Alley farming for improving small ruminant productivity in West Africa: ILRI's experiences

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ALLEY FARMING FOR IMPROVING SMALL RUMINANT PRODUCTIVITY IN WEST AFRICA: ILRI'S EXPERIENCES

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Preface

This document contains a synthesis of most of the alley farming related research conducted during 1978 to 1993 by the ex-ILCA Humid Zone Programme based in the International Institute of Tropical Agriculture, Ibadan, Nigeria. Some of the research was done in collaboration with IITA; University of Ibadan; Obafemi Awolowo University, Ile-Ife; University of Science and Technology, Port Harcourt; Michael Okpara College of Agriculture, Owerri; Calabar Polytechnique, Abio Akpa Campus; all in Nigeria and Project Petit Ruminants, Atakpame, Togo. We very much appreciate the contribution of these institutions to the collaborative research projects.

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Most of the work synthesized here have been published in some form or another by the scientists who participated in the research programme over several years. The present authors are (were) among the most recent participants in the programme. Although scientists addressed perceived important problems of their times, in making the synthesis, we did not follow the sequence in which various research issues were addressed rather we tried to put together common issues under a theme irrespective of the time the research was conducted. Thus, the synthesis summarises the total stock of knowledge and experience gathered over a period of time. The main credit goes to the scientists who generated the knowledge and experience.

At various stages of the development of the document, very useful comments and suggestions on specific topics or chapters were received from colleagues Kwakwu Agyemang, Sherr Lebbie, Bernard Rey, James Smith, Paschal Osuji and Sagary Nokoe. M A Mohamed Saleem, Peter de Leeuw and Simeon Ehui have reviewed an earlier version of the document and provided many useful comments and suggestions. However, we alone are responsible for the content, views expressed and remaining errors. W/o Almaz Zewdie has diligently typed and edited many changes in the manuscript and deserves much appreciation.

The Authors

Executive summary

Background and objectives

Small ruminants are the principal type of livestock in the humid zone of West and Central Africa. Systems of management vary from free range in less populated to year round confinement and cut and carry feeding in densely populated areas. Long-term monitoring of village herds revealed diseases and undernourishment as major problems particularly with confined animals. This indicated the importance of better quality feed as small ruminant management under confinement have been increasing with increased population density and crop cultivation.

The Humid Zone Programme of ex-ILCA (now ILRI; henceforth any reference to ILRI will include ex-ILCA) was established in 1978 in Ibadan, Nigeria to undertake research for developing low cost interventions to improve animal nutrition and health as means to increase small ruminant productivity. Since small ruminants are a minor component of the crop dominated farm systems in the zone, it was envisaged that for better nutrition, a technology beneficial to both crop and livestock would have a better prospect for adoption.

At the time the HZP was established, International Institute of Tropical Agriculture (IITA) had developed alley cropping as a technology to improve soil fertility, control soil erosion and increase crop yields, thus eliminate or reduce the need for long fallow periods for fertility restoration. In alley cropping, leguminous tree prunings are applied as mulch during the crop season. So ILRI considered the possibility of using the non-crop dry season prunings and a part of crop season prunings as protein-rich feed supplement to traditional village diet to increase small ruminant productivity. ILRI called this alley farming and pursued a research programme with three main components: agronomic studies, on-station and on-farm, to modify alley cropping for using tree foliage as mulch and fodder; animal nutrition studies, on-station and on-farm, to determine animal response to browse supplementation and develop appropriate feeding strategies for utilizing limited feed supply; socioeconomic studies aimed at assessing the benefits of feed supplementation and identify factors related to potential for adoption. It may be noted that ILRI research addressed a specific niche within the broad framework of general agroforestry research pursued by IITA and International Centre for Research in Agroforestry (ICRAF).

Research approach

Alley farming essentially required integration of crop and livestock within the framework of household objectives, resources and production practices. Therefore, a systems approach was pursued in the research programme. Since adaptation of alley cropping for both crop and livestock was the primary focus, ILRI research was considered complementary to IITA's much broader research agenda on alley cropping. So some activities were pursued in collaboration with IITA. A number of education and research institutes in Nigeria and elsewhere were partners in several activities. Extension and development organizations were partners in on-farm research.

Highlights of research results

Agronomic studies

Germplasm evaluation: IITA's early work concentrated only on *Leucaena leucocephala* which was considered to be risky due to its susceptibility to psyllid insect. In order to diversify tree species, ILRI included *Gliricidia sepium* in its programme, evaluated 40 locally adapted lines along with 27 accessions collected from Costa Rica, and identified 4 best performing ones. These were crossed into a single composite high yield variety called High Yield Bulk (HYB). This and other best bet accessions from Oxford Forestry Institute were evaluated at 15 sites in West and Central Africa through a network coordinated by ILRI. Results showed marked variation in growth characteristics among accessions across sites indicating location specificity in the choice of accession and the need for adaptive research. Wide variation in palatability among accessions was also found.

Leucaena is generally established from seeds but *Gliricidia* used to be established from stakes which was cumbersome, labour demanding and less efficient in terms of survival rate. Method of propagation of *Gliricidia* from seed was developed along with method of collection, storage and treatment of seeds. Methods of establishing tree seedlings in arable crop fields and on established pasture were also developed.

Leucaena and *Gliricidia* performed well on alfisols and related soils where most of IITA and ILRI's early works were concentrated. Later these tree species were found to perform poorly on acid soils which cover a significant portion of the humid zone. Consequently two lines of action were pursued: (a) Lines of *Leucaena* suitable for acid tolerance were screened and accessions K28 and K150 were found to be the most promising. (b) Over 40 local browse species adapted to acid soil and used by farmers as browse were identified, then the methods of propagation, establishment and performance under intensive management of most commonly used species were studied. *Alchornea cordifolia* and *Rauwolfia Vomitoria* were found to be the best performing.

Trees and shrubs in alley farming systems: Research on integration of hedgerow species into alley farming involved studies on spatial and temporal management of hedgerows, utilization of prunings for mulch or fodder and the role of fallow in alley farming systems.

Best maize grain yields were received when hedgerows were spaced 4 meter apart with 4 rows of maize in-between. Maize grain yield was highest when 50% of each of 4 crop season prunings or the entire first two prunings were applied as mulch indicating diminishing returns from mulch application and the scope for using prunings as feed. These results were confirmed in on-farm trials.

A long-term trial showed that on alfisol alley cropping with or without a 2-year fallow improved crop yield through maintenance of higher organic matter and total nitrogen status than non-alley cropping. However, exchangeable potassium and available phosphorus status were higher in non-alley than alley plots. In all cases, a steady decline in soil nutrient status with period of cultivation was observed but such decline was slower in alley cropping with fallow indicating that even with alley trees, short fallow might be required to maintain long-term fertility of soil.

Rather than extracting prunings from alley crop fields to feed animals, intensive feed garden with only trees or tree and grass may be established. Suitable tree grass combinations, and their methods of establishment and management have been developed.

Animal nutrition studies

Controlling the effects of mimosine in Leucaena: *Leucaena is* highly productive and palatable but its unrestricted consumption may lead to death of animals because of high levels of toxicity due to its mimosine content. Based on experiences in Australia and the Pacific, successful studies were conducted to overcome the problems of toxicity by introducing rumen microbes able to degrade mimosine. Later a more novel technique was found in growing *Leucaena* and *Gliricidia* in alternate rows and offering them to animals in a 1:1 ratio to avoid the possibility of toxicity.

Response to supplementation: Generally food intake increased but grass intake decreased significantly as the level of supplementation in the diet increased. The main effects of supplementation were on growth and survival rates. At any level of supplementation, West African Dwarf (WAD) sheep were 1.7 to 2 times more responsive than WAD goats. Males grew faster than females. Supplementation at about 600 g DM per day for young animals and 800 - 900 gm per day for adults gave the best growth and survival rates. Beyond these levels, diminishing return ensued.

Feeding strategies: In order to maximize benefit from the limited quantities of available feed, specific types of animals may have to be fed at strategic times, in appropriate quantities and forms. Comparison of no supplementation and supplementation at late pregnancy, early lactation and late lactation showed that the time of supplementation of the mother had no significant effect on the growth of lambs and kids but lambs grew about twice as fast as kids and supplementation generally increased survival of lambs and kids. Supplementing a given amount of feed regularly at a low rate or less frequently at a higher rate produced fairly similar growth rates in sheep.

Comparison of supplementary *Leucaena* intake and utilization in fresh and dry forms showed that intake of fresh *Leucaena* was higher but utilization was similar as indicated by similar digestibility and Nitrogen balance. Growth rates were also similar for the two groups indicating that any surplus fresh material from wet season could be dried and stored for use in the dry season when quality feed is in short supply.

Comparison of voluntary intake of *Gliricidia sepium* in fresh, wilted and dried forms by sheep and goats showed that neither the form nor the level of supplementation had any significant effect on the intake of basal diet *Panicum maximum* in the case of sheep but both significantly affected *Panicum* intake for goats. Intake of *Gliricidia* in fresh and wilted forms did not differ but intake in both these forms were higher than in dried form. Intake increased linearly as the level of supplementation increased except in the case of sheep supplemented in dried form.

Long-term monitoring of browse-feeding and non-browse-feeding village flocks managed by farmers under actual farm condition showed that adult survival rate and herd productivity were significantly higher for browse feeders. No other production parameters differed significantly. Animal response to browse supplementation showed similar pattern as those found in various on-station trials.

Socioeconomic studies

Economics of alley farming

When maize yield without mulch and yield response to mulching were both low, economic gains could be made by feeding animals with part of the foliage. Using 50% of crop season prunings as mulch and the remainder of crop season and all of dry season prunings as fodder give the highest return from crop and livestock. When maize yield without mulch and yield response to mulching were medium to high, only half of dry season prunings could be profitably used as fodder because the loss of maize yield would be higher than the gain from animal liveweight increase. In this case, in order to make browse feeding competitive with mulching, required rate of animal liveweight gain were very high, not generally observed in the on-station and on-farm nutrition trials.

Three production system were compared using long-term experimental data: non-alley farming with a 2-year fallow after 4 years of cropping and no browse supplement for small ruminants, continuous alley farming where up to 50% of tree foliage is used as feed supplement, alley farming with a 2-year fallow period where up to 50% of tree foliage are used as feed in both crop and fallow years. Results showed that continuous alley and alley with fallow systems generated 46 and 16% more returns compared to non-alley farming. Without livestock feeding, continuous alley farming yielded 30% more returns compared to traditional and alley with fallow systems. Inclusion of livestock in alley systems increased return by 13–16%.

The sustainability of the above three systems were measured by intertemporal total factor productivity indices. The results show that the sustainability measures are sensitive to changes in the stock and flow of soil nutrients as well as to material inputs and outputs. Sustainability is enhanced by inclusion of small ruminant in all the systems, but most significantly in continuous alley farming.

On-farm studies and factors related to potential for adoption

In 1982, alley plots were established with individual farmers receiving direct assistance from researchers but other villagers remained unresponsive without similar assistance. So in 1984, a developmental research approach was adopted whereby farmers were approached through the community leaders and elders, the role and functional mechanism of the technology were explained and volunteers were sought for its testing. As a result of this approach, by 1991, 139 farmers in Southwest Nigeria established 175 alley plots or feed gardens and 109 farmers established 119 plots in Southeast Nigeria. Over these years, some farmers discontinued alley farming while others replanted after initial failure to establish trees. In all, they provided opportunities to validate the on-station results on biological performance of the technology and identify farm household and other socioeconomic factors that might determine the potential for adoption.

Choice of crop and foliage use in alley systems: On-station studies were conducted with sole maize as an ideal option. Researcher and farmer managed on-farm trials were also conducted with sole maize and various biological parameters were validated (see above). Inter-cropping is the normal practice on farms and 45% of the alley plots under full farmer management were intercropped with tubers (cassava and/or yam) and another 34% with a tuber plus another food crop. This indicated farmer preference and adaptation and the need for research on alley farming with intercrops.

Over 96% of the alley farmers reported using inorganic fertilizer on conventional plots but only 9% applied it to alley plots. Hence the value of mulch as a replacement for fertilizer is well recognized by farmers. Over 85% of farmers had used tree foliage as both mulch and fodder and the extent of use for mulch was higher indicating a higher priority for crop production. Alley farming was discontinued mostly due to problems of poor establishment and survival of trees in mixed or intercrop fields or due to weedy fields.

Labour needs: The total amount of labour required for crop production was not significantly different between alley and conventional cropping but the distribution of labour over the year did vary. Pruning and weeding operations overlap, creating competition for labour, and as the former is judged by farmers to require more skill and energy, obtaining additional labour for pruning appeared difficult. However, labour productivity under alley system was significantly higher because of significantly higher yields obtained with little additional costs. Therefore, alley farming should be attractive where land is scarce and labour plentiful.

Gender issues: Although most women farmed along with their husbands, and owned small ruminants, very few were independent farmers. Also women did not own land except when they became widows. Therefore, few independent alley farms would be expected to be established by women. Alley farms established by women on land given to them by their husbands were later discontinued when the land was taken back to use for other purposes. However, women had access to the alley trees of their husbands for cutting browse to feed animals irrespective of ownership. Participation of women in alley farming was important and this should be sought within the framework of the family and the farm business rather than separately.

Land and tree tenure: Land and tree tenure was found to influence adoption, continuation and discontinuation of alley farming. In Nigeria, most alley farms were planted on purchased or divided inherited land on which the user had full control, also most of the functional alley farms were found on such land while discontinued alley farms were found on less secured land. In Nigeria, Togo and Cameroon, purchased and divided inherited land were found to be better managed, fertilized and planted with commercial trees than land with less secured tenure indicating that alley trees would be planted in more secured land. In Nigeria, rights on alley trees planted on rented land were lost when rental contract was discontinued.

Diffusion, extension and multizonal research

Based on farmer enthusiasm at the early stage of on-farm research, the National Livestock Projects Division in Nigeria undertook a pilot project for diffusion of alley farming for small ruminant production in several southern states. FAO undertook a similar pilot project in Nigeria, Ghana and Togo. The actual number of alley farming adopters in these projects are not known.

IITA and ILRI's early research on alley farming was concentrated in Nigeria. In order to test its adaptability and adoptability in different environments and regions, IITA, ICRAF and ILRI jointly established the Alley Farming Network for Tropical Africa (AFNETA) in 1989. AFNETA is now conducting research and training on various aspects of alley farming in over 20 African countries.

Conclusions

The biological benefits of alley farming for crop and livestock have been amply demonstrated by on-station and on-farm research particularly in the geographical areas where research on alley farming received most attention. However, farmer adoption still remains low mainly around the on-farm research areas. Large scale adoption presupposes that a technology is available, a formal or informal mechanism for diffusion is in place to take the technology where it has a role to play (e.g. where soil fertility and feed are problems). Moreover, potential adopters should have adequate knowledge about the technology, its functional mechanism, short and long-run benefits, adaptability to the resource endowment and farming system, its pay-off period and profitability.

The analyses in this study suggest that alley farming is a profitable and sustainable technology. Significant economic gains can be obtained by integrating small ruminants into alley farming. However, alley farming is a fairly complex technology. Farmers familiar with plantation crops and with management of trees under bush-fallow systems may find it easier to adapt alley farming. Yet significant amount of time may be required to learn several innovations in relation to planting and establishing trees within arable farm, their management for mulch and fodder, cutting and carrying feeds for animals, and altering land use and rotation patterns. The learning-adoption process is likely to be slow. Trees are more likely to be planted for mulching, crop being the priority enterprise, with subsequent diversification to feeding. The economic value of browse will be much appreciated if a market oriented activity such as fattening small ruminants for festivals and urban markets, and diary cattle production is pursued. These kinds of specialist activities need to be identified for specific locations and zones. Special educational and promotional activities may reduce the innovation lag as well as make it available to the resource poor farmers, who under normal circumstances, may not have adequate access to the technology.

More research, both biological and socioeconomic, by international and national research systems will be required to develop alley farming as a robust technology adaptable to diverse conditions. Wider choice of tree species suitable for different soil-climate and for different purposes is a priority research area. The generation and diffusion process should be, to a certain degree, simultaneous because much fundamental biological knowledge is already available. On-farm research has an important role in the technology generation diffusion process. Best practice technology on-station rarely performs at that level in actual farm conditions. Adaptive research results in a steady accretion of innumerable minor improvements and modifications. Since research should be aimed at solving farmers' problems, involving farmers and extensionists at the early stage of research, rather than waiting for them to be passive recipients at some future date, may yield many advantages in relation to diffusion. This position is supported by the experiences of ILRI's on-farm research in Nigeria and the research activities of AFNETA across several countries in Africa.

1. Background and objectives

The humid zone of Africa with over 1500 mm annual rainfall covers 4.1 million km², including coastal West Africa, much of central Africa, eastern Madagascar and part of Mozambique. Livestock production in 90% of the zone is restricted by trypanosomiasis, a blood parasitic disease carried by tsetse flies, hence trypanotolerant livestock breeds predominate. There are about 19 million small ruminants and 8 million cattle in the zone, of which about 9 million small ruminants are in the humid zone of Nigeria alone (Jahnke, 1982; ILCA, 1985; McIntire, *et al.*, 1992).

The typical farm family in the zone comprises 6 to 8 people, cultivating 2 to 4 ha of land and owning 3 to 5 small ruminants. Although small ruminants are a minor farm enterprise, it is frequently a source of cash for special needs of poor families, in addition to its other social and economic functions (Jabber, 1995). Systems of management of small ruminants vary from free ranging in sparsely populated areas to all year confinement in densely populated areas. For example, in less densely populated southwest Nigeria, animals are generally free roaming while in more densely populated southeast Nigeria, 25–35 percent of the owners confine animals all year and another 5-6 percent confine seasonally (Mosi *et al.*, 1982, Mack, 1983; Francis, 1988). The size of flock is smaller in confined than in free roaming herds. Labour for collection and carrying of feed, and the availability of housing space appeared to be the main constraint on animal numbers (Francis, 1988).

Long term monitoring of village herds in southern Nigeria revealed diseases and undernourishment, particularly in the dry season when quality of feed is poor, as main problems for improving productivity. Sarcoptic mange and Peste des Petit Ruminants (PPR) were found to be the major diseases accounting for respectively 43 and 16% morbidity in goats. Seventy per cent of all animals suffering from PPR died (Mosi *et al.*, 1982; Mack, 1983). Overall productivity was generally low, and lower for goats than for sheep (Table 1.1). With PPR control using Tissue Culture Rinderpest Vaccine (TCRV) and ectoparasite control through dipping, overall productivity of goats increased to the level of sheep without PPR control.

Table 1.1 *Productivity of West Africa Dwarf sheep and goats with and without PPR control in southern Nigeria.*

Production parameter	Southwest			Southeast
	Sheep	Goats	Goats	Goats
Treatment: PPR control + dipping	No	No	Yes	Yes
Parturition interval (days)	322	259	272	295
Litter size	1.23	1.49	1.65	1.30
Birth weight (kg)	2.12	1.57	1.61	1.23
Survival to 90 days	0.84	0.77	0.86	0.73
Survival to 12 months	0.70	0.52	0.65	0.41
Daily weight gain to 90 days (g)	74	35	46	40
Productivity index (kg/year)[a]	10.28	6.64	10.71	5.67

a. Productivity index = kg offspring weaned at 90 days/dam/year.

Source: Mosi *et al*. (1982); Mack (1983); Adeoye (1985).

Animals in the southeast were less productive than in the southwest primarily due to dietary differences. Since a significant proportion of the animals in the southeast were tethered and confined, they did not have the same freedom to select diet as their southwestern counterparts (Carew, 1982; Mack, 1983). This indicated the importance of better quality feed as increased population density and crop cultivation forces farmers to raise small ruminants under confinement.

West African Dwarf (WAD) goats and sheep found in the region are considered trypanotolerant. A study on the interaction between nutrition and trypanotolerance showed that undernourished animals were more susceptible to trypanosomiasis infection as evidenced by lower survival rates among both adults and lambs, depressed food intake and weight loss, and lower birth weight of lambs (Murray et al., 1982; Reynolds and Ekwuruke, 1988; ILCA, 1987). Thus better nutrition increases resistance to the effects of trypanosomiasis and other diseases, and enhances productivity.

The former International Livestock Centre for Africa (ILCA) (now ILRI, henceforth reference to ILRI will include ex-ILCA) established its Small Ruminant Programme (subsequently called Humid Zone Programme) in 1978 at Ibadan, Nigeria, near the boundary between the humid and derived savanna zones, to undertake research on developing low cost interventions to improve animal health and nutrition as a means to increase small ruminant productivity. The nutrition aspect of research was concentrated on providing cut- and-carry fodder from leguminous trees such as *Leucaena leucocephala* and *Gliricidia sepium* as supplementary feed. Leguminous trees were chosen as a feed resource for three reasons.

First, as tropical grasses mature, they become less palatable because the lignin content rises and cell wall contents fall. During the dry season crude protein (CP) levels in standing hay may fall below 7% which limits intake (Minson, 1980). The CP level in leguminous browse ranges from 15–30% and is maintained through the dry season so browse helps to maintain the overall intake and quality of diet in the dry season (Le Houerou, 1980; Carew *et al*., 1981).

Second, farmers in the humid zone of west Africa cut browse from the bush to feed small ruminants. Browse constitute about 25% of diet of small ruminants raised under confinement (Francis, 1988). Potential for adoption of cultivated browse was considered to be high because a new technology is accepted more readily when an existing less productive technology is replaced rather than when a completely new technology is offered (Mahajan and Peterson, 1985; Thirtle and Ruttan, 1987).

Third, at the time of establishment of the ILRI humid zone research programme, the International Institute of Tropical Agriculture (IITA) had already developed alley cropping which is an agroforestry system in which crops are grown in alleys formed by leguminous trees and shrubs. The hedgerows are periodically pruned and the pruning is applied as mulch for improving soil fertility, controlling erosion and increasing crop yields as well as eliminating or at least drastically reducing the need for long periods of fallow for fertility restoration as required under traditional bush fallow system (Kang *et al*., 1981; Kang et al., 1984). Mulching is required only in the crop season and mulch applied during the later part of the crop season benefit crop very little. So, ILRI proposed that part of the crop season prunings and all of the non-crop dry season prunings could be used as protein rich feed supplement to traditional village diet to increase small ruminant productivity. If alley crop fields were located far away from the household requiring significant amount of labour time for regular collection of feed, intensive feed gardens with leguminous trees could be planted near the homestead only for feeding animals. Thus within a farm, tree-crop and/or tree for only forage plots could be established to benefit both crop and livestock enterprises and increase overall farm productivity and income. ILRI called the system alley farming (ILCA, 1983; Okali and

Sumberg, 1985).

With this background, ILRI pursued a programme of research on alley farming in three areas: (a) agronomic studies to modify IITA developed alley cropping for use of tree foliage both as mulch and fodder and to find best methods of producing tree foliage in intensive feed gardens, (b) animal nutrition studies aimed at evaluating tree species for their feed value, finding animal response to feeding and develop appropriate feeding strategies, (c) socioeconomic studies aimed at identifying factors related to potential for adoption of alley farming.

Initially, on-station agronomy and animal nutrition studies were conducted. Then on-farm research was conducted to test the biological adaptability and to identify socioeconomic factors affecting adoption. Most of the on-station and on-farm research by both ILRI and IITA were conducted in the humid zone of Nigeria, which represent a small proportion of humid tropical Africa where soil degradation, erosion and poor quality animal feeds are major problems. There is also a high degree of diversity within humid tropical Africa in relation to resource endowment, physical, environmental and socioeconomic conditions. In order to verify and test the suitability of alley farming as a potential solution to the problems of this vast diverse region, need for adaptive research in different environments across the continent was felt. To that end, IITA, ILRI and ICRAF (International Centre for Research in Agroforestry) jointly sponsored the establishment of the Alley Farming Network for Tropical Africa (AFNETA) in 1989. AFNETA has completed the first phase of adaptive research activities in 20 countries in sub-Saharan Africa and is now in the second phase with expanded research agenda and more countries involved.

Although on-station and on-farm studies have shown the benefits of alley farming in terms of crop yield, soil improvement and animal performance, the rate of adoption of the technology remains low and slow. IITA recently noted that positive results from research station experience over many years are difficult to reproduce under actual farms conditions (IITA, 1992). ICRAF has also made a review of alley cropping/hedgerow intercropping research issues and methodology and concluded that (a) potential benefits of this technology in some station based research might have been over estimated due to inherent experimental design problems (Coe, 1994), (b) existing knowledge was insufficient to recommend the technology to sites with acid soil, low moisture and low soil fertility because of problems of tree establishment, and (c) previous research has placed undue emphasis on the timing of nitrogen release from mulch and on the demand for it by the alley crop, ignoring the negative effects of tree-crop interaction for above - and below ground resources (Ong, 1994).

The objective of this document is to synthesize the results of over a decade of agronomic, nutritional and socioeconomic studies done by ILRI on alley farming in West Africa, particularly in Nigeria, so that important lessons learned in the process are documented in a comprehensive manner for their relevance to the specific geographical region and beyond. The next four chapters will deal with agronomic, nutritional and socioeconomic studies. Conclusion will be drawn at the end.

2. Agronomic studies

2.1 Introduction

During the early years of IITA's alley cropping research, *Leucaena leucocephala (L. leucocephala)* was used as the primary tree species (Kang *et al*. 1981; Kang *et al.*, 1984). Experiences from southeast Asia (Gray, 1968; NAS, 1977; Jones, 1979) indicated the good potential of *Leucaena* as a planted forage. However, in trying to modify alley cropping for incorporation of livestock, ILRI decided to diversify tree species because in southeast Asia, *Leucaena* was found to be susceptible to psyllid insect (*Heteropsylla cubana*), so dependence on a single species for either mulch or fodder or both mulch and fodder was considered to be highly risky for smallholder farmers and this would have implications for adoption of the technology.

To this end, *Gliricidia sepium (G. sepium*) was chosen because it was already adapted to the local environment and was extensively used as a fence or shade tree in cacao fields. Its value as feed was not well known. Subsequently, it was observed that although *Leucaena* and *Gliricida* performed well on alfisols and related soils, they did not perform well on acid soils which cover a significant portion of the humid zone (Kang *et al*., 1984; 1990). On the other hand, several indigenous browse species well adapted to local environment including acid soils were used by farmers, but some of these species were disappearing from the natural range due to over exploitation, and quantitative information on their performance under planted and managed conditions were not available (Reynolds and Atta-krah, 1987).

Agronomic research on alley farming were conducted on two major themes: multipurpose fodder tree and shrub species evaluation and, their integration into production systems to assess their impact on soil fertility and crop production.

2.2 Fodder trees and shrubs germplasm evaluation

2.2.1 Collection and evaluation of *Gliricidia sepium*

In 1983, forty lines of *G. sepium* were collected in Ibadan-Oyo-Ife area of southwestern Nigeria and evaluated (Reynolds and Atta-Krah, 1986). Variations among accessions in several growth characters were observed. In order to evaluate broader array of *G. sepium germplasm*, a collection of *G. sepium* germplasm from Costa Rica, where the genus originated, was organized by ILRI in collaboration with Centro Agronomico Tropical de Investigation Y Ensenanza (CATIE). A description of the collection and initial evaluation of the Costa Rican materials was reported by Sumberg (1985a). In that study, four accessions consistently outyielded the local Ibadan *G. sepium* accession by an average of 30% over six prunings. These high yielding accession were subsequently crossed to a single composite accession identified as "High Yield Bulk (HYB)" (Atta-Krah, 1989).

Best-bet accessions of *G. sepium* collected by the Oxford Forestry Institute and HYB were evaluated at 15 sites in ten West and Central African countries through a network coordinated by ILRI (Atta-Krah, 1989). Results showed marked variation in growth characteristics among accessions across sites.

The entire *G. sepium* collection (Table 2.1) was evaluated in Burkina Faso, Mali and Nigeria (ILCA, 1989). At Ibadan, edible dry matter (DM) production ranged between 3 to 6.5 t ha^{-1}, over a period of two years, with three prunings per year (Cobbina and Atta-Krah, 1992). *Gliricidia sepium* accessions ILGs 55, 58, 59 and HYB significantly outyielded the local variety ILG 50 (Fig. 2.1). The wide variation in production characteristics among the *G. sepium* accessions indicated a scope for development of improved cultivars through selection and breeding.

Table 2.1. *Accessions of* Gliricidia sepium, *country of origin, altitude (m) and annual rainfall (mm) of collection sites.*

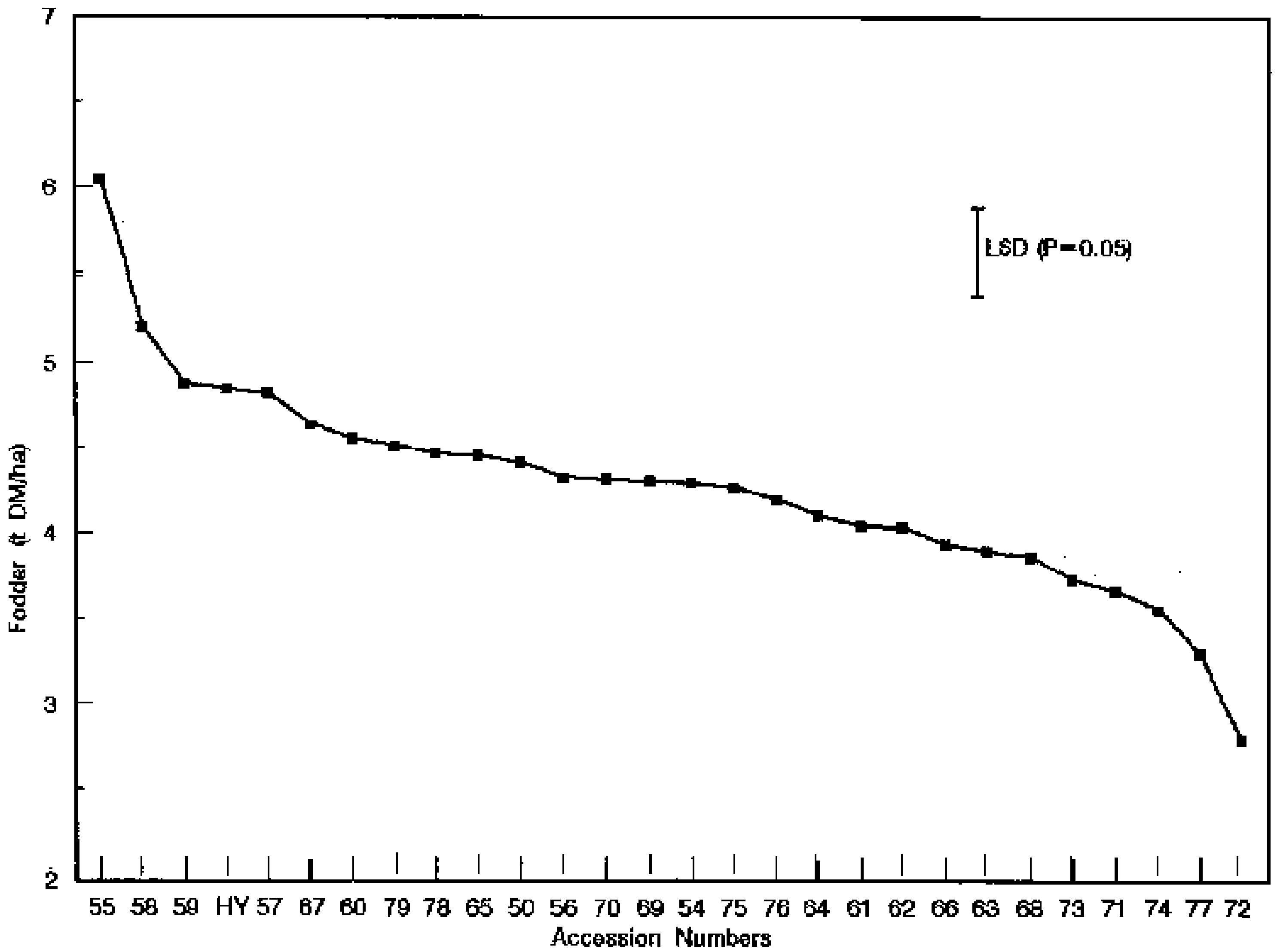
Accession No[1]				
ILCA	OFI	Origin	Altitude	Rainfall
50	–	Nigeria	160	1500
54	13/84	Guatemala	950	1060
55	14/84	Guatemala	330	3500
56	15/84	Guatemala	150	700
57	16/84	Guatemala	450	830
58	17/84	Guatemala	5	1650
59	24/84	Honduras	480	1400
60	25/84	Honduras	825	1100
61	29/84	Nicaragua	220	1200
62	30/84	Nicaragua	605	800
63	31/84	Nicaragua	60	1100
64	33/85	Mexico	1100	650
65	34/85	Mexico	10–50	1130
66	35/85	Mexico	10–30	950
67	36/85	Mexico	100–150	1500
68	37/85	Mexico	600–700	1030
69	38/85	Mexico	0–30	900
70	39/85	Mexico	30	1400
71	40/85	Mexico	30	1796
72	41/85	Mexico	60–100	905

73	1/86	Venezuela	520	800
74	10/86	Honduras	450	1200
75	11/86	Costa Rica	20–100	1000
76	12/86	Costa Rica	20–100	1000
77	13/86	Panama	5–10	850
78	14/86	Nicaragua	75	1650
79	24/86	Colombia	20–50	950
HYB[2]	–	Costa Rica	–	160

1. Accession number: ILCA= International Livestock Centre for Africa; OFI=Oxford Forestry Institute.

2. HYB: Composite of four Costa Rican accessions.

Source: Cobbina and Attah-Krah(1992).



Rapid methods of estimating foliage yield of intensively managed *L. leucocephala* and *G. sepium* were investigated by Sumberg (1985b). Branch diameter was less accurate in predicting foliage yield. Fresh foliage yield (FY) could be accurately predicted from the fresh weight of the intact branch (BW) aged 4 –16 weeks, using the following equations:

L. leucocephala,	FY = 14.78 + 0.47BW,	r^2 0.93
G. sepium,	FY = 11.18 + 0.43BW,	$r^2 = 0.89$.

Although *G. sepium* had been used in West Africa for several years, no disease of the plant had been identified. A survey on farms in southern Nigeria organized by ILRI (Lenne and Sumberg, 1986) detected two foliar diseases of *G. sepium*, *Collectotrichum gleosporiodes* and *Cercosporidium gliricidiasis*. *Collectotrichum gleosporiodes* was more frequent than *C. glirdiasis.*

Traditionally, *G. sepium* had been established from stakes with limited information on flowering and seed production. Seed collection had not been previously considered because, on drying, mature pods split, scattering the seeds, making collection difficult.

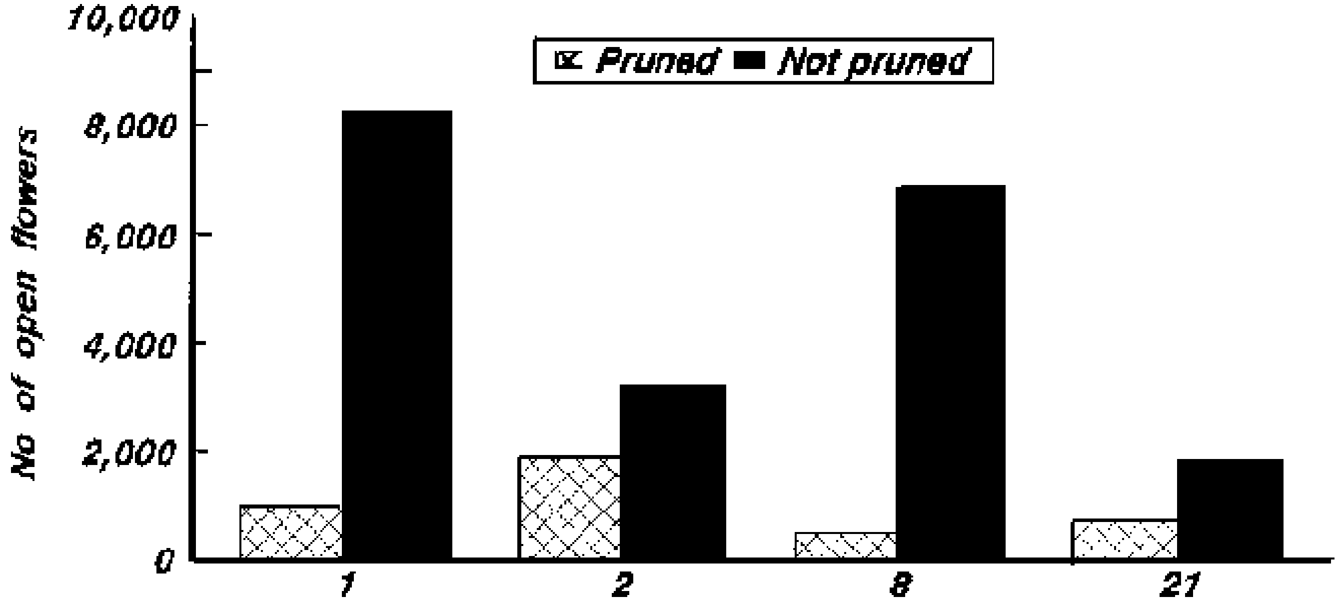
Studies on flowering and seed production characteristics at Ibadan, showed that effective flowering and fruiting period for *G. sepium* is between November and March (Sumberg, 1985c; Atta-Krah and Sumberg, 1988). Although many flowers are produced, most trees set relatively few pods (Table 2.2). Pruning delayed flowering and reduced seed yield (Fig. 2.2), because. *G. sepium* flowers and set seed on mature wood, but not on young shoots. The response of flowering and seed yield to pruning varied among accessions. *Gliricidia sepium* seeds could be collected from mature green pods and sun dried (Sumberg, 1984).

Table 2.2. *Range, mean and coefficient of variation (CV, %) for flowering and seed production variables among 20 sample* Gliricidia sepium *trees at Ibadan, southwestern Nigeria.*

Variable	Range	Mean[1]	CV
Total racemes/plant	16 – 633	312	67
Set racemes/plant	0 – 219	74	87
Raceme set (%)	0– 46	22	54
Buds/raceme	18 – 40	26	20
Pod/raceme	1 – 2	1	18
Pod set (%)	4– 9	6	23
Seeds/pod	3 – 5	4	16
Seeds/plant	0–1442	420	96
Days to maturity	37 – 45	41	8

1. Includes only trees which set pods, n = 18.

Source: Sumberg (1985b).



Source: Atta-Krah and Sumberg (1988).

2.2.2 Screening *Leucaena leucocephala* for acid tolerance

In an attempt to test adoptability of the alley farming and intensive feed garden agroforestry technologies, ILRI introduced *Leucaena leucocephala* in southeastern Nigeria in 1980. Growth of the *L. leucocephala* variety used was poor and variable due to the acidic soil conditions. The soil acidity problem could be solved by applying lime, and phosphorus separately or in combination. Liming being too expensive for smallholder farmers to use, selection of accessions with acid tolerance was considered a simpler and less expensive solution.

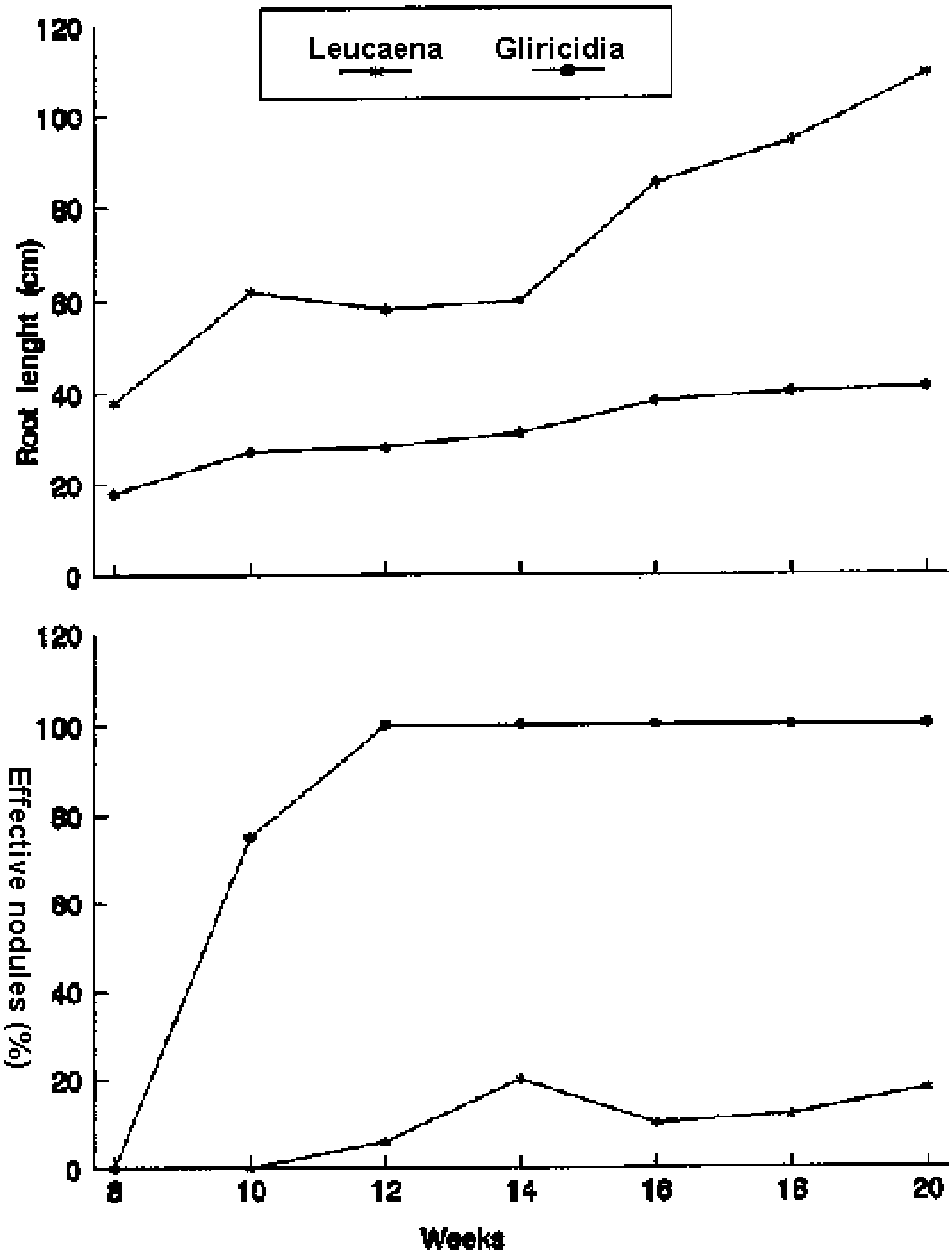
A trial was conducted on an Ultisol in southeastern Nigeria to screen *L. leucocephala* accessions for acid tolerance (Cobbina *et al.*, 1990). Accessions K28 and K150 produced 6.8 and 5.8 t DM ha^{-1} respectively, and were the most promising of six accessions evaluated.

2.2.3 Establishment of *Leucaena* and *Gliricidia* hedgerows

On alfisols and related soils, *L. leucocephala* and *G. sepium* are the most promising hedgerow species (Kang *et al*., 1990). They can be established by direct seeding in association with growing crops (Kang *et al*., 1984). However, on-farm observations showed variable establishment success of *L. leucocephala* and *G. sepium* hedgerows when established with arable crops (Atta-Krah and Kolawole, 1987). This was due in part to the different degree of shading by various associated crops (Atta-Krah and Francis, 1989). Results of experiments conducted on-farm and on-station attributed the poor and variable establishment of the species to low soil organic matter and nutrient status and, absence of effective strains of Rhizobia for nodulation and nitrogen fixation (ILCA, 1988; Cobbina *et al*., 1989a; Cobbina, 1991). These studies suggest that on-farm establishment of *L. leucocephala* and *G. sepium* hedgerows can be improved by application of fertilizer phosphorus and nitrogen, and inoculation with effective strains of Rhizobia.

Inter-species variation in establishment could also be related to morphological differences in below and above ground characteristics responsible for resource acquisition. Experiment conducted on an Alfisol, to study root and shoot growth during early development by Ezenwa and Atta-Krah (1990) showed emphasis on development of lateral roots and active nodules in *G. sepium* (Fig. 2.3a). In contrast, the emphasis in *L. leucocephala* was on tap root elongation (Fig. 2.3b). The early development of tap root in *L. leucocephala* could be a strategy to safeguard against drought. Thus, *G. sepium* can be readily established in soils with low native nitrogen status because of the plant's early effective nodulation, while *L. leucocephala* could survive drought during early growth.

Fig. 2 3. *Development of tap root length and effective nodules In* Leucaena Leucocephala *and* Gliricidia sepium *during early growth.*



Source: Ezenwa and Atta-Krah (1990).

2.2.4 Collection and evaluation of indigenous fodder species

Because very few *L. leucocephala* and *G. sepium* accession were adapted to acid soils, ILRI conducted surveys in collaboration with three national agricultural research institutes to identify and collect browse species fed to small ruminants in southeastern Nigeria in 1986 (Reynolds and Atta-Krah, 1987). More than forty species were identified and collected.

The surveys revealed paucity of information on germination and establishment of the indigenous species. This information was needed in order to study the growth and performance of the species under cultivation. Subsequent propagation studies showed that seeds of *Alchornea cordifolia Dialium guineense, Harungana madagascariensis* and *Dactyledenia barter)* germinated without scarification (ILCA, 1989). Seeds of several other species needed to be scarified either with hot water or concentrated sulphuric acid. Many of the species, especially *D. barteri, A. cordifolia, Baphia nitida, Ficus capenses, Macaranga barteri* and *Mannniophytum fulvum*, sprouted readily from stem cuttings. Cuttings from basal and middle sections of stems sprouted better than those from the apical section. *Macrodesmis puberula,* a very palatable species, was difficult to germinate. Further studies on its propagation and establishment are needed.

Following successful establishment of some species, fodder production and nutritive value of those identified to have potential for development of agroforestry technologies were evaluated (Cobbina *et al*., 1990; Larbi *et al.*, 1993a). This line of research complemented multipurpose tree evaluation research of ICRAF and IITA which do not emphasize livestock feed aspects. The research also developed options for alley farming and intensive feed gardens on acid soil in humid West Africa with indigenous species which are adapted to the environment and well known to farmers.

The productivity and nutritive value of some indigenous species on acid Ulfisols in southeastern Nigeria were comparable to *L. leucocephala* and *G. sepium* (Table 2.3). Further studies are currently being undertaken to investigate seasonal effects on fodder production and nutritive values (ILCA, 1994).

Table 2.3. *Edible forage production (kg DM ha^{-1}) and concentrations (g kg^{-1} DM) of crude protein (CP) and neutral detergent fibre (NDF)* Gliricidia sepium *and some indigenous multipurpose fodder tree and shrub species on acid soil in southeastern Nigeria.*

Species	Yield[1]	CP	NDF	Reference[2]
Gliricidia sepium	1687	225	–	1
Albizia adianthifolia	582	233	–	1
Alchornea cordifolia	3320	170	500	1
Diallum guineense	1400	130	370	2
Baphia nitida	1000	210	360	2
Homalium aymeri	800	120	380	2
Glyphea brevis	860	190	520	2
Rauwolfia vomitoria	1800	180	530	2
Manniophytum fulvum	1620	110	130	2

1. Mean of three prunings from 2–3 year old trees.

2. Reference : 1. Cobbina *et al.* (1990); 2. Larbi *et al*. (1993a).

2.3 Fodder trees and shrubs in alley farming systems

ILRI considered two forms of alley farming systems for producing feed: tree-crop system and intensive feed garden. Research on integration of hedgerow species into alley farming involved studies on spatial and temporal management of hedgerows, response to fertilization, utilization of hedgerow prunings for mulch or fodder and comparison of different alley farming systems with other systems.

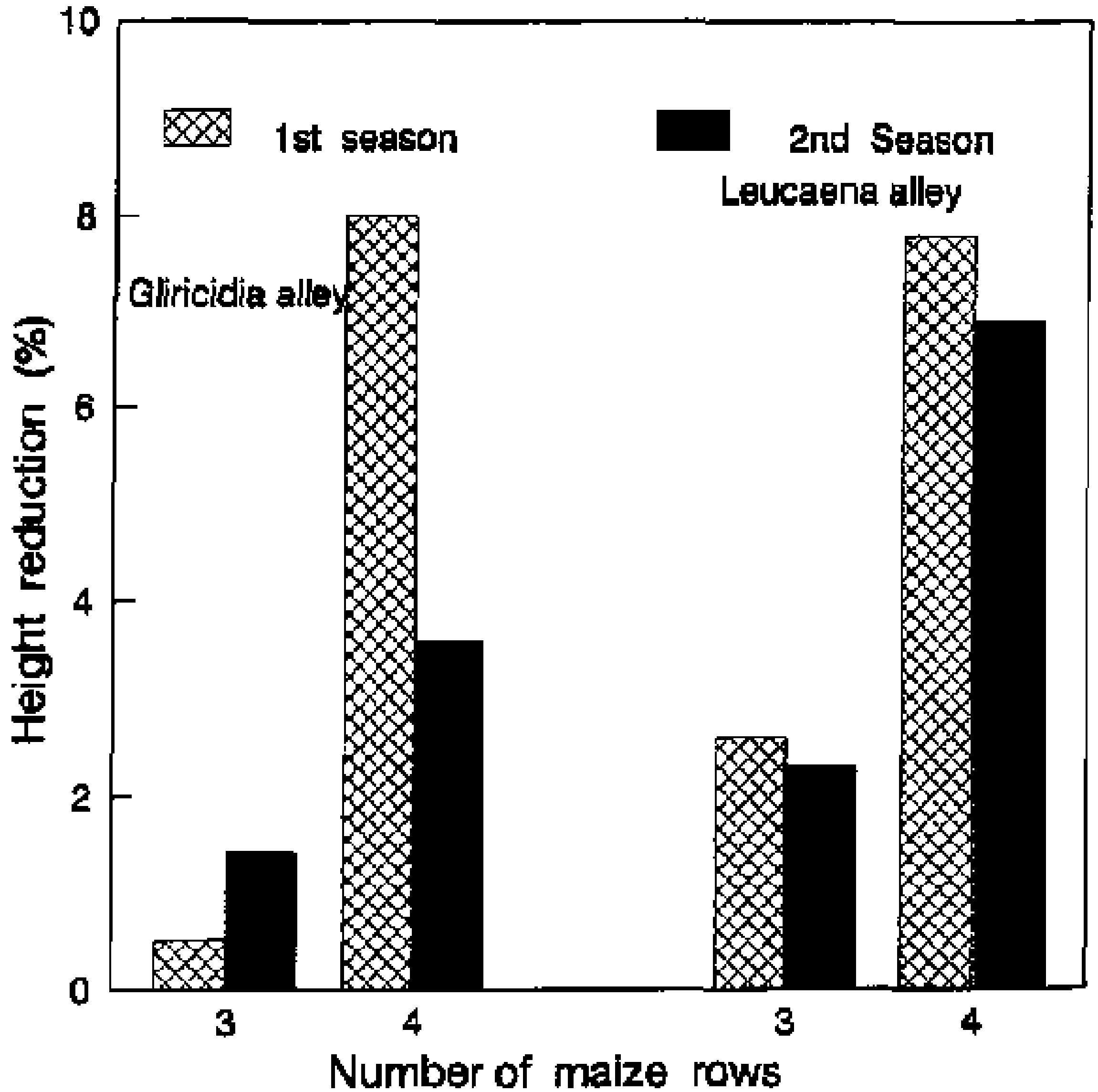
2.3.1 Tree-crop interactions

Crop productivity in alley farming depends upon availability of resources (water, light and nutrients) and the competition between hedgerow species and crops for these resources. Hedgerow shading reduce yield of associated crops, particularly those grown adjacent to the hedgerow. The effect varies with hedgerow species, pruning regimes and spatial arrangement of crops in the alleys.

The effect of competition between maize and *L. leucocephala*, and maize and *G. sepium* hedgerows spaced 4 m apart was studied by planting either 3-rows or 4-rows of maize in the alleys using the same planting density (Atta-Krah and Sumberg, 1988). Inter-species competition between maize and tree rows was higher in the 4-rows than the 3-rows arrangement. This resulted in height reduction of maize plants in external rows compared to plants in the middle rows (Fig. 2.4). The height reduction in the 3-rows arrangement was greater in *L. leucocephala* than *G. sepium* hedgerows, probably due to the faster and more vigorous growth of *L. leucocephala*. Maize grain yields in the 4-rows were greater than 3-rows arrangement by 5% and 21% in the *L. leucocephala* and *G. sepium* hedgerows respectively. [1]

> 1. ILRI considered tree-crop competition an important researchable issue, but further research on this was not pursued because such fundamental issues were considered the domain of IITA and ICRAF. Both of these institutions are recently giving priority attention to this issue (Ong, 1994).

Fig. 2.4. *Effect of number of maize rows between* Leucaena leucocephala *and* Gliricidia sepium *hedgerows on height reduction of maize plants adjacent to the hedgerow compared to maize plants in the middle maize rows, on an Alfisol at Ibadan, southwestern Nigeria.*



Source: Atta-Krah and Sumberg (1987).

2.3.2 Proportion of hedgerow prunings as mulch on crop and soil

In alley farming hedgerow prunings can either be used as mulch to maintain soil fertility and subsequent crop yields or as livestock feed. Therefore there was need to develop management strategies to ensure that farmers get the most benefit from the system while maintaining its sustainability.

An trial was conducted on-station and later on-farm on an Alfisol to study the effect on maize grain yield of removing various proportions of tree foliage from *L. leucocephala* and *G. sepium* hedgerows as cut-and-carry feed for livestock (ILCA 1989). After three years of alley cropping, maize grain yield, soil organic carbon, total nitrogen and available phosphorus status of surface soil (0–15 cm depth) increased as the percentage of total hedgerow pruning applied as mulch increased from zero to hundred. The following linear relationships were observed in the on-farm trial for rates of mulch application (X) as the independent variable:

Organic carbon (%)	= 0.708 + 0.003X,	R^2 = 0.99;
Nitrogen(%)	= 0.762 + 0.002X,	R^2 = 0.89;
Phosphorus (meq/100g)	= 9.35 + 0.103X,	R^2 = 0.99.

As shown in Table 2.4, maize grain yields followed similar trends, probably in response to the differences in soil organic carbon and nutrient status. In these trials, the incremental increase in maize grain yield obtained when more than half the foliage was applied as mulch was relatively small, suggesting that half the foliage may be removed as feed if the economic benefits of feeding exceed the value of crop foregone (see section 4 for economic analysis).

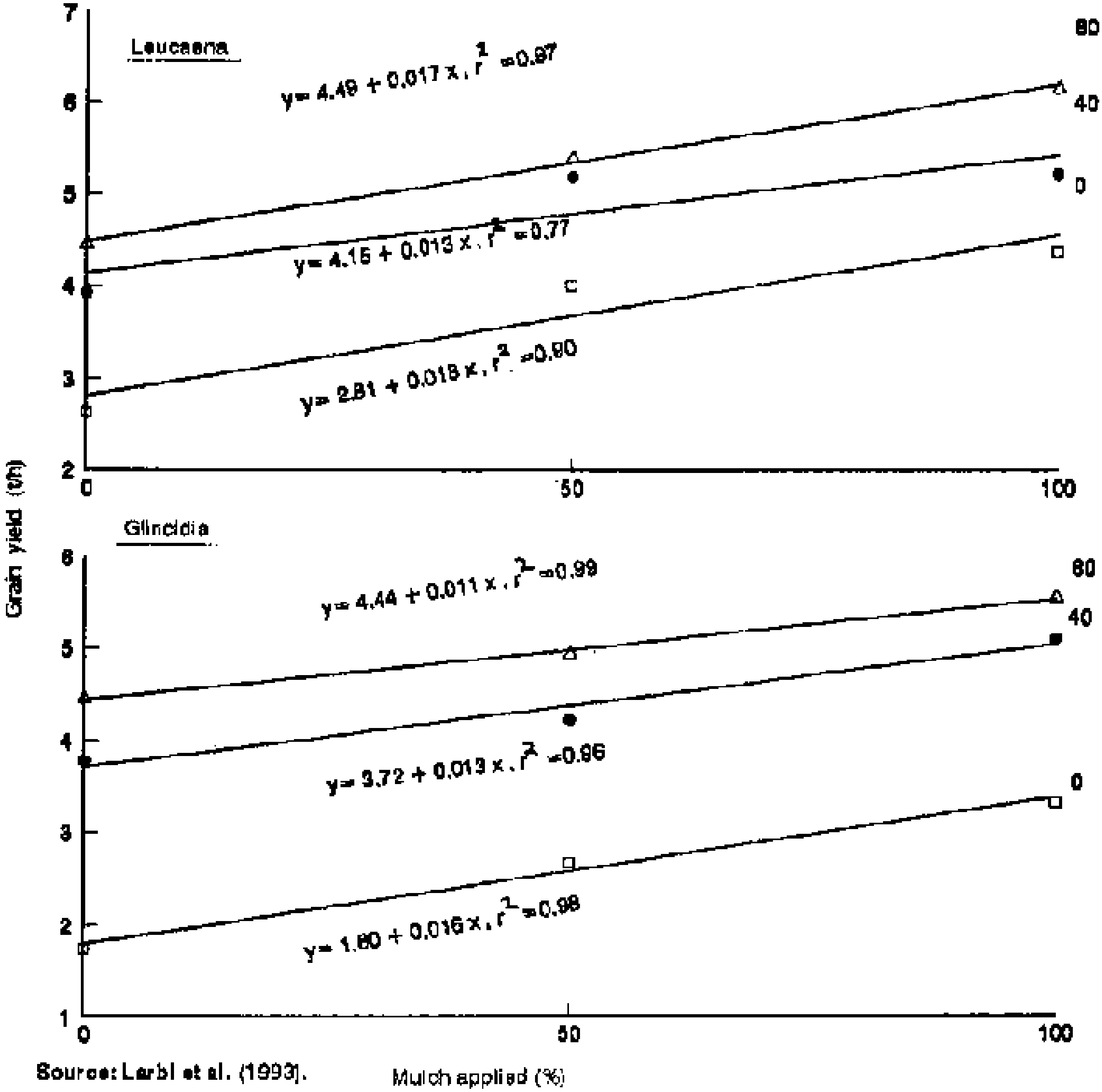
Table 2.4. *Effects of proportion (%) of total hedgerow prunings from* Leucaena leucocephala *and* Gliricidia sepium *hedgerows applied as mulch on maize grain yield (t ha^{-1}) on an Alfisol, on-farm, southwestern Nigeria.*

% Pruning applied[1]	Year		
	1988	1989	1990
0	1.20	2.09	1.76
50	2.15	3.12	2.09
100	3.04	3.63	2.19
SE	0.19	0.28	2.3

1. 0% = No mulch, 50% = 3.9 t ha^{-1} and 100% = 7.9 t ha^{-1}.

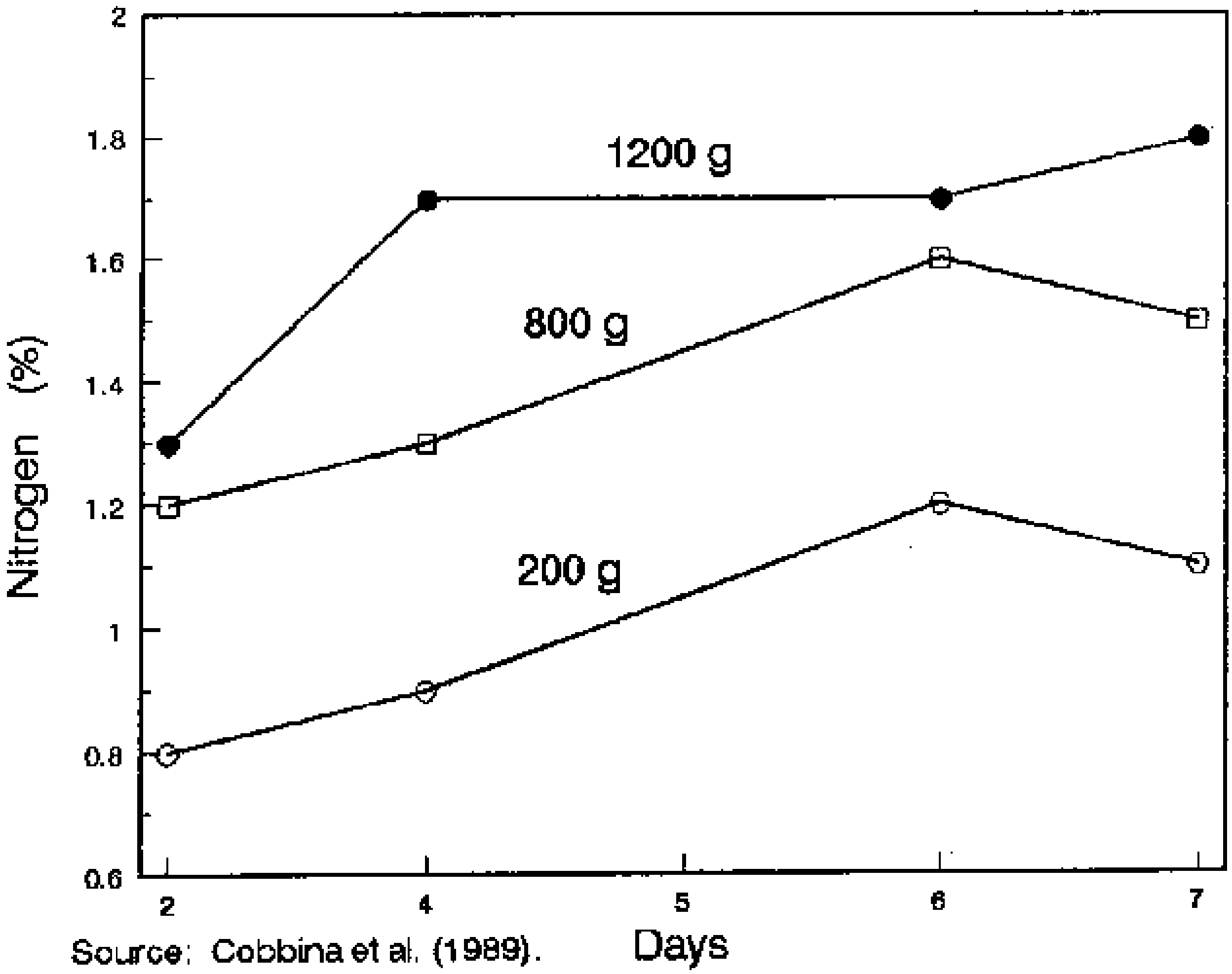
Source: Larbi *et al.*, (1993b).

When prunings were supplemented with fertilizer nitrogen in an on-station trial, higher grain yields were maintained even at the highest level of hedgerow pruning application (Fig. 2.5, Larbi *et al.*, 1993b). These observations confirmed that some external input in the form of organic or inorganic fertilizer may enhance crop yields under alley cropping (Evensen *et al.,* 1991). As chemical fertilizers are expensive and not readily available, poor farmers may take advantage of this complementary relationship only after gaining experience about the potential benefits of alley farming. Sanchez *et al*. (1995) recently proposed mulch-inorganic fertilizer interaction as a priority research area for developing strategies to replenish soil fertility in sub-Saharan Africa, but they recognise that the practical value of this interaction may be derived only at higher level of nitrogen application.



Source: Larbi et al. (1993).

An alternative is to feed the hedgerow prunings to animals and use organic manure as fertilizer. Increasing leguminous fodder supplementation in the diet improved agronomic value of sheep and goat manure (Fig. 2.6). The actual effect of mulch-manure or manure-fertilizer interaction was not studied. However, the practical problem of using small ruminant manure for crop production in the humid zone is the limited quantity available per farm. It may be noted that small ruminant manure and household wastes are intensively used in home garden.



Source: Cobbina et al. (1989).

2.3.3 Number of prunings as mulch on crop and soil

The response of a crop to hedgerow prunings applied as mulch could vary with stage of growth of the crop at which mulch is applied. In the humid zone of southern Nigeria, hedgerow species in alley farming can be pruned three times between planting and harvesting of maize crop. The first pruning is applied as mulch when the food crop is planted, the second at the time of tasseling (6–8 weeks later) and the third at the hard dough stage, as the plant approaches senescence.

A trial conducted on an Alfisol in Ibadan showed that, in unfertilized plots, the first pruning had the greatest effect on maize grain yield (Table 2.5). The second and the third prunings added very little to the grain yield obtained from the first pruning. This could be partly due to immobilization of soil nitrogen, making it unavailable to the maize crop during tasseling and cob formation. Use of supplementary fertilizer reduced the relative yield increase following the different mulch treatments and, reduced the degree of crop loss following use of some prunings as fodder (Reynolds and Jabbar, 1994). The results suggest that the second and third prunings should be for forage on mixed crop–livestock farms, but forage off-take should preferably be kept to a minimum in low soil fertility situations receiving little or no fertilizer nitrogen.

Table 2.5. *Effect on maize grain yield (t DM ha^{-1}) of different prunings from* Leucaena leucocephala *hedgerows applied as mulch during two cropping seasons on an Alfisol at Ibadan, southwest Nigeria.*

Number of prunings as mulch	Year		
	1988	1989	1990
None	3.1	3.0	2.0
First (preplanting)	4.4	4.6	3.6
First and second	4.7	5.4	4.0
First, second and third	4.8	5.9	4.5

Source: ILCA, Ibadan (Unpublished data)

2.3.4 Short fallow effects on crop and soil

Originally, it was hypothesized that mulching by leguminous tree foliage would allow continuous crop production by eliminating the need for fallow for fertility restoration as practiced in bush fallow systems (Kang *et al.* 1984). However, on-station trials showed that crop yield under alley cropping decline over time though remain significantly higher than that under bush-fallow system indicating that in the long-run, alley cropping would allow longer cropping cycles than bush-fallow but would not completely eliminate the need for fallow.

A long-term (1982–1992) on-station trial was conducted on an Alfisol at Ibadan with *L. leucocephala* hedgerows. The objective was to compare the effects of traditional farming (non-alley) with a two year fallow, alley farming with a 2-year fallow (alley-fallow) and continuous alley farming (continuous-alley) on crop yield and chemical properties of the surface soil. Originally, it was planned that after the crop was harvested, the plots would be grazed by goats and sheep so that nutrient would be recycled through manure to complement next seasons foliage mulch. This was done after the first crop season but was soon found that the animals were debarking alley trees. Anticipating that debarking might lead to death of trees, the animals were withdrawn and grazing as a treatment was also discontinued (Atta-Krah, 1990; ILCA, 1988). Manure from grazing in the first season did show some positive effect on soil organic matter and nutrient status the following season but it was assumed not to have any long-term effect.

The fallow periods were introduced into non-alley and fallow systems at different times. Consequently direct comparison of the effect of fallow is rather difficult. However, results show that crop yields increased significantly immediately after fallow in both non-alley and alley-fallow systems but yield declined thereafter more quickly in non-alley than alley fallow system (Table 2.6). Moreover, short fallows in alley cropping were effective in controlling noxious weeds such as *Imperata cyliricida* and *Chromolaena odorataum* (Aken'Ova and Atta-Krah, 1988).

Table 2.6. *Maize grain yield (t/ha/year) from* Leucaena *alley cropping with and without fallow and non-alley cropping with fallow.*

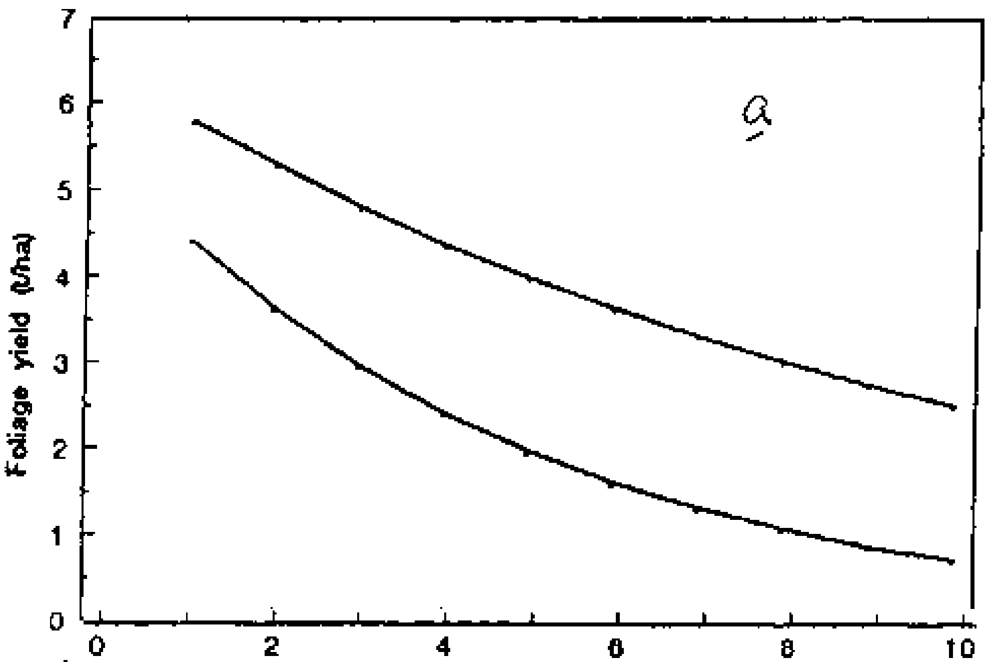
Year	Non-alley cropping	Alley cropping with fallow	Continuous alley cropping
1983	1.96	2.29	2.26
1984[1]	3.28	4.16	4.60
1985	3.06	Fallow	4.21
1986	2.10	Fallow	3.36
1987	Fallow	6.14	4.13
1988	Fallow	3.35	2.90
1989	4.20	3.03	3.02
1990	1.55	1.65	1.51

1991	1.41	fallow	1.68

1. All plots received 45 kg N/ha/yr as urea in all years except in 1984 when 60 kg N/ha was applied.
Source: ILCA (unpublished data)

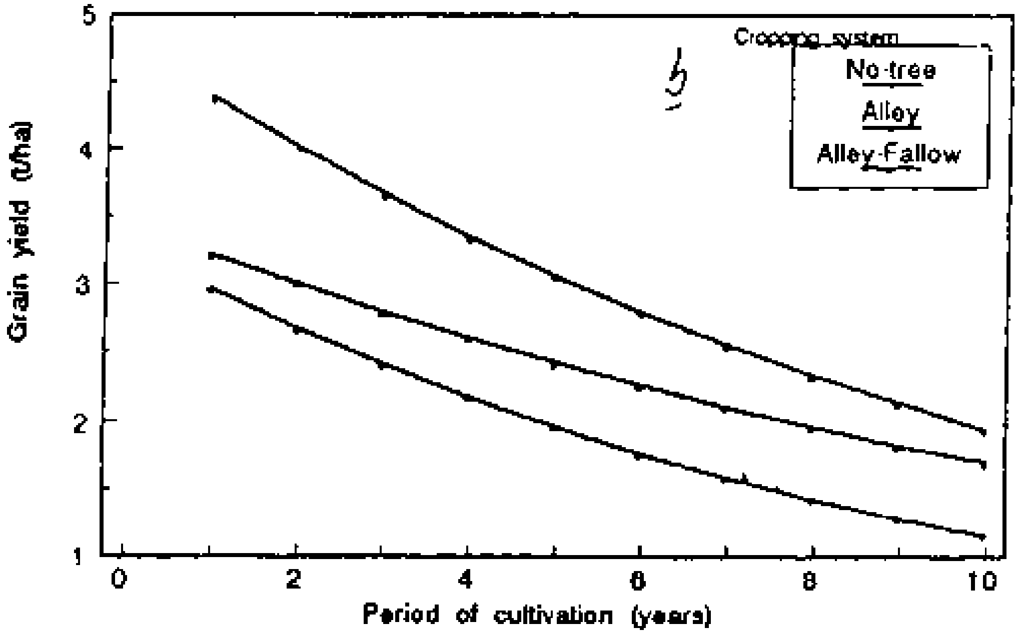
Although changes in yearly crop yields are important, in alley-farming yield trend over the entire life cycle of the trees (and total benefits from mulch and fodder in crop and fallow years) may be more important. Over the entire experimental period, yearly yield of maize grain declined in all three systems with increasing period of cultivation but continuous alley system maintained a higher yield than the other two systems (Fig. 2.7b) partly because during fallow years no crop yield was received. Continuous alley system also maintained a higher hedgerow pruning yield (Fig. 2.7a) because during fallow years no mulch was applied.

Fig. 2.7(a) *Decline in yields of (a) hedgerow prunings applied as mulch (y) in relation to period of cultivation (x) in* Leucaena leucocephala *alley farming with a 2-year fallow after a 4-year cropping (alley-fallow), continuous alley cropping (continuous-alley) and a non-alley cropping systems. Curves are drawn from predicted values according to the following regression relationships.*



a) Continuous-alley: $y = 6.34exp^{-0093x}$; Alley-fallow: $y = 5.42exp^{-0.221x}$.

Fig. 2.7(b) *Decline in yields of (b) maize grain (y) in relation to period of cultivation (x) in* Leucaena leucocephala *alley farming with a 2-year fallow after a 4-year cropping (alley-fallow), continuous alley cropping (continuous-alley) and a non-alley cropping systems. Curves are drawn from predicted values according to the following regression relationships:*



b) Non-alley: $y = 3.29exp^{-0.103x}$; Continuous-alley: $y = 4.80exp^{-0.090x}$; Alley-fallow: $y = 3.47exp^{-0.71}$

The declining maize yield trends could be in response to fall in soil organic matter and soil nutrient status with period of cultivation. Results showed that, soil from alley farmed plots generally maintained relatively higher organic matter and total nitrogen status than soil from non-alley plots (Fig. 2.8a, b). The higher levels of soil organic matter and total nitrogen in the alley farmed plots could be partly due to the return of nutrients through addition of tree litter fall, prunings, root residues and increased fauna activity.

Fig. 2.8 *Decline in soil (a) organic carbon in relation to period of cultivation (x) in* Leucaena leucocephala *alley cropping with a 2-year fallow (alley-fallow), continuous alley cropping (continuous alley) and a no-tree cropping systems. Curves are drawn from predicted values according to the following regression relationships.*

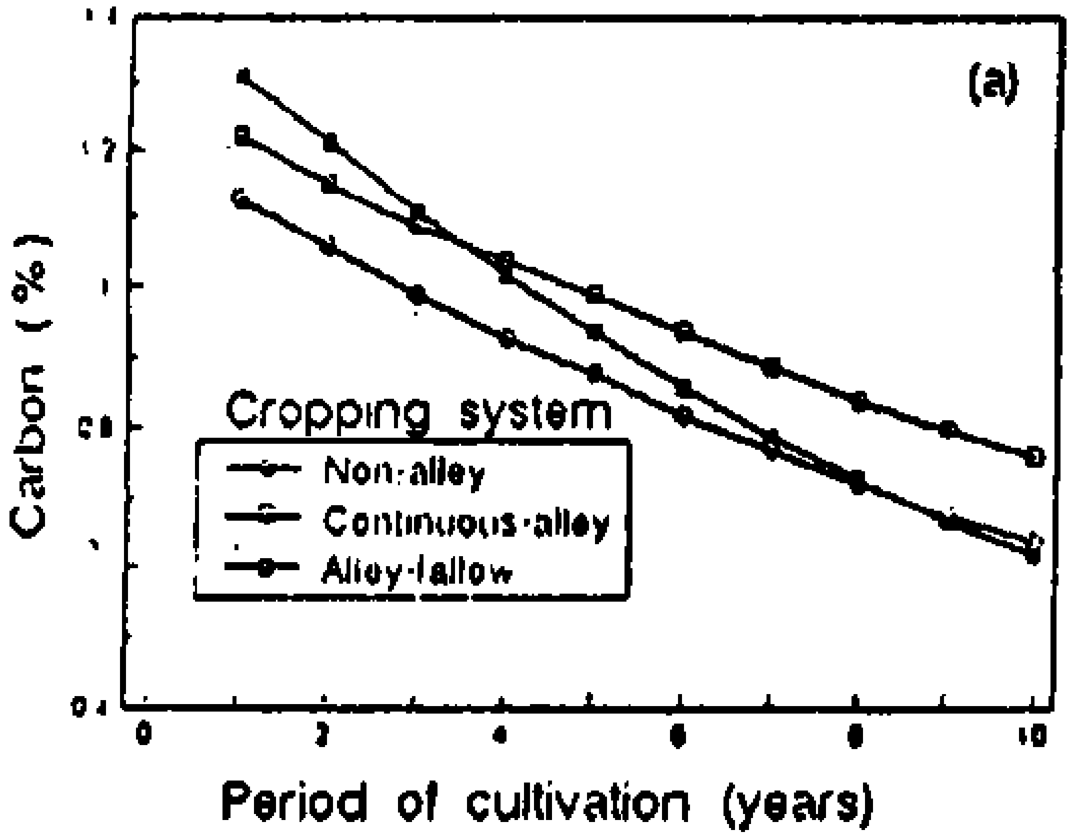


Fig. 2.8 *Decline in soil (b) total nitrogen in relation to period of cultivation (x) in* Leucaena leucocephala *alley cropping with a 2-year fallow (alley-fallow), continuous alley cropping (continuous alley) and a no-tree cropping systems. Curves are drawn from predicted values according to the following regression relationships.*

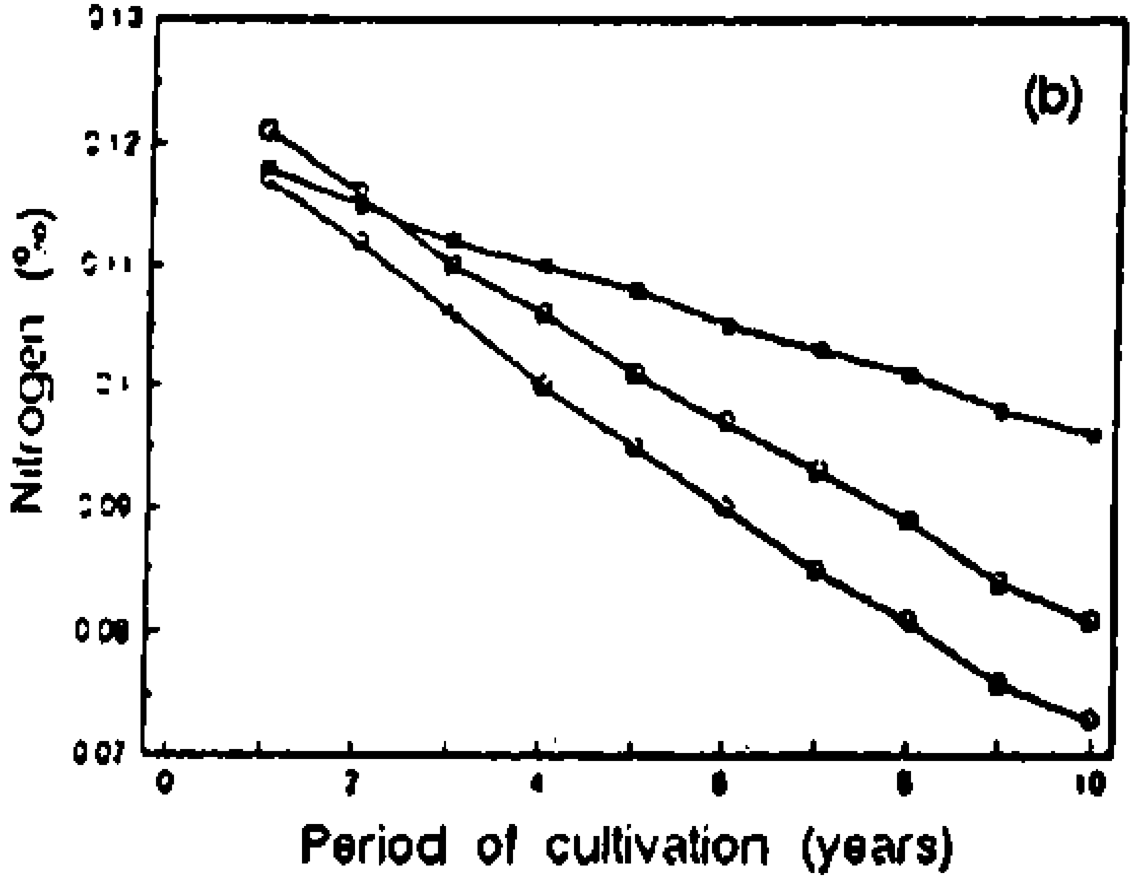


Fig. 2.8 *Decline in soil (c) available phosphorus in relation to period of cultivation (x) in* Leucaena leucocephala *alley cropping with a 2-year fallow (alley-fallow), continuous alley cropping (continuous alley) and a no-tree cropping systems. Curves are drawn from predicted values according to the following regression relationships.*

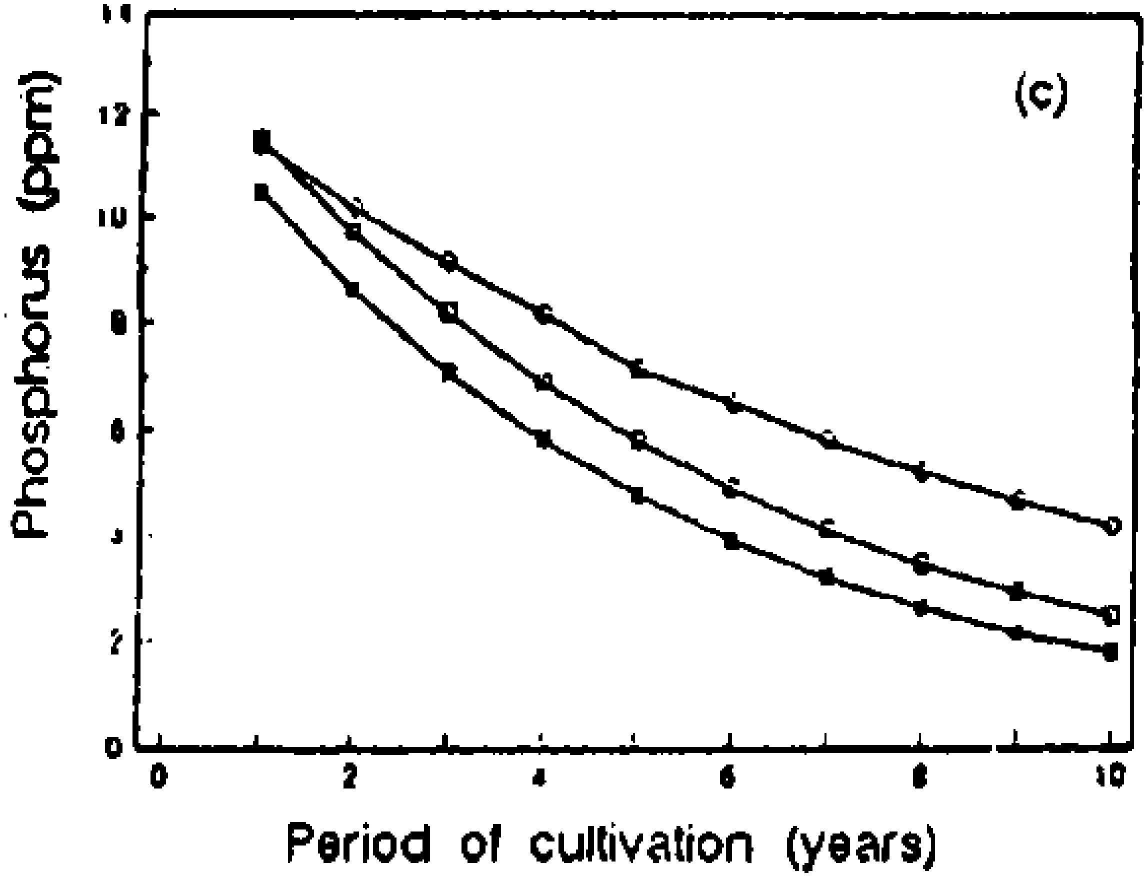
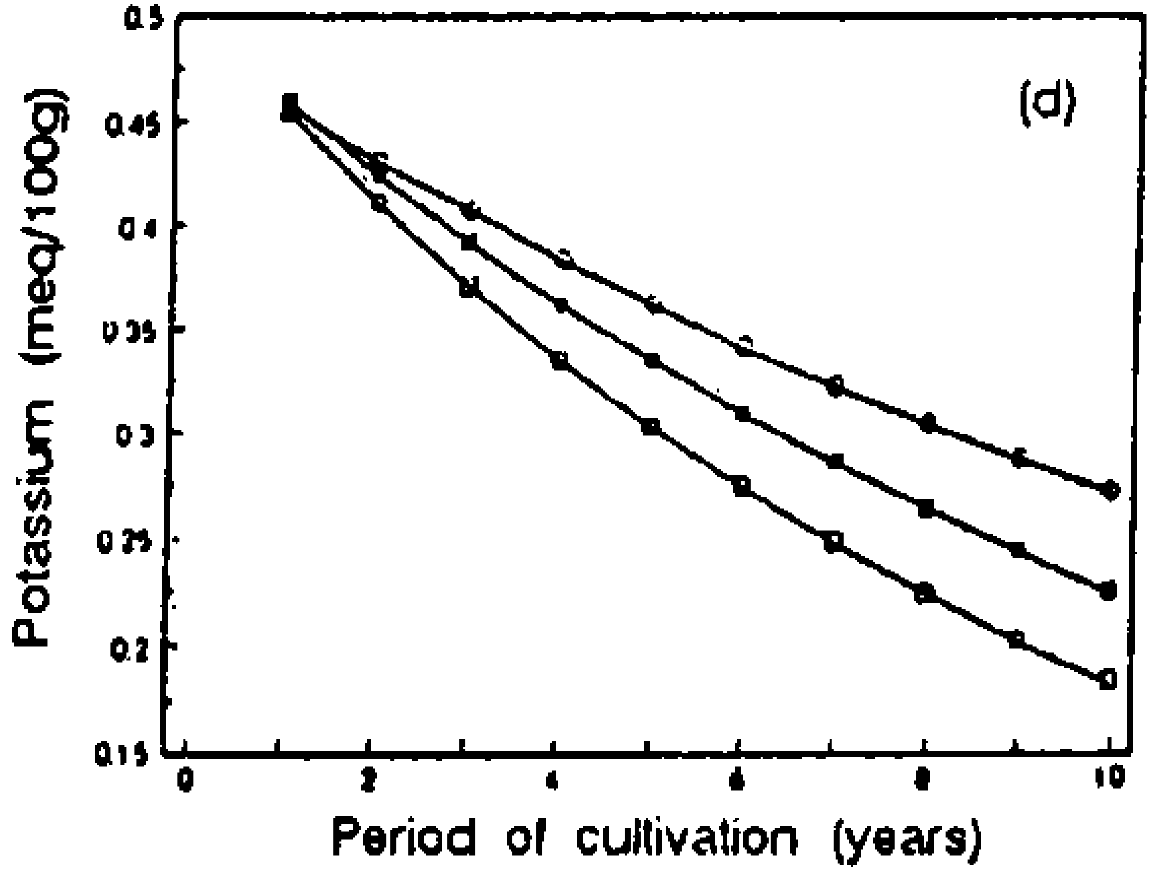


Fig. 2.8 *Decline in soil (d) exchangeable potassium in relation to period of cultivation (x) in* Leucaena leucocephala *alley cropping with a 2-year fallow (alley-fallow), continuous alley cropping (continuous alley) and a no-tree cropping systems. Curves are drawn from predicted values according to the following regression relationships.*



a) Non-alley: $y = 1.21exp^{-0064x}$; Continuous-alley: $y = 1.28exp^{-0.052x}$; Alley fallow: $y = 1.43exp^{-0.084x}$.

b) Non-alley: $y = 0.124exp^{-0.053x}$; Continuous-alley: $y = 1.27exp^{-0.045x}$; Alley fallow: $y = 1.23exp^{-0.121x}$.

c) Non-alley: $y = 12.8exp^{-0.112x}$; Continuous-alley: $y = 13.7exp^{-0.171x}$; Alley fallow: $y = 12.8exp^{-0.196x}$.

d) Non-alley: $y = 0.485exp^{-0.058x}$; Continuous-alley: $y = 0.504exp^{-0.101x}$; Alley fallow: $y = 0.499exp^{-0.079x}$.

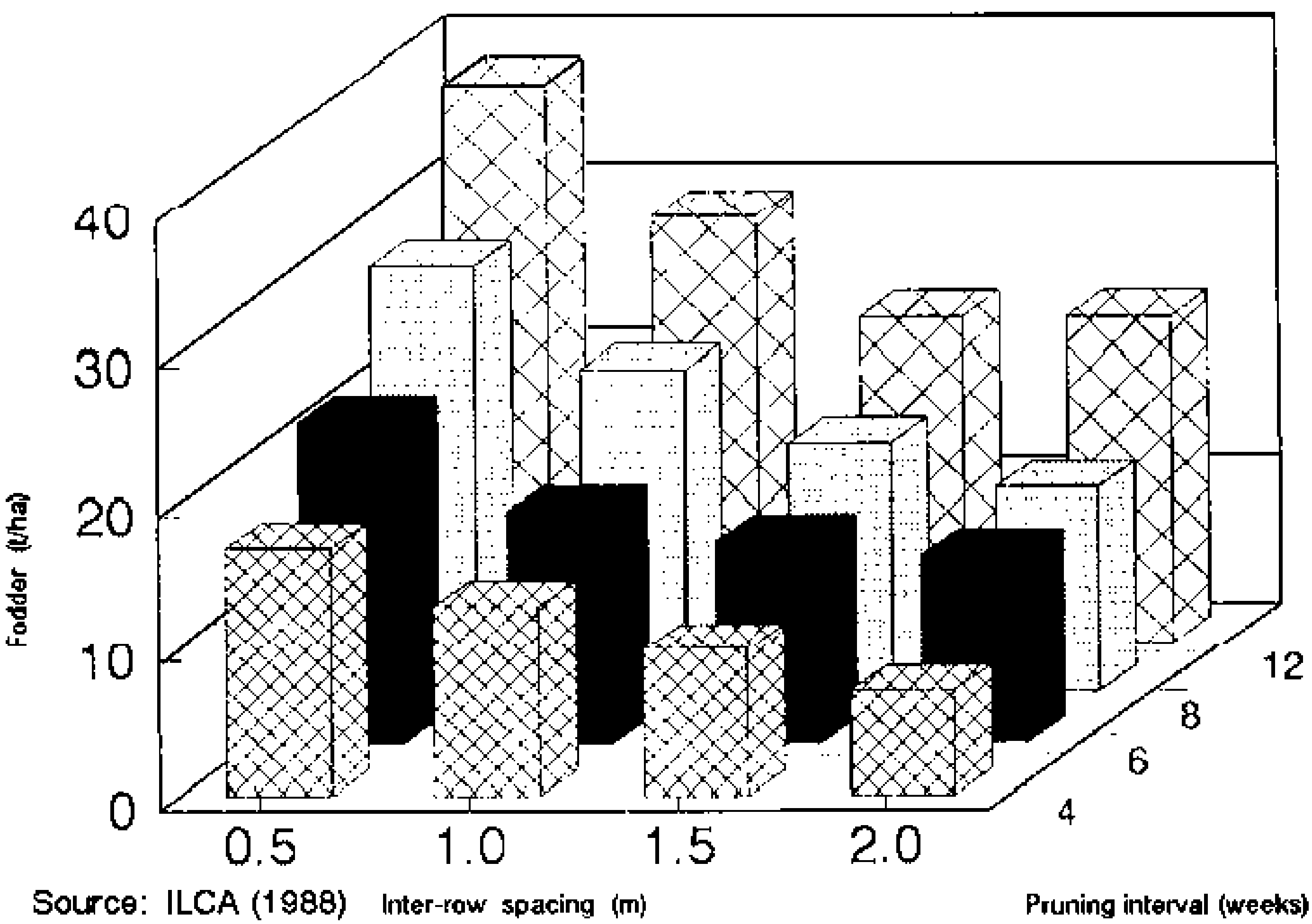
In contrast to trends in soil organic matter and total nitrogen, exchangeable potassium and available phosphorus status were higher in non-alley than alley farmed plots (Fig 2.8c, d). A possible explanation for this could be accumulation of potassium and phosphorus in *L. leucocephala*. Evidence in the literature show that some tree and shrub species actively accumulate certain nutrients. For example, *Cecropia* species appeared to accumulate calcium and phosphorus (Odum and Pigeon, 1970) and *Gmelina arborea* accumulates calcium (Sanchez *et al*., 1985). Another explanation could be higher rate of removal of phosphorus and potassium through maize grain in alley farmed plots than non-tree farming.

Young (1991) defined sustainability as continued plant production combined with the conservation of the resources on which that production depends. Based on this definition, and the trends in soil organic matter and total nitrogen status (Fig. 2.8a, b), as well as yields of hedgerow pruning applied as mulch and maize grain (Fig. 2.7a, by the non-alley system appears to be the least sustainable, because this system not only give low and declining crop yield, it mines the soil faster than the alley farming systems (see section 4 for an economic assessment of sustainability of these systems).

2.3.5 Intensive feed gardens

In order to partly resolve the competition between crop and livestock for hedgerow prunings in alley farms, farmers could plant small feed gardens with tree-only or tree-grass combination (Atta-Krah *et al.*, 1986). The intensive feed garden technology was developed for densely populated areas where alley farming may be an inappropriate feed production technology (Atta-Krah and Sumberg, 1988).

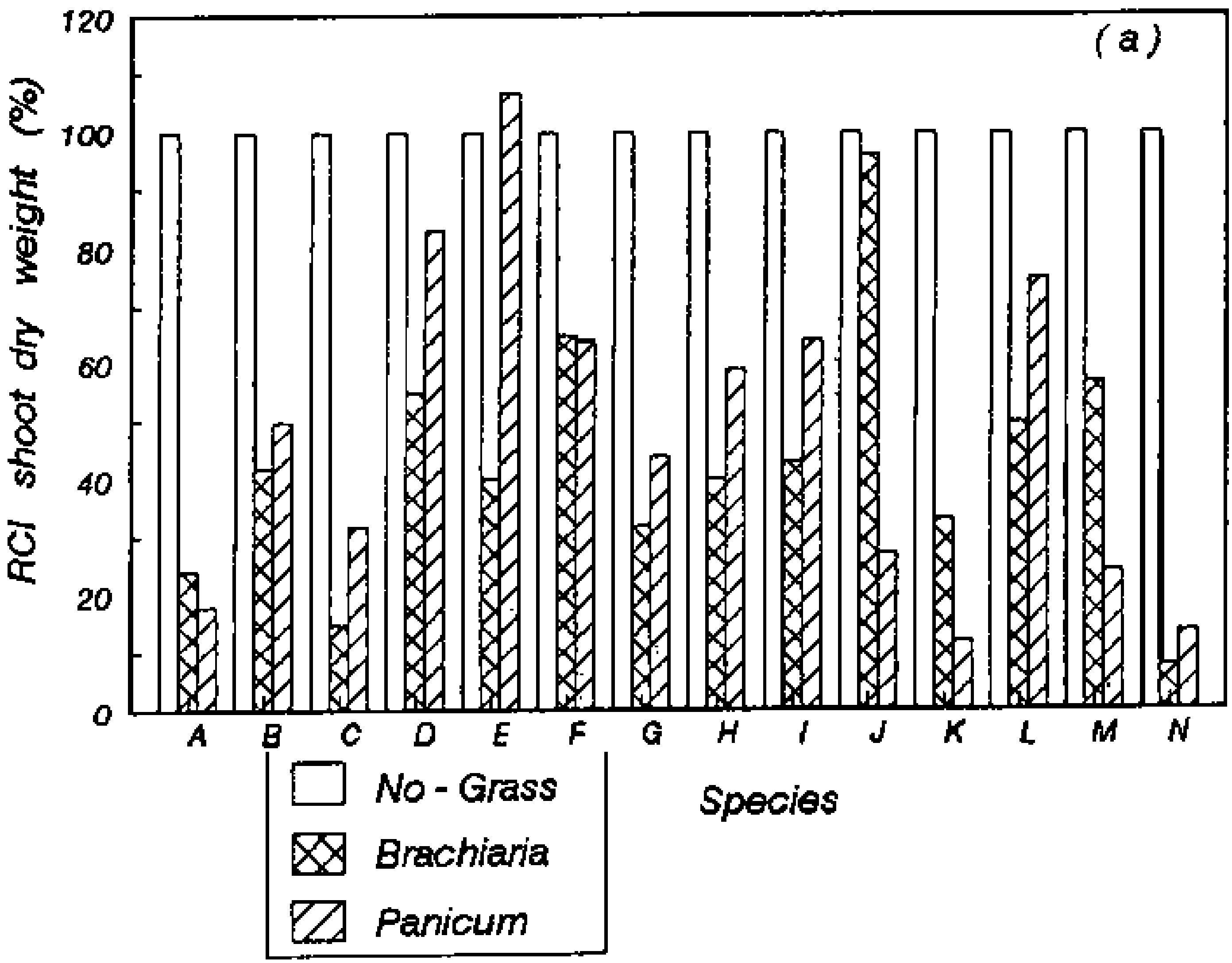
Biomass production in tree-only plots is dependent on the inter-row spacing and the cutting interval. A trial was conducted at Ibadan over a 3-year period to determine the optimum inter-row spacing or planting density and cutting interval on fodder yield of *L. leucocephala* (Sumberg, 1986; ILCA, 1988). Fodder production decreased with increasing inter-row spacing and decreasing defoliation interval (Fig. 2.9). During the three year period, the highest yield of fodder was obtained from the combination of 0.5 m inter-row spacing and cutting interval of 12 weeks and, 0.5m inter-row spacing gave highest yield at all cutting intervals.

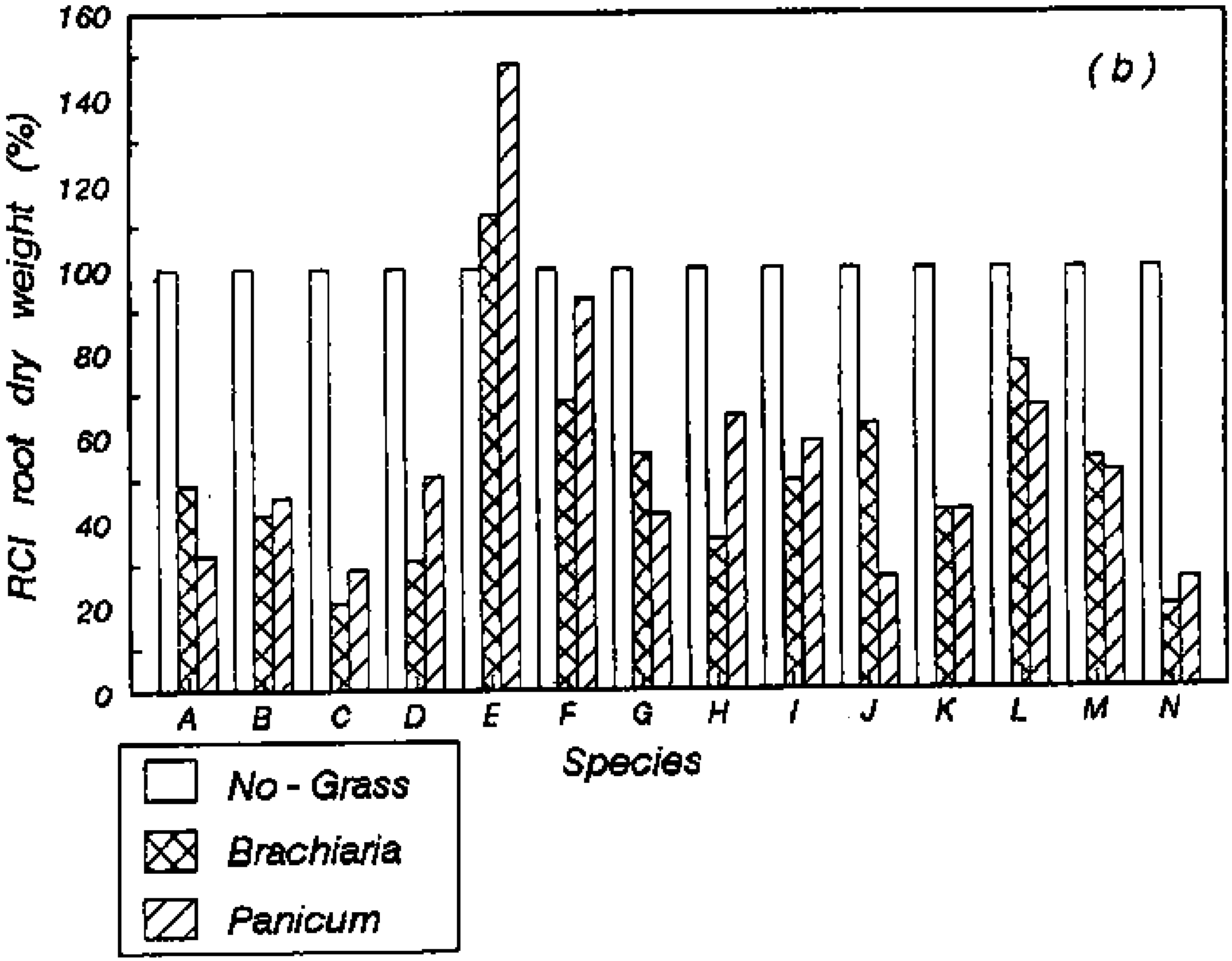


Source: ILCA (1988).

With tree-grass intensive feed gardens, hedgerows are established 4 m apart, with four rows of grasses sown in the alley. The hedgerows may also be established 2.5 m apart with 2 rows of grasses. Both designs are productive. Atta-Krah *et al*..(1986) reported more than 20 t DM ha^{-1} from both designs for *L. leucocephala* and *G. sepium,* mixed with *Panicum maximum.*

When fodder tree or shrub species are planted at about the same time in tree-grass intensive feed gardens, competition from the grass can result in poor survival and growth of seedlings of hedgerow species during establishment. Investigations on survival and growth of 14 multipurpose tree and shrub species when grown alone or in association with *Brachiaria mutica* or *Panicum maximum* showed that grass competition significantly reduced tree and shrub seedling survival, height and diameter and, above and below-ground phytomass (Fig. 10). Response of tree and shrub species to the competitive stress differed, partly due to physiological and morphological variations in below and above-ground characteristics associated with resource acquisition and utilization (Ruhigwa *et al.,* 1992). Therefore, in the selection of multipurpose fodder tree and shrub species for tree-grass agroforestry technologies, plant attributes pertaining to stress and competitive ability should be considered.





Species: A) <u>*Dactyladenia barterii*</u>, B) *Afzelia belle*, C) <u>*Albizia niopoides*</u> E) <u>*Albizia ferruginea*,</u> F) <u>*Albizia lebbeck*</u>, G) <u>*Anthonotha macrophylla*</u> H) <u>*Bauhimia monandra*</u>, I) <u>*Dialum guineese*</u>, J) <u>*Flemingia macrophylla*</u>, K) *Inga* <u>*edulis*</u>, L) <u>*Napoleona imperalis*</u>, M) <u>*Prosopis africana*</u>, N) <u>*Terminalia superbra.*</u>

2.4 Summary and research needs

Evaluation of exotic multipurpose fodder hedgerow tree and shrub species resulted in a composite *Gliricidia sepium* variety that was more productive than the local variety. Indigenous browse species, adapted to acid soils and comparable to *G. sepium* and *L. leucocephala* in biomass production and nutritive value were also identified.

Investigations on allocation of *L. leucocephala* and *G. sepium* hedgerow prunings either as mulch for soil fertility maintenance and crop production or fodder for livestock feeding showed that maize grain yield, soil organic matter, total nitrogen and available phosphorus status increased linearly as the proportion of total hedgerow prunings applied as mulch increased from zero to 100%. Application of about 50% of each pruning, as mulch gave the highest response in crop yields.

Long-term trials showed that alley farming with or without a 2-year fallow improved crop yield through maintenance of higher soil organic matter and total nitrogen status than non-alley farming on Alfisols. In contrast, exchangeable potassium and available phosphorus status were higher in non-alley than alley farmed plots. In all cases, a steady decline in soil nutrient status with period of cultivation was observed. Based on long-term trends in soil organic carbon, total nitrogen, grain yields of maize and pruning applied as mulch, non-alley farming appeared to be less sustainable than alley farming with fallow and continuous alley farming.

Priority areas for research in alley farming have been previously outlined by several authors in recent publications (Kang and Van den Beldt, 1988; Kang *et al*., 1990; Tripathi and Phychas, 1992; Reynolds and Jabbar, 1994) therefore, crop–livestock aspects of alley farming research is emphasized on this occasion. From the foregoing overview, several gaps in alley farming information are visible and the following research needs are proposed to bridge the gaps.

1. Studies on forage quality of best-bet hedgerow species. Research should include: a) development of simple methodologies for predicting forage quality at the initial stages of evaluation, b) environmental effects on intra-and inter-species variation in fodder production and nutritive value among hedgerow species, since allocation of hedgerow pruning either for fodder or mulch is season dependent, c) evaluation of promising hedgerow species in cattle, sheep and goats since farmers rear mixed ruminant species and inter- species variation in utilization is known to exist and d) practical methods for small-scale conservation and storage of forage from hedgerow species.
2. Impact of livestock on the resource base in alley farming systems: a) long term effects of alley grazing or cut-and-carry management on soil biota, physical and chemical properties, crop and hedgerow species productivity, and changes in botanical composition, b) factors responsible for variation in debarking intensity among hedgerow species by sheep and goats in grazed fallows and c) carrying capacities of tree-only and tree-grass intensive feed gardens.
3. Further research on the long term effects on crop production and soil fertility of hedgerow prunings, and the proportion of prunings obtained during the growing season, as mulch or fodder is also needed.
4. Long terms studies on utilization of hedgerows prunings either as mulch or manure.

3. Animal nutrition studies

Nutrition studies conducted during the period could be classified into four groups. First, some early studies aimed at developing strategies to control the effects of toxic mimosine in *Leucaena* and the role of energy in diet. Second, studies aimed at finding animal response to levels of supplementation. Third, studies aimed at finding the effects of alternative feeding strategies. Fourth, on-farm performance of animals reared by alley farmers, under farmer management.

3.1. Studies on mimosine in *Leucaena* and role of energy in diet

3.1.1 Strategies for controlling the effects of mimosine in *Leucaena*

The initial choice of *Leucaena* as a potential source of planted forage was based on experiences in southeast Asia (Gray, 1968; NAS, 1977; Jones, 1979). However, a potential constraint to the unrestricted use of *Leucaena* as a feed is the presence of mimosine, a toxic amino acid. *Leucaena* is highly palatable, and given the opportunity, livestock will consume more than the safe level. Sheep appear to be more susceptible to mimosine than goats, showing loss of hair around the face. Depressed appetite, low weight gains and alopecia are early signs of toxicity. Ulceration of the oesophagus may also occur. At very high levels of toxicity, animals may die. That is why, The National Academy of Science of United States recommended restricting intake of *Leucaena* to below 30% in ruminant diets (NAS, 1977). However, restricting intake was not initially considered practicable under African farm conditions, so two strategies to control the effect of mimosine were tried.

Rumen microbes degrade mimosine to 3 hydroxy 4 (IH) Pyridone (DHP) which is then absorbed into the blood stream before eventually being excreted in urine. In Hawaii and Indonesia, goats fed high levels of *Leucaena* were found to excrete urine free of DHP due to the presence of rumen microbes able to degrade DHP (Jones, 1981). Rumen fluid from goats adapted to *Leucaena* diets were transferred to unadapted animals in Australia allowing the latter group to eat diet comprising only *Leucaena* due to the ability to degrade DHP. It was also reported that the introduced bacteria could be passed from animal to animal, and would persist for at least six months after removal from *Leucaena* feeding (Jones, *et al*., 1985).

Presence of DHP in the urine of WAD goats and sheep in a trial on *ad lib Leucaena* diet in southern Nigeria indicated the absence of detoxifying rumen microbes in those animals. So, in a joint study by ILRI and the University of Ife, sheep and goats on *Leucaena* diet were inoculated with cultures of isolated bacteria brought from Australia in 1985. DHP concentration in the urine of these animals, determined using high performance liquid chromatography, declined rapidly over the first 14 days following inoculation and leveled to trace amounts after 25 days (ILCA, 1986). In another trial, no signs of toxicity from mimosine or its metabolite, DHP, were observed with individually fed sheep but toxicity was present in group fed sheep receiving the same level of supplementation, in which some animals were observed to consume more *Leucaena* than average. In early 1986, toxicity was also observed in sheep grazing in *Leucaena* alleys, and two animals eventually died. Then the rumen of the other animals on the trial were inoculated with bacteria that detoxify mimosine and DHP and the sign of toxicity disappeared. Healthy lambs were born to these animals in the following season (ILCA, 1987). Apart from mimosine toxicity, susceptibility of *Leucaena* to *Psyllid (Heteropsylla cubana*), an insect pest, encouraged diversification of browse species with good feed value. *Gliricidia*, originally from Central America, but well adapted to west Africa as a shade tree for cocoa and as a live fence, was chosen for investigation for its productivity and feed value (section 2.2). Having found some accessions of *Gliricidia* highly productive and nutritious, its suitability as a sole supplement to various roughages, and the effect of combined *Leucaena* and *Gliricidia* supplement as a strategy to maintain high protein quality of the feed while reduce the risk of mimosine toxicity were examined. When *Leucaena* and *Gliricidia* were offered at 1:3 ratio, animals ate almost all the *Leucaena* but left some *Gliricidia*. With a 1:1 mixture, animals were not selective (Ademosun *et al*.,1985a). Growth rates of goats and sheep were higher with a 1:1 mixture of *Leucaena* and *Gliricidia* supplement compared to the same level of supplement with either sole or predominantly *Leucaena* or *Gliricidia* (Carew, 1982; Reynolds and Adeoye, 1985; Ademosun *et al*., 1988).

Based on these experiences, 1:1 mixture of *Leucaena* and *Gliricidia* was adopted as a simple strategy to control the effect of mimisine. In the villages where on-farm research was conducted (see below), farmers were advised to grow *Leucaena* and *Gliricidia* in alternate rows and offer them to animals in equal quantities to avoid the possibility of toxicity.

3.1.2. Role of energy in diet

Free roaming or confined village goats and sheep are not offered commercial protein supplements but they are given farm by-products such as cassava peels, maize chaff and other household wastes. These energy rich feed can be offered with or without protein rich browse. The benefits of such combination were studied.

Dry matter digestibility (DMD) of *Gliricidia* as a sole feed was found to be 54–57% while the addition of cassava tubers (Ademosun *et al.*, 1985a) or cassava peel (Ifut, 1987) raised DMD to 70–74%. In *Panicum maximum* plus *Gliricidia* diet, DMD fell as the proportion of *Panicum* in the diet increased (*Ademosun*, 1985a; *Ademosun*, 1985b; Ifut, 1987). For a combination of *Panicum*, *Gliricidia* and cassava peel diet, DMD tended to increase as the level of consumption of cassava peel increased (Ifut, 1987).

These results indicated that the presence of a fermentable energy source in the diet allows high nitrogen feed such as *Gliricidia* and *Leucaena* to be utilized more efficiently (ARC, 1980). Based on these experiences, a small amount of sun-dried cassava peel (about 50g/day) was used as a routine in most supplementation trials at ILRI.

3.2 Response of small ruminants to levels of supplementation

3.2.1. Supplementation of West African dwarf sheep

In a group feeding trial on-station over a two year period (1983–85), five ewes of breeding age plus their followers replicated twice were assigned to each of four treatments. All animals received *ad lib* chopped *Panicum*, water and a mineral lick. *Leucaena* and *Gliricidia* were offered in a 1:1 ratio at the rate of 0, 200, 400 or 800 g DM/animal/day. These diets were offered throughout the period of the trial irrespective of physiological condition of the animals. Rams had continuous access to females. Dipping against external parasites and deworming were done monthly. Samorin was administered every three months as a prophylactic measure against trypanosomiasis. Animals were weighed weekly, lambs were weighed at birth and weaned at 90 day postpartum (Reynolds and Adeoye, 1985).

The results summarized in Table 3.1 show that supplementation had significant effect on all production parameters except litter size. The group without supplement performed either equally or slightly better than the group with the lowest level of supplementation on a number of parameters. However, the overall productivity index, measured as the weight of lamb surviving to 90 days per dam per year, shows that the highest level of supplementation gave

55 % higher productivity than the group without supplementation.

Table 3.1 *The effect of browse supplementation on the productivity of West African Dwarf Sheep.*

Production parameter	Level of supplement (g Dmd^{-1})			
	0	200	400	800
Parturition interval (days)	262a	228b	226b	241c
Litter size	1.26	1.27	1.19	1.17
Birth weight (kg)	1.80a	1.61b	1.52b	1.72a
Survival to 90 days	0.65a	0.52b	0.65a	0.82c
Daily weight gain to 90 days (g)	64.4a	60.31	73.4b	83.8c
Productivity index	8.67a	7.44a	10.15b	13.46c

Productivity index = kg offspring weaned at 90 days/dam/year

Source: Reynolds and Adeoye (1985).

Two other trials were conducted with weaned lambs, each lasting 6 months. In trial 1, thirty nine sheep of 6 months of age were divided into three groups. Animals were penned and individually fed, each animal serving as a replicate. All animals received a basal ration of ad lib chopped *Panicum* plus 50g/day of sun dried cassava peel, water and mineral block. In addition, one of three levels (200 g, 400 g, 600 g) of a 1:1 mixture of *Leucaena* and *Gliricidia* was offered as a supplement. In trial 2 conducted in a different year, 27 lambs of 6 months of age were divided into three groups and individually penned as before. All animals received a basal ration same as in trial 1 and one of three levels (300, 600 and 900g) of 1:1 mixture of *Leucaena* and *Gliricidia* as a supplement.

Food intake and growth rates are shown in Table 3.2. In each trial, total feed intake significantly increased ($P < 0.05$) as the level of supplement in the diet increased, but grass intake declined significantly ($P < 0.05$). Growth rates tended to rise as intake increased but the rate of increase slowed down showing diminishing return at the highest level of supplementation.

Table 3.2 *Effects of supplementary browse on feed intake and growth rate of lambs offered* Panicum maximum ad-libitum.

Level of supplement	Browse intake gd^{-1}	Grass intake gd^{-1}	Total intake* gd^{-1}	Growth rate gd^{-1}
Trial 1				
200	166	452a	665a	23.6a
400	362	397a	805a	35.0b
600	511	234b	793b	45.6b
Trial 2				
300	144	416a	608a	29.4a
600	298	331b	675b	39.7b
900	392	283c	721c	41.0b

* Includes cassava peel.

Within a trial, values in a column with a different letter are significantly different ($P < 0.05$).

Source: ILCA (1988).

3.2.2 Supplementation of wad sheep and goats

West African Dwarf goats and sheep were studied over two reproductive cycles. All animals received a basal diet of chopped *Panicum* and 50 g of sun-dried cassava peel for the last two months of pregnancy and during lactation. Ewes were divided into five groups and supplementated with *Leucaena* and *Gliricidia* (1:1) at the rate of 0, 200, 400, 800, or 1200 gDM/day. Does were offered the four rations containing supplement. Weaned kids and lambs from the treatments received *Panicum ad lib* plus supplements at a corresponding level to their dams, as shown below.

Age group	Cassava peel (g/day)	Supplementation (gDM day)				
		1	2	3	4	5
12–16 weeks[a]	12	0	50	100	200	300
16–20 weeks	16	0	62.5	125	250	375
20–24 weeks	20	0	75	150	300	450

a. This age group was not used in the goat trial.

There were 7 does and 8 ewes per treatment for the respective species. The animals were penned and individually fed. The effects of supplementation were measured in terms of growth rate and survival rate of offspringup to weaning and dam productivity, measured as kg offspring weaned per dam per year (ILCA, 1987; Reynolds and Adediran, 1988; Reynolds, 1989).

The results show that growth and survival rates of offspring increased significantly $P < 0.05$ with the level of supplementation (Table 3.3). Sheep were 1.7 to 2 times as responsive to supplementation as goats. Selection of browse in preference to grass was more marked with goats than with sheep but the goats were unable to utilize the higher nutritive value of browse as effectively as sheep. On average, dam productivity of sheep and goats increased, respectively, by 1.41 kg and 0.64 kg for each additional 100 g of browse dry matter consumed per day.

Table 3.3 *The effects of* Leucaena *and* Gliricidia *supplementation on the growth and survival rates of offspring of West African Dwarf goats and sheep.*

Species & Treatment	Browse intake		Growth rate (gd^{-1}) to		Survival to 24 weeks
	Dam	Offspring[a]	Weaning[b]	24 weeks	
Sheep					
1	0	0	39.0	25.4	0.50
2	120	34	46.7	30.7	0.62
3	239	77	57.2	34.0	0.70
4	441	136	66.3	44.5	0.89
5	741	250	84.0	50.3	1.00
Goats					
2	143	39	17.4	14.0	0.36
3	254	83	28.7	20.1	0.46
4	554	160	25.9	20.9	0.82
5	719	246	31.9	29.3	0.94

a. From weaning to 24 weeks. Weaning at 12 weeks for lambs and 16 weeks for kids.

b. Weaning at 12 weeks for lambs and 16 weeks for kids.

Source: Reynolds and Adediran (1988).

Having found sheep as more responsive to supplementation, six months old weaned lambs were supplemented to slaughter at 18 months for males, and to first conception at 15 months for females. Twenty three males and 16 females were divided into 3 groups. Animals were individually penned and received ad lib chopped *Panicum* plus 50g/day of cassava peel, and supplemented with mixed browse comprising *Leucaena* and *Gliricidia* (1:1) as follows: from 6–12 months of age: 300 g, 600 g, or 900 g DM per day; from 12–18 months (12–15 months for females) of age: 400 g, 800 g, or 1200 g DM per day. Females were removed from experiment at 15 months for breeding. Water and mineral blocks were continuously available. Animals were weighed weekly, and dipped and drenched monthly against internal and external parasites.

Mean daily food intake was lowest at the lowest level of supplementation and highest at the medium level of supplementation. However, substitution of browse for grass occurred with increased browse supplementation (Table 3.4). Growth rates were significantly improved by increasing the level of browse on offer, rising from 30.0 to 48.9 g/day in males and from 25.8 to 37.7 g/day in females. The growth rate of males was faster than that of females.

Table 3.4 *Effects of different levels of* Leucaena *and* Gliricidia *as supplementary feed to growing male and female WAD sheep.*

Animal sex and level of supplementation	Period weeks	Intake (g DMd^{-1})			Growth rate gd^{-1}
		Panicum	Browse	Total	
Male	48				
1		630a	237a	915a	30.3a
2		613a	491b	1155b	41.7b
3		379b	689c	1116b	48.9c
Female	36				
1		670a	196a	914b	25.8a
2		605b	453b	1106b	29.0a
3		337c	604c	989c	37.7b

Within a sex group, values in a column with different letters are significantly different ($P<0.05$).

Source: Reynolds (1989)

From the start of the trial, males on the highest level of supplementation consumed 232 kg browse and gained 16.4 kg, compared with 165 kg browse and 14.0 kg, and 80 kg browse for 10.1 kg weight gain for medium and lowest levels of supplementation respectively. Thus, additional weight gains of 3.9 kg between lowest and medium level supplementation required 85 kg browse (21.8 kg browse/kg weight gain), and a further 2.4 kg weight gain between medium and highest levels of supplementation required 67 kg browse (27.9 kg browse/kg weight gain), demonstrating the law of diminishing returns. The growth rates seen here compare favourably with those reported earlier in supplementary feeding trials with lambs up to 6 months of age.

The trial was repeated the following year with WAD sheep and the same treatments except that at 15 months of age, females were put on a uniform diet, mated and the carry-over effects of the previous treatment assessed. Results show that grass intake decreased with increased supplementation. For the 6–15 month period, growth rate was 24, 35 and 44 g/day at the low, medium and high levels of supplementation ($p<0.05$).

Males supplemented from 15 to 18 months showed no benefit from higher levels of supplementation when the experiment period coincided with the on-set of the rainy reason and an improvement in the quality of basal *Panicum* diet. For the females, previous nutritional treatments during growth up to 15 months of age had no effect on birth weight or growth of lambs up to four weeks.

3.3 Effects of alternative feeding strategies

In alley farming systems the main use of tree foliage is expected to be for mulch due to the dominance of crop in the farm business. The need for mulching is determined by cropping and crop growth patterns, so that tree forage availability is seasonal. Hence, continuous supplementation of animals may not be possible. In order to maximize benefit from the limited quantities of available feed from alley crop fields or feed gardens, specific types of animals should be fed at strategic times, in appropriate quantities and forms. The following strategies were considered to achieve this objective:

a. Supplement the mother to improve the growth and survival of youngstock,
b. Improve the performance of adults through varying feeds and feeding strategies,
c. Compare performance with fresh and dried material.

3.3.1. Optimum period for supplementing adult sheep and goats

A study was conducted on-station separately with goats and sheep to compare the effects of giving extra supplements in late pregnancy, early lactation or late lactation. The null hypothesis was that the time of extra supplementation had no effect on the performance of the offspring. The effects were measured in terms of growth and survival of offspring up to weaning

For each species, 24 adult females were divided randomly into four treatment groups. Each animal was penned and individually fed serving as a replicate. All animals received a basal diet of *ad lib* chopped *Panicum* plus 50g/day of sun dried cassava peel. Supplements were given as follows:

a. Basic supplementation of 400 g DM/day of 1:1 *Leucaena* and *Gliricidia* from late pregnancy to late lactation (control).
b. Extra supplementation of 400 g DM/day of 1.1 *Leucaena* and *Gliricidia* during late pregnancy (12 weeks to lambing/kidding).
c. Extra supplementation (as in b) during early lactation (first 6 weeks after lambing/8 weeks after kidding).
d. Extra supplementation (as in b) during late lactation (7–12 weeks after lambing/9–16 weeks after kidding).

The treatments in sheep or goats had no effect on kid birth weight or growth rate to weaning. However, growth rates of WAD lambs were about twice that of WAD kids at any time of supplementation of mothers. In goats, average daily growth rate varied from 22.1 g for the control group to 27.8 g for group 4 i.e late lactation. In sheep, average daily growth varied from 42.7 g in control group to 56.5 g in group 2, i.e late pregnancy.

Extra supplementation increased survival rate of both kids and lambs to weaning irrespective of time of supplementation. Survival rate of kids from all extra supplemented groups and control were respectively 87 and 58 percent. For lambs, the rates were respectively 92 and 70 percent. Both the differences were significant ($P<0.05$)

3.3.2 Growth of WAD sheep during continuous vs periodic supplementation

Experiences from on-farm research (see below) indicated that the farmers were using their limited browse either by supplementing for a few days each month, or supplementing more frequently but with less material on offer for each occasion. A trial was performed on-station to determine the effect of periodic vs continuous extra supplementation with the same quantity of available browse. The null hypothesis was that a given amount of browse could be supplemented daily at a low rate or less frequently at a higher rate without any significant difference in results.

Forty two pregnant sheep were divided into three groups. Each animal was penned and individually fed, serving as a replicate. All animals received a basal ration of *ad lib Panicum*, 50g of dry cassava peel and 400 g DM *Leucaena* and Gliricidia browse (1 :1 ratio) daily to produce a similar performance as free-roaming village animals. In addition, Group 2 received a continuous supplementation of 80 g DM per day of the same browse every day. Group 3 had 280 g DM browse/day on two days each week. The pregnant ewes were on trial for 24 weeks from 12 weeks prior to lambing to weaning of the lambs at 12 weeks of age. At weaning, the lambs were randomly reassigned to three groups for no supplementation, continuous and periodic supplements for 12 weeks with quantities 0, 50 g, 100 g, for group 1, 2 and 3. The effect was measured in terms of growth rate of lambs (ILCA 1989).

From birth to 24 weeks, growth rates of lambs under no supplement, continuously and periodically supplemented group averaged 43.7, 50.1, 44.0, g/day. The differences were not significant ($P>0.05$). Also no significant differences in growth rate of lambs between weaning at 12 weeks and the end of the trial at 24 weeks were observed. No significant correlation was observed between pre-and post weaning dietary regimes and growth rates. The non-significance of differences across treatments may indicate that the levels of supplementation considered were too low to make any significant impact through timing of supplementation.

3.3.3. Supplementation of *Leucaena* in different forms

Agronomy trials have shown that *Leucaena* and *Gliricidia* foliage yields are higher in the wet season, so any wet season surplus could be dried and preserved for use in the dry season. A trial was conducted to assess the effect of sun-drying on intake and growth of lambs. Twenty four lambs aged about 10 months were offered two levels (100 and 200 g/day) of fresh or sun-dried *Leucaena* with *ad lib* chopped *Panicum* and 50 g/day of sun-dried cassava peel. The trial was run in the dry season, so the quality of panicum would be expected to be lower than in crop season (ILCA, 1990).

Both forms of *Leucaena* were readily consumed, though at higher level of supplementation, intake of dry *Leucaena* was lower. Over a seven week period the animals on dried *Leucaena* grew significantly faster than those on fresh material (Table 3.5), but there was no difference in growth rates between the two levels of supplementation on offer in either fresh or dry form. Sun drying process might have reduced mimosine levels in *Leucaena*, though no chemical analysis of the feeds was done to establish the effect of drying.

Table 3.5 *Effect on lamb growth rate of supplementing the diet of sheep with dry and fresh* Leucanea *at two levels in the dry season.*

Supplement	Browse offered $gDMd^{-1}$	Intake ($gDMd^{-1}$)		Growth rate (gd^{-2})
		Leucaena	*Panicum*	

Dry *Leucaena*	100	84	581	41.71
Fresh *Leucaena*	100	91	580	13.1bc
Dry *Leucaena*	200	119	576	38.4a
Fresh *Leucaena*	200	187	556	11.9c

Within a column, means followed by the same letter are not significantly different (P > 0.05).

Source: ILCA (1990).

In order to understand the differences in performances of dry and fresh *Leucaena* their digestibilities were investigated. Six growing male sheep were penned individually in metabolism crates and offered a basal diet of chopped *Panicum ad lib* plus 50g/day of cassava peel, with either 1100 g/day of fresh or 400 g/day of dry *Leucaena* A 10 day adjustment was followed by a seven day trial period. At the end of the trial period, the trial was repeated by changing those receiving fresh *Leucaena* to dry *Leucaena* and vice-versa. Dry matter content of the samples were estimated.

Panicum intake was unaffected by the form of supplement offered. Intake of fresh *Leucaena* was higher than that of the dry material, 389 v 359 g DM/day, but total intake (1690 vs 1688 g DM/day) was unaffected by treatment. Nitrogen intake was higher in the fresh *Leucaena* group (22.0 v 19.6 g/day) but faecal N and urinary N (3.40 vs 3.25 g) outputs were not different. Digestibilities of DM (0.69 vs 0.67) and N (0.48 vs 0.45) were the same in the two groups, as was the N balance. Thus the utilisation of fresh and dry Leucaena was similar (ILCA, 1990).

The quality and the mimosine content of dried *Leucaena* can be affected by the method of drying and the temperature used. The material in the present trial was sun dried in partial shade under a roof made of transparent plastic sheets. The results indicate that sun drying surplus wet season *Leucaena* leaf can be used as a method of preservation by smallholder farmers for the supplementation of animals during the dry season when feed is generally in short supply.

3.3.4. Palatability and voluntary intake of *Gliricidia sepium* in different forms

Gliricidia sepium is highly productive and well adapted to humid west Africa, but it is rarely used as feed for ruminants. Some farmers consider it 'poisonous' to sheep and goats (Atta-Krah and Sumberg, 1988) and it has been characterized as a plant having rodenticidal potential (Everard, 1966). *Gliricidia* was also found as the least preferred by goats when eight indigenous browse species were compared with *Leucaena* and *Gliricidia* (Larbi et al., 1993a). However, small ruminants reared on ILRI experimental farm ate *Gliricidia* once introduced to it as youngstock. Experimental animals purchased from market ate *Gliricidia* after a period of adjustment. Farmers' animals on trial in the villages also ate *Gliricidia* but in all cases, *Leucaena* was preferred to *Gliricidia*.

Two experiments were conducted to explain the low acceptability of *Gliricidia* by village animals. In the first experiment, the cafeteria technique using three-year-old West African Dwarf sheep was employed to determine relative palatability differences within 28 provenances of *Gliricidia sepium* collected from West Africa and Central America. Significant differences (P < 0.05) in relative palatability were detected among the provenances considered and Mexican ecotypes appeared to be of low relative palatability compared to those from Cost Rica (Larbi *et al.*, 1993c). This result indicated possibility for selection on the basis of both yield and palatability, thus enhance the adoptability of *Gliricidia* leaves as a feed resource in alley farming systems.

In the second experiment, voluntary intake of *Gliricidia* in fresh, wilted and dried forms were examined (ILCA, 1993). Two trials were conducted - one with 54 WAD sheep and another with 54 WAD goats — 12–18 months old. A completely randomised design was used in each case and *Gliricidia* offered in fresh, wilted or dried form at 10, 20 or 30% of a daily DM allowance of the individually penned animals with fresh *Panicum* harvested after 12 weeks regrowth as the basal diet. The DM requirement of the animals were calculated on the basis of 50g/kg initial body weight. The basal and supplemental diets were fed separately and intake was calculated daily. The experimental period consisted of 7 days adaptation plus 7 days collection.

Neither the form nor the level of supplementation of *Gliricidia* had any significant ($P > 0.05$) effect on the intake of *Panicum* in the case of sheep, but both significantly ($P < 0.05$) affected panicum intake for goats. Form and level of supplementation and their interaction had very significant ($P<0.01$) effects on intake of the supplement *Gliricidia* by both sheep and goats (Table 3.6). Intake in fresh and wilted forms were significantly higher than in dried form. Intake in fresh and wilted forms did not differ significantly ($P>0.05$). Intake increased linearly as the level of supplementation increased except in the case of sheep supplemented in dried form.

Table 3.6 *Voluntary intake of* Gliricidia sepium *offered in different forms and at different levels to West African Dwarf sheep and goats.*

Trial species and level of supplementation	*Gliricidia* intake by form (g/kg $w^{0.75}$)		
	Dry	Wilted	Fresh
Sheep			
10% of daily DM allowance	4.6	9.0	9.1
20% of daily DM allowance	7.7	14.0	16.2
30% of daily DM allowance	5.0	24.3	19.6
Goats			
10% of daily DM allowance	6.7	7.5	7.9
20% of daily DM allowance	7.0	11.0	12.2
30% of daily DM allowance	12.0	17.7	23.2

Source: ILCA (1993).

3.4. Supplementation of free-roaming village flocks

In order to validate the results obtained on-station, on-farm studies were undertaken for two years with free-roaming small ruminants in two villages — Owu-Ile and Iwo-Ate— in southwest Nigeria where on-farm studies on different aspects of alley farming were conducted (for details of the on-farm research activities and methods, see ILCA, 1992 and section 5 below). Twenty two farms were visited on 20 days per month and those offering browse on more than 10 percent of the occasions visited were categorised as browse feeders and those offering browse less than 10 percent of the occasions visited were categorised as non-browse feeders. On this basis, there were 10 browse feeders and 12 non-browse feeders. *Leucaena* and *Gliricidia* browse was fed principally from the alley farms but a small quantity of indigenous browse was also harvested from the forest.

Farms were visited in the morning and the quantities of supplementary feed available for feeding goats/sheep was weighed before being offered to the animals. The remains of any feed from the previous day was weighed to estimate refusals. Animals were tagged at birth or entry to the flock and weighed at birth and every two weeks. All entries and exits to the herds were recorded. Farmers managed the animals as they wished without interference from researchers. Animals were allowed to roam freely around the village scavenging, grazing and browsing on indigenous plants. No attempt was made to determine intake during this free roaming period. At the end of the day, animals returned to the vicinity of the household to receive supplementary feed, usually household wastes, cassava peels and tubers with or without browse. It was not possible to determine the DM content of the feeds offered and refused, and therefore values are shown on an as-fed basis.

The characteristics and performance of the two groups of herds are shown in Table 3.7. Browse feeding households had nearly twice as many animals per household as non-browse feeders over the two year period, though initially the difference was not large. Browse feeding households fed browse intermittently for 6–8 days per month at the rate of about 300g fresh material per animal per day or 33 kg per year. They offered cassava peels and household wastes less frequently than non-browse feeders. Browse feeders also fed significantly smaller quantities of cassava peels and household wastes per animal. Any effect of supplementary feeding on consumption in the free range was not monitored.

Table 3.7 *Characteristics and performance of browse feeding and non-browse feeding village herds, Southwest Nigeria, 1989–90.*

	Browse feeders	Non-browse feeders
Number of households	10	12
Animals per household—1989 beginning	9.7	7.3
– 1989–90 Average	12.2	6.5 *
Adult females per household—1989 beginning	4.5	3.4
– 1989–90 Average	6.1	3.5*
Frequency of feed offer (% days visited)	29.6	1.4*
Browse	50.2	57 2
Cassava peels + tubers	37.2	45.0
Other household wastes		
Feed consumed (kg/household/yr) ("as fed" basis)	398	7*
Browse	627	433*
Cassava peel + tubers	404	482*
Household wastes	1429	922*
Total		
Feed Consumed (kg/animal/year) ("as fed" basis)		
Browse	32.7	1.1*
Cassava peel + tuber	51.6	66.5*
Household wastes	33.2	74.0*
Total	117	141.6*
Production parameters		
Litter size	1.48	1.41
Parturition interval (days)	280.00	298.00
Weight at 12 months (kg)	9.50	10.10
Survival of adults	0.67	0.64
	0.92	0.70*
Productivity indices to 12 months post partum (kg)		
Doe productivity	12.28	11.18
Herd productivity	11.29	7.82*

Only * marked items differ significantly (< 0.05) between browse feeders and non-browse feeders.

Source: ILCA unpublished data.

Production parameters did not differ significantly between the two groups except in the case of adult survival rate and herd productivity. Overall performance of the herds were measured by two indices: Doe Productivity = (kid weight at n months post-partum x kid survival to n months x 365)/kidding interval; and Herd Productivity = Doe productivity x Doe survival rate. Doe productivity measures weight of offspring at n months of age per doe per year. Herd productivity is equivalent to aggregate doe productivity when doe survival rate is taken into account. It reflects the offspring produced and surviving to a useful age/size when they can enter the breeding herd as replacement. In that sense, herd productivity measured on an annual basis, is a better measure of performance on a household basis. Doe productivity did not differ significantly ($P > 0.05$) but herd productivity did differ significantly ($P < 0.05$) between browse feeders and non-browse feeders. Herd productivity was lower among non-browse feeders due to higher adult mortality.

Based on herd productivity, it was calculated that compared to non-browse feeders, browse feeding herds gave 53 g of additional liveweight gain per kg of tree browse fed. This response rate was comparable to some of the on-station results described earlier.

3.5 Discussion and summary of results

The importance of browse in ruminant diet in Africa has been well documented (Le Houerou, 1980). Increased population pressure and intensity of crop cultivation require more animals to be raised under confinement requiring more cut-and-carry feed of good quality. At the same time, indigenous browse supplies decrease due to land clearance, and due to cutting by everybody and planting by none. Sometimes feed may be available far away from the household, requiring substantial labour time for regular collection. Undernourishment is one of the major constraints to raising small ruminant productivity. Planted forage, even of small quantities, may help enhance productivity significantly. Highly productive and nutritious leguminous trees and shrubs such as *Leucaena* and *Gliricidia* good options.

Mimosine toxicity in *Leucaena* may be a potential constraint to its use as a major feed supplement. However, the chances of over feeding with *Leucaena* causing mimosine toxicity appeared to be limited under smallholder farm conditions where very high level of cut and carry supplementation or grazing were not practiced. Moreover, the risk of toxicity was reduced by producing both *Leucaena* and *Gliricidia* and offering them in a 1: 1 mixture. This is a novel easily usable technique.

Presence of a fermentable energy source such as cassava peel or tuber was found to increase the efficiency of utilization of protein rich feeds such as *Leucaena* and *Gliricidia*. Studies in the tropical semi arid region of Tanzania also showed that correlation between growth and intake of metabolisable energy was significantly higher than correlation between growth and protein intake. So, best effects on growth of weaned lambs and kids can be expected from supplements with high energy and moderate protein contents (Hai, 1988; Susuma, 1989; Mtenga and Madsen, 1992).

The potential of browse supplementation to improve animal resistance to disease was shown by Murray *et al*. (1982), ILCA (1987), and Reynolds and Ekwuruke (1988). Supplementation increased resistance in pregnant and lactating females, and increased offspring survival rates. Trypanosomes increase the nitrogen turnover rates of infected animals, raising maintenance requirements and hence reducing available N for the products of conception or milk production. Improved nutrition has also been shown to alleviate the consequences of Haemonchus contorts infection in sheep, which is a more widespread problem for smallstock than trypanosomiasis (Blackburn *et al*., 1991).

Supplementation of a grass diet with mixed *Leucaena* and *Gliricidia* browse increased total DM intake, but substitution of browse for grass occurred, particularly in the dry season when grass quality is low compared to the wet season, while browse quality remains relatively constant throughout the year. Similar results were reported for Malawi (Banda *et al.*, 1985), Australia (Van Eys *et al*., 1986) and south and southeast Asia (Devendra, 1993). Browse intake of WAD does and kids were higher than for WAD ewes and lambs when Offered the same levels of supplement, but the growth response of lambs were considerably higher. Effects on litter size and survival rates were similar across species. This suggests a poor conversion of dietary nutrients to milk in the dams and/or poor food conversion efficiency in kids, as compared to ewes and lambs.

Continuous supplementation throughout the last 3 months of pregnancy and the entire lactation period requires a steady supply of tree foliage, which farmers are unlikely to be able to supply from their own resources. Periodic supplementation with tree foliage at levels that farmers can provide, gave no significant improvement on growth performance. However, on-farm studies of farmer practice showed that herd productivity in animals receiving browse was significantly higher than for non-browse feeders because of differences in mortality rates of adult animals. On-station trials had not shown this effect on adults, probably because of environmental differences on-farm include greater disease stress. Hence, predictions of improved performance as a result of browse feeding were borne out on-farm, but not for the expected reasons. This emphasises the need for controlled on-station trials to be confirmed by on-farm trials under farmer management. Bosman and Ayeni (1993) showed that the productivity of free roaming animals on-farm was more sensitive to disease control measures, than to measures targeted specifically at improving growth rates, whereas the reverse was true for confined animals. This confirms the observation of our own on-farm work.

Unlike *Leucaena Gliricidia* is not known to contain any substance toxic to ruminant livestock, so can be used as a major component of the diet for extended periods without causing problem. *Gliricidia* has been used extensively as a fodder source in Central America and Asia, often from living fence lines, and as a hand cut supplement (Devendra, 1993; Chadhokar and Kantharaju, 1980). In West Africa, *Gliricidia* are rarely browsed by animals indicating low palatability of the fresh material and *Gliricidia* accessions also vary in palatability indicating the need for careful selection for planting. The form in which *Gliricidia* may be fed is also important.

Free roaming village animals exist in humid West Africa mainly by foraging and scavenging through household wastes. Supplements in the form of cassava peel and cassava tubers are provided. In on-farm studies in southern Nigeria, goats in non-browse feeding households consumed 141 kg (as fed) of cassava peel and household waste, compared to 85 kg in browse feeding households. In the former group cassava peel and tubers comprised almost half the ration, while in the latter group it comprised over 60% to which 33 kg of browse was added. However, an additional 1 to 3 hours a day will be spent grazing and browsing (Carew *et al.*, 1980), but intake was not recorded during this period. Measured food intake was equivalent to around 70 g DM/day for the browse fed group, considerably below the expected intake of 400 g DM/day for an animal of 10 kg body weight (which is the estimated overall mean for the herd). Extrapolating from on-station observations it might be expected that the browse fed group would consume less grass than the non-browse feeders, but might also consume less self selected browse. The nitrogen content in the offered browse legumes, and hence the nutritional value, would be higher than that of the browse locally available for self-selection.

Reynolds and Jabbar (1994) reported on the basis of experiments conducted in sub-humid coastal Kenya that gross financial return was 3.3 times higher when all the tree foliage was used for feeding dairy cows. In the humid zone of West Africa, WAD goats and sheep are the principal animals reared but they are not milked and their milk production potential is rather low. However, with reduced risk of trypanosomiasis, Fulani cattle rearers are settling in increasing numbers with milk producing Zebu cattle (Jabber, 1993; Jabbar, *et al.*, 1995). Dry season feed is a particular problem for these farmers and, among other things, legume tree based crop-livestock production may become an attractive option for them.

4. Economics of alley farming

A technology should be profitable and fit the objectives and resource endowments of the farm household to be adoptable. In this section, three important economic aspects that may affect adoption are discussed: (a) optimum allocation of tree foliage between mulch and fodder in order to maximize farm returns, (b) long-term profitability of alley farming with and without livestock and, with and without fallow for fertility restoration, (c) sustainability of alley and non-alley farming.

4.1 Optimum allocation of tree foliage between mulch and fodder

In the west African humid zone, tree foliage from alley farms may be used as mulch or as feed supplement for small ruminants or as both mulch and fodder in varying proportion. Other things remaining given, optimum allocation of foliage between mulch and fodder will depend on crop response to mulching, animal response to supplementation and, market prices for crop and animal.

If L is defined as the extra returns from livestock when part of the foliage is used as feed rather than as mulch, then for a given allocation, L may be estimated by the following partial budgeting procedure:

$$L = [(Q_1 WP_1) - (QRP_2 - Q_1RP_2)] - E$$

where		
L	=	extra returns from livestock (*Naira*)
Q_1	=	quantity of tree foliage used as feed (tons)
Q	=	total quantity of foliage available (tons)
W	=	animal body weight gain per unit weight of feed (g/kg feed)
R	=	crop output (tons) per ton of tree foliage if applied as mulch
P_1	=	price per unit of animal output (*Naira*)
P_2	=	price per unit of crop output (*Naira*)
E	=	extra labour cost for feeding, if any (*Naira*)

The equation shows that for any particular allocation of foliage between mulch and fodder, extra gain from feeding animals is to be calculated by deducting the value of maize yield forgone from the value of animal liveweight gain. The value of L is zero when no foliage is used as feed or when the gain from feeding is exactly offset by the loss of crop output. The value of L is positive or negative depending on the balance of gain from feeding and the loss of crop output. The allocation option that gives the highest extra return from animal feeding may be considered the optimum allocation of foliage between mulch and fodder.

Ideally, foliage from the same plot should have been allocated between mulch and fodder to generate actual values of Q, Q1, W and R in the equation. No such integrated experiment was conducted. However, on-station and on-farm agronomy trials have shown that the quantities of foliage corresponding to application of about 50% of each of six yearly prunings or the entire first two prunings as mulch gave the most additional grain yield. The remaining prunings gave smaller responses, so could be used as feed (section 2.3.2 and 2.3.3). Animal nutrition studies have shown varying rates of liveweight gain at different levels of supplementation (section 3).

These two sets of data were used, with additional assumptions, in the above partial budgeting procedure to assess the implication of using the entire foliage as mulch or as feed supplement or various combinations of feed and mulch (Jabber *et al.*, 1992).

Results showed that when maize yield without mulch and yield response to mulching were low, economic gains could be made by feeding small ruminants with part of the foliage (Table 4.1). Using 50% of crop season prunings as mulch and the remainder of crop season and all of non-crop dry season prunings as fodder gave the highest total returns. Most nutrition studies (Section 3) gave animal liveweight gain of 40-50 g per kg (DM) browse supplement but at low maize yield and low response to mulching animal weight gain of 30 g per kg browse supplement was enough to make browse feeding profitable.

Table 4.1 *Estimated extra returns from small ruminants in three situations and under different fodder mulch allocation of prunings from one ha of alley farm.*

% foliage applied as mulch		Use of foliage (t DM)		Extra returns from small ruminants (Naira)		
1st season	2nd season	Mulch	Fodder	Situation 1	Situation 2	Situation 3
100	100	7.21	0	0	0	0
100	50	5.72	1.49	46	267	432
100	0	4.23	2.98	216	72	–698
50	50	3.61	3.60	389	– 945	265
50	0	2.11	5.10	545	–1173	–898
0	0	0	7.21	– 611	– 2237	–3722

Assumptions	Maize yield (t)		Animal liveweight gain per kg feed (gm)
	No mulch	100% mulch	
Situation 1	1.7	2.7	50
Situation 2	1.8	3.5	60
Situation 3	2.5	4.5	60

Source: Jabbar *et al.* (1992).

When maize yield without mulch was medium to high and yield response to mulching was high, only half of dry season prunings could be profitably used as fodder. Animal liveweight gain of 60 g per kg browse supplement would be required to make browse feeding competitive with mulching, and such high response rates were rarely observed in experimental WAD sheep and goats.

4.2 Long-term profitability of alley farming with and without livestock

Alley farming involves flows of costs and benefits over the life cycle of the trees. Once established, they require regular maintenance and management to derive benefits. The flow of benefits and costs will depend on whether the foliage is used for mulch or fodder as both mulch and fodder, and whether any fallow period is incorporated in the alley system as in the bush fallow system.

A number of economic analyses have shown that alley cropping was more profitable than conventional bush fallow systems in humid West Africa (for example, Raintree and Turay, 1980; Verinube *et al.*, 1984; Ngambeki, 1985; Ashraf, 1990; Ehui *et al.*, 1990). Some studies (Ashraf, 1990; Ehui *et al.,* 1990) have additionally shown that alley cropping may not be profitable under low population density, i.e. under land abundant situations, or where fertilizer is easily accessible and cheap. Sumberg *et al.* (1987) compared bush fallow, alley cropping, and alley farming with small ruminants and found alley farming less profitable than alley cropping but Ashraf (1990) found alley farming with small ruminants more profitable than alley cropping.

These studies used different methodologies (partial budgeting, capital budgeting, linear programming) and used some experimental data combined with different sets of assumptions about cropping and fallow cycles, life span of threes, rates of soil erosion and yield losses, crop response to mulching and animal response to feeding, all of which had influence on the results. Some of the assumptions were unrealistic in view of more up to date experimental results.

For example, in most studies continuous alley cropping of different durations ranging up to 20 years (i.e. the implicit life span of the trees) were compared with bush fallow systems of different cycles (Ehui *et al.*, 1990; Ashraf, 1990). After several years of experimentation by both IITA and ILRI, it is now apparent that crop yield and soil nutrient status may increase initially but tend to decline in the long-run under continuous alley cropping, and that the trees may not have productive life of more than 10 years under intensive management (section 2.3.4). Therefore, alley cropping may reduce but not altogether eliminate the need for short-fallow for maintaining long term productivity and soil fertility. Alley farming turned out to be less profitable in Sumberg *et al.* (1987) primarily because they assumed crop response to mulching at rates which were significantly on the high side judged by recent agronomy trials.

Using data from long-term agronomy and animal nutrition studies conducted by ILRI, an ex-post analysis of long-term profitability of alley farming with and without fallow, and with and without livestock was conducted (Jabber *et al.,* 1994). Profitability of non-alley farming with fallow, alley farming with fallow, and continuous alley farming was compared by using a capital budgeting procedure of the following form:

$$G = \sum_t C_{it}\, b_t \pm \sum_t F_{jt}\, b_t \pm \sum_t L_t b_t - U_T b^T$$

where

G	=	Total present value of gross margin (*Naira*),
C	=	Gross margin of crop i in year t (*Naira*), In a fallow year, C=0.
F	=	Value of soil nutrient j (nitrogen, phosphate, potash) increased/decreased in year t compared to year 0 (*Naira*),
L	=	Extra gross margin or loss from livestock in year t when part of the foliage is used as feed (*Naira*),
U	=	Land clearing/tree uprooting cost (*Naira*) in year T. the terminal year of the project or tree life.
b	=	$(1 + r)^{-1}$, i. e. discount factor.

A brief explanation of the components of the model and the relevant data are given below. Gross margin of a crop was calculated by deducting costs of seeds, labour and fertilizers, if any, from the value of crop output. Gross margin was used as a measure of performance because (a) in the absence of a developed land and rental market in the study area determination of land use cost would be inaccurate, (b) capital investment in the traditional system was very small in the form of hoes and cutlasses, the yearly user cost of which would be negligible to affect relative profitability. Crop yields from the long-term experiment described in section 2.3.4 were used to estimate crop gross margin. Labour was a major input. Quantities of labour were assumed from a synthesis of on-station and on-farm studies (also see section 5.3). Crops and inputs were valued at 1988 constant prices and a 10 percent discount rate was used to obtain present values.

The indirect benefits or costs due to enhancement or decline of soil nutrient status are accounted for by F. At the early stage and after a fallow period, mulching may increase crop yield as well as improve the nutrient content of soil but in the long-run both crop yield and soil nutrient may decline as in the case of non-alley cropping. An increase in the soil nutrient status may be considered as equivalent to an output of the system in addition to crop while a decrease in soil nutrient may be considered as equivalent to a cost (Farrell and Capalbo, 1986). Accounting of these indirect costs or benefits gives a more objective assessment of different land use systems. Yearly increase or decrease in the quantities of nitrogen, phosphate and potash in the long-term experiment (section 2.3.4) were quantified and valued at market prices of chemical fertilizers.

L in year t was calculated by using the partial budgeting procedure described in section 4.1 but yearly crop and foliage yields from the long-term experiment (section 2.3.4) were used as data. Feeding foliage was not used as a treatment under this experiment, so L was estimated by assuming that 50% of foliage output in both crop and fallow years would be used as teed, the remainder as mulch, and that animal liveweight gain would be 50g per kg browse dry matter, which was the modal value in nutrition experiments.

At the end of their productive life (terminal year of the project), the trees were assumed to be uprooted, the land cleared, and the costs internalized to the current project. The uprooted tree stumps might have some value as fuelwood but transportation costs would cancel that, so salvage value was assumed to be zero. Although alley cropping reduced the need for clearing labour after fallow compared to conventional cropping, at the end of the life cycle of the trees clearing and uprooting might require substantial investment in labour costs to make the land usable for the next production cycle. Normally such costs are treated as investment for the next project cycle, but there was some merit in internalizing this cost in the current project cycle. This helped to examine whether the perceived relative merit of alley farming was maintained after the terminal clearing cost was internalized.

Estimated present values of gross margins for the three land use systems are shown in Table 4.2. If only returns to crops were considered, continuous alley farming gave 30 percent higher returns than non-alley and alley farming with fallow systems. This was the case in spite of the fact that crop yield under continuous alley farming almost monotonically declined while yield under both non-alley and alley farming systems with fallow increased sharply immediately after fallow but declined sharply thereafter. The post-fallow short-lived yield increases were not adequate to cover the yield loss of two fallow years.

Table 4.2 *Present values of gross margins (Naira/ha) of three alternative land use systems in Southwest Nigeria.*

		Land use system		
Model components		Non-alley farming with fallow	Alley farming with fallow	Continuous alley farming
Crop return	(C)	16325	16324	21255
Nutrient loss (-)/gain(+)	(F)	– 149	–120	– 189
Extra return from livestock	(L)	–	+2590	+ 2679
Terminal clearing costs	(U)	– 102	– 305	– 305
Total present value of				
Gross margin	(G)	16074	18489	23444

Source: Jabbar *et al.* (1994).

The value of nutrient loss amounted to ₦ 49, ₦ 120 and N 189 respectively under non-alley,

alley farming with fallow and continuous alley farming. It may be recalled that long-term decline in nitrogen was higher and that of phosphate and potash lower in non-alley than alley systems. Lower values of nutrient loss under systems with fallow indicated that fallowing had contributed to slow down the rate of mining the soil. Looked at differently, these figures would be interpreted as the amount of investment required in nitrogen, phosphate and potash in order to keep these nutrients at the base year levels. A trial conducted earlier combining levels of chemical fertilizers with mulching indicated that with higher levels of chemical fertilizers, diminishing returns ensued but the status of soil nutrients remained better than under only mulching (ILCA, 1992).

The addition of livestock to alley cropping increased gross margin by about 16 percent in case of alley with fallow and by about 13 percent in case of continuous farming. The advantage of alley farming over non-alley system increased with the addition of livestock.

Returns from livestock under continuous alley and alley with fallow systems were nearly the same because it was assumed that tree foliage under fallow would be used as livestock feed. If trees were not used during fallow, alley farming with fallow would still remain more profitable than non-alley system, though the margin would reduce.

The internalization of terminal clearing cost did not significantly change the relative position of the three systems. Moreover, gross margins under alley farming with and without fallow still remained significantly higher than under non-alley system.

In summary, the results indicated the following: (a) continuous alley cropping was significantly more profitable than non-alley or alley cropping with fallow; (b) short fallowing in alley cropping reduced the rate of mining the soil, thus helped preserve future productivity, (c) addition of small ruminants significantly enhanced profitability of alley systems and increased its advantage over the non-alley system, (d) alley systems remained sufficiently attractive even when terminal clearing costs were internalized in the current project cycle.

4.3 Sustainability of alley and non-alley farming

4.3.1 Background

Research on the development of alley farming as an alternative to traditional bush-tallow system was initiated because of the apparent unsustainability of the latter system (Kang *et al*., 1984; 1990). It was, therefore, necessary to empirically determine whether alley farming was indeed a sustainable system or a more sustainable system than bush-fallow.

Sustainability as a concept has been in vogue for quite some time but it still remains a general guide to research rather than as a guide to practice because of the lack of a comprehensive definition and analytical methodology. While volumes have been written on the meaning of sustainability, mostly in an abstract manner, only a few attempts (see for example, Frye and Blevins, 1989; Flach, 1990; Korsching and Malia, 1991; Xu *et al.*, 1992; Ehui and Spencer, 1993; Ehui and Jabbar, 1995) have been made to measure sustainability of specific production technology/system.

Among many definitions of sustainability, the one given by Lynam and Herdt (1989) provide a practical basis for empirical measurement. In their view, sustainability is the "capacity of a system to maintain output at a level approximately equal to or greater than its historical average, with the approximation determined by its historical level of variability. The appropriate measure of output by which to determine sustainability at the crop, cropping or farming system level is total factor productivity (TFP), defined as the total value of all output produced by the system over one cycle divided by the total value of all inputs used by the system over one cycle of the system; a sustainable system has a non-negative trend in TFP over the period of concern." Further, Young (1989) defines sustainable land use system as one which "achieves production combined with conservation of the resources on which that production depends, thereby permitting the maintenance of productivity."

The rationale behind the use of TFP as a measure of sustainability is that the growth of TFP over a period of time measures the residual growth in aggregate output not accounted for by the growth in aggregate factor input, so it is a measure of shift of a production function solely as a result of changes in time. If the shift of the production function is a long term continuous process without any backward shift, then the production process can be regarded as sustainable and the amount of shift a measure of sustainability. In the real world, the shift of the production function may not be continuously positive over time rather may at times involve backward shifts due to resource constraints, resource depletion and externalities. In that case, the net shift over the time period concerned, i.e. difference between the sum of the forward shifts and sum of the backward shifts, is a measure of sustainability, and net positive shift is an indication that the system is sustainable (Islam, 1995)

In the conventional approach to growth accounting, only direct inputs and outputs are considered in TFP calculation and the rate of growth of TFP is considered a measure of technical change (Chambers, 1988; Capalbo and Antle, 1989). However, agricultural production involves use of common pool resources whose stocks may change positively or negatively in the production process. For example, soil nutrient may decease due to uptake by crop, leaching and volatilization or it may increase due to nitrogen fixation by plants. A decline in the stock of resources implies a decline in productive capacity and a cost to the producer in terms of forgone productivity or an increased investment required to replace the lost resources. Similarly, an increase in the stock of resources implies an increased benefit from the system. If these implicit unpriced costs and benefits are not accounted for in TFP calculation, the results will be biased. So Ehui and Spencer (1993) argued that when all the unpriced contributions from natural resources and environments, and unpriced production flows are accounted for in TPF to take account of Young's concerns about maintaining productivity, the productive capacity becomes a measure of sustainability.

4.3.2 The general model

Following from the above conceptual background, Ehui and Spencer (1993) employed the growth accounting framework as developed by Denny and Fuss (1983) to construct intertemporal total factor productivity indices as a measure of sustainability. First they solved a general maximization problem stated as:

$$\text{Max } p_t = P_{yt} Y_t \pm P_{zt} Z_t - G(Y_t, Z_t, W_t, B_t, t) \qquad (1)$$

$[y_t, z_t]$

where,

p_t is a measure of aggregate profit in period t including all benefits and costs of resource exploitation;

Y_t is an index of crop outputs for time period t;

Z_t is an externality denoting the net resource flow in time period t ($B_{t+1} – B_t$) which is considered an output when the net resource flow is positive, and an input or cost when the net resource flow is negative;

P_{yt} and P_{zt} are the product and resource flow prices;

B_t is a technology shift variable representing the level of resource abundance in period t.

G (•) is the variable cost function for the optimal combination of variable inputs.

When Z_t is negative, d G (•)/d B < 0 and d G (•)/d Z < 0; when Z_t is positive, d G (•)/d B < 0 and d G (•)/d Z > 0;

W_t is a vector of variable input prices for time period t;

t is the time trend representing the state of technical knowledge.

Using the first order conditions of (1), development of the continuous time Divisia index by method of the growth accounting approach gives:

$$- d\, LnC/d\, t = [P_yY/C]\, Y^* \pm [P_zZ/C]\, Z^* - S_j\, [(W_j.X_j)/C]\, X_j^* - B^* \quad (2)$$

The * on variables imply the logarithm derivation of the associated variable with time. When changes in the resource stock (second term in equation 2) are positive, $C = S_j\, W_jX_j = P_yY + P_zZ$ = total revenue, assuming constant returns to scale. When changes in resource stock are negative, $C = S_j\, W_j X_j = P_yY - P_zZ$, assuming constant returns to scale (for full derivation of equation 2, see Ehui and Spencer, 1993)

Equation (2) indicates that TFP is measured as the residual after the growth rate of output (P_yY/C) has been allocated among changes in inputs $[S_j\, (W_j X_j/C)_j]$, and resource abundance (B) and flows $[(P_zZ/C)\, Z]$.

A discrete time approximation to the continuous time Divisia index of equation (2) is given by the Tornqvist approximation. Allowing for resource abundance and flows, this approximation gives the following measures of the intertemporal TFP indices (Ehui and Spencer, 1993).

When net changes in resource stock are positive:

$$T_{st} = 1/2\, S_j\, [R_{js} + R_{jt}] \bullet [LnY_{js} - LnY_{jt}] + ½\, [R_{zs} + R_{zt}]\, [LnZ_s - LnZ_t] - ½\, S_k\, [S_{ks} + S_{kt}] \bullet [LnX_{ks} - LnX_{xt}] - [Ln\, B_s - Ln\, B_t]$$

(3)

When net changes in resource stock are negative:

$$T_{st} = S_j\, [LnY_{js} - LnY_{jt}] - ½\, [S_{zs} + S_{zt}] \bullet [LnZ_s - LnZ_t] - ½\, S_k\, [S_{ks} + S_{kt}] \bullet [LnX_{ks} - LnX_{xt}] - [Ln\, B_s - Ln\, B_t]$$

(4)

where, s and t represent two distinct time periods; $R_j = (P_jY_j)/ S_j\, P_jY_j$ is the revenue share of output Y_j; $S = (W_kX_k)/ S_k\, W_kX_k)$ is the cost share of variable input k; and S_z and R_z are the cost and revenue shares of resource flow Z. It is clear from equations (3) and (4) that productivity differences across time periods can be broken into four components: an output effect, a resource flow effect, an input effect, and a resource stock effect.

4.3.3 Model application and results

Ehui and Jabbar (1995) used equations (3) and (4) to compare the sustainability of three production systems: non-alley farming with fallow, continuous alley farming, and alley farming with fallow. These are the same systems (and experiment) which were subjected to long-term profitability analysis in Section 4.2. In operationalizing the model, an output index was calculated by dividing the total value of all output by a price index. Maize was the principal crop and cowpea was grown as a second crop in some years. The price index was obtained by weighing the maize and cowpea prices by the revenue share of each crop.

Three major inputs were distinguished: planting materials, fertilizer and labour. Planting materials for each crop was aggregated to a single index from bilateral Tornqvist chain indices for each type of planting material, then weighted by the cost share of each planting material. Labour and fertilizer input quantities were used as observed.

The Divisia index for the soil nutrient stock was calculated by share-weighting the total quantities of principal soil nutrients (nitrogen, phosphorus and potassium) available in the top soil (0–10 cm). The opportunity cost of each soil nutrient was approximated by its replacement cost, i.e market price for chemical fertilizer. Resource flows were derived as the difference between nutrient abundance levels for a given production system between 1983 and 1990, the experimental period.

Intertemproal total factor productivity indices for the three production systems were calculated under three scenarios: (a) taking into account only direct inputs and outputs for crop and not accounting for nutrient stock and flows, (b) taking into account crop production, and nutrient stock and flows, (c) taking into account crop and small ruminant livestock production, and nutrient stock and flows.

The results are given in Table 4.3. When only crops are produced and changes in the stock and flows of nutrients are not accounted for, continuous alley farming is a highly sustainable system while the other two systems are not. In continuous alley farming, about 1.5 times as much output was produced in 1990 as in 1983 using the 1983 input bundle. When changes in nutrient stock and flows over this period are accounted for, none of the systems is sustainable and continuous ally farming is even worse than non-alley farming. This is because, continuous ally farming gives a higher flow of crop output but at the same time mines the soil in the long-run. On the other hand, intermittent short follow in alley farming allows resource stock to be maintained but because of loss of output in fallow years, the system is not sustainable. (see section 2.3.4 for agronomic details)

Table 4.3 *Intertemporal total factor productivity indices for three production systems under experimental conditions in southwest Nigeria, 1983–1990.*

Systems	Crops, not accounting for nutrient stock and flows	Crops + accounting for nutrient stock and flows	Crops and livestock + accounting for nutrient stock and flows
Non-alley farming with fallow	0.92	0.69**	0.78**
Continuous alley farming	1.46	0.64**	1.28**
Alley farming with fallow	0.60	0.56*	0.60*

* = positive resource flow ** = negative resource flow

Source: Ehui and Jabbar (1995)

The performance of all the systems improve when small stock livestock is mixed with crop production. However, only continuous alley farming with livestock is sustainable, the other two are not. Continuous alley farming produce 1.3 times more output in 1990 as in 1983 with the 1983 input bundle.

There are two practical implications of this result. First, tree foliage productivity decline over time under continuous pruning (see section 2.3.4) but from the evidence given here, continuous pruning may be sustainable for 8–10 years. Tree life cycle may be extended beyond 8–10 years with intermittent short fallow but overall the system may not be sustainable if nothing is produced during fallow years while using all or some of the fallow year tree foliage to raise livestock may improve sustainability. Secondly, a real world farmer is unlikely to put all his/her land to alley-farming because of its unsuitability to certain crops such as yam and cassava which the farmer's crop plan would normally include. So alley-farming may be rotated with non-alley farming, the cycle of rotation being determined by the profitable life cycle of the trees. At the end one profitable cycle of tree life, the alley plot may be converted to a non-alley plot with suitable crop(s) and rotation and vice versa. Adding livestock to the alley system will make the whole farm more profitable and sustainable.

5. On-farm research, diffusion and extension

5.1 The approach and the setting for on-farm research

The final test of the appropriateness of a technology is its wide adoption by potential users. On-farm research (OFR) is an important step in the process of testing and adoption. Within the framework of farming systems research, OFR is generally started once biological/physical aspects of a technology are sufficiently developed and standardized for testing in real farm conditions. The involvement of the farmer in the management and evaluation of the technology is increased generally by sequencing on-farm trials from researcher managed to researcher and farmer managed, to farmer managed (Matlon, 1982; Zandstra, 1982). Moving from researcher to farmer managed trials also involves gradual simplification of trial designs with fewer but more promising treatments and collection of data on fewer but more important variables. On-farm research may be followed by a pilot project in a limited area before wider extension initiative is taken.

The importance of OFR was realized by the ILRI alley farming research team in the west African humid zone quite early in the research process but in pursuing OFR, no predetermined procedure or sequence was followed, rather it evolved with experience. Initially, a semi-extension 'developmental' approach was taken and researcher-managed on-farm experiments were introduced at a later stage[2] (Atta-Krah and Francis 1987).

2. IITA followed a standard pre-determined sequence in its OFR programme with alley cropping and for several years focused on researcher and researcher-farmer managed trials to collect intensive bio-physical data (Dvorak. 1991). More recently, ICRAF has adopted a somewhat similar sequence in on-farm trial as was done by ILRI (Shepherd *et al.*, 1994).

On-station agronomic and animal nutrition studies to modify alley cropping for inclusion of livestock were started in 1978. By 1981, some aspects of the technology were considered sufficiently at an advanced stage for testing in real farm conditions. So, during 1981 and 1982, five volunteer farmers were identified through consultation who agreed to participate with ILRI in testing the viability and performance of alley trees. Three of them were located in Badeku village, 30 km east of Ibadan, and two in Fashola village, 60 km west of Ibadan. One alley plot (Intensive Feed Garden) was established on each farm with *Leucaena* seeds and *Gliricidia* stakes with a single treatment using the best performing tree-spacing (50 cm intra-row and 50 cm inter row) and cutting regime (12 weeks interval) found in on-station trials. ILRI provided labour and inputs and was largely responsible for managing the plots while the farmers participated in the evaluation. This was not a 'researcher-managed' trial in the strict sense because systematic quantitative data was not collected, evaluation was done subjectively. However, a number of lessons were learned over the two years.

First, establishment of *Gliricidea* from stakes appeared to be costly in terms of time and resources, and hazardous for transporting long distances. This led to the initiation of on-station research in 1982 on the establishment of *Gliricidia* from seed. This was successfully done and subsequently a small *Gliricidia* plantation was established on-station for seed production. Seeds were also collected by ILRI from the range for distribution among researchers and farmers who wanted to establish alley farms.

Second, although farmers used tree browse from the feed gardens to feed their animals, they expressed more interest in the mulching function of the trees, indicating the need for combining crop and animal in the system.

Third, one of the five feed gardens was established in a fallow land managed collectively by an established farmer cooperative. However, the idea of an improved fallow for feeding animals was not familiar and the members of the cooperative were uncertain about the mode of distribution of any benefits. Consequently farmer participation was poor and the farm also performed poorly.

In 1983, 12 more alley farms were established in crop fields in Fashola and Badeku with researcher-farmer participation, but quantitative data were not collected. Both *Leucaena* and *Gliricidia* were established from seed. ILRI's involvement in planting and management were considerably reduced and the participating farmers were encouraged to contribute to the development of the system by modifying it to suit their individual circumstances and requirements. Consequently, both the researchers and the farmers were able to test some new elements in the operation of the system.

First, in order to show that the system was compatible with mechanized tillage, some of the farms were cultivated by plough. Second, at the end of the dry season, two farmers successfully used fire in the traditional way to clear the land between the alleys for planting the next crop. Third, rather than spreading mulch over the entire surface between the alleys, one farmer put the prunings between two old ridges (planting on ridges is a common practice in the area) and cover them by splitting the old ridges to form new ridges. Subsequent on-station trial has shown that incorporation of mulch under the soil gives better response than surface mulch (Atta-Krah and Francis, 1987).

By demonstrating the flexibility and viability of the technology under farm condition, these trial farms were expected to create "neighborhood effect" and "innovation waves" (Mahajan and Paterson 1979) through farmer to farmer lateral learning and horizontal diffusion in the adjoining areas. But this was not forthcoming primarily because ILRI's continued, if reduced, involvement in the management and monitoring of the trials did not encourage other farmers to try the technology without similar assistance. Moreover, ILRI being an international research agency did not have any extension mandate and up to that time, no national extension agency was involved in the on-farm trials. Involvement of national extension service was considered essential, in line with farming systems research approach, for refining the technology on-station and further testing on-farm and wider diffusion.

In 1984, the farms in Badeku and Fashola were left to the participating farmers for their own management and use though they were infrequently visited to monitor progress. In order to involve extension service in the research process, to increase farmer control and management of alley farms, and to test the viability of the technology under different ecological and farmer conditions, two new sites were selected. One covering the adjoining villages of OwuIle and Iwo-Ate located about 20 km northeast of Oyo town and another consisting of the villages of Okwe and Mgbakwu, located about 15 km out of Umuahia in Abia State in eastern Nigeria. Both the locations were far enough away from nearest major towns for majority of the inhabitants to be full time agriculturalists. Despite their rural settings local transport provided a regular service for the inhabitants.

For site selection, the ILRI team was assisted by senior extension officers from the Ministry of Agriculture and Natural Resources, Oyo and Imo States. The team made use of ground survey data, previous knowledge, key informant interviews and extensive visits to select suitable locations. In Oyo, aerial survey results were also used. Active involvement in arable farming and significant presence of small ruminants were major criteria for selection.

The villages in Oyo lie on the fringe of forest and savannah, have population density of 190 per sq km, have small ruminants which are mainly free roaming but household wastes and crop by-products are given as supplements. Cutting browse to feed animals was (is) not common. Cassava, yam, maize and vegetables are major crops. Cocoa, fruits and oil palm are major perennial crops. Land management includes 3–4 year cropping with 4–5 year fallowing. Chemical fertilizers are used by some farmers at low dozes (Francis, 1987). Mulching by maize stover and other crop residues is practiced by some farmers.

The villages in Imo lie in the high rainfall acid soil zone, have population density of over 300 per sq km, have small ruminants which are mostly confined and tethered, so browse is cut and fed in addition to household wastes and crop by-products. Cassava, yam and vegetables are major crops. Oil palm are major perennial crops. Compound plots are yearly cultivated, near plots are used in a 2–3 year cropping 5–6 year fallowing cycle. Distant plots are used in a 1–2 year cropping, 5–6 year fallowing cycle (Francis, 1987).

Once the villages were selected, village chiefs and other important figures in the community were contacted, the purpose of the research project explained and through them village meetings organized to explain the project to the wider community. Samples of browse and browse seeds were displayed and posters depicting the various stages of tree establishment, management and use were distributed to the farmers. The respective commitments and responsibilities of the researchers and the farmers were also explained.

Farmers from Oyo state showing interest in the project were taken to visit the earlier on-farm trial sites in Fashola and Badeku to enable them to see established alley farms and exchange ideas with farmers who established them. Following these visits, 78 farmers from Own-Ile and Iwo-Ate registered to participate in the project. The land on which they intended to plant alley trees were inspected and several were rejected due to their unsuitability because of intense shading from standing trees or presence of noxious weeds. Some new farmers replaced them. Then meetings were held to discuss planting arrangements and techniques, tree and crop management in alleys, and planting demonstrations were held and seeds distributed. Eighty six farmers planted alley trees in the 1984 crop season.

No visit was organised for the interested Imo State farmers but other procedures were followed. Nine farmers planted one alley farm each and 10 planted one feed garden each in that year.

A baseline survey was conducted among all the farmers in the selected villages prior to project implementation to record their household characteristics, land and animal ownership, cropping pattern and their perception about constraints to crop and livestock production. Scarcity of land, poor soil fertility, diseases of crops and animals, unavailability of fertilizers and veterinary drugs were identified as major problems. Shortage of good quality feed was perceived as a more important problem in Imo than in Oyo. Blood samples were collected from the small ruminants of participating farmers to establish prevailing disease patterns. Free vaccination against PPR (Peste des Petit Ruminants, an important disease in the area) was provided to all willing farmers in the research villages irrespective of acceptance of alley farming.

An extension staff seconded from the Oyo State Ministry of Agriculture and Natural Resources was trained by ILRI and he was placed with the ILRI technical staff in the research villages. In Imo, the State Extension Department participated in the project on an irregular basis but no staff was permanently seconded. In both the sites, each alley farm was regularly monitored through fortnightly visits and data were collected on planting date, germination rate, tree conditions, crop(s) planted, weeding done, farmers' perception at each stage. Overall performance of the farms was evaluated at six month intervals.

By the end of the 1985 dry season, 68 out of 86 alley farms planted in 1984 in the Oyo villages survived with different degrees of tree condition. In Imo, 14 out of 19 survived. In the 1985 crop season, 40 more farms were planted voluntarily in and around Own-Ile and Iwo-Ate and 18 (8 alley farm and 10 feed gardens) were planted in and around Okwe and Mgbakwu. Free vaccination against PPR to all willing farmers within the research villages was continued.

In 1985, instead of general monitoring of all alley farms, the research team for the first time decided to undertake multiple treatment experiments on a few established alley farms in farmers' fields to validate the findings of some of the on-station agronomy and animal nutrition experiments. An adequate number of established alley farms were available for choosing a small number of fairly similar farms to undertake controlled experiment. Eight volunteer farmers were selected from Own-Ile and Iwo-Ate to undertake researcher and farmer managed trials. No such experiment was done in Imo State. In subsequent years, this number increased to a total of 24 but not all of them were involved in each experiment each year. The results of some of the on-farm agronomy and nutrition experiments have been discussed in sections 2 and 3. Labour and inputs for the agronomy trials were paid by ILRI. Each household participating in the nutrition experiment, which lasted two years, was given an ewe on condition that the offspring would be retained by the farmer and the parent would be returned to ILRI on completion of the trial. This was done in order to keep the farmer interested in the regular monitoring over a long period.

From 1985 onwards, the primary focus was on the researcher and farmer managed trials. Although an active extension programme was not operated, free seeds and advise was given to anybody in and around the research villages who voluntarily wanted to plant alley farms. Up to 1991, a total of 139 farmers planted 175 alley plots in and around the two research villages in Oyo and 109 farmers planted 119 alley plots in and around the two research villages in Imo state. Out of these, 62 alley plots in Oyo and 52 in Imo either did not establish or were discontinued after some year(s) of operation. On the other hand, 15 plots in Oyo and 4 in Imo were replanted. Towards the end of 1990 monitoring of the functional alley farms in Imo state was handed over to the state Extension Department. In 1991, farms in Oyo state were handed over to the state Agricultural Development Project, a multilacet extension agency.

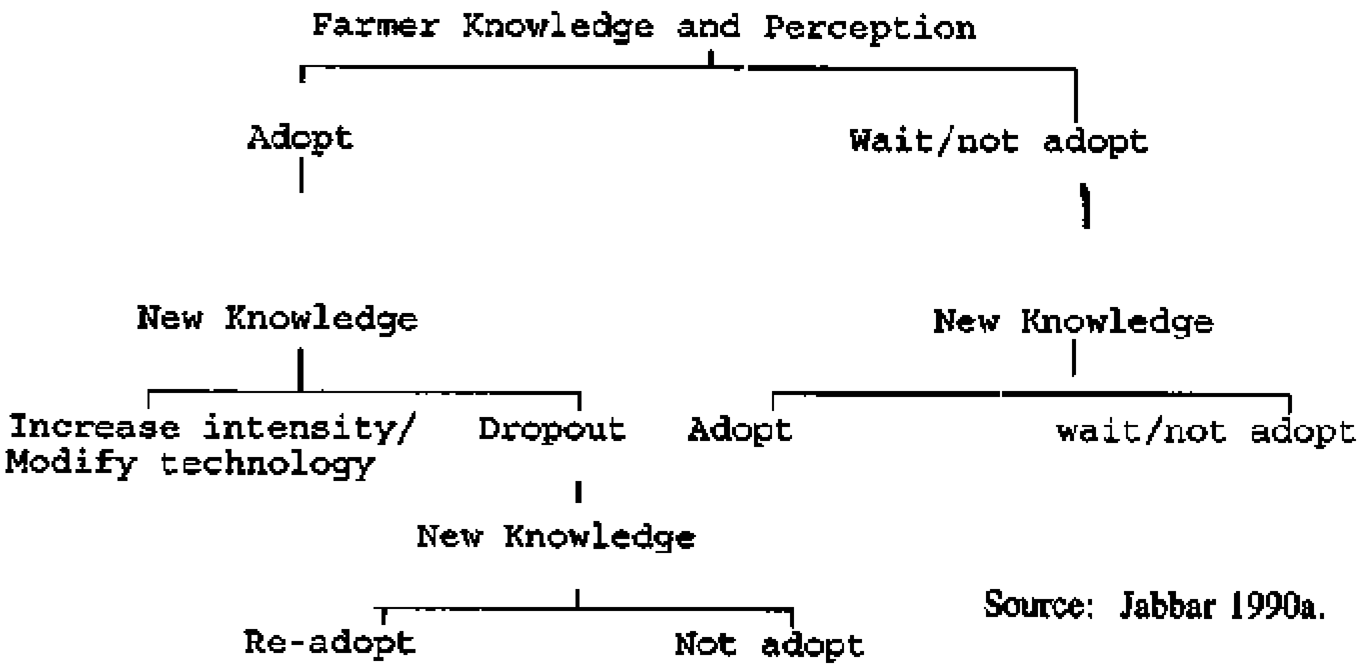
The combination of the semi-extension 'developmental' and the 'experimental' on-farm research approaches yielded two main advantages, though originally unanticipated, to assess the adaptability and adoptability of the technology. First, farmers' own modifications, adjustment mechanisms and experiences became important inputs towards learning the biophysical adaptive process of the technology and their implication for adoption (see below). These inputs would be unavailable if the research team had waited to find the best practice technology and took it to the farmers as passive recipients at some later date. Moreover, such waiting would perhaps be unproductive because the on-station best practice technology rarely performs at that level in actual farm conditions while the adaptive research results in "...a steady accretion of innumerable minor improvements and modifications" (Rosenberg, 1982) that helps to reduce the time required for standardization and adaption of the technology to various specific environmental and farmer situations.

Secondly, planting of alleys by a good number of farmers and their subsequent behaviour in terms of management, continuation and discontinuation brought into focus three important issues — labour, gender and land tenure — which were considered to have implications for adoption. These issues were then subjected to detailed investigation (see below).

5.2 On-farm research and the learning-adoption process

The wide adoption of any new technology, particularly complex ones, may go through a process of initial learning. At a given point in time, the decision to adopt or reject a technology or wait is influenced by the belief derived from the knowledge and perception at that point in time. Only limited amount of information may be available initially or only a limited amount of available information may be digested initially. So adoption decision may be taken on the basis of knowledge accumulated over a period of time. The prior belief may be modified on the basis of new knowledge and/or observed performance, and a new decision about adoption may be taken (Jabbar, 1990a). Thus, the "innovation assessment lag" defined as the time required between initial awareness and actual use of technology (Linder *et al*., 1979) may vary depending on the complexity of the technology, farmer's access to knowledge, his/her ability to decode that knowledge and formulate decision. The process of learning and adoption of a technology is shown in figure 5.1.

During 1984 to 1991, several examples of learning–adoption process were observed among the farmers who planted alley farms. First, farmers were given the option of planting alley farms with crop or intensive feed gardens for only feeding animals. However, the idea of feed garden was not attractive in the beginning in Oyo area because animals were free roaming and cutting browse was not so common. Crop was a priority and soil fertility was a major problem. Though quality feed was scarce, additional benefit for livestock was of marginal importance. So tree-crop system was preferred. In 1990, only 41 percent of the alley farmers in Oyo area were using 10-15 percent of tree foliage as feed, rest as mulch. Others were using only for mulch. After years of demonstration of a feed garden in the village and after observing that animals on on-farm nutrition trial eating tree foliage performed much better than those not fed tree foliage, some farmers became interested in planting feed gardens. During 1990/91, 9 gardens were planted in a village next to the on-farm research area.



Source: Jabbar 1990a.

In Imo State, where animals were confined and tethered, and browse collected from the range, the idea of feed garden was received with some enthusiasm but the interest declined over time. Out of 37 alley plots planted during 1984 and 1985, 20 were feed gardens. Out of another 82 alley plots planted up to 1991, only 11 were feed gardens. Moreover, some of the feed gardens were later cleared and returned to crop production, some feed gardens were converted into tree-crop system by replacing some tree rows with crop. However, in 1990, 51 percent of the farmers with functional alley farms were using 10-30% of their tree foliage as feed and 49% were using only for mulch.

Thus, it appeared that the mulching function of alley trees was of greater importance than the feed function in both Oyo and Imo States, though the importance of the feed function was slightly higher in Imo. A survey of alley farmers in 1989 showed that almost none of the alley plots were fertilized while non-alley plots were fertilized indicating that farmers appreciated the mulching function of the trees (Reynolds *et al.*, 1991)[3]

> 3. Because of the small number of feed gardens planted and small extent of tree use as feed by participating farmers, questions were sometimes raised both within ILRI and by outside visitors about the justification for devoting resources in an on-farm research programme in which majority of the benefits were going to crop which was not ILRI's mandate. A joint on-farm research programme by ILRI, IITA and NARS would have been the most ideal in terms of addressing the issues which are common and complimentary, and in terms of cost effectiveness. This did not happen because the institutions had different mandates and priorities, and they adopted different approaches as mentioned earlier. So without pursuing the programme, ILRI would not know the priorities of the farmer and constraints to adoption of alley farming, particularly for feeding animals.

Second, at the onset of on-farm research, farmers were told that maize or short statured crop such as cowpea and pepper was ideal for alley farming (in fact on-station research was done only with maize and cowpea) and that alley farming with mixed crop particularly with cassava might be problematic for management. Creeping crops such as yam (if unstaked), and melon could shade or strangle the tree seedlings. Yet, majority of the farmers who planted alley plots did so under sole cassava or maize-cassava systems (Table 5.1). Tree establishment with cassava was found to be satisfactory if both were planted at about the same time. Trees planted into already established stands of cassava suffered severe shading and did not establish well. Based on these experiences some farmers later changed from sole maize to maize-cassava or other crop systems while a few also changed from mixed to sole crop maize. This was an indication of farmers' own preferences, their ability and willingness to learn and modify the technology to their preferences and needs.

Table 5.1 *Distribution of alley plots in Southwest Nigeria according to crop(s) grown.*

	% alley plots by year					
Crop mix	1984	1985	1986	1987	1988	1989
Cassava	5.0	11.1	22.5	36.1	38.6	25.0
Yam	21.0	6.2	13.8	10.8	13.6	7.4
Maize	33.0	14.8	8.7	6.0	13.6	10.3
Vegetable/Others	5.0	3.7	1.3	9.6	6.8	4.4
Yam– Cassava	9.0	9.9	15.0	2.4	6.8	4.4
Maize–Cassava	18.0	35.8	22.5	7.2	4.5	35.3
Vegetable–Cassava	–	6.2	7.5	6.0	–	2.9
Maize–Yam	9.0	7.4	1.3	4.8	6.8	4.4
Vegetable–Yam	–	2.5	6.3	4.8	9.1	–
Vegetable–Maize	–	2.5	1.3	12.0	–	1.5
All combinations	100.0	100.0	100.0	100.0	100.0	100.0
(N)	(66)	(81)	(80)	(83)	(44)	(88)

Source: Atta-Krah and Francis, 1987; and Field Survey 1989.

Third, alley farming in thirty five percent of the plots in Oyo and 44% in Imo were discontinued at different times after planting but a small number were also replanted. Reasons given for discontinuation are mostly related to problems of establishment and poor growth (Table 5.2). One of the main reason for poor establishment and growth was that most farmers planted trees on plots which had gone through a major part of full cropping cycle and were ready to go into fallow soon. Therefore, these plots were of very poor fertility. Choice of such plots for planting trees might have been influenced by the research team's message that a major function of the trees was to enhance soil fertility and enable continuous cropping. The choice also reflected a risk management strategy in that the farmers' loss would be minimum in case the trees did not survive. In Imo, the acidic nature of the soil was a major additional problem for establishment.[4]

4. Agronomic studies were initially conducted in Alfisols. On-farm studies in eastern Nigeria were initiated on the implicit assumption that *Leucaena* and *Gliricidia* would perform as well in acid soil. Poor establishment and growth of these trees on acid soil led to two lines of action: screen lines of *Leucaena* and *Gliricidia* for acid soil tolerance and identification of local browse trees and study their propagation and performance under intensive management (see section 2). However, OFR in Imo state was discontinued before the results of these latter agronomic studies were available for on-farm testing.

Table 5.2 *Distribution of alley plots in southern Nigeria according to reasons for discontinuation of alley farming.*

Reasons for discontinuation	% discontinued alley plots	
	Oyo State	Imo State
1. Poor establishment/poor growth due to poor soil/shading by trees or crops	22.2	26.0
2. Weedy plot/weeded out/purposefully destroyed/poor-handling/poor management	18.5	34.0
3. Farmer moved/died/left village/old age/sick	42.6	2.0
4. Lost interest/lack of interest	9.3	6.0
5. Land used for building or other purpose	–	8.0
6. 1 and 2 above	7.4	18.0
7. 2 and 4 above	–	6.0
Total	100.0	100.0
(N)	(54)	(50)
(Missing data)	(8)	(2)

Source: Field Survey 1989

The prevailing status and farmers' perceived future plans for functional alley plots as observed in 1989 are shown in Table 5.3. While a significant number of plots in Oyo were in good condition and would continue to be used, few in Imo were so. Nearly 50 percent in good condition and would continue to be used, few in Imo were so. Nearly 50 percent of the Oyo plots were poorly managed but farmers apparently intended to continue using them. About a quarter of the plots in Imo would discontinue and another quarter with poor maintenance might face the same fate eventually. A significant number of farmers in Imo expressed intention to expand the area or number of plot or replant.

Table 5.3 *Present and future status of functional alley plots as perceived by the farmers, 1989.*

Perceived status and future plans	% farms by state	
	Oyo State	Imo State
1. Well maintained; shall continue	39.8	12.1
2. Shall plant new hedgerows/new plots/fill gaps	4.1	28.8
3 Poorly maintained; shall continue	47.9	30.3
4. Poor condition of trees; shall discontinue	8.2	28.8
All	100.0	100.0
(N)	(73)	(66)
Missing data	(31)	(1)

Source: Farm Survey 1989

At the end of 1992, one year after the on-farm research staff was withdrawn from the research villages, all the 73 farms in Oyo area who indicated their future plans about alley farming in 1989, were revisited to ascertain their actual status. Out of 73 plots, 20 (27%) were cropped in 1992 and 53 (73%) were under fallow. Out of 20 alley crop fields, trees from 10 were used only for mulch and from another 10 for mulch and fodder. Out of 53 fallow plots, 10 were fallowed for restoring fertility and tree growth and 43 due to labour shortage. Small amount of browse was collected from 33 out of 53 fallow plots. Thus, 43 (59%) plots were still functional to some degree. However, the general trend was one of gradually dropping out of alley farming.

By 1992, some of the fallowed alley plots had trees 6–9 years old and in poor conditions. Theoretically, these old plots could be cleared and replanted with trees or these could be fallowed and replaced by planting new plots. The fact that neither of these options was taken by the farmers indicated either that the operation and management of the technology was difficult or that the problems of soil fertility and feed shortages were not yet so severe in the area as to create a strong need for alley farming technology. In the latter case, alley farming was tested in an unsuitable location. It may be recalled that in Oyo area, population density was low, reasonable fallowing was still possible for fertility restoration and cutting browse to feed animals was not very common - conditions that would indicate no strong need for alley farming type technology.

5.3 Labour requirement for alley farming and its implications

In humid west Africa, land is scarce as manifested in reduced fertility and a reduced fallow period for natural fertility restoration under the slash-and-burn system of cultivation. So, according to the theory of induced innovation (Binswanger and Ruttan, 1978; Hayami and Ruttan, 1985), a land augmenting technology is appropriate for the situation.

Alley cropping has been shown to be a land augmenting technology because it increases crop yield per unit of land, improves soil fertility, and eliminates or reduces the need for fallow. However, the land augmenting characteristic of alley cropping may not be adequate for its adoption. Labour is the main input in traditional bush fallow system and the size of holding is often limited by available family labour. If alley cropping is to replace traditional system, labour demand and labour productivity in alley cropping may be one of the major factors affecting its adoption. Inclusion of livestock may be affected if alley plots are located too far away from the homestead and substantial time is required for regular collection of feed. In areas with low population density labour is a constraint to expand farm size, but alley farming is not yet attractive in such areas.

Raintree (1983) argued that if the labour requirements for a new technology exceed by a wide margin from the level of labour used in the technology to be replaced, the majority of the farmers may not adopt the new technology. However, experiences from pre and post-green revolution Asia suggest that increased labour demand of a new technology may not necessarily constrain its adoption. Before the advent of seed-fertilizer-water technology, Asian agriculture was highly labour intensive. In order to support increased population on limited land, large quantities of labour were used for land improvement, land levelling, drainage and water control measures all of which contributed to higher land productivity. After the introduction of green revolution technologies, labour intensity increased further due to the need for improved irrigation, land and crop management. Consequently, both crop yield and employment increased. For example, in Bangladesh a shift from traditional farming to using improved seed fertilizer technology resulted in an employment elasticity of output of 0.5 to 0.7, i.e. a 10 percent increase in output was accompanied by a 5–7 percent increase in labour use (Khan and Lee, 1981; Jabbar, 1981). Labour saving technologies are only emerging in some of the countries experiencing the green revolution.

Three inter-related questions are important in relation to labour demand for alley farming in humid west Africa: (a) is alley farming labour demanding or labour saving in relation to traditional system? (b) assuming that farmers may practice alley and non-alley systems in different plots of a farm, is there competition or complementarity between these systems for labour? (c) how does alley farming affect participation of women in farming activities? Available information is insufficient to adequately answer these questions. However, the available information is summarized below so that gaps in knowledge become evident for further research.

On the basis of an on-station experiment conducted in Ibadan, Ngambeki (1985) reported labour requirement of 82, 125 and 153 person-days per hectare for producing maize respectively under bush-fallow, 4-meter alley and 2-meter alley systems. On the basis of a researcher and farmer managed on-farm trial by four alley and four non-alley farmers over two crop seasons, Reynolds *et al.* (1991) reported 35.6 and 32.5 person-days per hectare per season for land clearing, ridging, tree pruning and planting maize under alley and non-alley systems.

During 1991, labour utilization of 16 randomly selected farm households out of 73 with functional alley plots around ILRI on-farm research area in southwest Nigeria were recorded through multiple visit survey (ILCA 1992). The area under cultivation ranged from 0.57 to 5.28 hectare per household with an average of 2.32 hectare but the size of the alley plots ranged from 0.07– 0.35 ha with an average of 0.13 ha. For each household, separate records were kept for alley and non-alley plots. All the alley plots were planted with trees 3–4 years before the survey year, so labour for tree establishment was not available. Collection of harvesting labour was initiated, then discontinued because in most cases mixed crops of maize, yam, cassava and vegetables were grown in both alley and non-alley plots, and harvesting of each crop was staggered, so maintenance of accuracy of harvest labour input became difficult. None of the farmers used tree foliage as feed during the crop season. Some of them fed animals infrequently during the other periods but accurate information for such pruning labour was not available. Mixed cropping was the dominant system in both alley and non-alley plots, so it was difficult to measure labour input for each crop separately. Instead, labour input per unit area cultivated during the entire year under alley and non-alley system were derived and compared.

For crop mixes produced under alley and non-alley systems, 68 and 76 person-days of labour were required for various activities from land clearing up to weeding (Table 5.4). The differences were not significant. ($P > 0.05$). Non-alley plots required more labour for land clearing because all the alley plots were under cropping for different durations prior to the survey so natural bush regrowth was small while such regrowth was higher in non-alley plots. Moreover, some of the non-alley plots were newly cleared for cropping hence required more labour. Ridging and planting under alley cropping required less labour because the soil was softer due to mulching and in most cases ridges of the previous year were reshaped while in non-alley system, new ridges had to be made in most cases. Pruning labour is primarily a function of the extent of regrowth in the hedgerows. The trees in the sample farms were few years old and were not in their best condition. So under better condition of trees, more pruning labour than found in this survey might be needed.

Table 5.4 *Labour requirements per hectare per year for alley and non-alley cropping.*

Activity	Person-days ha^{-1} $year^{-1}$	
	Alley cropping	Non-alley cropping
Land clearing	3.3	11.6
Ridging	2.7	7.9
Tree pruning for mulching	8.6	–
Crop planting/sowing	2.6	7.2
Weeding	50.8	49.5
Total	68.0	76.2

Source: Field survey 1991.

Kang (1989) reported that in alley cropping systems hedgerows suppressed weed growth, so less labour was required for weeding under experimental alley cropping maize. However, under complex crop mixes in actual farm conditions, no difference in weeding labour between alley and non-alley cropping was observed.

Since tree establishment is not a yearly activity and harvesting labour is primarily a function of output, it may be concluded on the basis of the above information that for regular yearly field activities, total labour requirements for alley and non-alley farming with similar crop or crop mixes may not differ significantly. However, alley farming has important implication for the time distribution of labour.

Under the bush-fallow system, every year some plots may come to the end of a cropping cycle and go into fallow while new plots may be cleared to replace them. Land clearing is normally done during dry season over a long period (December - April) partly by family labour but mostly by hired migrant labour from northern and eastern Nigeria. Most of the time, such labourers work in a gang or team and they clear plots of land on a fixed cash contract basis rather than on a daily rate basis. Since alley farming reduces the extent of yearly need for clearing new land, adoption of alley farming reduces the pressure on family labour and the need for cash for land clearing during the dry season.

Under the traditional system, May–July is the period of peak labour demand when crop planting and weeding are done. Under alley farming, tree pruning is a vital additional activity and this may compete with weeding although the quantity of labour required for tree pruning for mulching may be a fraction of labour required for weeding. If trees are not pruned at appropriate times, crop yield may suffer due to shading from overgrown hedgerows and lack of timely mulching. Untimely weeding may also depress crop growth and yield (Reynolds *et al*., 1991)[5]. However, all the farmers complained more about the difficulty of pruning as a job than about the competition for labour as such. They found it more difficult to get labour for pruning than for weeding. Similar complaints from farmers participating in on-farm trials were reported by Swinkels and Franzel (1995) and Swinkels and Ndufa (1994) for western Kenya.

5. Mwanza and Place (1994) also posited that labour competition between hedgerow establishment and traditional bush-fallow activities

may initially become a constraint for adoption of improved fallow (hedgerow intercropping) system in Zambia. On the other hand, Swinkels *et al.* (1994) posited on the basis of on-farm trial data from western Kenya that farmers commonly fallowed part of their land due to labour shortage and improved fallow required less labour, so by implication labour should not be a constraint to adoption of improved fallow.

Participation of women in field activities differed not so much between alley and non-alley plots in general but between male and female headed households. Although only three out of the 16 households monitored were female headed, on the average, female participation in field activities was higher in female headed households (Table 5.5). Moreover female participation in harvesting, transportation, processing/marketing was reported to he 30–60 percent in male headed and 60-–70 percent in female headed households, though exact quantities of labour for these operations were not available.

Table 5.5 *Sources of labour for different farm operations for male and female headed farms.*

Farm operation	Male headed farm			Female headed farms		
	Male members	Female members	Male hired	Male members	Female members	Male hired
	% of total labour in each operation					
Land clearing	23	–	77	–	14	86
Ridging	7	–	93	–	14	86
Planting	86	–	14	10	20	70
Weeding	4	39	57	22	17	61
Fertilizing	62	13	25	33	67	–
Pruning for mulching	89	–	11	14	72	14
Pruning for feeding	92	8	–	43	57	–

Source: Field survey 1991.

The above pattern of labour time allocation is a reflection of the gender division of labour and households in the area. Most Yoruba women are engaged in trade, so have little time for field operations. Palm oil harvesting by men, and transporting and processing by women is an important activity in the area. This activity overlaps with some field activities. So women combine palm oil processing, trade and care of small animals while men engage in field activities. Most female headed households are operated by either widows or separated wives so they have little choice but to perform some of the field activities (Cashman, 1985). Although tree pruning is a difficult job, females in female headed households performed most of this task.[6]

6. On the basis of farmer assessment of hedgerow intercropping in western Kenya, women were often found unwilling or unable to prune trees. They considered the task heavy, and hired labour or found someone else to do it (Swinkels and Franzel, 1995).

In summary, limited amount of available information suggest that total labour requirement for field operations may not differ significantly between alley and non-alley systems with similar crops or crop mixes. There may be some competition for labour mainly between weeding and pruning in peak cropping season. With similar labour input and higher crop yield, labour productivity should be higher in alley cropping (cost of other variable inputs should not differ significantly between alley and non-alley systems), so alley cropping should be more attractive than bush-fallow system. To validate this conclusion, more detailed labour data need to be collected from different locations with different population pressure and cropping pattern.

5.4 Gender concerns in alley farming

Within the framework of farming systems research, specific attention is given to gender analysis in order to understand the various roles of men, women and children in existing farming systems and the way these roles are affected by introduction of a new technology or a production system. Particular attention is given to the role of women because they carry a major responsibility in all the stages of agricultural production — field operations, harvesting, processing and trading — in addition to performing various household tasks.

During the first phase (1982–83) of on-farm trial in Badeku and Fashola, only male farmers were contacted. Soon the importance of involving women in the testing programme was realised. So during the second phase of work in Own-Ile and Iwo-Ate that started in 1984. both male and female numbers of the household were invited in the initial village discussion meetings in which benefits and operational procedures of alley farming were explained and volunteers were sought for participation in the on-farm testing programme. The baseline survey in the two villages showed that women made up 31 per cent of the farming population, 29 per cent of the adult women had farming as the major occupation and women owned over 50 percent of the small ruminants (Okali, 1984; Okali and Sumberg, 1985). Therefore, the research team expected establishment of a good number of independent alley farms by women although attendance of women in the village meetings was not high.

In 1984, out of 86 alley plots planted in the two villages, 12 (14%) were planted by women. This proportion was considered low in relation to the share of women in the farming population and several hypotheses were developed to explain this apparent low participation of women in alley farming. First, the village extension worker and the on-farm researchers were all male, so it was assumed that either the invitation to the meetings were not extended to the women effectively or if it was, they were not convinced about the appropriateness of the technology for their needs and resources. Second, the main village contacts in the initial stages were men who might have passed information to other men leaving the women in the background; they also fixed meetings at times which were not always suitable for women because of their various household responsibilities. Third, the responsibilities and the economies of men and women were separate, so women would be interested in getting direct benefits of their work. Although women owned a lot of livestock, they owned none or very little land. They usually grow food crops on land temporarily allocated to them by their husbands. If women planted trees on the family land and fed animals, the benefit would be shared by all members of the household, so the women might have little incentive to plant trees. These intra-household processes and dynamics might have been responsible for few women establishing independent alley farms (Okali, 1984; Youdeowei, 1984; Francis and Atta-Krah, 1988).

In order to understand the actual reasons for low involvement of women in alley farming and to promote their participation, a female research-cum-extension worker was employed in 1985. She worked alongside the core on-farm research team but contacted, organized, and communicated with the women separately through visits to their houses individually, through church and cooperatives, and through local school children who were taught and persuaded to take the message to their mothers. In that year, 27 women planted small alley plots most of which were suitable as feed gardens. The trees were planted on land given to the women by their husbands (Cashman, 1985).

By the time the trees established and were ready for use, the female research-cum-extension worker finished her contract assignment and left. The core ILRI on-farm research team then tried to integrate the women alley farmers within the project but without full success. Once the special status, facilities and advice given to this women's group were replaced by the general advisory approach, they gradually became disinterested and most of them ultimately gave up managing the alley trees. As of 1990, only 3 out of 27 special alley plots were functional while all 15 women alley plots established under the general community approach during the first 2 years were still functional in various degrees.

A number of lessons have been learned subsequently about involvement of women in alley farming. First, a distinction has to be made between women farmer and farming women. While most women in the study area, albeit in Nigeria and other parts of West Africa, participate in farm activities in various degrees, very few women are farmers. Generally, a farmer is the one who takes major decisions about the farm business. For example, the 1983 baseline survey in the two on-farm villages showed that 23 (16%) out of 148 household heads were female and they were farmers. Fourteen of them were widows, one a divorcee, and the rest were second/third wives left to themselves by their husbands. There were 39 widows in the sample which means that all widows were not farmers. out of 293 other adult women, 62 (21%) had farming as the exclusive occupation and another 30 (10%) had farming as a major occupation (Okali 1984, p.14). It is essential that all the women farmers and women whose exclusive or major occupation is farming alongside their husbands and other family members, should be exposed to any new technology so that they understand implications of adoption. However, only independent women farmers should be expected to establish independent alley farms, if they need it (Jabber, 1990b).

Secondly, the land tenure study in Nigeria, Togo and Cameroon (see below) confirmed earlier notion that women normally do not own and inherit land except as gift from their parents and until after the death of their husbands. But some women get separate land from their husbands for farming in order to perform some of their designated responsibilities. Such land given to wives may be taken back at any time. For example, 12 alley plots planted by women in Oyo area were later taken over by their husbands along with the trees. Other women alley-plots also reverted to their husbands once the women discontinued management of the trees. Therefore, although, cultivation of separate plots by women in a farming household may be fairly common, the temporary nature of access to such land may make them unsuitable for establishment of independent alley farm.

Thirdly, women own a lot of small ruminants but they are managed together with animals owned by other members of the family. These animals are primarily free roaming and they are given household wastes and crop by-products (cassava and yam peels, maize chaff) as supplements. Women are mostly responsible for feeding the animals. They generally do not discriminate between animals owned by different members of the family. Cutting browse to feed animals is rare and both men and women may cut browse, if needed (see section 4.3). Women are allowed to harvest browse from the trees on their husband's land (Okali 1984, p. 20). Therefore, a family alley farm is likely to benefit both men and women and establishment of separate alley farms by women may not always be necessary.

Fourthly, although there is gender-division of work and of responsibilities, at the end those work and responsibilities are performed for the welfare of the entire family. Therefore, establishment of independent alley farms may not be an essential condition for women's participation in alley farming. The presumption that women will have little incentive to participate in an activity which may not directly benefit them may also be considered untenable. What may be required is an understanding by both male and female members of a family as to how they may individually and collectively gain or loose from the adoption of a new technology. After pursuing a separate approach to alley farming for women, the female researcher-extension worker concluded at the end, "after my village experience and interactions with alley farming men, women and children, I would suggest.... building up the common identify of families and compounds with alley farming members" (Cashman, 1985, p. 143).

Fifth, the female researcher-cum-extension worker was allowed to pursue most of her activities separately from the core research team and use quite different methods of contact, information dissemination and organization, most of which were not replicable when the core team tried to integrate the special women farmers into the main project. The lesson to be learned is that participation of women should be sought within the framework of a team rather than as individual or special approach which may not have good replicability.

5.5 Land tenure and the potential for adoption

5.5.1 Background, objectives and methodology

Tangible benefits from alley farming trees become available after 1–2 years and once established, trees have to be well maintained for at least 8–10 years in order to derive the long-term benefits. This will require long-term secured access to land. If the potential benefits of the technology can be internalized by the user, the incentive for adoption will be higher.

At the early stage of ILRI's on-farm research in Southern Nigeria, it was found that land tenure systems in Southeast Nigeria were different from those in the Southwest and that these might have implications for adoption of alley farming. In the Southwest on-farm research site, most farmers had long-term individual heritable use right to land. Though they might not always have individual propriety, the arrangements were not unfavourable for adoption of a technology like alley farming. In the Southeast research site, land are distinguished into three categories: compound land, near field and distant field. While compound land is controlled and used by the individual household, the use of near and distant fields are to a varying degree controlled by the extended family and community level decisions. Because these lands are reallocated for use after every fallow cycle, the same person or family may not get the same plot every time. Under such conditions, there may be little incentive to plant alley farming trees on near and distant fields (Francis, 1987).

Based on this initial experience, it was felt that the impact of land tenure on the potential for adoption of alley farming should be studied in detail across countries because although most research on alley farming was conducted in Southern Nigeria, the recommendation domain for the technology extends throughout the entire forest and derived savanna zones in West Africa. As such, it was decided that a study would be conducted in the forest and savannah zones of Cameroon, Nigeria and Togo in order to get a representative picture of the West African situation. The objective of this project was to determine whether the areas in which alley farming had been tested were representative with regard to land tenure and to clarify what aspects of land tenure would help or hinder adoption of alley farming (for details see, Lawry and Steinbarger, 1991; Lawry *et al*. 1994).

The relationship between land tenure status and the potential for adoption of alley farming was studied by examining three sets of issues: First, examine the general land tenure characteristics in the study areas and predict, on the basis of *a priori* theoretical ground, whether the existing land tenure systems were congenial for adoption of alley farming. For example, widespread private ownership would be a favourable condition for adoption of alley farming because it provides needed long-term security.

Second, in west Africa, land and tree tenure, particularly for commercial trees such as oil palm and cocoa, are separated and land and tree management practices may vary depending on the nature of land and tree tenure. Trees used in alley farms may be perceived by farmers as commercial trees because of their economic value. Since alley farming is not yet practiced every where, the current land and tree management practices in relation to commercial trees such as oil palm and cocoa, under different tenure arrangements was examined in order to predict on the basis of *a priori* theoretical ground, whether the practices related to different land tenure systems were congenial for adoption of alley farming. For example, if current land and tree management practices were good under a given land tenure system, then that tenure system might also be congenial for adoption of alley farming.

Third, land tenure status of alley and non-alley farms, and of maintained and discontinued alley farms was studied in Nigeria. A good number of alley farms were established in and around IITA and ILRI on-farm research sites in the forest and derived savannah regions of Nigeria. The National Livestock Projects Division, a Nigerian Federal Agency for dissemination of livestock technologies, adopted alley farming for diffusion and established alley farms in several states in Southern Nigeria (see section 5.5). In each case, some alley farmers discontinued alley farming at some stage, while others continued to practice it. This aspect of the study was limited in scope because data on alley farming was not available in Togo and Cameroon and even in Nigeria, most farmers established only one alley plot, so the tenure status of that particular plot might not be representative of the tenure status of the farm as a whole.

In order to collect data, a pilot survey was conducted with samples drawn from forest and savannah zones in Nigeria and Cameroon and from maritime (savannah) and plateau (forest) zones in Togo. The objective was to sharpen the research questions and see their suitability and relevance. Then a detailed survey was conducted which included 240, 146 and 400 households sampled respectively in Nigeria, Cameroon and Togo. The Nigerian sample included 133 alley farming adopters and 107 non-adopters. Among alley farming adopters, 84 had functional alley farms at the time of the survey and 49 had discontinued alley farming. Data were collected through single visit interviews using a questionnaire. (For more detailed description of the methodology used in each country, see Fabiyi *et al*., 1991; Tonye *et al.,* 1991; Foli *et al*., 1991; Lawry and Steinbarger, 1991).

5.5.2 General characteristics of land tenure in the study areas

Tenure systems in the study areas generally treat land and trees as separate entities. Individual members of households often farm discrete parcels of land but control over the allocation of land parcels ordinarily rests in the hands of a larger corporate group or its representative, usually based on lineage. This may be of matrilineal, patrilineal or double-descent types. Women are rarely allocators of land rights even their rights; to use land generally comes through men, either from a husband as a part of his holdings or from other male family members. Group rights to and control over land allocation rarely belong to groups larger than the village, where descent is direct and demonstrable. At a lower level, the head of a family, be it extended or nuclear, allocates land-use rights to members of his immediate family who will actually work the land. The rights to allocate pasture may reside at a higher level than that for farmland (Steinbarger, 1990; Lawry and Steinbarger, 1991).

With population pressure increasing, the amount of land under higher level lineage control is diminishing and land is being loaned, pledged, rented and sold, although such transactions may not have the sanction of law. Farmers using land under a temporary arrangement are prohibited from making long-term investments such as planting trees. Under the system of fallow rotation practiced in West Africa, a land user may not get access to the same plot of land at the end of each rotation. Even if an individual is accorded long-term use rights for farming, the land often reverts to communal grazing after the crop is harvested.

Fields owned or used by the sample households were found to fall into four tenure categories: purchased or received as gift, divided inheritance, undivided inheritance and secondary access. Land held under divided inheritance means that land is divided among the heirs giving each full control over their own parcel of land. Land held under undivided inheritance means that land passes to heirs collectively, with the result that no one person has absolute control over any part of the land. Secondary access generally implies that land is obtained through a rental agreement, pledge or loan.

Land area under each tenure system could not be measured. Assuming that number of fields under the control of each household was proportionate to the land area, the relative importance of the systems were estimated (Table 5.6). In all three countries, purchase and gift accounted for a tiny share of the fields indicating a poorly developed land market. Only purchased and divided inheritance land provides long term security that is required for alley farming. In Cameroon and Nigeria, 66 and 54 percent of the fields were under these categories, providing good opportunities for alley farming. In Togo, only 36 percent of the fields were under these categories, 31 percent of the fields were under secondary access and 33 percent under undivided inheritance. Therefore, two thirds of the land area in Togo was under tenure that is unfavourable for alley farming.

Table 5.6 *Distribution of sample fields according to tenure status in Nigeria, Cameroon and Togo.*

Tenure status	% fields by country			
	Nigeria	Cameroon	Togo	All
Purchased/gift	5.7	10.0	11.1	9.4
Divided inheritance	48.6	56.0	25.2	37.3
Undivided inheritance	33.8	33.6	32.8	33.2
Secondary access	11.9	0.4	30.9	20.1
Total	100.0	100.0	100.0	100.0
(N)	654	411	1240	2305

Source: Lawry and Steinbarger (1991), Lawry *et al.* (1994).

5.5.3 Land and tree management practices

Rights over trees may be held separately from rights over the land they grow on, and may depend on whether the trees were planted or self-sown, who planted and owns them (the state, a group, an individual, male, female), what species they are, what spatial planting arrangements are used, how they are used (subsistence, commercial), the form in which they are used (gathered, cut, harvested, standing), how they are disposed of (destroyed, lent, leased, pledged, sold, given away) and under what tenure system the land is held (inherited, purchased, rented, pledged, share-cropped, leased). When all these aspects are combined, some tree-tenure rights will appear to be partial and overlapping, thus creating problems of long-term investment in tree planting (Steinbarger, 1990).

In order to study current land and tree management practices as they relate to the tenure status of the land, six characteristics were compared: location of the field, soil fertility, fallowing frequency, external input use such as chemical fertilizers, incidence of tree planting, and incidence of commercial and fruit trees. The results are summarized in Table 5.7. In general, compared to purchased and divided inheritance fields, fields under undivided inheritance and secondary access were located far from the household, were of poorer fertility, were fallowed less frequently, were fertilized/mulched at a lower rate, were less frequently planted with new trees, and had fewer fruit and other commercial trees.

Table 5.7 *Land and tree management practices by tenure status in Nigeria, Togo and Cameroon.*

	Purchased/divided	Undivided	Secondary

Management practices	inheritance	inheritance	access
Distance from household	Close	Far	Very far
Soil fertility	Good	Moderate	Poor
Fallowing	Frequent	Less frequent	Less frequent
Input use	High	Medium	Low
Incidence of tree planting	High	Medium	Low
Incidence of commercial/			
fruit trees	High	Medium	Low

Source: Lawry and steinbarger (1991); Lawry *et al*. (1994).

These characteristics reconfirm Francis's earlier finding from Southeast Nigeria that more distant farms are likely to be jointly controlled leading to poor management of the soil (Francis, 1987). The results also showed that purchased and divided inheritance fields are well managed and planted with trees. Therefore land under such tenure would be congenial for the adoption of alley farming, and in Nigeria and Cameroon, this applies to a significant proportion of the land. Land under secondary access and undivided inheritance would also benefit from alley farming type technology to improve soil fertility, but they do not provide the long term security and incentive for planting trees as indicated by current practices. In Nigeria, Cameroon and Togo respectively 45, 34 and 62 percent of the land fall under these unfavourable categories.

5.5.4 Tenure status of alley, non-alley and ex-alley farms

Because alley farms were available only in Nigeria, the results of this section are directly relevant for Nigeria, though the general lessons are relevant for other countries. Three levels of comparisons were made to establish the relationship between land tenure and adoption of alley farming. First, the tenure status of all fields of farms who adopted alley farming and those who did not were compared. It was found that adopters had a significantly higher proportion of their fields under more secured tenure than non-adopters (Table 5.8). Second, the tenure status of alley and non-alley fields of adopters were compared and no significant differences were observed indicating that adopters were indifferent about the tenure status of the field in which they planted alley trees. Third, the tenure status of functional alley fields were compared with those fields where alley farming had been discounted. A significantly higher proportion of functional alley fields were found to be under more secured tenure (Table 5.9).

Table 5.8 *Tenure status of fields of farms adopting and not adopting alley farming in Southern Nigeria.*

	% fields by alley farming adoption status		
Tenure status	Adopters	Non-adopters	Total
Purchased/gift	4.9	6.5	5. 7
Divided inheritance	54.2	42.4	48.6
Undivided inheritance	32.5	35.3	33.8
Secondary access	8.4	15.8	11.9
Total	100.0	100.0	100.0
(N)	345	309	654
Chi-Square = 13.333, DF = 3, Prob = 0.004			

Source: Lawry and Steinbarger (1991); Lawry *et al*. (1994).

Table 5.9 *Land tenure status of functional and discontinued alley fields in Southern Nigeria.*

Tenure status	% alley fields by status of alley farming		
	Functional	Discontinued	Total
Purchased/gift	8.3	4.1	6.8
Divided inheritance	67.3	30.6	54.1
Undivided inheritance	14.3	57.1	30.1
Secondary access	9.5	8.2	9.0
Total	100.0	100.0	100.0
(N)	84	49	133

Chi-Square = 27.72, DF = 3, Prob = 0.000

Source: Lawry and Steinbarger (1991); Lawry *et al.* (1994).

From the foregoing it would appear that more secured land tenure had a positive relationship with initial adoption and continuation of alley farming. It was shown earlier from on-farm monitoring that alley farming was discontinued due to various technical problems (Table 5.2). Questions on land tenure were not included in the monitoring forms and none of the farmers mentioned land tenure as a reason for discontinuation. However, it appears that both technical problems and unfavourable land tenure played an important part in discontinuation. It is possible that less attention was given to alley farms under less secured tenure leading to their poor performance and discontinuation.

In summary the study showed that in Nigeria, Cameroon and Togo 66, 54, and 36 percent of the land were under tenure systems that provided long term security, and was therefore favourable for alley farming. Current land and tree management practices showed that land with less secured tenure required alley farming technology but they provided the least incentive for adoption of such technology. Such unfavourable situation was most widely prevalent in Togo. In Nigeria, the adoption and maintenance of alley farming was associated with security of tenure. These results indicate that land tenure plays a significant role in the adoption, continuation and discontinuation of alley farming. The adoption of any technology progresses over time from more favourable to less favourable situations. Since a significant proportion of the land in each country was under a favourable tenure system, land tenure is not likely to be a major constraint to adoption yet.

5.6 From on-farm research to diffusion and extension

One of the function of on-farm research is to link research with extension and development activities in order to improve the technology generation and diffusion process. In this particular case, this was done in SW Nigeria through collaborative work with the Directorate of Livestock Services of Oyo State. The initial selection of sites and on-farm research planning was done together. Later, an extension agent of the Directorate was assigned to the villages specifically to work with the on-farm research team and with farmers who planted alley farms but were not involved in any formal research trial. The "neighbourhood effect" described earlier resulted from this activity of the team. But a vigorous extension campaign was not pursued because extension was not a primary function of the on-farm research team. Had it been done, many more farmers in the nearby villages would possibly adopt the technology.

Attracted by the interest of farmers in and around the research villages, National Livestock Projects Division (NLPD), a world Bank funded Federal Government agency in Nigeria responsible for disseminating improved livestock technology, became interested in alley farming. In 1989, NLPD initiated a pilot project in several states in southern Nigeria to establish plant nurseries, distribute them to selected farmers in selected villages along with a package of animal health care, credit and advice. A target of 5000 alley farms (mainly feed gardens) in 4 years was set. After a slow start, the project has taken off. Two batches of NLPD staff were trained by ILRI to work in this project. The actual number of alley farms established so far is not known but latest indications are that the target has not been achieved yet.

FAO sponsored a study in 1989, through a group of consultants, to examine the potential for diffusion of alley farming in West Africa. On the basis of the recommendations of that study, FAO launched in late 1991 a two year pilot project in Ghana, Togo, and Nigeria, to disseminate alley farming through national extension/development agencies. The mechanism for establishing pilot alley farms was set in motion by assessing the alley farming situation in these countries in consultation with the extension/development agencies (FAO 1992). In Nigeria, the NLPD, the Agricultural Development Projects (responsible for integrated crop livestock extension), Federal Agricultural Coordination Unit, and the Universities were involved in this exercise. In Ghana and Togo, similar national institutions worked with FAO to assess the potential for alley farming. In identifying the potential geographical areas for dissemination, this project gave importance to the standard technology developed by IITA and ILRI as well as various forms of traditional and rudimentary alley farming practiced by farmers. The objective was to link the formal and informal alley farming systems through extension on the assumption that those who practiced rudimentary traditional alley farming might adopt the standard technology sooner. Training for both farmers and extension agents were emphasized in the project activity. The performance of the project is yet to be evaluated. However, the general impression is that the national agencies did not pursue the project with full commitment and vigour after the pilot project phase ended.

5.7 AFNETA and multizonal research

ILCA and IITA on-station and on-farm research have been conducted in medium to high rainfall (over 1200 mm) areas with soil pH of over 5.2. Such soil and environmental conditions cover only a small proportion of the total area of humid tropical Africa where soil degradation and erosion and animal feed are serious problems. There is a high degree of diversity within this vast area in relation to resource endowment, physical, environmental and institutional conditions. In order to test the suitability of alley farming as a potential solution for the problems of this vast diverse region, substantial adaptive research in different environments would be required. The major responsibility for this should be taken by NARS of different countries but most NARS have inadequate prior experience in alley farming or similar technology research. In order to fill this gap, Alley Farming Network for Tropical Africa (AFNETA) has been established in 1989 under the joint sponsorship of IITA, ILRI and ICRAF. The function of AFNETA is to work together with NARS and Agricultural Development Agencies in the organization, initiation and execution of research on alley farming and to assess workability and adoptability of such technology for the farmers of tropical Africa.

To achieve this goal, three main activities are pursued: collaborative research, training, and information dissemination and exchange. Since its establishment in 1989 up to the end of 1992, AFNETA initiated collaborative research on 95 trials at 54 sites with 32 NARS institutions in 20 countries (Sanginga *et al.*, 1992). Table 5.10 shows number of experiments by main research areas and ecological zones. Over 25 tree species, including *Leucaena* and *Gliricidia* which received most attention so far, are being tested for their suitability under different soil types and conditions. Livestock and socio-economic related research are at present underrepresented but will become important once initial screening finishes and on-farm research starts. The general expectation is that once research across different zones at many sites are taken to the farmers' fields and extension/development agencies are linked with such on-farm research, "innovation waves" will likely spread from many centres and speed up both generation and diffusion of the technology. At the initial stage, a large extent of horizontal (farmer-to-farmer) diffusion is likely to take place due to lateral learning within the immediate vicinity of each research location. Large scale adoption may follow only after public institutions adopt the technology for promotion and diffusion.

Table 5.10 *Distribution of AFNETA initiated collaborative trials by topic and ecozone.*

Topic	Highlands	Semi-arid	Sub-Humid	Humid	Total
MPT Screening	2	13	10	3	28
Alley farming management	4	12	16	11	43
Livestock integration	1	–	3	2	6
On-farm/socio-economics	2	2	9	5	18
Total	9	27	38	21	95

Source: Sanginga *et al.* 1992

In order to adequately validate and extrapolate results, a minimum data set is collected and standard methodology is followed. This has been developed by a Task Force composed of scientists from IITA, ILRI and some local NARS in Nigeria.

Two major activities in the area of training are group and individual training. Initially, NARS scientists were brought in to IITA in batches for training. IITA, ILRI and ICRAF used to provide resource persons and other back up services like training materials etc. Later, a train the trainer model has been adopted where batches of scientists are brought from 4 zones for imparting training to enable them train other people in their designated zones. Four such zonal training courses were organized in 1991 and 3 more in 1992. The multiplier effects of this approach is envisaged to be high. Already, over 200 NARS personnel have benefitted from the overall training programme.

For information dissemination, seminars/workshops are organized where latest findings of research are exchanged and shared. A quarterly newsletter is distributed to general members to keep them up to date about activities of AFNETA and alley farming or similar research around the world. AFNETA also collects and distributes seeds for collaborative researchers.

6. Conclusions

The biological benefits of alley farming crop and livestock have been amply demonstrated by on-station and on-farm research particularly in the geographical areas where research on alley farming received most attention. However, farmer adoption still remains low mainly around the on-farm research areas. Large scale adoption presupposes that a technology is available, a formal or informal mechanism for diffusion is in place to take the technology where it has a role to play (e.g. where soil fertility and feed are problems). Moreover, potential adopters should have adequate knowledge about the technology, its functional mechanism, short and long-run benefits, adaptability to the resource endowment and farming system, its pay-off period and profitability.

The analyses in this study suggest that alley farming is a profitable technology. Significant economic gains can be obtained by integrating small ruminants into alley farming. Such gains will be higher at low crop yield levels and when crop response to mulching is low. Increased survivability is the major benefit from supplementing free roaming small ruminants in West Africa. Supplementary forage is best directed to late pregnant and lactating females. Alley farming requires about the same amount of labour as traditional farming so it should be more attractive because of its higher land and labour productivities. Some land tenure systems may not be favourable for alley farming adoption but in most west African countries, favourable land tenure for adoption exists for a high proportion of land, therefore, adoption should not be constrained by land tenure at the early stage. Participation of women in the adoption decision is important and since farming women and women farmers are part of a household, their involvement in the decision-making process should be sought together with other members of the household, rather than separately.

Alley farming is a fairly complex technology. Farmers familiar with plantation crops and with management of trees under bush-fallow systems may find it easier to adapt alley farming. Yet significant amount of time may be required to learn several innovations in relation to planting and establishing trees within arable farm, their management for mulch and fodder, cutting and carrying feeds for animals, and altering land use and rotation patterns. The learning-adoption process is likely to be slow. Trees are more likely to be planted for mulching, crop being the priority enterprise, with subsequent diversification to feeding. The economic value of browse will be much appreciated if a market oriented activity such as fattening small ruminants for festivals and urban markets, and dairy cattle production is pursued. These kinds of specialist activities need to be identified for specific locations and zones. Special educational and promotional activities may reduce the innovation lag as well as make it available to the resource poor farmers, who under normal circumstances, may not have adequate access to the technology.

More research, both biological and socio-economic, by international and national research systems will be required to develop alley farming as a robust technology adaptable to diverse conditions. Wider choice of tree species suitable for different soil-climate and for different purposes is a priority research area. The generation and diffusion process should be, to a certain degree, simultaneous because so much fundamental biological knowledge is already available. On-farm research has an important role in the technology generation diffusion process. Best practice technology on-station rarely performs at that level in actual farm conditions. Adaptive research results in a steady accretion of innumerable minor improvements and modifications. Since research should be aimed at solving farmers' problems, involving farmers and extensionists at the early stage of research, rather than waiting for them to be passive recipients at some future date, may yield many advantages in relation to diffusion. This position is supported by the experiences of ILCA's on-farm research in Nigeria and the research activities of AFNETA across several countries in Africa.

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