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Nutrient Cycling by *Acacia Albida* (syn. *Faidherbia albida*) in Agroforestry Systems

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Agroforestry provides a number of land-use options that can enhance agricultural sustainability by increasing the diversity and quantity of useful outputs from a land area while helping to conserve and protect the area's natural resources. Agroforestry practices, under study and implementation in the Tropics, range in management complexity from simply mulching crops with leaf litter collected from nearby forested areas to intensive intercropping systems using alley or multistoried arrangements (see for example, Nair, 1990; Attah-Krah & Kang, 1993).

Effective intercropping involves a careful balance between competitive and complementary processes. Because trees may have root systems that extend far more deeply than those of annual crops, agroforestry may enhance opportunities for complementary use of soil resources, especially nutrients that may be recycled from below annual crop root zones. Further, N-fixing trees may create a positive balance with respect to that nutrient. However, intense competition for water, light and nutrients may occur during the growing season and result in significantly reduced crop production in the vicinity of trees not carefully managed (e.g., Fernandes et al., 1990). Therefore, there would be a great advantage to an agroforestry system in which the periods of peak resource use by the tree and crop components were largely not overlapping. The cultivation of agronomic crops under the canopies of *Acacia albida* (Del.) [syn. *Faidherbia albida* (Del.) A. Chev.] appears to be such a system.

CULTURE AND USE OF *ACACIA ALBIDA*

Acacia albida [also known as *Faidherbia albida* (French), Kad (Ouolof), Gao (Hausa), Msangu (Chewa), apple ring acacia, and winter thorn] is commonly found throughout the subhumid and semiarid zones of sub-Saharan Africa at elevations below 2000 m (Wickens, 1969; Miede, 1986) as well as in parts of the Middle East (Halevy, 1971). It is a thorny, leguminous tree that can grow to 25 m in height and more than 1 m in diameter. It is most common on alluvial soils or other areas with relatively shallow perennial water tables, but also can be found on upland slopes if the soils have sufficient water-holding capacity (Miede, 1986; Radwansky & Wickens, 1967). Vandenberg (1991) describes two distinct ecotypes, Ecotype A adapted to deep-water tables and severe drought in the western Africa plateaus, and Ecotype B of eastern and southern Africa requiring riparian environments. The most unique characteristic of this acacia species is its deciduous behavior known as "reverse foliation" (NAS, 1984). In most environments, the mature tree retains its leaves during the dry season and sheds them early in the rainy season. This behavior results in a temporal pattern of growth and resource use nearly opposite to that of most agronomic crops.

Although not normally used for human food, *A. albida* provides many valuable products including fuelwood, wood for building and tool-making, thorny branches for fencing, mulch, fixed N, proteinaceous forage (NAS, 1979) from its pods and leafy branches, and shade for livestock and people. The latter two products are especially valuable because they are produced during the dry season when forage and shade are scarce (Miede, 1986).

In addition to the above benefits, scientists and traditional farmers (Felker, 1978; Sturmheit, 1990) generally recognize that crops grow better in the soil under *A. albida* canopies than in areas outside the trees' influence. Unlike in other agroforestry systems, there appears to be little direct competition between *A. albida* and associated annual crops. In fact, Vandenberg (1990) stated that, "There are no definitive reports of species other than *Prosopis cineraria* (in India) and *Acacia albida* (in Africa) that exhibit the ability to increase crop yields under their canopies."

Because of these unique beneficial effects, efforts have been made to propagate *A. albida* and systematically plant it on cropland. Several large-scale efforts in Francophone West Africa prior to 1965 met with failure because of difficulties with seed germination and seedling survival after transplanting (Felker, 1978). Subsequent work has developed methods of mechanical and acid scarification, nursery methods and transplanting techniques using 30 cm long polyethylene tubes and precise timing that result in 80 to 90% germination and 60 to 90% survival after 1 yr (Poschen, 1986; Felker, 1978; Sandiford, 1988). *Acacia albida* is slow to moderate in early growth and there is great variability among individual trees produced from seed with respect to growth rate and vigor. The trees also may be highly sensitive to variability in soil fertility and physical properties. Some recent studies indicate that, on sandy soils of Niger, the higher fertility conditions often found under the trees may, in part, precede the establishment of the tree (Geiger

et al., 1993; Vandenbeldt & Geiger, 1991). In these studies, improved soil properties such as increased subsoil clay content and decreased exchangeable acidity were associated with the occurrence of relic termite (*Macrotermes* spp.) mounds that correlated with enhanced growth and survival of newly planted trees. It may therefore be possible to improve planting success on poor soils by observing the growth of an indicator crop (eg., millet, *Pennisetum typhoideum*) to identify the best microsites, and then concentrating *A. albida* planting on those sites the following season. This hypothesis is currently being tested at the ICRISAT Sahelian Center in Niger (J. Brouwer, 1992, personal communication).

INTERCROPPING WITH *ACACIA ALBIDA*

By far the greatest agroforestry use of *A. albida* is the opportunistic protection of naturally occurring trees on cropland and cultivation of crops under their canopies. Nair (1985, 1990) classifies this type of use as an "agrisilvicultural system of multipurpose trees on farmland." This is a traditional technique practiced by African farmers for centuries. *Acacia albida* is mentioned with respect in African proverbs from Malawi to Senegal, and the Sultans of Zinder in the Sahel are said to have cut off the hands of people who illegally felled one of these trees (NAS, 1984). Despite efforts to protect the trees, *A. albida* on farmland are usually very unevenly spaced, leaving much of a given field without the beneficial effects of the tree.

There is little agreement in the literature as to what is the optimum spacing or number of *A. albida* per hectare (recommendations range from 12–100). Some of this confusion may result from different assumptions about the age and size of the trees. In Malawi, mature *A. albida* are often 20 to 25 m high with canopy radii of approximately 8 to 12 m and trunk diameters of 0.5 to 1.3 m. Approximately 20 such trees could give nearly complete coverage of 1 ha. This is the number of trees per hectare recommended in a report by NAS (1984). While this density of mature trees does occur in a few localized areas in eastern and southern Africa, in many areas only 6 to 10 mature trees per hectare have been observed, and scattered individual trees at densities of 1 or 2 per hectare are most common in this region.

Effects of *A. albida* on crops grown under them have been well documented in several parts of the Sahel and in the Sudanese and Ethiopian highlands (Charreau & Vidal, 1965; Poschen, 1986). Millet, groundnut (*Arachis hypogaea* L.), and sorghum [*Sorghum bicolor* (L.) Moench] have been reported to yield 1.5 to 3 times as much under *A. albida* canopies as outside the canopies. However, such yield enhancement does not occur in all cases. Poschen (1986), for example, found a 50% or greater yield increase in 20 out of 40 paired samples, but in 10 of the pairs sorghum or maize (*Zea mays* L.) yielded about the same or even less under the *A. albida*. Bunderson et al. (1990, unpublished data) reported similar inconsistent effects on the yield of maize at several locations in Malawi. The reasons for these inconsistencies have not been well defined. Perhaps there are genetic differences in the

trees and/or crops at different sites. Or perhaps *A. albida* is only beneficial where certain environmental factors are limiting crop growth. The reports do not indicate whether there was any relationship between the vigor of the *A. albida*, soil physical properties in the tree's microsite, and observed effects on crop growth. It is clear from several studies that reported crop densities and yield components that the observed yield increases resulted principally from more vigorous growth and not from increased crop populations under the *A. albida* (Dancette & Poulain, 1969).

Relatively little has been published on microclimate factors under *A. albida* in attempts to explain the enhanced crop growth. Dancette and Poulain (1969) found soil moisture to be enhanced under *A. albida* during heavy rains, but less moisture under the trees during light rains. They also posited, but did not measure, reduced evaporative demand and lower maximum temperatures under the tree canopies. Felker (1978) cites one report of greater water-holding capacity of soil under *A. albida*, possibly as a result of increased soil organic matter.

SOIL FERTILITY UNDER *ACACIA ALBIDA*

Several authors have studied soil properties in paired soil samples taken under and away from *A. albida*. Charreau and Vidal (1965) analyzed soil in the vicinity of four *A. albida* trees near Bambey, Senegal, and reported approximately twice as great a concentration of organic C, total N, and exchangeable cations and extractable (but not total) P under the *A. albida* canopies. Dancette and Poulain (1969) found less dramatic, but still significant, increases in all these properties except extractable P. The organic C levels in both studies were very low (0.3–0.6%) and C/N ratios were just under 10:1. In the Sudan, Radwanski and Wickens (1969) compared two slopes, one dominated by *A. albida* and the other by nonleguminous trees. They reported that the soil with *A. albida* had approximately two times the organic C (1.3%) and six times the total N (0.43%) giving an unexplicably narrow C/N ratio.

Workers at the ICRISAT Sahelian center in Niger have shown that the greater fertility under *A. albida* in young plantations near Niamey is largely an artifact of the better survival and growth of the trees in pre-existing microsites with better soil conditions, especially increased clay content, associated with termite activity (Brouwer et al., 1991). Also, in some places droppings from cattle attracted by the shade in the dry season and increased dust accumulation due to reduced wind velocity may contribute to the greater soil fertility under *A. albida*. However, the leaf litter probably has sufficient nutrient content to account for the observed effects through nutrient cycling. Charreau and Vidal (1965) determined that leaf litter from the relatively small (approximately 100-m² canopy) *A. albida* they studied contained per tree 1.13 kg N, 0.4 kg P, and 2.75 kg Ca. Jung (1970), studying larger *A. albida* (approximately 230-m² canopy) reported leaf litter containing 4.3 kg N, 0.09 kg P, and 5.1 kg Ca per tree.

It is the conclusion of most workers who have studied the effects of *A. albida* on crop productivity that N plays the key role. Dancette and Poulain (1969) stated that "without denying the improvement of other fertility factors, nitrogen appears the essential factor in soil productivity under *Acacia albida*." The study of Radwanski and Wickens (1969) comparing *A. albida* to nonleguminous trees would seem to support this point of view. *Acacia albida* seedlings have been shown by Habish and Khairi (1968) to form effective (red) nodules with rhizobium isolated from *A. albida*, but not from 20 other legumes species. Attempts to observe nodules on *A. albida* in the field under natural conditions have been unsuccessful (e.g., Jung, 1970), possibly due to high temperature and low moisture in surface soils during the dry season. Although N fixation by *A. albida* has not been demonstrated in the field (NAS, 1975), the high N content of the pods and the accumulation or maintenance of soil N under *A. albida* even where cattle are not present and grain crops are grown and removed, suggest that N fixation does take place.

Nutrient uptake from deep soil layers may be another important mechanism of nutrient cycling and enrichment of surface soils under *A. albida* with both cations and anions. This mechanism is likely to be especially important with regard to S which is present partly as an anion relatively mobile in sandy surface soils but subject to adsorption in Fe- and clay-enriched subsoils (Parfitt, 1978). Although S is known to be present in many African soils in amounts insufficient for optimal crop production, no information is available on the effects of *A. albida* on soil S. The only data available on S in *A. albida* systems are some leaf tissue analyses given by Charreau and Vidal (1969). They reported that S concentration in *A. albida* leaves was 0.9% and that the S concentration of Millet leaf tissue was significantly lower under *A. albida* (0.31 vs. 0.56%).

CURRENT RESEARCH IN MALAWI

The Malawi Ministry of Agriculture has recently formed an Agroforestry Commodity Team to conduct research and collaborate with the Ministry of Forestry and Natural Resources and the Agricultural Development Districts. This team plans to promote "systematic planting of *Acacia albida* trees on smallholder farms to improve the productivity and sustainability of crops and livestock, and to reduce the need for expensive fossil fuel-based fertilizers" (Saka et al., 1990). Homestead and boundary plantings also are being encouraged. Saka et al. (1990) report that interest among farmers and extension workers is high. The program began in 1990-1991 with the production of 5 000 to 10 000 seedlings in each interested Agricultural Development Division.

To further investigate nutrient cycling by these trees, we studied the soil and maize crops in farmers' fields associated with nine individual mature *A. albida* trees: three east of the town of Bolero in Northern Malawi and six west of Salima in east central Malawi (see Fig. 8-1). The soils near Sali-

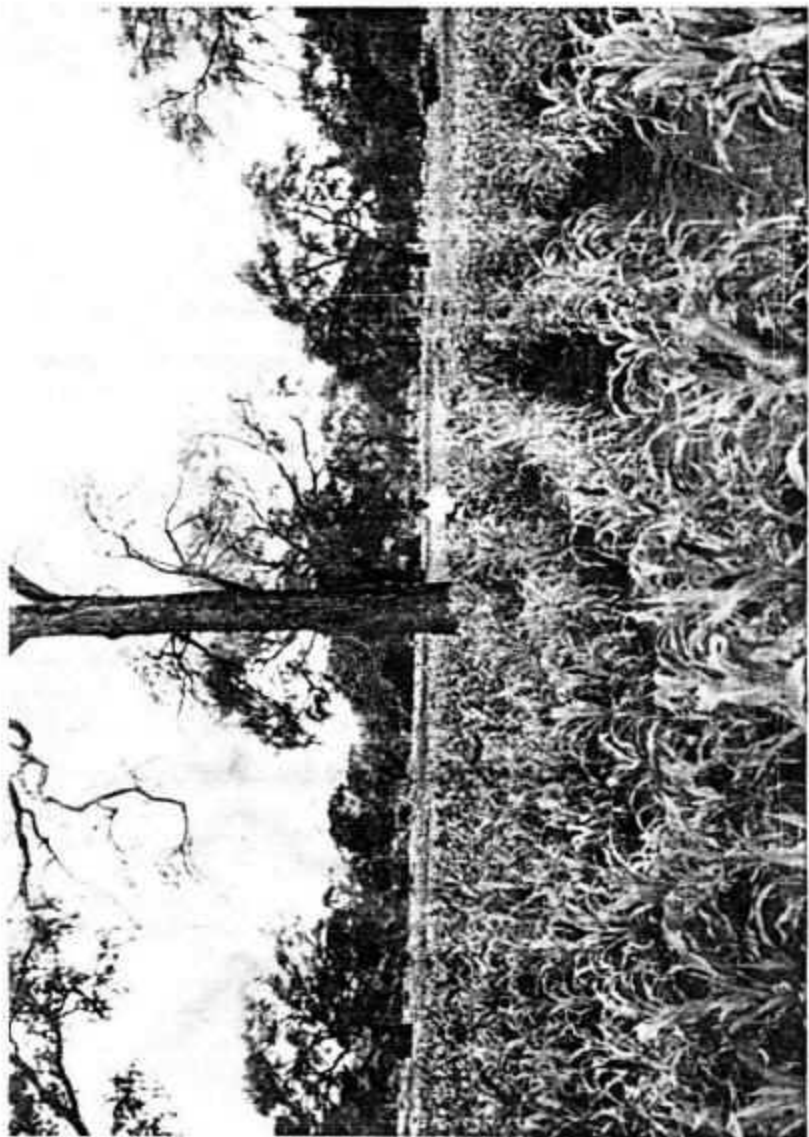


Fig. B-1. Maize growing in association with mature *A. albida* near Sallima, Malawi (Site S8) at the time soil samples were obtained.

ma (Tropepts) were developed on sandy and loamy lacustrine deposits. Those near Bolero (Fluvents and Tropepts) were on old sandy alluvium. Annual rainfall in both areas is 800 to 1000 mm coming between December and May. Each site met these criteria: (i) *A. albida* trunk circumference was greater than 175 cm, (ii) maize was planted and uniformly managed under the tree's canopy and to at least 10 m beyond, (iii) soil and topography appeared to be uniform under and to at least 10 m beyond the tree's canopy, (iv) no fertilizer had been applied to the site in the current or previous cropping season. The area covered by the *A. albida* canopies ranged from 300 to 650 m². The *A. albida* in these areas are distributed non-uniformly with densities ranging from 2 to 12 trees per hectare.

At every site studied, maize was visibly taller and more vigorous under rather than beyond the *A. albida* canopy. Maize plant heights at the 10- to 12-leaf stage for the sites near Salima are shown in Fig. 8-2. It is worth noting that under the *A. albida*, not only the maize grew more vigorously, the weeds did too. Optimum crop production and valid yield comparisons involving intercropping with *A. albida* may require more frequent and timely efforts to manage weeds.

When the maize was in the 10- to 12-leaf growth stage and again in the tasseling stage, leaves from 20 random plants in two roughly concentric sampling areas were collected and analyzed, the one 5 m beyond the edge of the *A. albida* canopy and the other under the *A. albida* midway between its trunk and the edge of its canopy. Concentrations of N, S, P, and Zn in these leaves are shown in Table 8-1. The concentrations of N, S, and Zn were significantly higher under the *A. albida* canopy, but only for S was the effect highly significant at both growth stages. Foliar symptoms of S deficiency in maize were observed at most of these sites on maize beyond, but not under the *A. albida* canopy. Phosphorus was more concentrated away from the tree at maize tasseling stage, possibly because of greater dilution of P taken up by the larger plants under the tree. Concentrations of other

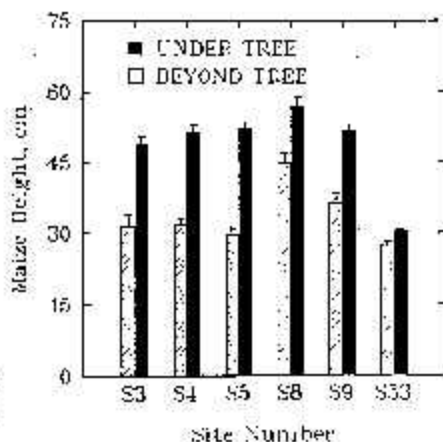


Fig. 8-2. Effect of *A. albida* on the height of maize in the 10- to 12-leaf growth stage at six sites near Salima, Malawi. Error bars are standard errors of the means.

Table 8-1. Concentrations of selected elements in maize leaf tissue at two growth stages as affected by association with *A. albida*, with means of nine sites in Malawi.

Element	Seedling stage		Tasseling stage	
	Under tree	Beyond tree	Under tree	Beyond tree
N (g/kg)	26.3	† 22.0	22.9	** 16.6
S (g/kg)	1.36	** 1.06	1.09	** 0.74
P (g/kg)	1.62	NS 3.05	2.15	* 3.13
Zn (mg/kg)	13.2	** 11.3	12.0	† 11.4

*, **, † indicate adjacent means are different by paired *t*-test at the 0.05, 0.01, and 0.1 levels of probability, respectively.

nutrients (K, Ca, Mg, Fe and Cu, not shown) were not significantly affected by the *A. albida*.

Figure 3-3 shows the association of *A. albida* with some properties of the surface (0-15 cm) soil at the nine Malawi sites. The effect of the *A. albida* canopy on total soil N ranged from 200% increase to 30% decrease. The effect on total soil C followed a similar pattern, but the differences were not as great. Across all nine sites, the probabilities of greater *t* values in paired *t* tests of the effect of *A. albida* on soil N and C were 0.09 and 0.45, respectively. Also, there was no consistent nor statistically significant effect of *A. albida* on extractable soil P (Bray P1 soil test). Only at site S4 did extractable P increase dramatically in the manner reported by Charreau and Vidal (1965) for their sites in Senegal.

In contrast, total soil S was higher under the *A. albida* at eight of the study sites and unaffected at one. Across all sites, the effect of *A. albida* on total soil S was highly significant. Sulfate-S in the upper 15 cm of the soil also was higher under the *A. albida*, except at the very sandy sites in northern Malawi (Sites A1-A3). At the latter sites, the soil samples were collected at the end of the growing season instead of early in the season as at the Salima sites. Figure 8-4 indicates that sulfate S had leached down in these very sandy profiles. The effect of *A. albida* in increasing the sulfate S was much more apparent (and highly significant) in the samples from 30 to 45 cm deep than in the surface soil. A series of on-farm fertilizer trials currently being conducted at similar sites in Malawi indicate that S is often yield limiting for maize in these soils, especially where N fertilizer is used.

The source of the increased nutrients under *A. albida* is not certain (Dunham, 1989). Although manure from cattle seeking dry season shade and forage under *A. albida* is considered to play a role in nutrient concentration under these trees in parts of the Sahel, the local scarcity of cattle and use of communal grazing lands makes this an unlikely mechanism of nutrient enrichment under *A. albida* in the Malawi study areas. Much of the *A. albida*'s N is most probably biologically fixed from atmospheric N₂ gas, but the proportion that derives from N dissolved in rainfall, from dust accumulation, and from increased efficiency of N cycling within the soil profile is unknown. Even less is known of the sources of the enhanced S under *A. albida*. In addition to uptake of S released from mineral weathering or sorp-

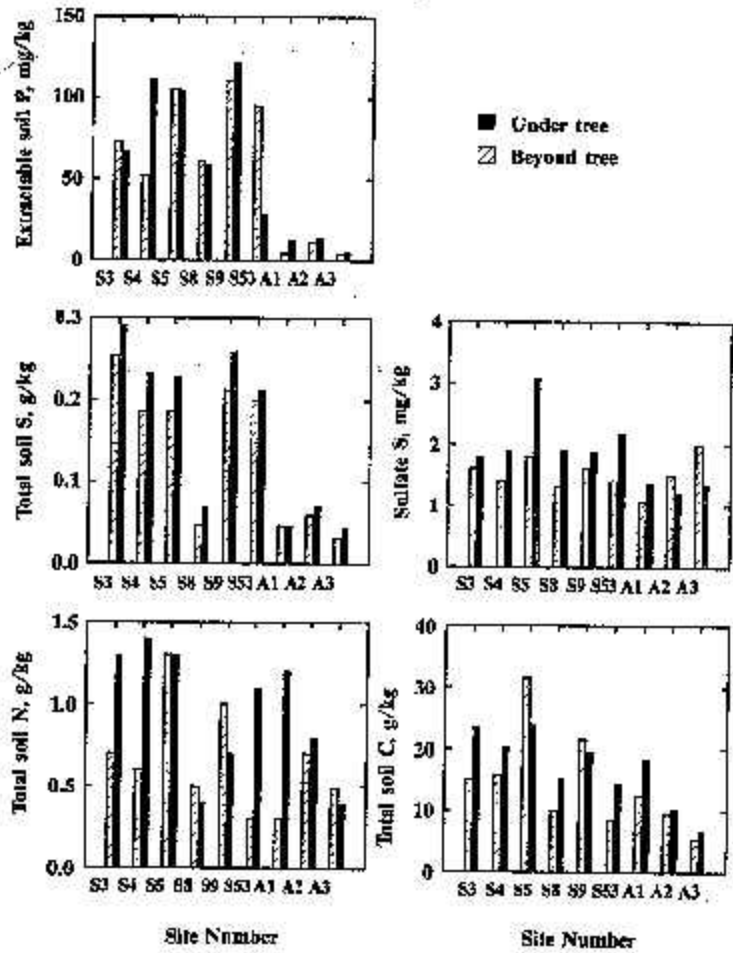


Fig. 8-3. Concentrations of extractable (Bray P1) P, total S, sulfate S, total N, and total C in the upper 15 cm of soil under *A. albida* canopy and beyond the canopy at nine sites in Malawi.

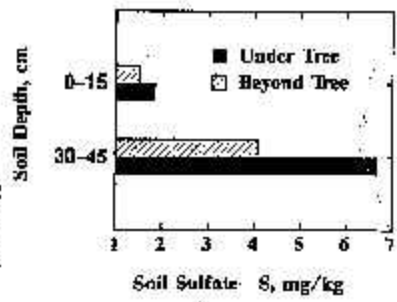


Fig. 8-4. Sulfate S concentrations at two soil depths under and beyond the canopies of *A. albida*. Means of three sandy soils near Bolero, Malawi. The difference is significant by paired *T*-test only at the lower depth.

tion deep in the soil profile, the *A. albida* foliage may absorb SO_2 from the atmosphere during the dry season when savannah vegetation and crop residues are burned over wide areas. This type of atmospheric S input may not be included in the measurements of S in rainfall. While no data are available for Malawi, Bromfield (1974) estimated that rainfall annually added 0.5 to 1.9 kg/ha S to soils of the Nigerian savannah, an amount insufficient to replenish soil S removed by even the modest grain yields common on unfertilized savannah soils.

RESEARCH NEEDS

Existing plant and soil data taken together would suggest that *A. albida* is important in enhancing soil fertility both by N fixation and by nutrient cycling from deep soil and atmospheric sources. The unique aspect of *A. albida* in agroforestry is that the tree apparently provides so little competition during the growing season that crops growing under its canopy can take advantage of the soil fertility enhancement without suffering from overriding shading or moisture stress that results from close association with most other tree species. This, coupled with the fact that African farmers already appreciate the benefits of growing crops in association with *A. albida* (Saka et al., 1990; Sturmheit, 1990), makes it very likely that successful programs can be implemented to more intensively and systematically take advantage of *A. albida* in agroforestry systems. To do this, however, considerable research remains to be done in a number of key areas.

Much work is needed to better understand the dynamics and mechanisms involved in the ability of *A. albida* to enhance soil fertility. The rate of N_2 fixation and the sources and rates of accumulation of S and other nutrients must be identified in order to predict what level of crop production the system can sustain in the long term. Nutrient balance models should be developed for the principal crop production limiting nutrients in each major *A. albida* region. This will most likely require measurements of atmospheric inputs and changes in deep soil profile concentrations over many years. Soil physical properties unlikely to be affected by vegetation, such as clay content, should be determined to evaluate the possible role of termite activity or other pedogenic processes that may create soil variability independently of the trees. The effect of *A. albida* on local water tables also should be evaluated before large-scale planting programs are implemented.

Progress has been made in understanding the factors that affect the success of mass propagation of *A. albida* (eg., Bahuguna et al., 1987; Favre & Traore, 1987; Gassamà & Duhoux, 1987; Harsh & Muthuna, 1985; Sary & Some, 1990), but nursery and propagation techniques will continue to need further refinement. More critical, perhaps, are technologies for maximizing the survival and early growth of *A. albida* seedlings planted out on semiarid and subhumid cropland. Considerable work is needed to accurately identify the geographic and ecological range of adaptation for intercropping with *A. albida*. There are reports of *A. albida* established on upland and mountainous

terrain (eg., Foschen, 1986; Miche, 1986), but comparative studies have not been conducted to determine the relative potential of *A. albida* intercropping in these diverse environments.

Other questions as yet inadequately answered include: How much of the regional variability in size and vigor of *A. albida* is environmental and how much is genetic? Can *A. albida* be established in even stands, and not just as scattered individual trees, on upland soils with no shallow water table? In a specific environment, what is the optimum density of *A. albida* in order to maximize the beneficial effects on crop yields while encouraging the long-term survival and growth of the *A. albida*? How can the benefits of logging *A. albida* for firewood be balanced with obtaining optimum soil fertility enhancement in an intercropped field? What is the sustainable yield potential of *A. albida* intercropping under improved crop management and are supplemental inputs needed to optimize the benefits of this agroforestry system? Finding answers to these critical questions will require both research experiments and careful on-farm observation of existing *A. albida*-associated cropping systems.

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