ALLEY FARMING RESEARCH ON HIGH BASE STATUS SOILS

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Abstract: *Results of long term alley cropping trials show that the inclusion of N_2- fixing hedgerow species maintain higher levels of soil fertility than control treatment (no hedgerow) on high base status soils in the humid zone. Hedgerows contribute to nutrient cycling and higher faunal activity. With good husbandry, maize grain yield can be sustained at relatively high levels with lower fertilizer input. Hedgerows are also effective in reducing erosion on sloping land. Additional research effort is needed for adaptability trials, to provide the basis for developing a decision support system package.*

1. Introduction

Agricultural research institutions in the tropics have been searching for farming systems which are more productive than the traditional slash and burn cultivation system. The traditional system of production, despite its low productivity, is biologically stable when the fallow period is adequate. This system is easily destabilized if the fallow period is shortened, resulting in land degradation, more weed infestation and reduced crop production [Kang and Wilson 1987].

Although scientists now have a better understanding of the problems and management options for food crop production on inherently infertile and erodible upland soils which are dominated by low activity clays [SMSS 1986], there is still little progress in the development of alternative more productive, viable and sustainable food crop production systems for the vast areas dominated by these soils. Because of their inherent limitations, these soils are unsuited to conventional mechanized farming and high chemical input. [Kang and Spain 1986, Lal and Greenland 1986]. The use of fertilizer alone fails to maintain soil productivity, as these soils require a regular supply of organic matter in addition to chemical nutrients. Moreover, fertilizers and other chemical inputs are seldom a viable option for smallholder farmers in sub-Saharan Africa because of their high cost and scarcity.

To deal with the problem of sustaining food crop production on the rainfed uplands dominated by low activity clay soils, scientists of the International Institute of Tropical Agriculture (IITA), have since the 1970s, experimented with the interplanting of woody species with crops. This has led to the development of the alley cropping system [Kang et al. 1981]. This paper highlights the results of some recent and on-going trials on high base status soils in the humid and subhumid zones and future programs related to alley cropping and farming at IITA.

2. Hedgerow Establishment and Management

2.1 Establishment

One of the main benefits from hedgerows are the prunings. Therefore, a rapid and uniform establishment of the hedgerows is essential for early gains from the system. Cobbina et al (1989) showed that early growth of *Gliricidia sepium* and *Leucaena leucocephala* at six locations in southwestern Nigeria was positively correlated to soil organic C and total N levels. Onafeko et al. (1995, see part Va in this volume) in on-farm trials in the derived and wooded savannah of Nigeria showed that both species responded to rhizobium inoculation at over half of the test sites, and responded more to N than to P applications. It appears that, whenever feasible, rhizobium inoculation and N and P applications can be recommended for a uniform and early establishment of *Gliricidia* and *Leucaena* hedgerows.

2.2 Management

Pruning techniques need to be adopted which maximize biomass production without jeopardizing food crop yield. Hedgerow species are known to react differently to intense pruning. *Sesbania grandiflora* can yield abundant prunings, but mortality is high, unlike other species which have a lower biomass yield [Duguma et al. 1988]. Little is known about the physiological basis for the differences in regrowth following pruning. An investigation of the effect of pruning frequency and height on carbohydrate reserves in *Gliricidia*, showed that the stem carbohydrate fraction was present in sufficient concentration to support initial coppice shoot growth after cutting and the species did not use its root reserve stem carbohydrates [Erdmann et al. 1992]. Further studies are in progress with other species to look into these relationships and the seasonality of carbohydrate accumulation in stems and roots.

2.3 Resource competition

Although closer interhedgerow spacing can provide a higher biomass yield per unit area, if too close, it results in an undesirable competition for the use of growth resources (solar radiation, moisture and nutrients) between hedgerows and the associated crops. The zonal arrangement between hedgerows and crops in alley cropping provides a flexible option to reduce competition and increase complementarity in resource use.

2.4 Competition for light

In alley cropping, the shade cast by hedgerows may reduce the yield of associated crops, particularly those grown adjacent to the hedgerows. The effect varies with hedgerow species and spacing, crop species and pruning regime.

Lawson and Kang (1990) observed in an interhedgerow spacing trial with four woody species in the humid zone, that maize yield declined as pruning dry yield increased Maize yield was lower with 2 m than with 4 m interhedgerow spacing.

The lower yield was associated with higher partial shading by the narrowly spaced hedgerow. Vigorously growing species, such as *Leucaena,* caused a higher degree of shading than the other species tested. Similar findings were reported by Duguma et al. (1988) in an alley cropping trial with three hedgerow species. Welke et al. (1995 see part 5a this volume) determined the effect of pruning frequencies of *Leucaena* hedgerows planted in 4 m alleys on the performance of intercropped maize and cassava. They observed that the effect of hedgerow shading on maize grain yield was negligible with pruning frequencies of up to six weeks. However, delayed pruning of hedgerows reduced the root yield of intercropped cassava. This may be attributed to double shading of the slower growing cassava crop by the maize crop and hedgerows during early growth of the cassava.

The effect of hedgerow shading has a more pronounced negative influence on short stature crops, like cowpea [Lawson and Kang 1990]. Kang et al. (1985) showed that *Leucaena* hedgerow shading on cowpeas was twice as high, when compared to the taller maize crop. Gichuru and Kang (1989) also reported that the yield of cowpea adjacent to the hedgerows of *Calliandra calothyrsus* was depressed, while that of maize was not.

The above results show the importance of timely pruning in order to prevent the hedgerows from shading associated crops and reducing their yield. Although lower pruning height, more frequent prunings and wider alleys minimize shading from the hedgerows, they also reduce biomass production and the effectiveness of the hedgerows in nutrient cycling. Optimal pruning regimes and alley widths need to be adjusted to the hedgerow species and the crops grown to minimize shading of the associated crop while optimizing biomass yield and labor requirements for pruning.

2.5 Moisture competition

Measurements of soil moisture regimes in alley cropping plots in the humid zone showed large spatial variation during the cropping period. Lateral surface soil moisture content varies according to rainfall and pruning intensity. With high pruning intensity, the area near the hedgerow retains a higher surface soil moisture level than in the middle of the plot. The reverse occurs with lower pruning intensity. Mulching, using hedgerow prunings, helps to maintain a higher soil moisture content [Kang et al. 1985] which can be beneficial during short dry periods. Profile soil moisture measurements in an Psammentic Ustorthent showed uniform soil moisture distribution during the rainy season, while during a short dry spell, two moisture depletion zones occurred at 0-30 cm and 30-60 cm [Kang et al. 1985]. As few maize roots grew deeper than 40 cm, it was inferred that the second moisture depletion zone was due to uptake by the *Leucaena* hedgerows, whereas moisture loss from the topsoil layers was due mainly to uptake by the maize (figure 1).

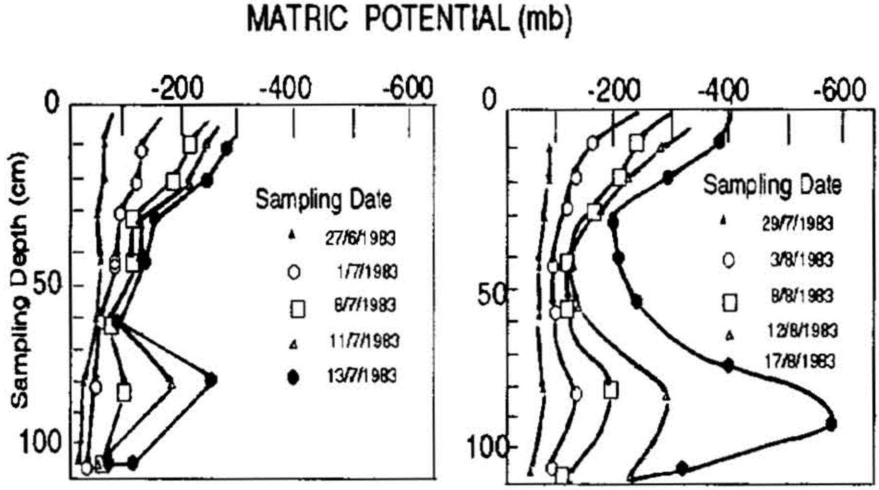

Figure 1. Soil moisture matric potential as a function of sampling time and depth. Sampled at the end of the main maize growing season (June to August) [Kang et al. 1985]

Recent measurements on water use on an Alfisol in the humid zone under undisturbed forest, bush fallow, and in maize/cassava intercropped *Pueraria phaseoloides* live mulch, *Leucaena* alley cropping and control plots, showed that after the last rain of the season, tension increased rapidly under forest, bush regrowth and *Pueraria* fallow. In contrast, under the maize/cassava intercrop, control plot water withdrawal was slower; it took 60 days to reach a similar tension as in the other systems. The alley cropped plot showed a different soil moisture distribution pattern (figure 2). Water tension under the hedgerows increased as fast as under forest, while water tension increase was delayed for about 40 days, at 1 to 2 m distances away from the hedgerows. This differential water regime was also observed at the start of the rainy season. Water uptake by perennial vegetation, such as hedgerows, can contribute to a reduction in downward water movement and thereby reduce nutrient leaching and improve nutrient recycling.

2.6 Nutrient competition

The presence of hedgerows introduces spatial soil chemical microvariability within the alley cropped plots. Observations on an Oxic Paleustalf in plots alley cropped with *Dactyladenia barteri, Alchornea cordifolia, Gliricidia* and *Leucaena* in the sixth cropping year, showed differential nutrient levels in the surface soil under hedgerows and in the middle of alleys. The magnitude of differences in soil pH, soil organic C, exchangeable cations and extractable P under the hedgerows and in the middle of alleys varies with hedgerow species. *Leucaena* introduces the largest differential [B.T.

Kang and O. Onafeko, unpublished data]. In an established alley cropping plot with *Leucaena* on a similar soil, Hauser (1990) reported higher Ca, Mg and NO_3 concentrations in soil solution in the upper soil layers which decreased with depth under the hedgerows (figure 3). This pattern was maintained for a period of about three months during the rainy season. In the alleys, the nutrient profile was reversed, with lower nutrient concentrations observed in the upper soil layers, increasing with depth, due to nutrient uptake in the upper layers by the crops. These results indicate that the presence of hedgerows improves the ability of the system to retain or recycle nutrients to the soil surface, and that nutrient competition between hedgerows and crops on high base status soil is not significant.

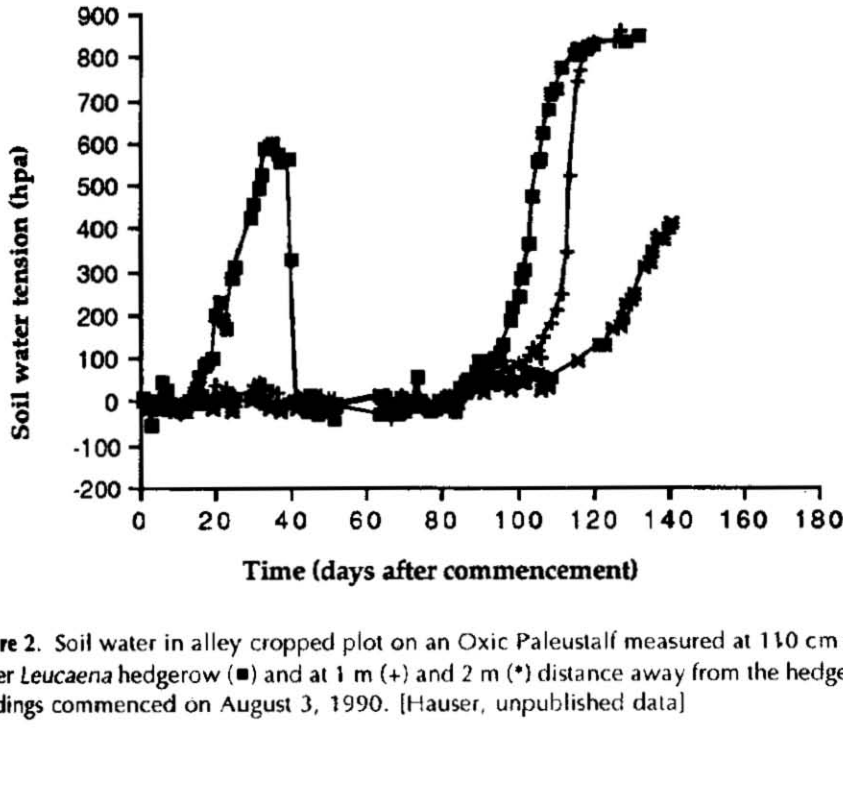

Figure 2. Soil water in alley cropped plot on an Oxic Paleustalf measured at 110 cm depth under *Leucaena* hedgerow (■) and at 1 m (+) and 2 m (*) distance away from the hedgerows. Readings commenced on August 3, 1990. [Hauser, unpublished data]

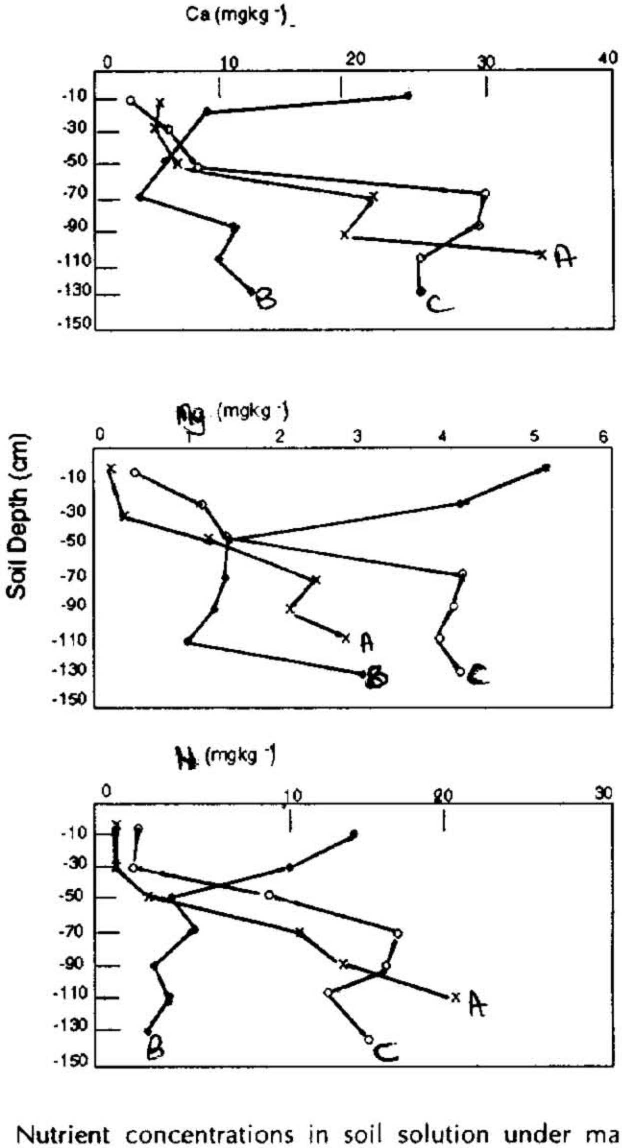

Figure 3. Nutrient concentrations in soil solution under maize in control (no hedgerow) treatment (A) and in alley cropped plots under *Leucaena* hedgerows (B) and in the alleys (C) on an Alfisol [Hauser 1990]

2.7 Faunal activity

The presence of hedgerows is also known to stimulate more earthworm activity in alleycropped plots than in the control (no tree) treatment on high base status soils. This effect varies with hedgerow species [Kang et al. 1990]. Hauser (1992) also observed that the amount of N, K, Ca and Mg in *Hyperiodrilus africanus* earthworm casts under *Leucaena* hedgerows was respectively nine, eight, ten and three times higher than in control (no tree) treatment plots (table 1). Since earthworm casts are also known to have a higher organic C content, stimulation of earthworm activities in the presence of hedgerows and by adding prunings to the soil will enhance nutrient and organic C recycling and retention.

Table 1. Total amounts of nutrients in *Hyperiodrilus* earthworm casts collected from April to November 1990 [Hauser 1992]

	Org C	N	K	Ca	Mg
	(t/ha)	.........(kg ha^{-1})..........			
Alley cropped plots					
Under *Leucaena* hedgerow	4.53	401.0	41.9	191.41	23.0
In alleys	.0.76	72.2	7.5	26.8	3.2
Weighted average	1.51	138.0	14.5	59.8	7.2
No-tree control	0.49	46.0	5.4	19.1	2.7

*Assuming that 20% of the plot is occupied by *Leucaena leucocephala* hedgerows.

3. Soil Fertility and Erosion

An important component of the alley cropping system is the addition of large amounts of mulch or green manure to the soil from pruning [Kang et al. 1990]. The periodic addition of organic material is known to have a favorable effect on the physical and chemical properties of soil and its biological activities and, therefore, increases soil productivity. Some of the effects of alley cropping on the properties of soil and on soil erosion are discussed below.

3.1 Effect on soil fertility

There is sufficient evidence to show that alley cropping has beneficial effects on the maintenance of soil fertility on high base status soils [Atta-Krah 1990, Kang and Ghuman 1991, Kang et al. 1985, Lal 1989c, Yamoah et al. 1986]. The magnitude of effects, however, varies with the hedgerow species, as these influence the quantity and quality of the prunings produced. Quality factors such as C/N ratio, lignin, and to a lesser extent, polyphenol contents determine their decomposition and nutrient release patterns and nutrient contribution potential.

A better understanding of the contribution of the hedgerow prunings to the labile and stable soil organic pool is needed. Results of preliminary studies to characterize the C and N flow patterns, following the application of *Leucaena* prunings, which decompose very rapidly, showed large but temporary increases in the surface soil of the light organic matter fraction and microbial biomass C, which contribute to the nutrient pool [B. Vanlauwe, unpublished results]. These levels, however, declined exponentially with time, and reached low levels six months after application. Further work needs to be done on the contribution of C from various prunings to the stable soil organic matter pool.

Hedgerows differ in their effects on soil fertility parameters. Yamoah et al. (1986) observed that soil organic matter and nutrient status were maintained at higher levels with hedgerows of *S. siamea* than those of *Flemingia macrophyla, G. Sepium.* Hauser and Kang (1992) showed that alley cropping with *Leucaena* maintained higher levels of soil organic C than in the control (no hedgerow) treatment. Six years of alley cropping with *Leucaena* on an Oxic Paleustalf, showed that the organic C level in the surface soil in the alleys was 0.94% C, but declined to a very low level in the control (no hedgerow) treatment (0.59% C) (table 2). High soil organic C level was also maintained under the *L. leucocephala* hedgerow (1.23% C).

Table 2. Chemical characteristics of surface (10 - 15 cm) soils in alley cropped plots with *Leucaena leucocephala* and in control treatment [Hauser and Kang 1993]

Chemical parameter	Alley Cropped		Control
	Hedgerow	In alleys	(No hedgerows)
Organic C (%)	1.23	0.94	0.59
Exchangeable cations (cmol/kg):			
Ca	1.47	1.24	1.37
Mg	0.46	0.37	0.45
K	0.39	0.58	0.52
pH (H_2O)	5.3	5.1	5.3

In a trial comparing plow-till and no-till control treatments with plow-till, *G. sepium* and *Leucaena leucocephala* alley cropped treatments over six years, Lal (1989c) observed the least decline in soil fertility parameters in the *L. leucocephala*-based systems compared to the control groups, particularly the plow-till control treatment. Kang and Ghuman (1991) continued this trial using lower fertilizer levels, and confirmed this trend. They showed that the alley cropped plots maintained higher soil organic matter, extractable P and exchangeable cations status than the control tilled plots.

3.2 Effect on soil erosion

A large number of experimental results have confirmed that alley farming plays a significant role in reducing runoff and soil erosion [Hawkins et al. 1990, Kang and Ghuman 1991, Lal 1989b, Young 1989]. Lal (1989b) showed that erosion in plots tilled and alley cropped with *Gliricidia* and *Leucaena* was reduced by 73% and 83% respectively compared to tilled control treatment. Kang and Ghuman (1991) using the same facilities in a follow up trial showed larger reduction in runoff and soil erosion with alley farming (table 3). In plots tilled and alley cropped with *Gliricidia* and *Leucaena* at 2 m interhedgerow spacing, runoff and soil erosion were comparable to that observed in non tilled treatment. Alley cropping controls soil erosion because of mulch protection of the soil surface and to lesser extent because of the barrier effect of the hedgerows [Young 1989].

Table 3. Water runoff and soil loss under maize grown with and without alley cropping, and tillage from March to July, 1988 (first season) [Kang and Ghuman 1991]

Treatment	Runoff*	Soil Loss
	(% rainfall) mm	($t\ ha^{-1}$)
Without alley cropping		
tilled control	66.6 (9.4)	6.18
non tilled control	5.6 (0.8)	0.43
Alley cropped and tilled		
**2 m *Gliricidia*	4.8 (0.7)	0.57
4 m *Gliricidia*	23.1 (3.3)	1.44
2 m *Leucaena*	2.6 (0.4)	0.17
4 m *Leucaena*	10.7 (1.5)	0.82

*Rainfall (March-July 1988) = 704.2 mm
**Interhedgerow spacing

4. Effect on Crop Yield

Information on the effects of alley cropping with various hedgerow species on crop production in various parts of tropical Africa is increasingly available thanks to research by the Alley Farming Network for Tropical Africa (AFNETA). Preliminary results from different sites showed different food crop responses to alley farming in the humid and subhumid zones. The response of maize (44 cases), rice (6 cases), and grain legumes such as cowpea (9 cases) to alley farming have consistently been positive; while those of cassava (10 cases) and cotton (4 cases) have been negative. It appears that the effect on crop yields depends mostly on the interactions between the hedgerow trees and the companion food crop. Lower cassava yields may be partly attributed to shading, as discussed earlier.

The field yield index (FYI) which is the ratio of alley crop to monocrop productivity [Woomer and Swift 1992] was found to be correlated with soil N and P levels. Nitrogen deficient soils are more likely to respond to alley farming interventions, while success in alley farming is dependent rather than contributory to the reserve of P in soils.

The results of some long term trials on high base status soils in the humid zone showed positive results from alley cropping with N_2-fixing leguminous hedgerow species [Atta-Krah 1990, Kang et al. 1990, Yamoah 1986]. In contrast, Lal (1989a) reported a large decline in maize and cowpea yields in a six-year trial on a runoff plot where fields alley cropped with *Gliricidia* and *Leucaena*, and tilled and non tilled control plots were compared. In the sixth cropping year, maize yield was reduced to 60% and cowpea yield to 31% of the initial yield. There was no difference among treatments. However, the results of the continuation of this trial with different crop husbandry and lower fertilizer rate showed significantly higher maize yields with alley cropping than in the tilled and non tilled control plots, showing that soil productivity was better maintained with alley cropping [Kang and Ghuman 1991].

A problem in alley cropping is the low N-use efficiency of the prunings [Kang 1988, Kang and Mulongoy 1992, van der Meersch et al. 1992, Sanginga and Mulongoy 1994]. Only 20-25% of the N from prunings is for example utilized by the associated maize crop. Measurements by van der Meersch et al. (1991) showed that about half of the N is unaccounted for. Further study is therefore needed to better understand N-use in alley cropping.

An important aspect of alley cropping is its claim to sustain yields in the long-term. To address this issue, several long-term trials have been carried out in southwestern Nigeria. The results of a trial conducted on a degraded Alfisol are shown in figure 4. Initially, with a high fertilizer rate, the yield of maize alley cropped with *Dactyladenia barteri* and *Leucaena* (using 4 m interhedgerow spacing) was the same as in the control plot. However, when the fertilizer rate was lowered, yields differed between treatments. With a low N fertilizer rate, the maize yield appeared to be sustainable when alley cropped with *Leucaena*. The ability of *Leucaena* to sustain high maize yield is due to its N contribution to the system and its ability to provide much needed organic matter for soil productivity maintenance.

Alley cropping appears to improve crop productivity when combined with a short fallow. Atta-Krah (1990) reported higher maize yields following short grazed fallow than with continuous alley cropping. A comparison of fallow systems showed better maize yields with no fertilizer application in alley cropping with *Leucaena* with or without fallowing, than with other fallow management systems (table 4).

Table 4. Effect of fallow management on grain yield of maize [B.T. Kang, unpublished data]

Fallow Period (year)	Fallow Management			Mean
	Bush fallow	*Pueraria*[1]	*Leucaena*[2]	
	............(kg ha $^{-1}$)			
Continuous	2334	1711	2485	2177
One year fallow Two years cropping	3009	3084	2853	2982
Two years fallow Three years cropping	3528	3220	3948	3565
Two years fallow Four years cropping	3502	2985	3677	3388
Mean	3093	2750	3240	

Between fallow management means; LSD (.05), 962; Between fallow period means; LSD (.05), 342
[1]Live mulch; [2]alley cropping

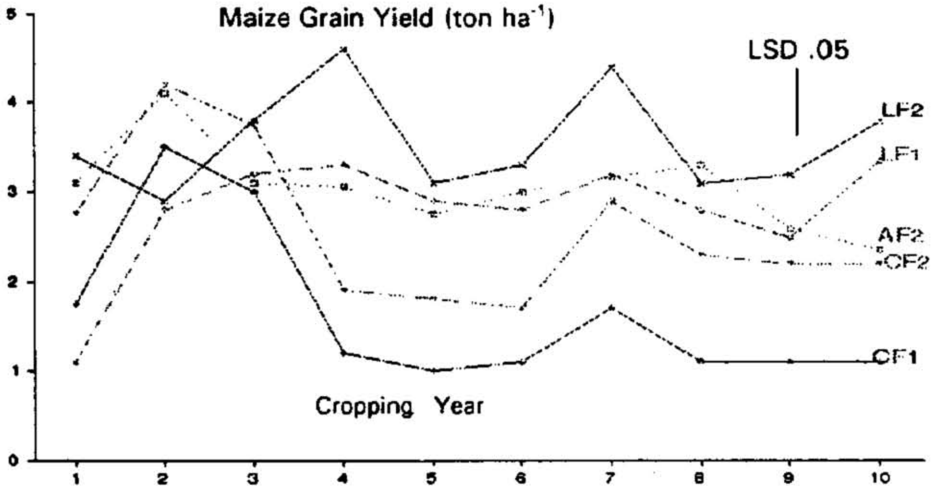

Figure 4. Long term effect of alley cropping with *Dactyladenia* and *Leucaena* on a degraded Alfisol on maize grain yield compared to control (no hedgerow) in the humid zone of southwestern Nigeria. (A = *Dactyladenia*, L = *Leucaena* and C = Control: Fertilizer rate year 1, F_1 = 0, F_2 = 90 - 40 - 40; year 2 - 3, F_1 = 45 - 20 - 20, F_2 = 90 - 40 - 40; year 4 - 10, F_1 = 0 - 12 - 25, F_2 = 45 - 12 - 25 as kg ha^{-1} of N-P-K (LSD .05 for year 10) [B.T. Kang unpublished data].

5. Conclusions and Future Research Directions

After more than a decade of research on alley cropping and alley farming, a better understanding has emerged about the potential and limitations of the technique.

On the high base status soil with moderate fertility in the humid and subhumid zones the following observations can be made:

1. Rhizobium inoculation and N and P applications can be recommended for good early establishment of *Gliricidia* and *Leucaena* hedgerows.
2. Competition for shared resources between N_2 fixing hedgerows and crops is mainly for solar radiation rather than for moisture and nutrients in the humid zone.
3. Alley cropping with *Gliricidia* and *Leucaena* maintains higher soil fertility levels than in control (no hedgerow) treatment. The presence of hedgerows contributes to nutrient recycling and higher earthworm activity. Alley cropping on sloping land can reduce soil erosion and water runoff. With proper crop husbandry, it is possible to sustain relatively high maize yields with lower fertilizer rates. Short fallowing improves crop yields, particularly when no fertilizer is used.

Further investigation is needed with respect to:

- factors affecting hedgerow regrowth following pruning
- contribution of prunings to various soil organic matter pools and on factors affecting the efficiency of N use in the system
- the root, moisture and nutrient interactions below ground
- nutrient contributions from roots to provide guidance on means of improving the technical efficiency of the system

On-farm trials gave variable results depending on hedgerow species, crop species, management and climatic factors. Further research should be directed toward adaptability trials which focus on defining and describing conditions under which alley farming will have the greatest impact in raising productivity and enhancing sustainability. As research results are being generated in other ecozones [Kang 1993] the potentials and research needs for these ecozones should be critically assessed. All studies should take into account both physical and socioeconomic parameters. The use of geographical information systems (GIS) and expert systems (E) should be explored.

The major focus in future research must take into account the issue of adoptability. Work is planned in collaboration with AFNETA and involving collaboration with NARS and development-oriented organizations. The key elements and components of this adoptability research will include the following:

- teamwork and interdisciplinarity
- farmer participatory research approach

- gender considerations/analysis
- links with non government organizations

Appropriate sites (villages) will be selected, and through the developmental on-farm research process [Atta-Krah 1985, Atta-Krah and Francis 1987], alley farming will be introduced, and its relevance and acceptability for farmers assessed through community-based pilot projects. Such projects will also enable an assessment of socioeconomic and cultural factors that might influence the practicability and adoptability of the system.

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