situation. Acacia albida can be recommended without reservation in regions where peanut and millet yields are now 500 ± 200 and where 900 ± 200 kg/ha yields are desirable.

B. Effect of Acacia albida on soil properties

While only four articles have described A. albida's effect on yield, several other articles have reported A. albida's effect on the soil chemical, physical, and microbiological characteristics. These additional articles are by Dugain (1960), Wickens (1966), Radwanski and Wickens (1969) and Jung (1966, 1967). For total organic carbon and total nitrogen, the following workers reported the following increases: Dugain (1960) N-231%, C-269%; Dancette and Poulain (1969) N-33%, C-40%; Radwanski and Wickens (1969) N-600%, C-200%; Charreau and Vidal (1965) N-194%, C-192%, and Jung (1966) N-110%, C-91%. Many of the above workers reported increased soil water holding capacity and cation exchange capacity in soils under A. albida, which would be expected as a direct consequence of a higher soil organic matter content under A. albida. A soil with a higher cation exchange capacity is important because cations like Ca^{++} and Mg^{++} (which arise from decaying leaf litter) are held in greater concentration by the soil where they can be absorbed by the plant. A soil with higher water holding capacity will have more water after a rain available to the plant.

In addition to the study of the chemical and physical soil properties, Jung (1966 and 1967) compared soil microbiological changes under and away from *A. albida* trees. Under the *A. albida* he found clear increases in invertase, dehydrogenase, asparaginase, and respiratory CO_2. Bacteria counts under and away from the tree were the same but under the *A. albida* tree there was a marked increase in the fungi and actinomycete population. In general, these latter organisms can degrade lignins and plant cell walls more easily than bacteria so that soil under *A. albida* could more quickly degrade leaf litter to release plant nutrients. The combination of the higher enzyme activities, and fungi and actinomycete populations were taken by Jung (1966, 1967) to indicate a general higher level of microbial activity. In the past, soils with active microflora have been used to indicate areas of high fertility.

C. Causes for *Acacia albida* induced soil fertility

The causes for the increased fertility under the *A. albida* have been a subject of controversy. From the *A. albida* data available, this reviewer believes there is little alternative but to conclude the higher fertility under *A. albida* is being driven by nitrogen fixation by the *Acacia albida*. The reasons for this point of view are as follows:

(1) Both Habish and Khairi (1968) and Jung (1967) have observed

nodules on A. albida seedlings and have shown them to increase the nitrogen content of greenhouse grown pots when supplied a complete nutrient solution minus nitrogen.

(2) Higher soil nitrogen and organic matter contents are not found under the non-leguminous bush Guiera senegalensis (Jung, 1967) or under the non-leguminous tree Balanites aegyptica (Wickens and Radwanski, 1969) indicating that the trees are not scavenging nitrogen from areas deep in the soil profile.

(3) The most compelling reason to believe A. albida is fixing nitrogen results from an analysis of the nitrogen cycle. Assuming the yield of peanuts growing under A. albida to be 800 kg/ha and assuming they contain about 3% nitrogen (18.75% protein), 24 kg/ha/yr of nitrogen will be removed from the fields to be sold in the city. An evaluation of the sources of fixed nitrogen coming into the continuous peanut culture under A. albida reveals: (a) nitrogen cannot arise from weathering of any bedrock or parent material as nitrogen unlike calcium or magnesium does not exist in these forms. If nitrogen were obtained by A. albida deep in the soil profile, that nitrogen cannot be the result of parent material degradation and must have been fixed at some point; (b) while peanuts can fix nitrogen, no nitrogen input is assumed to come from the peanuts since peanuts cannot sustain a high soil nitrogen and organic matter content or a high yield without A. albida; (c) no nitrogen is assumed to come from fertilizers; (d) fixed nitrogen coming from the atmosphere being fixed in electrical storms is about 2 kg N/ha/yr (Paul et al, 1971); (e) estimates of nitrogen fixed by free living nitrogen fixers are assumed to be

less than 1 kg/ha/yr (Paul et al, 1971). Therefore, one is left with a deficit of 24 - 2 kg/ha from electrical storms - 1 kg/ha from free living nitrogen fixers = 21 kg N/ha/yr coming from an as yet unidentified source. This deficit will be even greater if all the peanut roots and leaves are not returned to the soil. Cattle and other animals cannot be considered as a source of nitrogen to the cycle because they do not fix nitrogen but merely redistribute and transform fixed nitrogen from one kind of protein to another (cattle can cause a loss of nitrogen to the cycle if they eat plant products and if the cattle are sold in the city.) Since the soil nitrogen content does not increase under the non-leguminous trees Balanites aegyptica and Guiera senegalensis, while it does under A. albida, the most logical conclusion is that A. albida is the source of the 21 kg N/ha/yr.

(4) The failure to observe nodules on A. albida seedlings in the field can be explained by an adverse effect of soil moisture stress on nodulation. Habish's (1970) study of moisture stress on Acacia nodulation reports that at 7% soil moisture the number of nodules formed and total pot nitrogen was considerably less than at 15% soil moisture. At the end of the dry season, which is the end of A. albida's normal growth period, Dancette and Poulain (1969) reported soil moisture contents lower than 1.4% to a depth of 1.4 meters. Since in these soils 1.4% soil moisture content is the permanent wilting point (-15 bars or pF 4.2) it is apparent that many young seedlings would have difficulty nodulating.

(5) There is a different explanation to account for the failure to observe nodules on mature A. albida trees. Orchard and Darb (1956) when

measuring nitrogen fixation on Acacia mollissima in South Africa (they found 200 ± 45 kg N/ha/yr) reported that when Acacias were first established on the very poor infertile, but moist soils, nodules were abundant. Upon harvesting the Acacia mollissima every 8 years, they noticed that nodules were very abundant in the first 8-year cycle, less abundant in the second 8-year cycle, and even less abundant in the third 8-year cycle when the soil nitrogen and organic matter content was several fold higher. This decreasing nodule abundance with increased soil fertility could have been predicted from behavior in annual crops where either nitrate or ammonia supplied to the plant causes an immediate cessation of nitrogen fixation.

The absence of nodules on mature A. albida trees on soils with high nitrogen and organic matter content is perhaps related to the high accumulated soil nitrogen which causes nodules to stop functioning and being produced. Another possible reason why nodules are seldom observed on mature A. albida trees is that they may be formed at times of the year and at depths in the soil which have not yet been examined.

D. Concluding remarks for A. albida soil fertility and crop yield

A. albida trees in their present unmanaged natural state can be expected to increase peanut and millet yields in areas where the yields are now 500 ± 200 kg/ha to about 900 ± 200 kg/ha when the trees reach maturity. A concommitant 50-100% increase in soil organic matter and soil nitrogen content, a marked increase in soil microbiological activity, and an increase in soil water holding capacity will also be found beneath A. albida trees. The most plausible reason for the increase in soil fertility and yields is nitrogen fixation by Acacia albida.

E. Acacia albida pod yields

The maximum pod yields on Acacia albida appear to develop very slowly. Nongonierma (1976) reports that A. albida trees in the University of Dakar gardens first bore pods at eight years of age. Lemaitre (1954) reports "pod production begins when the A. albida trunk is 20 cm (7.8") in diameter, is maximum when the crown is large, and averaged over a period of years there are differences in pod production by various trees." The age of Lemaitre's 20 cm diameter tree can be calculated as Mariaux (1966) has determined A. albida diameter growth rates range from 0.61 to 2.9 cm/year. By using the average figure of 1.75 cm/year, a 20 cm diameter tree would begin pod production at about eleven years of age. For twenty A. albida trees, thirty years of age, Lemaitre reports the average pod productivity to be 6 to 8 kg/tree, but he states an exceptional tree might produce 40 kg. Assuming an average of 100 trees/ha, Lemaitre suggested a hectare should yield from 600 to 800 kg pods/ha.

These tree pod yield values are much lower than the values of 125 kg/tree and 135 kg/tree reported by Jung (1967), and Wickens (1966) respectively. This yield discrepancy is perhaps attributable to the younger age (30 years) of Lemaitre's trees. Using Jung's (1967) lowest pod yield density of 3000 kg/ha and assuming it came from the youngest (30 years old) and smallest tree (surface area of 98 m^2) a tree pod yield of 29 kg can be calculated. Thus Jung's (1966) data from his estimated thirty year old tree (29 kg/tree) is approximately fourfold higher than the 6 to 8 kg/tree average for 20 _A. albida_ trees thirty years of age reported by Lemaitre.

Only Jung's (1967) procedure is described in sufficient detail to permit evaluation of his method, but unfortunately this method appears to have a serious limitation to predict total tree pod yield since only two 2 m^2 sampling nets were used per tree, for an average projected canopy cover of 231 m^2.

The tree pod yield data is further complicated by calculations and assumptions required to arrive at pod production/hectare. Jung (1967) assumed 43 trees/ha to arrive at a maximum pod yield of 5400 kg/ha. As discussed in the review of Jung's (1967) paper, this tree density is four times higher than naturally occurs in the area (Jung, 1969), but _A. albida_ densities of 43 trees/ha have been reported in the Sudan (Wickens and Radwanski, 1969). The low estimate of _A. albida_ pod yield can be determined using a moderate _A. albida_ density (15 trees/ha) with the low pod yields of Lemaitre (7 kg/30-year old tree) to obtain a yield of 105 kg/ha. Thus _A. albida_ pod yields, from the data presented, can be calculated to range from 105 kg/ha to 5400 kg/ha.

In the absence of any description of Wickens' (1966) procedure to measure pod yield, and in view of the sharply contrasting tree pod yield data of Lemaitre (1954) and Jung (1967), average pod yields per tree and average pod yields per hectare must be considered unknown.

F. A. albida pod feeding value

Proximate analyses of the pods and seeds of A. albida have been reported by Gwynne (1969) to be: 10-13% protein for entire pods, 26-28% protein for seeds only, and 43-59% nitrogen free extract (carbohydrate) and by Wickens (1969) to be in the range: 10.6-15.5% protein for the entire pods, 27% protein for seeds only, and 44 to 58% nitrogen free extract (carbohydrates).

As discussed specifically for that paper Boudet and Riviere (1968) have performed chemical analyses on A. albida pods but it is not clear how these chemical values relate to proximate analyses defined by English and American workers. From the chemical analyses Boudet and Riviere (1968) estimate that A. albida pods have 77% of the available energy of an equal weight of barley. By applying a protein digestability coefficient derived from alfalfa hay to the A. albida pod crude protein percentages, Boudet and Riviere (1968) arrive at a forage unit stated to be applicable to cattle. The use of an alfalfa-derived protein digestability coefficient to assess A. albida pod protein is extremely questionable for the following reasons: (1) Wickens (1966) has demonstrated that if A. albida seeds are fed to a steer 66% of the seeds pass intact and undigested through the animal's rumen; (2) the presence of fiber, sucrose, and unknown plant metabolites could adversely affect the protein digestability. This reviewer believes Boudet and Riviere's (1968) International forage unit concept is at present not applicable to A. albida pods.

A useful breeding tool for the selection of high protein A. albida pods will be the fact that A. albida seed to pod weight ratio varied from

1:2.6 to 1:7.7 (Wickens, 1966). Since the seeds contain 26% protein while the pods alone only contain 13% protein (Wickens, 1969), selection for high protein can be done initially by selecting for pods with high seed contents.

G. Cultural aspects of Acacia albida

1. Seed germination techniques

Three basic techniques used to break seed dormancy in *A. albida* are: (1) soaking in acid; (2) mechanical scarification, and (3) boiling water treatments. Lemaitre (1954) obtained the optimum acid-induced germination rate of 77% by soaking in sulfuric acid for 5 minutes. Wickens (1966) compared seven boiling water treatments ranging from 0 to 3 minutes with mechanical seed scarification. Wickens found that boiling the seeds did not enhance germination over the control and it took 85 days to reach 90 percent germination for boiled and control seeds. In contrast the nicked seeds reached 87 to 97 percent germination in 10 days. Thus nicked seeds have better germination than sulfuric acid-treated seeds, which are much better than boiled seeds. Mechanical shaking devices have been used in the past to scarify hard-coated seeds and might profitably be employed with *A. albida*.

2. Growth rate

Diameter growth rates are reported by Mariaux to range from 0.61 to 2.9 cm annually, by Wickens to be 1.59 ± 0.59 cm annually, and by Anon (1966) to range from 0.31 to 2.9 cm annually. With the use of metal dendrometer bands, *A. albida* diameter growth was shown to be fast from

November to July and very slow from August until November (Anon, 1966). Part of the reason for the large range can be attributed to site variability (Mariaux, 1966), but this reviewer believes a major part of this variability can be attributed to genetic differences. It is important to realize that total stem growth is proportional to the square of the diameter growth rate, and therefore a five fold range in diameter growth rate represents a twenty-five fold range in stem volume growth. With the use of good nursery techniques, and with vegetative cuttings from fast-growing trees a 2 cm/year diameter growth rate would be a reasonable goal.

Less work has been reported on A. albida height growth with only Anon (1966) reporting an average annual height growth for 8 trees to be 92 cm with a 50 to 160 cm range. Flowering of A. albida has been reported at seven years of age and pod formation at eight years of age (Nongonierma, 1976).

3. Transplanting techniques

A method reported to yield 90% seedling survival at the end of the dry season and 75% survival 15 months later (Giffard, 1964) involved: harvesting fresh seeds from pods in April; treating the seeds with boiling water; sowing the seeds in polyethylene bags 30 cm deep; and in early August transplanting to the field. Lemaitre (1954) also found that 7 August was the best transplanting date for A. albida seedlings.

4. Tree spacing and configuration

At present this reviewer feels the major problem with the random positioning of A. albida trees in farmers' fields is not a hindrance to mechanical cultivation but rather unequal distribution of soil fertility. Since trees in farmers' fields result almost exclusively from natural regeneration by seed, young *A. albida* trees occur in the proximity of older *A. albida* trees. Fields, or sections of fields without any *A. albida* trees have no way of establishing new trees, while sections of fields with many *A. albida* trees may have unnecessary, greatly overlapping canopies. The result is that some fields have very good fertility with more trees than needed and other fields without *A. albida* have low fertility. Some of the farmers interviewed near Thies, Senegal, confirmed this, stating for one section of their fields that had no *A. albida* trees they just needed ten more.

To obtain the maximum windbreak effect Dancette (1968) has suggested planting *A. albida* in parallel rows and as borders around small fields.

Research required to manage and develop A. albida to its full potential

The *A. albida* literature contains many exaggerated claims for the benefits of *A. albida* which are experimentally unsubstantiated. There is experimental evidence strong enough to state that *A. albida* will, on the average, increase yields of millet and peanut crops growing under continuous culture by 300-400 kg/ha. Since the farmers are quite appreciative of *A. albida* (Pageard, 1971; Pelissier, 1967) and since *A. albida* provides other uses such as pods for livestock food, firewood, and building materials, the experimentally derived and anthropologically derived evidence would strongly favor an *A. albida* development project in the Sahel.

In the past at least three *Acacia albida* development projects have proceeded with large scale plantings using logical but experimentally untested methods and all three failed. These failures vividly point out the necessity for research to test techniques and cultural practices before they are adapted to large scale programs. Fortunately methods are now available which have been successfully used by the FAO nursery in Kebemer, Senegal and other places to plant large areas with *A. albida*. This reviewer believes the planting of large areas of *A. albida* with currently available technology is very important and should continue. At the same time, research should begin at once to anticipate and solve *A. albida* problems before they arise in large scale in the field, and to develop better cultural practices and *A. albida* cultivars to be used throughout Senegal and West Africa. Specifically, research is urgently needed to work on the following problems:

A. Hydrological balance and water use studies

Dense stands of trees with long tap roots can use large amounts of water. When large areas of a eucalyptus forest were cut in Casamance, Senegal, the water table in some areas rose 8 m (Charreau, 1974). In a study in the Sudan, the water table under *A. albida* was 2 m lower at the end of the dry season than in a nearby well, although the depth to the water table was the same at the beginning of the dry season (Wickens, 1966). It therefore becomes imperative to know: (1) how much water will a stand of *A. albida* use; (2) what will be the effect, if any, of *A. albida* water use on water availability by crop plants; (3) what will be the effect of *A. albida* on depth to the water table, and (4) how will *A. albida* age and stand density affect water use.

B. Genetics and A. albida cultivar development

Published information pertaining to *A. albida* genetics and sexual or asexual reproduction is non-existent. Work in other leguminous trees indicates that the flowers are self-incompatable and outcrossed by insects (Simpson, 1977). If such is the case with *A. albida*, seeds taken from an *A. albida* tree will not be genetically identical to the parent tree and offspring produced from seed will be extremely variable. Such extreme seedling height variability has been observed by this reviewer in Bambey, Senegal and is recorded in various reports (Mariaux, 1966; Anon, 1971).

It is desirable to be able to obtain uniform trees either with a desirable economic characteristic (growth rate, pod production, etc.) or for use in research to reduce variability in the genetic component while studying another parameter (e.g., pot size, nitrogen fixation, fertilizer treatment, etc.). Three methods which could be used to prepare genetically similar material are:

1. Propagation by cuttings.

By supplying bottom heat, various hormone formulations and appropriate mycorrhizae (Linderman and Call, 1977), many woody species can be induced to produce roots. This would be the simplest way of producing identical genetic material.

2. Propagation by apical meristem culture.

This technique has been successfully used to clone *A. koa* (Skolmen and Mapes, 1976), and might also prove useful for *A. albida*. Because of the requirements for tissue culture, this technique requires more elaborate facilities and better trained personnel.

3. Production of inbred lines by classical breeding methods.

If *A. albida* trees can be successfully crossed or selfed, desirable genetic material can ultimately be obtained. As Nongonierma (1976) reports pod formation in *A. albida* requires 8 years, this method will be rather time consuming. Fortunately, accelerated growth methods have been reported which reduce the time to flowering in many trees by severalfold (Hanover, *et al.*, 1976). If accelerated growth techniques could be developed for *A. albida*, they would be of immense value as a research tool by allowing early selection of pod characteristics.

The benefits arising from development of vegetative propagation techniques would be immediate since over fourfold variability in growth rate has been observed in the field. By vegetatively propagating the tree with the fastest growth rate, the average tree population growth rate can probably be doubled or tripled. Similarly, if high pod yielding trees can be identified, they can be immediately vegetatively propagated. An understanding of breeding mechanisms and development of sexual breeding techniques for *A. albida* would allow combination of high pod yield and fast vegetative growth or other useful characteristics such as disease resistance and nitrogen fixing attributes. Five years of active research in this field should produce *A. albida* trees with several fold faster growth rate.

C. Nursery and cultural techniques

A. albida seedlings have now been successfully transplanted in areas larger than 100 hectares by both the FAO-nursery in Kebemer, Senegal and by the CARE-supported nurseries in Chad. In spite of this success, research should continue to determine optimal seed scarification techniques, optimal pot sizes, optimal ages for transplanting, and the use of mycorrhizae and rhizobia. Evaluation of these nursery practices will be dependent on the availability of uniform genetic material. As previously noted, M. Hamel of the Centre Nationale Recherche Forestier (CNRF) in Dakar, Senegal, feels the genetic variability in *A. albida* trees produced from seed is so great as to obscure results from the above mentioned optimization experiments.

It would appear that nursery seedlings should be produced for two different economic strategies. The first strategy would produce seedlings to plant on the largest possible area with the lowest possible cost at the expense of growth rate and survival. A second economic strategy would produce more costly seedlings designed to provide maximum pod production and increased soil fertility in much shorter time periods. Perhaps faster growing seedlings could be produced in considerably longer pots to stimulate longer root development and enable seedlings to reach moist soils more quickly. These fast growing seedlings might be sold to farmers who would be willing to pay a premium for a few fast growing, quick-bearing trees to plant in one portion of a field devoid of *A. albida*.

One of the most urgent needs is the development of inexpensive structures constructed of locally available materials which will keep goats and other animals from eating young A. albida seedlings. The death of many A. albida seedlings by browsing animals is a very serious problem in Sahelian countries.

Research is also needed on tree planting configuration and spacing in order to optimize: fertility distribution; pod yield; minimal disturbance to mechanized agriculture; use as a windbreak; and use in land and water erosion control. From interviews with Senegalese peanut farmers, there appears a need to investigate the possible effects of pruning A. albida trees to increase peanut yields.

D. Plant pathology

The work of Brunck (1972) demonstrates that insect problems on Acacia albida can be quite severe. This reviewer has observed similar disease problems on a visit to the FAO nursery in Kebemer, Senegal, and therefore studies of prevalent damaging insects on Acacia albida, identification of sources of genetic resistance to those insects and identification of non-phytotoxic chemical control methods are warranted.

E. Herbicides

Acacia albida trees planted in sites where cultivation is not taking place will not have the advantage of the routine weeding which farmers do for their fields. The use of herbicides to weed A. albida trees may be necessary but would require evaluation of various herbicides for effectiveness in killing unwanted vegetation and for A. albida phytotoxicity.

F. Economic returns from A. albida

Lemaitre (1954) states that stands of A. albida in farming areas are capable of doubling the human carrying capacity of the land to about 30-40 persons/km^2. The human and livestock population data used to support Lemaitre's (1954) hypothesis is suggestive but not conclusive. Pelissier (1967, 1977) provides qualitative support for Lemaitre's contentions. It is important to know if the increased human and livestock carrying land capacity with A. albida is real, and if it is real, how long would be required for A. albida trees to have their impact. Large scale plantings of A. albida would provide a unique opportunity for agricultural economists to quantitate A. albida's effect on human and livestock land carrying capacities.

G. Nitrogen fixation

There is a clear influx of nitrogen into agricultural systems with A. albida trees. While A. albida seedlings have been shown to nodulate and increase total nitrogen in pot culture, nitrogen fixation has never been demonstrated in the field. Perhaps failure to observe A. albida nitrogen fixation in the field is the result of looking at the wrong time of the year, or at the wrong depth in the soil profile when or where soil moisture was limiting nitrogen fixation. For agronomic purposes it would not be absolutely necessary to know if, how, or when Acacia albida was fixing nitrogen, but it could provide insights useful for optimum management of Acacia albida. Of course such a study would be tremendously interesting and important in an ecological sense, as nitrogen fixation in the field has never been demonstrated for any of the leguminous trees which occur on 9 million square miles in the world (Griffith, 1961).

A useful nitrogen fixation experiment might be the year-round sampling of ethylene production from acetylene gas being incubated in holes similar to neutron access tube holes at different depths in the soil profile.

H. Effect of *Acacia albida* on albedo changes and weather modification

This reviewer is generally very skeptical of attempts to correlate tree cover with rainfall, but some very impressive data have been generated which will require this question to be reevaluated. Professor Jules Charney, an MIT meteorologist, has developed a theory that decreasing the albedo (or reflectance) in desert areas (increasing vegetative cover) will increase rainfall over areas where the vegetative cover was increased. When satellite-determined albedo values for bare desert and desert vegetation cover were substituted into NASA's general circulation model for weather prediction, rainfall in the Sahel was predicted to be higher in vegetated regions than bare desert regions (Charney, 1976). While Charney's (1976) data may not be conclusive, the weight of the results obtained from NASA's general circulation model make further study of vegetation-rainfall interactions in the Sahel a necessity.

I. Research on *Acacia albida* physiology

Very few basic plant physiological experiments have been conducted on any leguminous trees. In view of the peculiar foliage patterns in *Acacia* *albida*, it would be worthwhile to conduct greenhouse and growth chamber experiments to determine if foliage initiation and termination are under moisture regulation, photoperiod regulation or some other control. Experiments on the effect of moisture stress on growth, nitrogen fixation and other parameters would not be of direct economic importance, but would make research on applied aspects of *A. albida* easier to deal with.

J. *Acacia albida* research interests and capabilities among institutions

The *Acacia albida* research needs are extensive but there are several ways in which the research financial burden might be lessened. The first of these methods might be to support research through the well-equipped and trained research groups already present in Senegal.

Pod feeding trials could be carried out at the Laboratoire d'Elevage in Dakar (or the ILCA in Addis Abbaba, Ethiopia), vegetative propagation and genetic improvement research could be carried on at the CNRF - Dakar, hydrological balance studies could be carried out at the CNRA in Bambey, and nitrogen fixation studies could be carried out at ORSTOM-Bel-air-Dakar and CNRA, Bambey. If this approach to answering research questions were undertaken it would be exceedingly important to encourage more day to day research interaction among these groups to insure that the results of the research from each discipline would be compatable with each other, for example nitrogen fixation studies should be conducted under moisture conditions likely to occur in the dry season in farmers' fields.

The potential also exists for research cooperation support between the IDRC, which is sponsoring development projects with _Acacia senegal_ in northern Senegal. Research problems, equipment and facilities could be expected to be similar in these two _Acacia_ species so that cooperative research would avoid needless duplication of research facilities. The newly formed International Centre for Research in Agroforestry might also be interested in cooperative ventures.

Appendix A

Interviews with farmers in peanut basin --Thies, Senegal concerning Acacia albida

On 16 November, 1977, 10 farmers from three neighboring villages near Thies, Senegal were interviewed about Acacia albida (in this section A. albida will be referred to as Cadde, the Oulof name), with the capable assistance of Mr. Usman, a native Senegalese fluent in Oulof, who holds a B.A. from Dartmouth College in Massachusetts.

M. Huet of SODEVA introduced us to a local extension man living in one of the villages who accompanied us to the villages and who introduced us to the farmers. Notes were taken as the interviews progressed, as the local extension agent felt this would not make the farmers feel ill at ease. Before the questions were begun, the farmers were told that because an Acacia albida development project was being considered, policy makers would appreciate knowing their feelings on A. albida.

Farmers 1-3 were from Ndioukhane village of Serere and Peuhl farmers. Farmers 4 through 6 were from Babak village; farmers 7 through 9 were from Keurmatoure village, and farmer number 10 was the extension agent, who is also a farmer. These interviews cannot be considered representative, as the person conducting the interviews is a plant physiologist with no knowledge of demographical methods. The questions and unedited farmers' responses follow:

QUESTION 1: Did you plant the <u>Acacia albida</u> trees or did they come up naturally?

ANSWER: All 10 farmers responded that the trees resulted from natural regeneration.

QUESTION 2: Is this tree important to you? Why?

ANSWER:

1. It is important because you do not have to put on fertilizer as the soil is rich enough.
2. It is important because he has noticed peanuts planted around the tree have a good yield.
3. It is important because when you grow millet and peanuts around the tree it has a good yield. You can also give the pods to sheep and cows.
4. It is important because of the fertilizing effect on soil.
5. It is important to him because of the fertilizing effect of leaves. If he sees a young tree he will let it grow.
6. It is important:
   a. because of its fertilizing effect on millet and peanuts
   b. because of its fertilizing effects on other crops such as manioc or niebe (cowpeas)
   c. because the branches can be used for fences and to make houses. If the branches are not solid enough, they can be used for firewood.
   d. because the pods can be used for goats, sheep, and cows. Women collect and sell the pods.

7. It is important because he can use branches to build his house and because the leaves fertilize the soil. The pods can be fed to livestock and sheep, and the branches can be cut to feed leaves to the cattle.
8. It is important for soil fertilizer and for shade. If the tree is large enough it can be used to make a pirough (wooden boat). The pods are used to feed cattle.
9. It is important because of the fertilizing effect on millet and peanuts. The soil under the tree is richer than bare soil.
10. It is important for wood. The pods and leaves are important for livestock food. Even if the tree is cut down the soil is rich for 10 years. Places where the branches are burned also leaves fertilizer.

QUESTION 3: What exactly or more specifically is important about the tree?

ANSWER:

1. The pods are important. If the tree has fallen down the soil will have the same fertility as before. When the tree is old the wood can be used for fenceposts and firewood.
2. He uses branches in his house to make roofing and posts.
3. He uses it to make houses.
4. The wood can be used to build houses and for charcoal.
5. The branches can be used for fences and charcoal. The pods can be fed to cattle.
6. Already covered in Question 2 response.
7. Already covered in Question 2 response.

8. Already covered in Question 2 response.

9. Without killing the tree he can use the branches for fences and for his house. He can collect and store the pods.

10. Already covered in Question 2 response.

QUESTION 4: How do you use the tree?

ANSWER:

1. No other uses.

2. The dead tree can be used for firewood and charcoal. The live tree leaves fall and constitute fertilizer for soil.

3. He uses it for houses, firewood, or charcoal.

4. The pods are used for sheep, goats and cows. The live tree branches can be used for fencing and dead tree can be used for charcoal.

5. Trees can be used for building materials as the branches must be pruned from time to time to allow peanuts to have a good yield.

6. Answered in 2 and 3.

7. The dry wood can be used for charcoal or firewood.

8. The wood is used for fencing, charcoal and firewood.

9. Wood which falls from the tree can be used for firewood which he can consume or sell.

10. Can be used for charcoal, firewood, fences and houses.

QUESTION 5: Do you collect the pods and store them?

ANSWER:

1. He collects, stores, and rations the pods to sheep, cows, and goats. He has no idea of the amount he stores.

2. He usually does not store them, but he collects and gives them immediately to his cattle.
3. He collects and stores them. The amount he collects depends on how much he finds. He never weighed the amount. He feeds to cows, goats and sheep, but not to horses.
4. He collects the pods to store or to sell. If stock is large he sells some. The price is not fixed per unit volume or weight so that he bargains to sell a bucket or bagful.
5. He collects and stores the pods to give to his cattle. He has no idea of the quantity, but he notes the pods can be stored for as long as you want.
6. He collects and stores the pods. The amount depends on the "atmosphere." The most you can collect from several trees in one day is 5 kg. The pods are difficult to collect because the cattle eat them right away. It is necessary to go early in the morning to collect the pods before the cattle see and eat them.
7. He collects and stores the pods for his cows and sheep. He stores 500 kg of pods to feed his 6 beef cattle.
8. He collects and stores the pods for cattle. If you worked very hard you could collect ten 100 kg boxes. If you collected for 2 hours you could collect 4-100 kg boxes, or 400 kg.
9. He collects and stores the pods. If he collects all the pods on his fields he could collect eight 100 kg

bags. He has a 2.5 ha field with about 30 trees and a 2.0 ha field with about 25 trees.

10. He collects about 500 kg of pods per year to give to beef cows only.

QUESTION 6: Could the trees be excluded from the goats to make it easier to collect and store the pods?

ANSWER:

1. The goats cannot be excluded from the trees since goats can jump fences and are very hard to control. The goats jump at the chance to eat the pods.
2. It is on a first come first serve basis for people, cattle, goats, etc. Even if the pods are on your field anyone can take them.
3. The pods cannot be excluded from the goats.
4. It cannot be done.
5. It cannot be done because the trees are far from the village and the goats are by themselves.
6. It cannot be done.
7. The trees could not be excluded from the goats. When the children go to collect the pods they will drive the cattle away if they see them eating pods.
8. The goats cannot be excluded from the pods, but the sheep are tied and cannot go out to eat the pods.
9. The pods cannot be protected from the goats.
10. The pods cannot be protected from the goats.

QUESTION 7: Have you noticed any differences in growth rate among the seedlings?

ANSWER:

1. The growth rate depends on the soil.
2. Some are small and some are tall for the same age. It depends on the nature of the soil.
3. He has noticed differences in growth rate but the differences are due to the soil nature and fertility.
4. There are differences in growth rate just like human beings.
5. Yes, there are differences in growth rate just like human beings.
6. Yes, there are differences in growth rate depending on weed control, soil preparation, etc.
7. There are differences in growth rate among the seedlings. If you take care of the tree it will grow faster.
8. Probably there are only small differences in growth rate. It can also depend on the nature of the soil.
9. There are differences in growth rate mainly due to soil preparation and effect of cattle grazing.
10. There are differences in growth rate. If young plants are browsed by livestock they will grow slower.

QUESTION 8: For trees of the same age and size, are there differences in pod yield?

ANSWER:

1. The pod yields are analogous to human beings, some have many pods, others have few pods.

2. There are some differences in pod yield. It depends on nature and God. Sometimes the differences are really big. Sometimes a young tree gives a larger yield than old trees.
3. There are differences. Some trees give more than others. Trees that are not cut at all give more pods than those in which the branches are cut.
4. There are differences in pod yield just like there are differences in human beings.
5. There are differences just like human beings--some have lots of pods and others do not.
6. There are differences in yield between them. A young tree might give more pods than an old one.
7. Some trees give much more pods than others.
8. There are differences in pod yield. Some trees do not give any pods but next year they probably will give pods.
9. There are differences in pod yield among trees. The differences are variable and can be high or low.
10. There are only small differences in the yield of pods betwee trees.

QUESTION 9: Do the animals seem to prefer pods from any particular trees?

ANSWER:
1. The animals have no preference.
2. same
3. same
4. same
5. same

6. The animals have no preference. There are big pods and small pods but the animals eat them all.
7. no preference
8. same
9. same
10. same

QUESTION 10: Do animals ever get sick from eating pods?

ANSWER:

1. Animals can get sick when eating green pods, but they can eat as many pods as they want of the dry ones and not get sick. This is true for cows and goats.
2. The animals get sick when eating green pods. They can eat as many dry pods as they want and not get sick. This is true for cows too. If cows get a not too severe case of diarrhea the dry pods are a good remedy.
3. The green pods give animals diarrhea, but the dry ones are okay, regardless of the amount.
4. Neither green nor dry pods make the animals sick.
5. Animals never get sick from either green or dry pods.
6. The animals never get sick from dry or green pods. Cows that eat dry pods give much more milk.
7. The animals never get sick from eating dry or green pods. The cows like the pods because it makes them fatter.
8. The animals never get sick from eating the pods.
9. There is no adverse effect of feeding excess pods. A farmer listening to the discussion said he heard from herders that green pods give diarrhea to cows and sheep.

10. If cows, goats and sheep eat green pods they will get minor diarrhea. If they eat dry pods they can eat as many as they want. If you give pods to sheep and goats you must chop it up.

QUESTION 11: How does _Acacia albida_ affect the yield of millet?

QUESTION 12: How does _Acacia albida_ affect the yield of peanuts?

ANSWER:

1. It increases the yield of millet and peanuts very much.
2. It substantially increases the yield of millet. (See his response to question 1 for peanuts.)
3. The _Acacia albida_ increases the yield of millet and peanuts if the rain is sufficient. If the rainfall is deficient the yield under the tree will be lower than normal but still higher than away from the tree.
4. The yield of millet is better under the tree. The yield of peanuts also increases but the yield of peanuts is not as great as the increase in the yield of millet. The leaves plus the animal manure fertilizes the soil.
5. The tree will increase the yield of millet if you have good weed control. There are lots of weeds under the _Acacia albida_. For peanuts you must cut the branches off the _Acacia albida_ otherwise there are too many weeds. (He says reducing the number of branches reduces the leaves, which reduces the soil fertility, which reduces the weeds.)
6. The _Acacia albida_ increases the yields of both millet

and peanuts if the branches on the Acacia albida are not too thick. (For reasons stated by Farmer 5).

7. The Acacia albida increases the yield of millet and peanuts underneath the tree. It is necessary to reduce the number of branches of the Acacia albida otherwise the soil is invaded by many weeds.

8. Acacia albida increases the yields of peanuts and millet and does so in about the same proportion.

9. Acacia albida increases the yield of millet under the trees under years of normal rainfall. In abnormal low rainfall years peanuts have higher yields in fields without A. albida than with Acacia albida. In normal years Acacia albida increases the yield of peanuts.

10. Acacia albida will increase the yield of millet if you have a good rain and if you remove the weeds. It also increases the yield of peanuts. In the old days people grew millet around Acacia albida, but now they grow peanuts around it. The yield increases are substantial but he does not know by how much. He says the A. albida is the only tree useful for fertilizing crops and that no other trees are useful.

QUESTION 13: Approximately how many A. albida do you have on how much area?

ANSWER: 1. He appreciates the Caddes in his fields very much. He has 10 trees in his fields of about 3 ha.

2. He has about 15 trees in his fields of unknown size.
3. He has about 5 trees on his fields of unknown size.
4. He has lots of Caddes but he does not have any idea of the number or of the area he is farming.
5. No answer.
6. He has no idea how much area he has or how many trees he has, although he has lots of trees.
7. He has 40 or more caddes in a field of 3 ha and 5 caddes in a field of 4 ha. The yield of peanuts is greater in the field with 40 caddes.
8. He has about 16 caddes on 2 hectares and he would like to have assistance to have 10 more caddes in one part of his field that does not have any. On another field he has only 2 caddes and he needs 25 more.
9. He has 30 trees in a 2.5 ha field and 25 trees in a 2.0 ha field.
10. He has about 22 trees for a total of 5 ha in 2 different fields. He would like 20 more caddes, 10 in one field that only has 2 caddes and the rest in the other field.

QUESTION 14: How would you feel about a development project to increase the number of caddes and what other comments do you have?

ANSWER:

1. If he had his way the only trees in his field would be Cadde. He really appreciates caddes in his fields.
2. Personally, he has enough trees in his field, but Caddes should be put in other fields where there are not enough trees.

3. No comment on Cadde development project. He would like to have more Caddes. He is preserving young trees and if he sees a young seedling he will not cut it.

4. He would like to cut branches off the Cadde to reduce the soil fertility underneath the trees and thus the weeds. He would also like to trim the branches because birds sit on the branches and eat lots of millet. This pruning is forbidden by the Eaux et Forets which rather annoys him. He could also use the pruned branches for wood and charcoal. He would like to be able to reduce the number of Caddes. He does not want to cut them all, but just reduce them to the right amount.

5. He says the Cadde branches must be pruned from time to time to allow peanuts and millet to have a good yield.

6. He would like to have a program where it is legal to cut the branches. He would like to have the Caddes spaced at 20 meters. This spacing would fertilize a radius of 10 meters and everything would be fertilized. Having Caddes is a very good thing, but too many is definitely detrimental. He could cut branches to fix fences, lower the fertility and give a wide spacing. Cutting the branches does not hurt the Cadde. He has noticed an increased density of Caddes since 1955. The men at Eaux et Forets do not know what they are talking about since it is necessary to trim the branches.

7. He would like to have more Caddes in his low density field. He would like some assistance in taking care of his Caddes. In general Cadde is very useful to him and he would like more in his fields.

8. As mentioned in question 13, he would like 10 more Caddes in his field of low density. He feels a 20 meter spacing would be a good spacing.

9. He would like assistance to preserve the young seedlings in his fields which are eaten up by the herds. If the number of Caddes could be increased in both of his fields and the young seedlings could be preserved he would be much appreciative.

(During the interview of Farmer #9, about 15 farmers gathered around. At the end of this interview a farmer commented that he would like to have the authority to prune the Caddes which is now in violation of Eaux et Forets regulations. The other 15 or so farmers were in agreement with this statement).

10. The cutting of the Cadde branches from time to time lengthens the life expectancy of the tree. As mentioned in question 13 he would like to have more Caddes at a spacing of between 15 to 20 meters. In the zone from here northwards the Cadde density in the fields is low. He would like more Caddes here and he believes this could be done by protecting the number of seedlings in the area. He believes an extension-education program is needed for farmers on the benefits derived from the presence of Cadde in fields.

Appendix B

Discussions on _Acacia albida_ with researchers in Paris, France and Senegal, November 2-23, 1977

In addition to reviewing the literature on _Acacia albida_, discussions were held with various researchers and government officials to assess their feeling toward _A. albida_, to discover as yet unpublished results relating to utilization of _Acacia albida_ and to become familiar with nursery techniques and/or _Acacia albida_ development programs presently underway. The results of the discussion are grouped under various headings.

Plant and Soil Scientists

Dr. Claude Charreau, ICRISAT

Dr. Charreau was very much in favor of increased use and development of _Acacia albida_, but he noted the following serious _A. albida_ knowledge gaps:

(1) Information concerning the effect of _A. albida_ on the water table and hydrologic balance. In Casamance, Senegal, Dr. Charreau was involved in a study in which the runoff and water table were measured before and after large forested areas were cleared for annual crop cultivation. After the forested area was cleared, the water runoff increased 100 times, but surprisingly the water table rose 8 meters and new permanent springs appeared throughout the watershed. This Casamance study clearly illustrates the necessity of determining the effect of _A._

albida on the water table. The quantitation of A. albida's effect on the hydrologic balance Dr. Charreau felt would be a difficult task requiring a multidisciplinary team consisting of a hydrologist, a soil scientist, a plant physiologist, etc.

(2) A second important area which needed clarification was the role of Acacia albida in fixing nitrogen. In the short range, he felt this problem might provide more theoretical than practical results.

(3) In his study (Charreau and Vidal, 1965) a tree was deliberately picked which from visual observations markedly improved the yield of millet. In contrast, he stated that Dancette and Poulain tried to pick average trees for their study. He feels a large number of trees should be subjected to statistical analysis to determine average yield increase/tree.

(4) Simple experiments should be conducted to determine the best tree arrangement in farmers' fields so as not to hinder animal-drawn cultivation, while at the same time planting trees along contour lines to minimize soil erosion. In this regard, Dr. Charreau stated his 1966 paper was in error, as A. albida has no lateral roots to interfere with cultivation.

(5) Experiments should be carried out to determine the growth rate of A. albida.

(6) Dr. Charreau envisioned A. albida permanent pasture areas where the animals would receive forage from the grass beneath the trees as well as the pods which fell from the trees and he would be surprised if the pods from the A. albida did not provide more forage than the grass grown

under the trees. Even though Dr. Charreau is a soil scientist, he believes the feeding value of the pods has more potential for agriculture in Senegal than the effect of _A. albida_ in increasing soil fertility. In view of the potential of _A. albida_ pods for animal food, he felt much more work on their nutritional quality was needed.

(7) The following comments were offered by Dr. Charreau on the use of _A. albida_: "People favor either Karite (Shea butter nut tree - _Butyrospermum parkii_) or _A. albida_ but not both. The people who have cattle have _A. albida_ but the people who have no cattle have Karite."

(8) The amount of manure needed to increase the soil carbon percentage to the levels under _A. albida_ was often misquoted from Charreau and Vidal's (1965) paper. When green manure is added to the soil, 95% of the carbon is lost by microbial respiration with only 5% remaining in the soil. Thus, one ton of soil carbon provided by _A. albida_ would have come from 20 tons of added carbon. Corrections would have to be made for the moisture and organic matter content of the manure.

Dr. Charreau strongly emphasized that in the very sandy Senegalese soils organic matter contributes much more than just its chemical nutrient composition in the form of profound positive soil structure effects which increase crop yields.

M. Claude Dancette. Bioclimatologist, C.N.R.A., Bambey

M. Dancette felt _A. albida_ was very useful in enriching soils, and in providing pods for animal food. While he thought projects should be undertaken to increase *A. albida* in the countryside, he was very concerned that *A. albida* might adversely affect the water table. He felt it would be important to know how much rainfall would be used by the trees compared to annual crops and wild grasses. He suggested a large non-weighing 400 m^2 surface area lysimeter 5 m deep could be used to quantitate water uses of trees and crops.

M. Beye - Director C.N.R.A., Bambey

M. Beye felt *A. albida* projects would be useful, but along with Dr. Charreau and M. Dancette, he was very concerned that large stands of *A. albida* might adversely affect the water table and/or water use of crops.

M. Beye felt research was needed to arrive at the optimal spacing and arrangement for *A. albida* trees, e.g., squares, lines, rows, etc. to optimize weeding, sowing, windbreaks, and harvesting. In spite of the capability of *A. albida* to increase soil fertility, M. Beye emphasized it still is necessary to use mineral fertilizers. While *A. albida* will grow fine in Bambey where there is 650 mm annual rainfall, M. Beye stated *A. albida* would not grow in northern Senegal where the rainfall is only 400 mm.

While expressing enthusiasm for *A. albida* projects, M. Beye would appreciate more funding at C.N.R.A. for annuals like maize, millet, sorghum and peanuts to provide food for direct human consumption.

M. Pieri, Soil Scientist, C.N.R.A., Bambey

Mr. Pieri was very favorably impressed with *A. albida*'s ability to increase the fertility of farmers' fields. He commented that over a period of years annual cultivation tends to lower the soil organic matter content. As an example, Pieri noted the forest soil organic matter content in Casamance, Senegal dropped from 2% to 0.4% after 10-15 years of annual cultivation.

M. Pieri felt a very strong need to quantitate the possible effects of *A. albida* in depleting ground water supplies for annual crops. He mentioned that within 15 meters of windbreaks composed of Neem (*Azadirachta indica*) it was impossible to grow any crop because all available soil moisture had been extracted.

Nursery and Forestry Personnel

M. Hamel, Director, Centre National de Recherche Forestiere, Dakar

M. Hamel agreed with the soil scientists that the effect of *A. albida* on the hydrologic balance was the major research need. M. Hamel felt development of a working genetic framework to obtain phenotypically similar *A. albida* seedlings was urgently needed to optimize simple cultural practices and to develop new *A. albida* strains. For example, M. Hamel states it is not possible to carry out experiments to determine optimal pot dimensions because of the extreme seedling variability. (This reviewer would like to point out that it is not even known if *A. albida* flowers are self-compatable or if the trees outcross as in other leguminous trees like mesquite.)

M. Hamel feels the best method for overcoming the _A. albida_ variability is through cuttings. Although he has not made _A. albida_ cuttings, he has obtained cuttings from _A. senegal_ in conjunction with the Canadian government IDRC work. A growth chamber or greenhouse (Serre) will be completed in March 1978 at which time it will be possible to conduct experiments on _A. albida_ cuttings.

M. Hamel mentioned that the growth studies mentioned in "Etude Croissance Sommaire" (Anon, 1966) have been abandoned for lack of maintenance funds. Similarly about six _A. albida_ plantations made by Eaux et Foret and the CTFT have been abandoned now with low success because funds were provided for establishment but not maintenance and now due to fire, grazing, and no weeding, the plantations are in very bad condition.

M. Sene, Director, Eaux de Foret

M. Sene noted that since 1964 a program has been underway to protect _A. albida_ seedlings on 11,000 ha in Kebemer, Mback, and Louga area. New _A. albida_ stands are the result of this successful protection program. A second project to establish a 1,000 ha plantation near Diourbel from nursery-raised seedlings was not as successful, but these results are deceptive, since the top growth is a poor indicator of total _A. albida_ growth due to _A. albida_'s very low shoot/root ratio. M. Sene believes it is necessary to begin afresh on more methodical ways for planting _A. albida_. Eaux et Foret has been distributing _A. albida_ seedlings to nurserymen in the Diourbel area and this seems to be working rather well. M. Sene mentioned that the Canadian IDRC plans to develop efficient methods for raising and propagating the gum arabic-producing Acacia senegal. Of all the Acacia seedlings growing in the nursery Acacia albida was by far the slowest growing. On 15 November, 1977, M. Sene was finishing a report of the Eaux et Foret work with various Acacias for the Canadian IDRC, through whom he felt a copy of his report could be obtained.

Dr. Antoine Nongonierma, Botanist, IFAN, University of Dakar

Dr. Nongonierma has just completed a taxonomic study of Acacias in Senegal. He believes Acacia albida should properly be called Faidherbia albida. Dr. Nongonierma could provide no information on Acacia albida outcrossing or flower self-compatibility.

Nurseries in Bambey, Senegal

Two nurseries visited in Senegal were several kilometers apart. One was operated by the C.N.R.A. and the other by the E.N.C.R. (Ecole National Cadre Rurale). The A. albida fertilizer trials which were begun in 1969 and reported in the CTFT 1971 annual report were observed at the C.N.R.A. nursery. Since the nursery plan was carried along it was possible to determine the fertilizer doses of various trees. Strangely enough, one of the shortest A. albida (1.54 m) and one of the tallest A. albida (5.8 m) were only several meters apart. The tallest tree received 100 g of $(NH_4)_2SO_4$, while the shortest tree received 150 g of $(NH_4)_2SO_4$. This reviewer believes it very improbable that this

4.3 m height differential was caused by 50 g of $(NH_4)_2SO_4$, and believes the cause may be genetic heterogeneity in trees propagated by seeds.

The nursery at the E.N.C.R. was much better-maintained than the CNRA nursery grounds, although the E.N.C.R. nursery had no A. albida trees. The E.N.C.R. nursery did have many Acacia and Eucalyptus species as well as a few Parkia biglobosa (nere - a leguminous tree whose seeds are fermented and used directly for human food) and Prosopis juliflora (mesquite).

Nursery in Kebemer

This nursery, run by the FAO has Eucalyptus, Casuarina, and A. albida. Their objective is to plant about 1,000 ha of A. albida in farmers' fields per year. The nursery raises 45,000 A. albida seedlings per year which yields a density of about 45/ha. In one field that was visited the trees are being planted in 10-meter spacings to yield about 100 trees/ha. Funds for this project are soon to be terminated.

The A. albida seeds are sown in the nursery in April or May and are transplanted in August or September. The nursery is fairly well-equipped with sources of water, 4-wheel drive all-terrain unimogs, and ample space for raising Acacia albida seedlings. The nursery facilities while quite adequate for raising seedlings for field transplants are not suitable for studying rhizobial cross inoculation because of inadequate protection from cross contamination. Cross contamination could easily arise through rhizobial-infected irrigation water because all seedlings are grown in perforated polyethylene containers placed up to one-half their height in soil. Indeed, it is difficult maintaining more than one specific rhizobial infected plant, on well drained, perforated benches in the greenhouse.

A prevalent A. albida disease was noted at this nursery in which the leaves became very tightly bunched on branches without new terminal growth. Nematodes were reported to be quite a problem at this nursery, but were effectively controlled by Vapam. It seems clear that if a large scale A. albida project is undertaken the services of a good plant pathologist, entomologist, and nematologist will have to be secured.

Nitrogen Fixation

Dr. Dommergues' group centered at ORSTOM Bel-Air has very impressive credentials, appears to be well-motivated and is well-equipped to study nitrogen fixation. They have several gas chromatographs equipped for the acetylene-nitrogen fixing assay, a forced air sterile hood to perform transfers and fluorescent antibody equipment to distinguish and classify rhizobia. Dr. Dommergues' group has isolated rhizobia from several Acacia albida and has done work on Acacia albida nitrogen fixing capabilities using the acetylene assay.

Dr. Dommergues feels research is needed on Acacia albida's nitrogen fixing capabilities to determine why nodules disappear from the seedlings when transplanted from the nursery to the field and to determine the nodule soil profile distribution. In studies with peanuts Dr. Dommergues' group has found that nitrogen fixation is very poor under drought stress. Consequently he suggested a cooperative effort with a bioclimatologist to study nitrogen fixation in Acacia albida as a function of depth and soil moisture content would be valuable.

Due to the close relationship between the plant and the bacteria which form the nitrogen fixing nodule, Dr. Dommergues stressed it is imperative to have uniform plant genetic material before carrying out studies of plant-rhizobia interaction. Therefore before serious plant-rhizobia experiments can be undertaken, it will be necessary to reduce A. albida's genetic heterogeneity by either clonal propagation or classical breeding techniques. There are also two soil microbiologists working on nitrogen fixation in peanuts at C.N.R.A. Bambey. Although this reviewer has not seen the equipment it should also be sufficient for conducting nitrogen fixation assays on A. albida.

Animal Nutrition

Due to a lack of published A. albida feeding value measurements, the animal nutritionists at Institute d'Elevage et de Medecine Veterinaire des Pays Tropicaux (IEMVT) (Tropical Institute of Veterinary Medicine and Animal Husbandry) were contacted in Paris, France and Dakar, Senegal to learn of other unpublished information. In Paris, discussions with Drs. Chadelas, Riviere, and Peyre de Fabregues revealed that A. albida pod chemical analyses had been conducted, but no feeding trials had been carried out. Dr. Chadelas felt no more than several pounds of the

Acacia albida pods a day should be fed to livestock because the very hard pods are similar to concentrate and should be mixed with other feeds. It is certainly true that mesquite pods should be mixed with other feeds when fed to cattle (Dollahite, 1964). For these reasons the question, "Do livestock ever get sick from eating too many *A. albida* pods?" was included in the questions asked of the peanut farmers in Senegal. Somewhat surprisingly all farmers said livestock could eat as many dried *A. albida* pods as they wished without becoming sick.

Dr. Calvet at the Laboratoire d'Elevage in Dakar, Senegal knew only of chemical analyses being performed on the *Acacia albida* pods and seeds. Due to *A. albida*'s hard pods and seed coat he felt it would be difficult to predict the pod feeding value from chemical analyses.

The Laboratoire d'Elevage in Dakar is quite well-equipped to carry out feeding experiments as they have an atomic absorption spectrophotometer for measuring mineral nutrients, a gas chromatograph for measuring volatile fatty acids, routine chemical equipment to determine proximate analyses, and cannulated cows to obtain rumen extracts for *in vitro* digestability studies. *Acacia albida* pod feeding experiments have not been conducted at the Laboratoire d'Elevage in Dakar because of a lack of funds to pursue that research direction.

Other Leguminous Trees

During the visit to Senegal, this reviewer observed leguminous trees other than *Acacia albida* used by local people which are little known to Europeans and Americans.

The leguminous tree Parkia biglobosa (nere in Senegal) was frequently observed along an 80 kilometer stretch of highway, south of Kebemer. In the vicinity of Kebemer numerous Parkia biglobosa were observed in a region where the average annual rainfall of 350-400 mm. A previously harvested millet crop was observed under one Parkia biglobosa tree, but curiously, no millet appeared to have been planted away from the tree's foliage cover. A local laborer living in the area said Parkia biglobosa, like Acacia albida, increased the soil fertility. Approximately a dozen Parkia biglobosa trees were observed growing in the E.N.C.R. nursery in Bambey.

The seeds from the Parkia biglobosa are used to ferment a product, called soumbara, used by local people as a condiment for soups, etc. The fermented product soumbara was purchased in a local Bambey market for 5 CFA/2 cm diameter ball, but was prepared approximately 100 km away in Sine Saloum where Parkia trees are said to be more abundant.

The second leguminous tree noticed was a North American unidentified mesquite (Prosopis spp.). The mesquite was planted along the expressway from the airport to downtown Dakar, along the scenic seaside roads in Dakar, and was used as an ornamental in downtown Dakar. Mesquite was being tested in the E.N.C.R. tree nursery in Bambey. This reviewer met an elderly woman waiting for a bus in downtown Dakar with a large box of mesquite pods which she had collected in a nearby suburb of Cornish to take home for her sheep. A number of bystanders mentioned that when they were little they had eaten mesquite pods because of the sweet taste.

A thorough evaluation of mesquite (Prosopis spp.) and nere (Parkia biglobosa) is warranted since these leguminous trees can provide human and/or livestock food in regions of 250 and 350-400 mm annual rainfall respectively.