Institute of Hydrology

Overseas Development Report

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Natural Environment Research Council

Report on a visit by J.S. Wallace to ICRAF (International Council for Research in Agroforestry), Nairobi, Kenya on 29 and 30 May 1991

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Contents

		Page
1.	Summary	1
2.	Background	1
3.	Objectives of visit	1
4.	Visit to Machakos field station	2
5.	ICRAF Headquarters	3
	5.1 Discussions with Dr P. Cooper	3
	5.2 Discussions with Dr C. Ong	4
	5.3 Discussions with other ICRAF staff	5
6.	Conclusions	5
7.	Acknowledgements	6
8.	References	6

1. Summary

This report contains a summary of the background and objectives of a visit by Dr J. S. Wallace to ICRAF (International Council for Research in Agroforestry) in Nairobi, Kenya. Details of the facilities and current trials at the Machakos field station are given, as well as a short report on the facilities at ICRAF HQ. A summary of discussions with ICRAF senior staff is also reported. A key objective of ICRAF's new strategy is to develop sustainable increases in agroforestry output by understanding and improving the biophysical interactions between the system components. This is the type of approach the IH process division has used in many previous studies of crop and forest water use. The facilities at ICRAF HQ and the Machakos field site are suitable for supporting the kind of collaborative research activities envisaged and counterpart staff are enthusiastic about the prospects. The overall conclusion is that ICRAF is a highly suitable centre for the development of collaborative links with IH in the field of agroforestry research.

2. Background

The Institute of Hydrology has a long record of experience in working on the water use of trees and crops and, more recently, the consequences of this in terms of water resources, land degradation and climate change. In view of the now global objective of evolving sustainable systems of land use IH has been developing a research programme which includes the examination of the water use of mixed plant systems (for example, fallow savannah in Niger containing woody shrubs and a herbaceous understorey). This work has led to the development and testing of state-of-the-art techniques for measuring both the energy partitioning and the component water use of these complex multi-species systems. Furthermore, evaporation models have also been developed which are specifically designed to recognise the contribution of more than one plant species. It was therefore considered timely and appropriate to attempt to apply (and develop, as necessary) these methods and models to the challenging and important field of agroforestry.

The visit to ICRAF in Kenya was thought to be particularly appropriate at this time since ICRAF have recently appointed several new senior staff (including their Director General (Dr P Sanchez) and Director of Research (Dr P. Cooper) who are committed to developing a strong strategic research programme. ICRAF have also recently been incorporated into the CGIAR (the Consultative Group on International Agricultural Research) and have the global mandate for agroforestry research within this system.

3. Objectives

The specific objectives of the current visit to ICRAF were therefore:

(i) To obtain up to date information on ICRAF's new strategy for research.

(ii) To evaluate the possibilities for establishing a collaborative research project between IH and ICRAF on the partitioning of light and water in agroforestry systems.

4. Visit to ICRAF's field at Machakos

After arriving at Nairobi airport I was met by Dr C. Ong and Mr E. Akunda who took me to see ICRAF's field station at Machakos.

The experimental field station at Machakos is about 65 km south east of Nairobi in the East African highlands (1°33'S; 37°14'E) at an altitude of 1560 m above sea level. The rainfall is highly variable and bimodal with an annual average of 716 mm. The first rainy season starts around mid-March and last until the end of May, with an average precipitation of about 265 mm. The second rainy season starts around mid-October and finishes towards the end of December with an average precipitation of 240 mm. Most of the rainfall falls in comparatively small low intensity rainstorms (> 66% have intensities less than 10 mm h^{-1}). Annual potential evaporation is about 1450 mm, maximum air temperatures are around 25°C with a small (few degrees) annual variation. Further details of the site, climate and soils are given in appendix I, reproduced from Huxley, Pinney and Gatama (1989).

There are a total of about 16 staff who work at the Machakos site, including the farm manager (Mr Peter Kurira). The facilities on site are good, with some office space, basic soil/plant sample processing rooms and storage space. There is also a guest room with sleeping facilities and a small kitchen, which gives the possibility of occasional overnight stays on site, if necessary. The electricity supply is said to be unreliable during the rainy season and can be off as frequently as once/week for up to a day at a time.

Current experimental work at Machakos includes a trial looking at tree/crop competition for above and below ground resources. The main objectives are to examine the competetive effects between leucaena trees grown in association with a maize crop (Appendix II). To manipulate the above ground interaction, one treatment has the leucaena trees trimmed to a 'hedge'. In another treatment below ground interactions are minimized using barriers inserted into the soil. In some of the treatments light interception and soil moisture depletion are being monitored. The trials are all on sloping land (7-22%), but this is said to be typical of the type of land used for mixed agriculture in this part of the Kenyan highlands.

Another major trial is looking at the effects of tree/crop combinations on soil erosion and runoff. Despite the substantial slope, total runoff is reported to be very small. There have also been a number of tree/crop trials and demonstration plots involving tree species such as Cassia siamea and Grevillea robusta, in combination with crops such as maize, cowpea and castor beans. (Appendix III).

5. ICRAF Headquarters

In 1987 ICRAF moved into its newly built headquarters just outside Nairobi. The modern facilities include offices, conference/seminar room, library and smaller meeting rooms. There are a total of 35 senior staff, about half located at HQ and half posted at other ICRAF stations in Africa. ICRAF have recently published a new strategy document (ICRAF 1990) in response to the importance of developing sustainable land use systems and the potential for agroforestry in achieving this goal. The new research programme for the 1990's aims to conduct strategic and applied research in four major programmes:

(1) Agroforestry and land-use systems.

(2) Component interactions in Agroforestry systems.

(3) Multi-purpose tree improvement for Agroforestry systems.

(4) Agroforestry policy and International issues.

Of these programmes, area (2) contains several interesting strategic research proposals which are of interest to IH, in particular those proposals which aim to examine the detailed processes controlling the competition between trees and crops for light and water.

5.1 DISCUSSIONS WITH DR P. COOPER (Director of Research)

During this meeting the outline ideas for collaboration between IH and ICRAF were discussed. Dr Cooper reaffirmed the idea that ICRAF were in the process of developing new projects which looked at basic processes controlling tree/crop interactions, since this was one way in which the results of these types of study could be made more widely applicable and less site and species specific. From previous collaboration with IH (at ICARDA in Syria) Dr Cooper was well aware of the scientific approach and experience of the IH process division and welcomed the idea of collaboration between IH and ICRAF. Dr Cooper did, however, make the point that many people and institutes are now approaching ICRAF asking to work/collaborate with them. They will, therefore, have to be very selective and will only collaborate with those institutions which have something to contribute to the ICRAF general strategy which they do not already have themselves. In the area of competition for light and water and microclimatic interactions Dr C. Ong will be responsible for co-ordinating the collaborative institutes. For example, Reading University Soil Science Department have already made a proposal to work with Dr Ong at ICRAFs field station at Muguga on a soil water and fertility experiment. In order to properly facilitate their collaborating institutions the number of opportunities for further institutional links with this programme are limited.

5.2 DISCUSSIONS WITH DR C. ONG

Dr C. Ong has recently has recently joined ICRAF as their principal-crop physiologist and microclimatologist. He is currently starting to set up a number of projects specifically designed to examine the above and below ground interactions of some tree/crop combinations. He is involved in the soil water and fertility experiment mentioned above, has proposals to investigate the role of roots in below ground resource capture (Appendix IV) and is also planning a project to examine the water balance and light use in agroforestry systems on hillslopes. It is within this latter project that Dr Ong foresaw the possibility of an important input from IH. The question which this project would address is "Does the addition of trees to sloping agricultural land improve rainfall utilisation without reducing crop yield?" The project would, therefore, examine the amount of light intercepted and shade produced by the trees (Grevillea robusta (?)) and crop (maize) in a number of different arrangements on a sloping site at the Machakos field station. ICRAF would be responsible for the installation and maintenance of the trial and Dr Ong would have a programme of measurements including light interception, stomatal conductance (porometry), leaf area sampling, soil moisture measurements and growth analyses. The Institute of Hydrology contribution would be in the area of the measurement and modelling of the hillslope hydrology including:-

Rainfall	-	gross input, throughfall and spatial modification of rainfall input to surface by the trees.
Interception	-	effect of introducing trees on the overall interception loss of the system.
Infiltration	-	different infiltration rates beneath crop and trees?
Runoff	-	spatial redistribution of runoff between crop and trees. Effects on total runoff volume.
Drainage	-	does the presence of the trees reduce drainage?

Further important components of the water balance are the amounts of water evaporated by the individual species and from the soil. Is there less soil evaporation due to shading from the trees? How much real 'competition' is there between the trees and crops for water? Obtaining the data to address these questions could involve the use of a number of techniques including:-

Microlysimeter	for soil evaporation.
Stem heat balance gauges	for plant transpiration (trees and crop).
Deuterium tracing	for tree transpiration.
Heat pulse equipment	for tree transpiration (where diameter > ~ 10 cm)

By analysing the light partitioning, water use and growth data in this study it should be possible to develop process models for the utilization of light and water in this type of agroforestry system, which could also be used to predict the response of other tree/crop combinations in the same and/or different climates.

5.3 OTHER ICRAF STAFF MET DURING VISIT

Dr K. Shepard: Dr Shepard is an agronomist and has worked for ICRAF for about 1½ years. He spends about half of his time co-ordinating 'on farm' projects and is involved in the problems of the experimental design of nutrient studies and land resource assessment in farmers fields. His work has led to new methodologies and recommendations for these types of studies. He has close links with the Kenyan Forestry Research Institute (KEFRI) and the Kenyan Agricultural Research Institute (KARI). The remainder of Dr Shepards time is spent on more strategic research and he will be involved in the nutrient cycling project at Maguga. He has a sub-project on the role of phosphorous in agroforestry systems, in particular the use of rock phosphates by trees.

Dr P. Huxley: Dr Huxley is a Principal Research Adviser and has worked at ICRAF for 10 years. He has been involved in the development of the research activities at ICRAF since its inception and has carried out much of the early work on agroforestry research methodology (e.g. see Huxley Pinney and Gatama 1989, Huxley *et al.,* 1989). He is currently writing up much of this work and plans to visit IH to have further discussions with JSW/IRC/RJH re: IH projects in Niger and India.

Dr A. Young: Dr Young is a principal soil scientist who has a long and distinguished record of work at ICRAF. He has specialized in the role of agroforestry in soil conservation, (e.g. see Young 1989) in particular its potential for controlling erosion, maintaining soil organic matter and promoting nutrient cycling. He currently has links with Wageningen (School of Forestry) via Mr P. Kiepe, with whom he is developing water balance models for agroforestry systems.

Dr E. Torquebiau: Dr Torquebiau is a forest ecologist who has worked at ICRAF for 3 years. He had previously worked on light distribution in tropical forest canopies (Torquebiau 1988) and his current work at ICRAF is concerned with the partitioning of light in multistorey plants systems,including mixtures of, e.g. potatoes, tea/coffee, bananas and trees. Dr Torquebiau has also worked previously in Niger and was involved in a 'diagnostic and design' study on the potential for agroforestry in the semi-arid region in Niger (Hassane *et al.,* 1990).

6. Conclusions

It was clear that, even from this comparatively short visit, ICRAF'S future research strategy contains a substantial commitment to basic research into the processes and mechanisms involved in tree/crop systems. A key objective is to develop sustainable increases in agroforestry output by understanding and improving the biophysical interactions between the system components. This process orientated approach to plant community/environment interactions is very much in line with the IH process division approach used in many previous studies of crop and forest water use. The scientific philosophies of the two institutes are therefore well matched.

The facilities available at ICRAF HQ and at the Machakos field station are perfectly suitable for supporting the kind of research activities envisaged. Senior counterpart staff are keen and enthusiastic about the prospects for collaborative work, field staff are competent and logistical support (field site, offices and vehicles etc) are said to be available.

With the complementary resources and expertise of ICRAF and IH I would conclude that we could mount a comprehensive and successful collaborative project which would make significant advances in the understanding of agroforestry systems.

7. Acknowledgements

My visit to ICRAF was short, but very interesting and productive and I am grateful to Dr C. Ong for the substantial time and effort he put into the arrangements for my trip. I would also like to than Mr E. Akunda for showing me the trials at Machakos and Dr P. Cooper for his interesting and encouraging discussion. All the staff I met at ICRAF were helpful and informative about their work and I am grateful to them for their time.

8. References

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Appendix I :

BACKGROUND TO ICRAF'S FIELD STATION, MACHAKOS, KENYA.

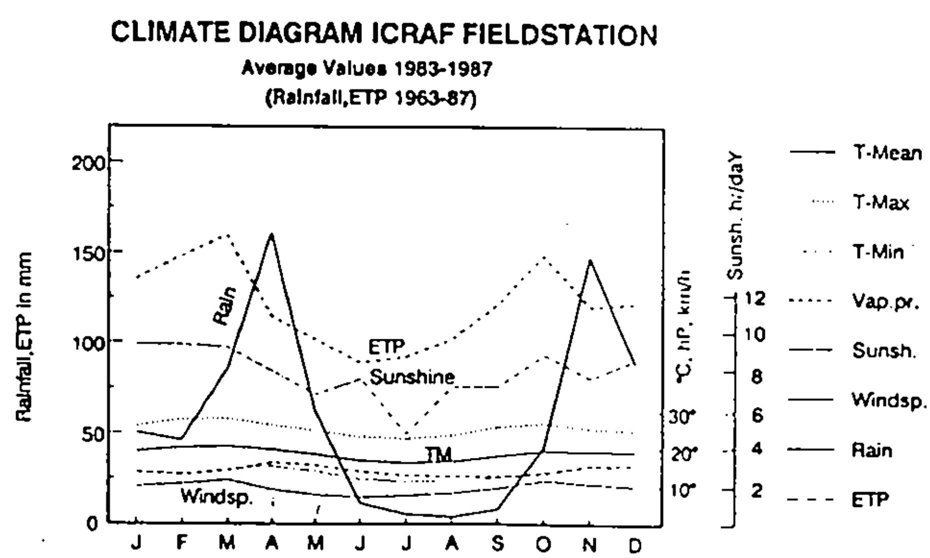
CLIMATE - **prepared by T. Darnhofer.**

The ICRAF Field Station is situated about 65 km south east of Nairobi in the East African Highlands at a latitude of 1 33' south, a longitude of 37 14' east and an altitude of 1560 m above sealevel.

In accordance with the equatorial bi-modal rainfall patterns, the average annual precipitation of 716 mm falls mainly in two seasons, the first one, locally called the Long Rains lasting statistically from 20 March to 31 May with approximately 265 mm rain, and the second one, also called the Short Rains, from 20 Oct. to 20 Dec. with 245 mm. There is an important annual variability both in the distribution as well as in the total amounts received. In the last 25 years the highest amount of rainfall was recorded in 1963 with about 1370 mm and the lowest in 1987 with 369 mm.

The water loss through potential evapotranspiration is estimated to be about 1450mm per year. This gives a rainfall/evapotranspiration ratio of 50 % which is typical for sub-humid areas at the edge to the semi-arid climatic zone.
The mean annual temperature is 19.2 C with the lowest monthly average in August (17.1 C) and the highest in March (21.3 C).

The wind is blowing with a high consistency from easterly directions (80 - 100 degrees) with average monthly speeds ranging from 7.2 (June) to 12.0 (October) km/h at 2m above the ground.



App. Figure 1a.1 Average climatic pattern as derived from data recorded at the ICRAF Field Station from June 1983 to December 1987, as well as from observations made at the adjacent Katumani Dryland Research Station (sunshine 1983-87, rainfall/ETP 1963-83). Seasonal climatic conditions 1985 -1988

Seasonal climatic conditions 1985 -1988

In accordance with the climatic conditions of the zone, the main factors affecting plant growth and development are rainfall, evapotranspiration and water availability in general. Therefore the following descriptions of the seasonal climatic patterns refer in particular to the water budget, and includes a 10 day graphical analysis of the respective parameters. The parameters used for the water budget assessments were rainfall, potential evapotranspiration as calculated with the Penman formula using actually measured climatic elements, and a soil moisture storage capacity of 200 mm. Figure 2 provides an overview of the 10 day rainfall totals, and the growing seasons for maize (planting to harvesting) at the ICRAF Field Station from January 1985 to March 1989.

1st Rainy season 1985 (March - June)

Abundant rains, after the timely onset of the season during the last decade of March, were followed by a dry spell at the beginning of April. During this period the 'climatic' water budget, became negative, but the available soil moisture was able to provide for a balanced edaphic water budget. The second decade of April was marked by very heavy rains yielding a total of 264 mm which was about five times the average for this decade. Maximal rainfall intensities of 64 , 88 and 130 mm were recorded for 1, 2 and 6 hour intervals respectively and should be mentioned with regard to their effects on soil erosion.

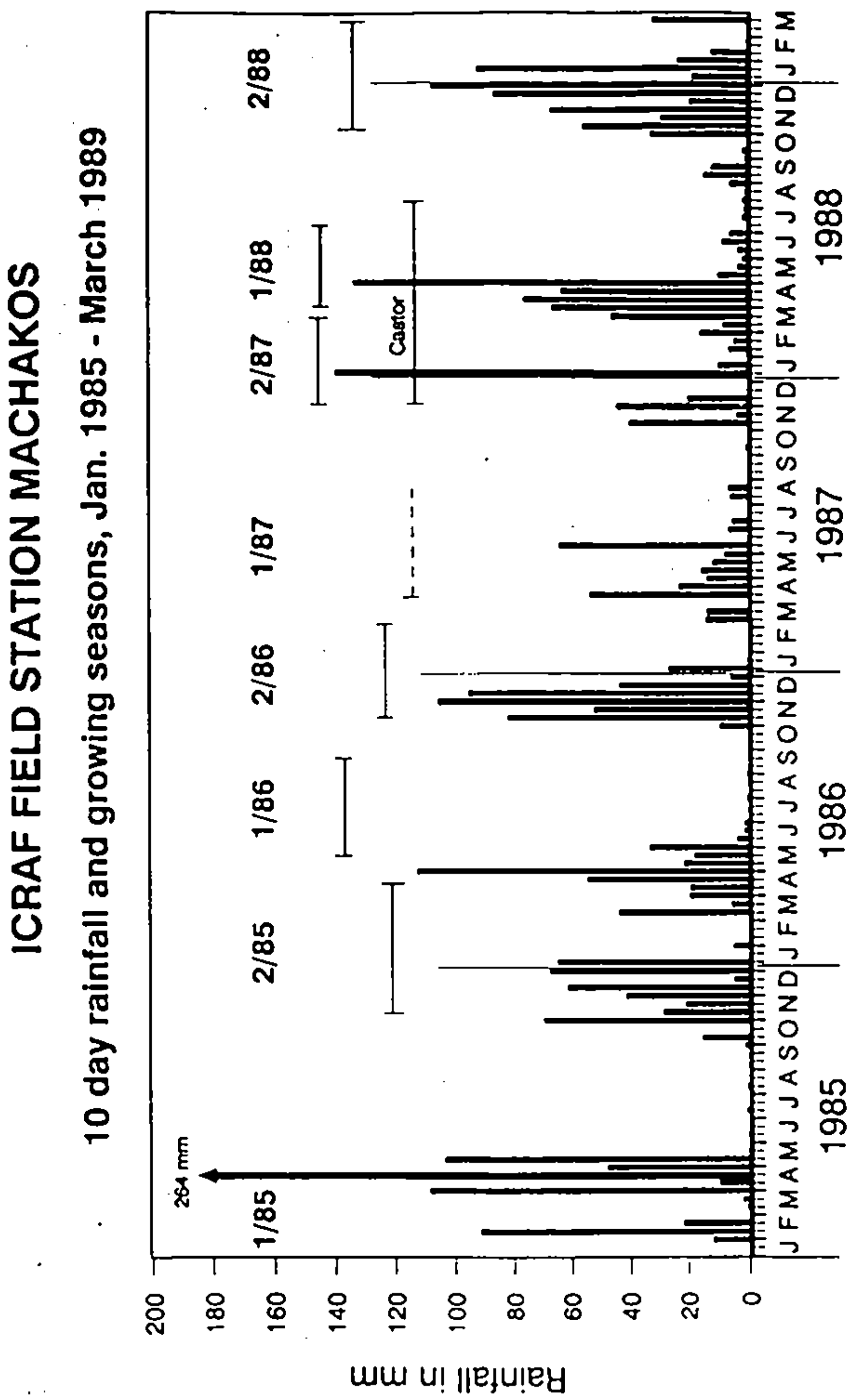
Above average rainfall until the 10 th of May kept the soil moisture at field capacity which was reached around the 19 th of April. Assuming a soil water storage capacity of 200 mm and evapotranspiration losses of around 30 mm per decade, good water availability conditions prevailed until early July. (see fig. 3) With an estimated total length of the growing period of 120 days the average was exceeded by 50 days allowing the first rainy season 1985 to be classified as excellent.

2nd Rainy season 1985 (October 85 -January 86)

In coincidence with the statistical average, the second rainy season 1985 started on October 23 rd. Well distributed rains during the last week of this month (69.8 mm) exceeded the potential evapotranspiration (44 mm) and provided good planting conditions. Although the water availability conditions remained fairly good during the month of November a dry spell from 12 th to 21 st might have caused some stress on the plants in their developing phase. Very similar distribution patterns occurred in December and above average rainfall in the first decade of January 1986 allowed for a modest soil moisture storage. From the onset of the rains until the depletion of the soil moisture reserves around the 20 th of January, 7 decades provided humid conditions while 2 could only be classified as sub-humid.

1st Rainy season 1986 (March - June 1986)

Exceptional rains between the 7th and the 10th of March have created subhumid conditions and prompted many farmers to plant early but the subsequent arid and semi-arid periods have in most cases caused the wilting of the emerged crops. The proper onset of the season occurred only during the 2nd decade of April and good rains in the last decade of this month allowed for a reasonable soil moisture recharge up to 93 mm. About average rainfall in May and low evaporation rates kept the water budget close to a balance and only a small amount had to be drawn from the soil water reserves. The remaining water was sufficient to balance ETP until the end of June



App. Figure 1a.2 10 day rainfall histogram and growing seasons (|----|) at ICRAF Field Station .

2nd Rainy season 1986 (October 86 -January 87)

The five decades following the delayed onset of the rains (1st November) had well above average precipitation and the soil could be recharged up to the assumed field capacity of 200 mm. After a sharp decline in rainfall as from 20 th December the water budget became negative but the soil water resources could compensate for the evaporation losses for almost 50 days. Thus, the water availability of the second rainy season 1986 provided above average conditions for plant growth and development.

1st and 2nd Rainy season 1987

From March to June only 222 mm or 69 % of the average were recorded. Figure 3 shows only three decades, the 1st in April, and decade 1 and 2 in June to have a balanced 'climatic' or edaphic water budget. For all other 10 day periods the water balance remained negative and hence bad conditions for plant development prevailed. For the second rainy season the situation did not remarkably improve, except that heavy rains during the first decade of January 1988 provided good water availability until the end of the month. Only very few crops however survived until the end of December 1987 and could thus benefit of these late rains.

Both rainy seasons 1987 can be considered as the worst ever, since records started in the area around 1933 and wide spread crop failures were common.

1st Rainy season 1988 (March - June 88)

After a timely onset of the season on 19 th of March the rainfall amounts recorded until the end of April were well above average and an even distribution of the rainy days provided excellent conditions for plant development. The rainfall in excess of the evapotranspiration allowed for a soil moisture recharge of about 180 mm which could complement the negative water balance (RR-ETP[1]) from the first decade of May until the end of June. The total estimated length of the period with appropriate water availability for plant growth can be estimated to have been between 100 and 110 days.

2nd Rainy season 1988 (October - January 1989)

The 26th October can be considered for the onset of the 2nd rainy season 1988. Well distributed precipitations provided good moisture conditions for planting and the first growing phase. A short dry spell in the second decade of November could be balanced by soil moisture stored the previous weeks. Similarly, the slight water balance deficit during the relatively dry decades at the beginning of December and January could be compensated by available soil moisture. Exceptionally high rainfall in the middle of January increased the ground charge close to the assumed maximum of 200 mm, and thus water for plant development never fell short from planting through to the harvesting period early March 1989.

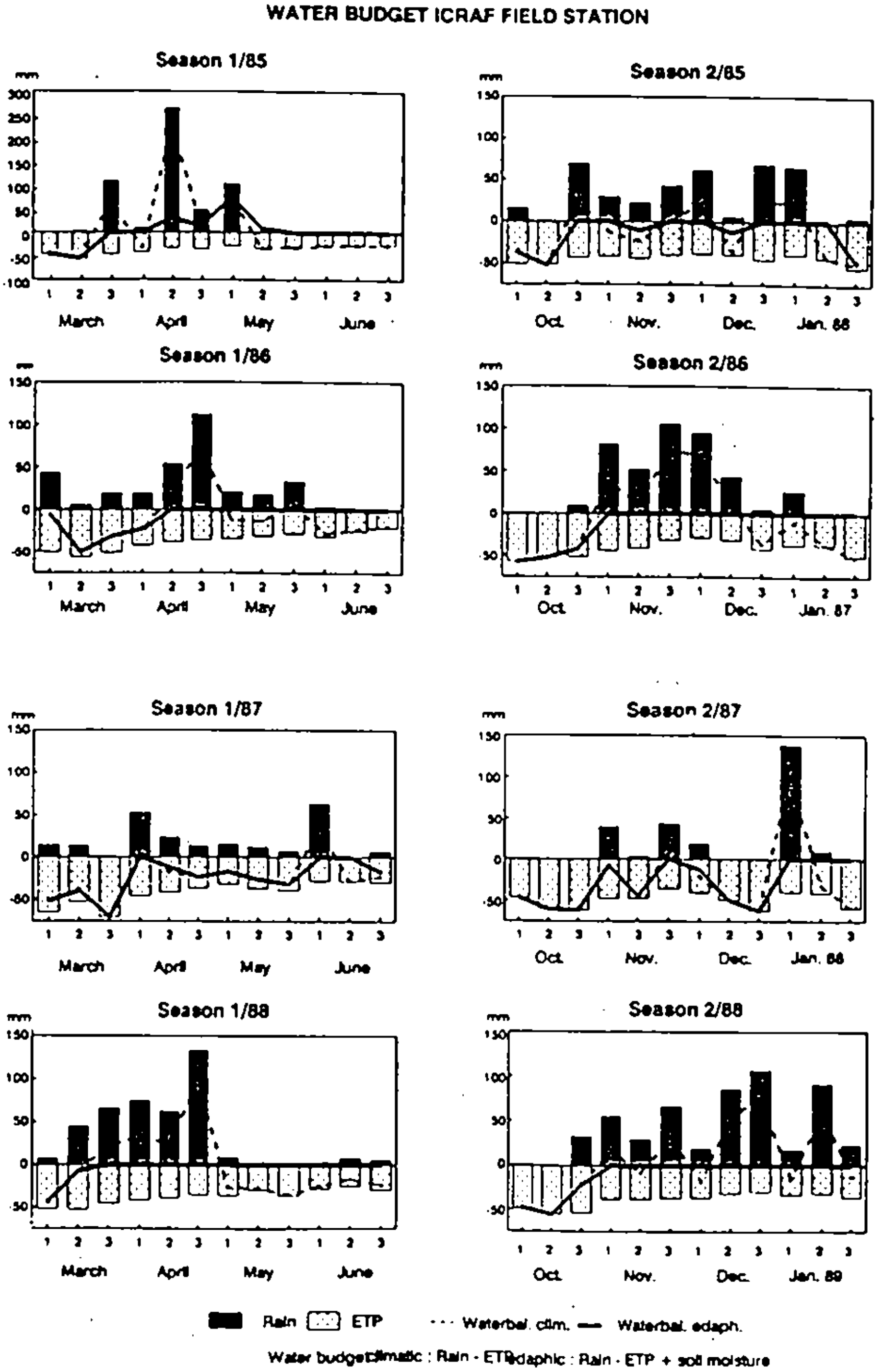
Note :[1] 'climatic' water budget: WB_c = RR - ETP;
RR = Rainfall
ETP = Potential Evapotranspiration

[2] edaphic water budget: WB_e = RR - ETP + (available soil moisture or the amount of soil moisture needed to balance ETP) + (runoff after soil moisture has reached field capacity) WB_e will be negative if . WB_c is negative and there is not enough soil moisture available to balance ETP.

WB_e will be negative if RR - ETP + available soil moisture or the amount of soil moisture needed to balance ETP) + (runoff after soil moisture has reached field capacity).

WB_e will be zero if RR - ETP can be balanced by the available soil moisture.

WB_e will be positive if RR is greater than ETP and the soil moisture is at field capacity and thus run off will occur.



App. Figure 1a.3 Water budget at ICRAF's Field Station for eight growing seasons (1985-1988).

APPENDIX 1b

GEOLOGY AND PHYSIOGRAPHY - prepared by A.Young.

The area is underlain with rocks of the Precambrian Basement System; the predominant rocks are biotite gneisses and banded gneisses. Along the stream channels, narrow band of recent alluvial deposits also occur.

Physiographically, the area belongs to the uplands. It consists of a ridge with a convex upper part (slopes 0-5%) and straight side slopes of 7-22%. Towards the stream, the side slopes grade into narrow stretches of nearly flat river terraces of less than 2 per cent slope.

Soils

A detailed soil and vegetation survey of the site was conducted by the Kenya Soil Survey in March 1981 (Kibe, J.M. et al 1982). ICRAF has carried out a further survey in 1988 (samples are not analysis). There is, however, considerable variability in both depth and topsoil variability over most of the area.

The predominant soil type is a well-drained, dark reddish brown sand clay, derived from the Basement Complex gneisses. It is friable, with a well-developed blocky structure and clay skins. The profile is deep to moderately deep on the convex upper slope, and also the meander core, becoming shallow on the steeper slopes. Nodular laterite concretions (murram occur in the base of the profile on the crest and mid-slope. There is a narrow belt of alluvial soils along parts of the valley floor.

The soils are weakly to moderately leached, with a weakly acid reaction (pH 6.0 - 6.5), a medium base saturation (50 -80%) and moderate levels of organic matter (topsoil organic carbon: 1.0 -1.4%). Nutrient levels are medium.

On both the FAO and Kenya Soil Survey classification systems, most of the Station area belongs to the class of Luvisols, including the pisoferric and lithic phases. The shallower profiles are lithosols, whilst small area on the ridge crest, where the reaction approaches neutrality, are classed by the Kenya Soil Survey as Phaeozems. On the US soil taxonomy the soils belong to the order Alfisols, suborder Ustalfs, including typic and lithic subgroups.

The deeper profiles have good physical properties, including easy root penetration and a good moisture-holding capacity, and a moderate level of natural fertility. They are suitable for annual crops with a short growing season, as well as for a range of multipurpose trees. On the general slopes, the main land use problem is drought. On the moderate to steep slopes there is a substantial erosion hazard, particularly important to control because of the shallowness of the soils.

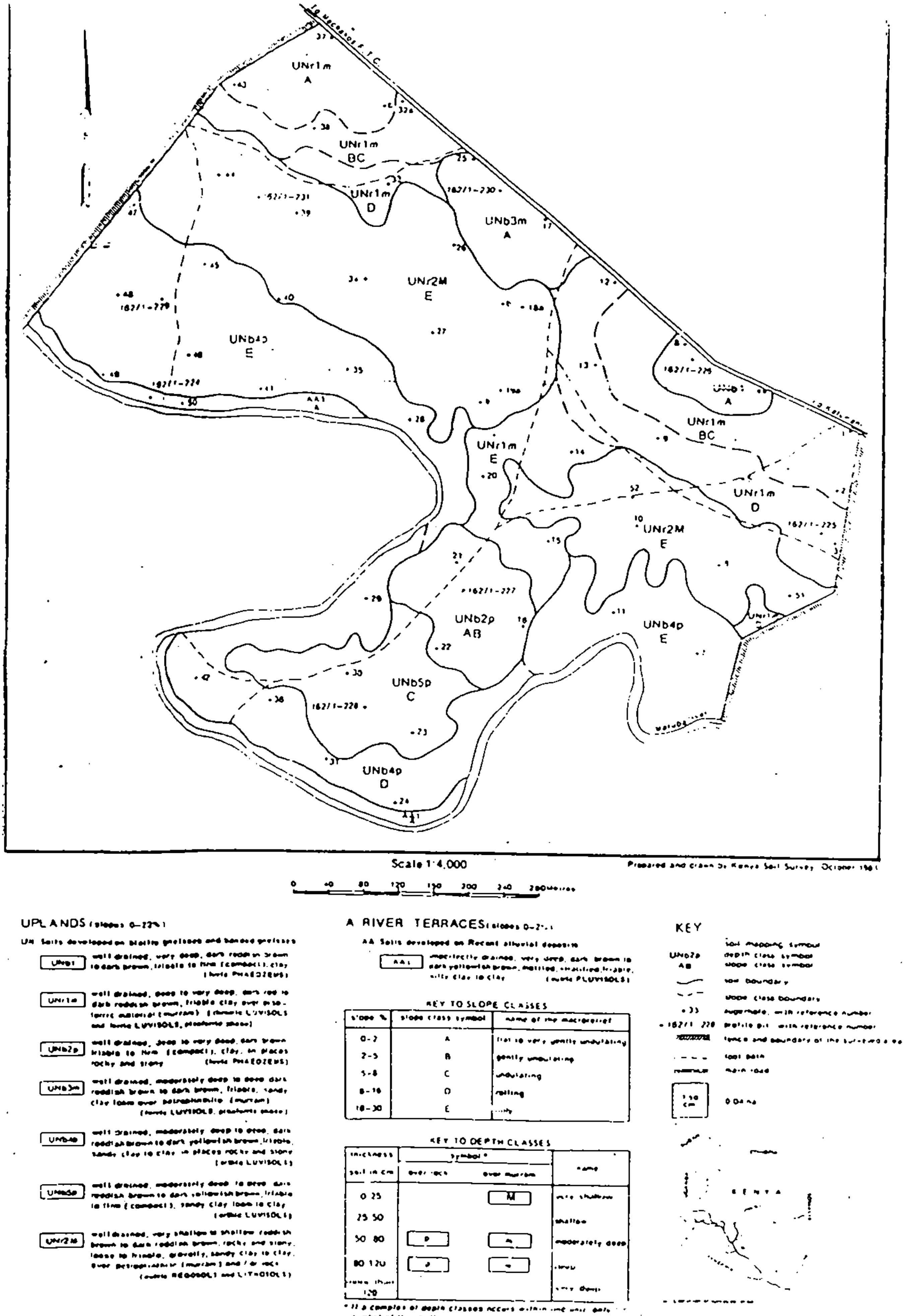
App. Figure 1b.1 shows the detailed soil map of the site and App. Table 1b.1 gives the summary of chemical analysis data for different soil units, both taken from the detailed soil survey report prepared by the Kenya Soil Survey. Based on a detailed topographic map of the site (1:1000 scale with 1m contour marking) prepared by a Nairobi-based professional firm, a few distinct land units can be identified on the site.

App. Table 1b.1: Summary of soil chemical analysis data for the Field Station (Date of sampling: April 1981)*

(See Figure 4 for description of mapping units).

Mapping unit	Element							
	Na	K	Ca	Mg	Mn	P	Org.C	Total N
	(..........		me/100g	........)		(ppm)	(%)	(%)
UNb1	0.2	0.6	6.0	2.0	0.4	55	1.2	0.2
UNr1m	0.1	0.6	3.2	2.8	0.4	16	0.8	0.2
UNb2p	0.1	0.5	7.2	2.2	0.6	228	1.0	0.2
UNb3p	0.1	0.5	2.0	1.3	0.5	6	1.5	0.1
UNb4p	0.1	0.4	6.1	3.2	0.3	570	1.5	0.1
UNb5p	0.1	0.3	2.9	1.8	0.3	50	0.5	0.1
UNr2M	0.1	0.6	5.2	2.3	0.4	216	0.9	0.1
AA1	0.1	0.6	7.2	2.4	0.6	162	0.1	0.2

* Kibe, J.M., Ochung' H. and Macharia P.N. 1982. Soil Vegetation of the ICRAF Experimental Farm, Machakos District. Detailed Soil Survey Report No. D23, 1981; Kenya Soil Survey, National Agricultural Laboratory, Nairobi. 68p. (mimeo).



App. Figure 1b.1 Detailed soil map of the ICRAF Field Station, Machakos District.

Appendix II:

1.3 Brief history of implementation

The original three plots for detailed observation were planted in the second rains, 1984[1]. German funding to support this project commenced in September, 1985. As at December 1988 eight observations/trials on tree/crop interface aspects had been established, one being a replicated field trial. Five other trials/demonstrations were set up in work parallel to that of the TCI investigations (Table 1: I-M). The main investigations reported here have been with A to F, as listed in Table 1. Trial J was the first of one of the parallel experimental projects which ICRAF has undertaken as a result of information arising from this TCI Project.

In the early 1980's very little was known about how to experiment with woody/non-woody plant mixtures other than in a general agronomic sense. Indeed, the whole concept of the TCI as an experiemental unit originated with this Project, and it has helped to shape a succession of further ideas about environmental influences on such mixtures. furthermore, the instructional aspects of these various demonstrations and research designs have, indeed, had a very considerable value for the many visitors and trainees (over 1400 in 1988 alone) who have visited the field station.

Table 1: Tree/crop interface demonstrations and trials established at ICRAF's Field Station, Machakos, Kenya (in chronological order of establishment).

A.	Species:	*Cassia siamea*/maize
	Layout:	Geometric 120° Y design, with trees in strip plots. Unreplicated.
	Planted:	May, 1984
	Purpose:	To explore TCI effects and interactions and to investigate assessment methodologies.
B.	Species:	*Grevillea robusta*/various crops (e.g.maize/cowpea, sunflower/cowpea).
	Layout:	Special systematic spacing, parallel-row design; planting density kept constant in any one plot, but between-row spacing changed. Two plots (= planting densities), unreplicated.
	Planted:	October 1984
	Purpose:	To demonstrate this particular type of spacing design and to explore TCI effects.
C.	Species:	*Cassia siamea*/castor bean
	Layout:	Geometric 120° Y single row hedge design. Unreplicated.
	Planted:	April, 1985
	Purpose:	Originally demonstration only; latterly for investigation of an unusual TCI effect.
D.	Species:	*Grevillea robusta*/maize
	Layout:	45° angle, spaced geometric 3-row hedgerow plots, 2 replicates.
	Planted:	May, 1986.
	Purpose:	To continue investigating assessment methodologies in a properly-replicated design.
E.	Species:	*Cassia siamea*/castor bean + inert shelter. Unreplicated.
	Layout:	Geometric 120° Y single row hedge design, and same Y layout for adjacent inert shelter.
	Planted:	October 1986
	Purpose:	To study this TCI in detail and to disaggregate shelter effects.

[1] The Machakos Field Station is in an area with bimodal rainfall distribution - Appendix 1.

F. Species: *Acacia nilotica*/natural sward mixture
Layuot: Single tree study
Planted: April 1987
Purpose: To investigate TCI effects and interactions around a single tree; especially with regard to appropriate methodolgies for on-farm research

Demnostration/observation plots

G. Species Guava/maize or maize + potatoes
Layout: Geometric 120° Y. single/double/treble hedgerow design, unreplicated.

H. Species: Guava/horticultural crops
Layout: Standard parrallel-row systematic spacing design; unreplicated.
Planted: April 1986
Purpose: Demonstration; and to investigate appropriate hedgerow pruning practices and TCI effects with vegetable crops (visual observations only

Parallel demonstration and experimental work (arising from but not carried out under this project - to be reported elsewhere).

I. Species: *Cassia siamea*/crops (cowpea/maize)
Layout: Modified (Chetty) diagonal hedgerow design; unreplicated.
Planted: October 1986
Purpose: Demonstration (a possible design for TCI and/or between-hedge spacing investigations).

J. Species: *Cassia siamea*/crops (cowpea/maize)
Layout: Rotational hedgerow intercropping plots; unreplicated
Planted: October 1986
Purpose: Demonstration

K. Species: Different woody species/crops (cowpea/maize)
Layout: Quadrat design
Planted: October 1986
Purpose: To explore the requirement for identifying sets of comparative quadrats, and as a demonstration for this approach to On-farm Experimentation.

L. Species: *Grevillea robusta/Chloris gayana*/maize (Katumani composite)
Layout: Randomized plots, two replications
Planted: October 1987
Purpose: To collect data, and to demonstrate, happens when an adapted woody perennial, perennial grass and a seasonal crop are all planted at the same site. Particularly with reference to their ability to exploit the available environmental resource pools: light, water, nutrients).

M. Species: *Citrus sinensis* (sweet orange)/crops (Cowpea/maize).
Layout: Fan (Nelder) Systematic spacing design modified for intercropping; unreplicated.
Planted: October 1987
Purpose: Demonstration.

Appendix III:

26. TREE/CROP COMPETITION FOR ABOVE-AND BELOW GROUND RESOURCES

M.R. Rao, M. Mathuva, J.H. Roger & E. Akunda

TYPE OF ACTIVITY

Experiment

BACKGROUND

At a tree/crop interface, the tree and the crop compete with each other for growth resources such as light; water, and nutrients. The resource-sharing by the components may result in complimentary or competitive effects depending on the nature of the species involved in the system, the manner in which they are grown, and the climatic factors. An understanding of the processes involved in resource sharing and quantification of the competitive effects are crucial for selection of proper species in agroforestry and managing the tree/crop interface for greater productivity. In much of the on-going AF studies there is very little quantification of below-ground resource use by the component species. The studies planned here are aimed at getting information on the above-and below-ground competitive effects in leucaena/maize interface plots, and also to serve the purpose of demonstrating the various methods used in resource sharing and utilisation research. This is a follow-up of the earlier tree/crop interface project work (Huxley et al. 1989).

OBJECTIVES

1. To examine and quantify the competitive effects between components of a tree/crop system for above-and below-ground growth resources.

2. To examine the scope of certain hedge and/or soil management practices to minimise competition and maximise complimentary effects between the tree and the crop components.

METHODS

Treatments

1. Woody perennial spaced 0.5 m apart within-row, allowed to grow normally (competition for light, water, and nutrients).

2. Woody perennial spaced 0.5 m within-rows, pruned at about 0.5 m height (competition mainly for water and nutrients).

3. Treatment 1+ soil barrier (a GI sheet is installed to 1 m depth on either side between the tree and the crop; competition for light only).

4. Treatment 2+ soil barrier same as in treatment 3 (No or little interaction between the tree and the crop).

5. Treatment 1+ irrigation (measured quantities of water is applied to eliminate moisture competition between the tree and the crop. Competition remains for light and nutrients).

6. Treatment 2+ irrigation same as in treatment 5 (competition exists for nutrients).

7. Hedge only.

8. Annual crop only.

9. Annual crop only + irrigation.

10. Sunken planting of the perennial, pruning of hedge. (Trees are planted in an open 40 cm x 40 cm trench).

Tree species: Leucaena leucocephala, Crop = maize

Design: Randomised Block Design, Replication: 3

Plot size: 15.75 m x 10 m.

Each plot has a row of perennial in the middle and 10 rows of maize at 0.75 m on either side. Measurements are made on individual rows leaving a border of one meter on each end.

Layout: (See figure). In view of multiple slopes, each plot was laid out independent of the other. The hedgerow in the middle was aligned to contour. To avoid trees of one plot interfering with another plot, they were separated from one another by 4 m distance. The gaps between plots and a 3 m area surrounding the whole experiment are cropped with an uniform crop of maize similar as in experimental plots. This cropped guard is very important to minimise edge effects in treatment plots.

Management: Leucaena was established by planting three month old seedlings at 0.5 m apart between plants. In the hedge treatments, the trees will be pruned to 0.5 m height and the prunings will be removed from the plots. Maize will be grown in both seasons of a year without any fertilizer and the residues will not be incorporated into the soil. Trash bunds on contour will be provided to avoid any erosion in the area.

ASSESSMENTS

1. Climate - routine

2. Soil - soil samples as a transect across plots in the beginning and end of the trial for Organic Carbon, N, P, pH

3. Soil moisture depletion pattern in selected treatments.

4. Light interception in selected treatments.

5. Tree heights, collar diameter, biomass production.

6. Crop yields row by row.

RESULTS

Leucaena was planted in November 1989 and its establishment was good. It was browsed by dik diks in the beginning but further damage was avoided by enclosing the hedges in wiremesh. Maize in the last two seasons has produced excellent growth. Treatments will be imposed beginning with the second rains of 1990.

Appendix IV:

ICRAF FIELD EXPERIMENTAL PLAN

1. HOME

Division: RESEARCH
Network: NONE

Status: October, 1991 Proposed

Country: Kenya
Location(s): Machakos Field Station
Project or Expt. no.

2. TITLE

Full: Resource capture of an agroforestry system with species of different rooting depths.

Short: Rooting depth and resource capture

3. INSTITUTIONS

International: ICRAF
National (or collaborating): Theoretical Production Ecology, Wageningen, Holland

4. SCIENTISTS

Principal investigator(s): C.K. Ong
Collaborating scientists: E. Akunda
Support staff: M. Mailu

5. BACKGROUND OR JUSTIFICATION

A major assumption in agroforestry is that a combination of a deep rooting tree and shallow rooting crops can maximise capture for below ground resources (e.g. water and nutrients) whilst reducing negative tree/crop interactions. But evidence verifying this assumption is lacking even in the most common agroforestry systems. It is assumed that trees can take up nutrients and water from deeper profiles in the soil, leading to increased biomass production. However, experience at Machakos and elsewhere has revealed that rooting depth of some trees in agroforestry is confined to the top soil profile, unlike that of forest stands. The rooting pattern of agroforestry systems may be strongly influenced by the relative competitiveness of the component species.

According to de Wit's competition theory (Berendse 1981), the shallow rooting species should be more competitive than the deep rooting species to compensate for the extra below ground resources accessible to the deep rooting species. This theory has been partly confirmed in

Holland on the ecological balance between grasses and _Plantago_ (Berendse, 1981) but has not been tested in agroforestry.

An understanding of the relation between rooting depth and utilisation of below ground resources is necessary to develop agroforestry technologies for dry areas where crop failure is common (Ong et al. 1989). This experiment will form the basis of our strategic research involving the role of roots in tree/crop interactions.

6. OBJECTIVES

1) To test the hypothesis that a combination of a deep rooting and a shallow rooting species can absorb more water and nutrients than annual crops.

2) To test de Wit's hypothesis that a shallow rooting crop species should be more competitive than a deep rooting tree to compensate for the extra below ground resources accessible to the tree.

7. EXPERIMENTAL SITE(S)

See ICRAF experimental site description for: Machakos Field Station
Location of experiment within site as a whole: next to inert Y design.

Latitude: 1' 33'S Longitude: 37' 14'E Altitude: 1660 m
Slope: angle: 1 (degrees), 2 (per cent)
position in catena:

Rainfall: mean annual: 740 mm One or two seasons: Two
number of dry months (<50 mm): 4

Soil type: FAO Haplic lixisol
US Kandic Rhodustalf
National Chromic luvisol

Description: Reddish brown sandy clay, low to moderate levels of organic matter

Cropping history: Sesbania spp. grown in November 1988 to November 1989 pH 6.0-6.5, cover cropped with maize in march '91

8. MATERIALS AND METHODS

8.1 Treatments

Factors investigated:

1. Soil depths: deep > 0.5 m, unrestricted
shallow < 0.5 m, restricted with porous mesh.

2. Growth rate of hedgerow: Fast, full light
   : Slow, 50% light

A single hedgerow of gliricidia at 2 m spacing, pruned to 0.5 m at the onset and end of each cropping season. Two rows of sorghum or maize to be planted between hedgerows.

	Treatments	Factors			
		Deep	Shallow	100% light	50% light*
1.	HI	X		X	
2.	HI		X	X	
3.	HI	X			X
4.	HI		X		X
5.	Crop	X		X	
6.	Crop		X	X	
7.	Tree	X		X	
8.	Tree		X	X	
9.	Tree	X			X
10.	Tree		X		X

*A pot trial will be conducted in the nursery to determine the critical light level required to reduce growth of the tree.

8.2 Plant material

Tree species provenances: Gliricidia

Crop species/cultivars: hybrid maize or sorghum for uniform plants.

8.3 Plot size

Gross plot: 6 x 8 m, each HI contains 4 rows of trees. All plots to be dugged by hand to 0.3 m, irrespective of soil depth. Shallow depth to be lined with 5 m wide porous mesh, (max. width available) impenetrable to roots. Shaded hedgerow to have vertical screens of 1 m, on both sides. Each plot to have 1 guard hedgerow i.e. total 4 rows of trees.

Net plot: Non-destructive growth sampling will be confined to 2 middle hedgerows and the crop within along a 4 m length (total 4 x 2 m).

Measurements: a) Regular measurements of stem diameter of tree and crop to estimate biomass production.

b) Light interception by plant canopies using mouse quantum sensor at weekly intervals during cropping seasons, all plots.

c) Moisture using neutron probe, 0.3 m in shallow and 1.5 m in deep treatments, all plots at weekly intervals.

d) Root studies at end of experiment, 24 months.

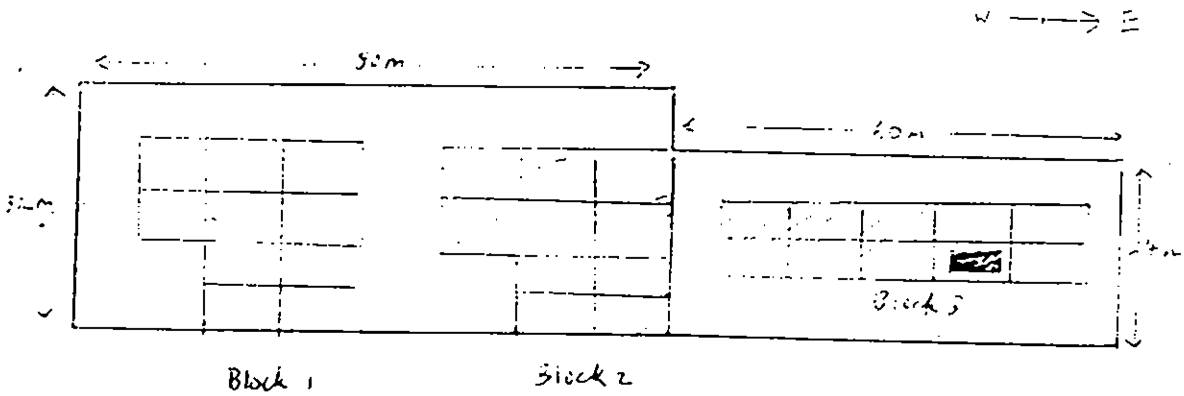
8.4 <u>Statistical design</u>

Randomised complete block design, 6 metre to be left between blocks.

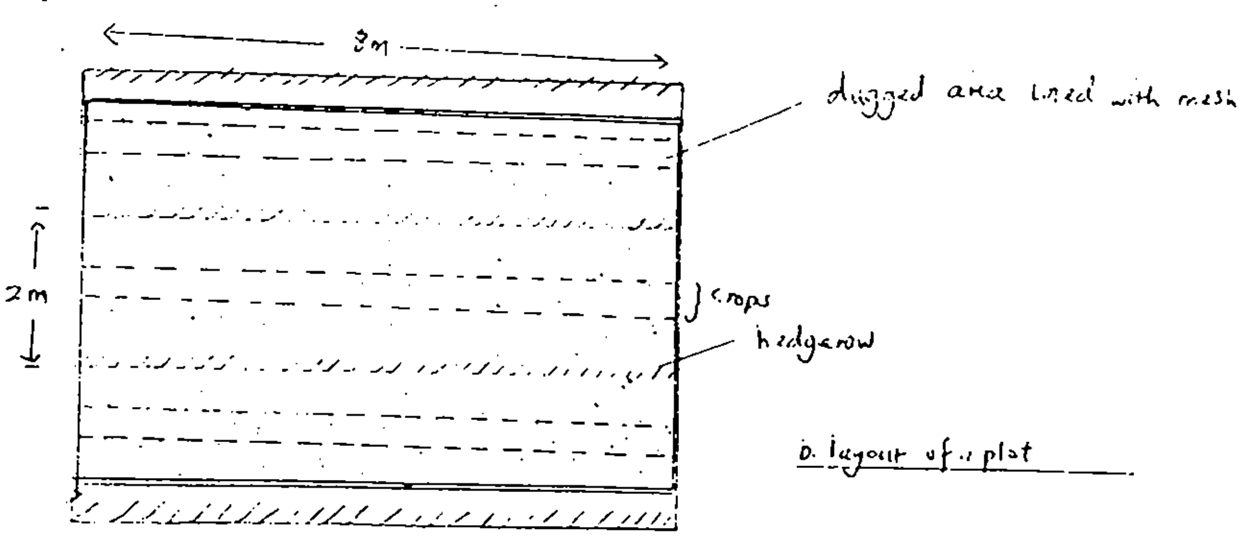
8.5 <u>Replications</u>

As this is a fairly uniform site, 3 replications are sufficient.

8.6 <u>Field layout</u>



a. LAYOUT OF BLOCKS



b. layout of a plot

8.7 Time Frame of the Experiment

Starting year:	Ending year:	Other details:
Oct 1991	Jan 1993	Initial sowing with sorghum, maize in the following season (March, 1992), then sorghum again (Oct. 1992)

9: MANAGEMENT

9.1 Soil

Field operation will be started during the dry season (July '91). Top 30 cm of soil will be removed by hand to avoid minimum compaction to all plot. A porous root mesh (5 x 8 m) will be used for the shallow treatments and the top soil return to all treatments before the onset of the rainy season (Oct '91). No fertiliser will be applied to the maize or trees since this is a relatively fertile field.

9.2 Trees

Seedlings will be raised in polythene containers provided with appropriate rhizobium. Each HI and tree treatments will require 80 seedlings and the total number of seedlings required for the whole trail is 640 but 800 will be raised to provide uniform seedlings. Intra row spacing of seedling is 0.5 m.

Seedlings will be allowed to grow for 6 months after transplanting to ensure good establishment. Shading will be imposed soon after transplanting so that any effect on rooting pattern will not be confounded by initial management. Pruning will be made at 0.5 m in all HI and tree treatments before sowing of crops and at crop maturity.

9.3 Crops

Maize or sorghum will be sown immediately after the tree seedlings have been transplanted. Crop row will be 0.7 m from the hedges and 0.6 m between crop rows and intra-row of 0.25 m. All crops will be weeded and protected against diseases and pests.

10. OBSERVATIONS/ASSESSMENTS

All observations will be recorded using PSION organisers and on proforma provided for Datachain.

10.1 Climate

Standard meteorological information from Met Station at Machakos.

10.2 Soil

Soil sampling will be taken after the top soil (0-0.3 m) has been returned to the plots for analysis of major nutrients. In the deep treatments additional sampling will be made at 1.0 and 1.5 m.

The influence of root mesh on infiltration of water down the profile will be assessed separately following a heavy storm.

10.3 Trees

Growth: Stem diameter and height will be taken to provide an assessment of the biomass accumulation in all treatments. Regular measurements will be made at the beginning and end of each cropping period.

Transpiration: A heat balance method will be used to relate stem diameter to transpiration rate for treatments 1 & 2 i.e. rooting depth.

Light interception: To monitor the effect of shading on canopy expansion a "mouse" travelling quantum sensor will be used to measure light interception.

Soil moisture extraction: This will be done by neutron moisture tubes for all treatments.

10.4 Crops As for 10.3

10.5 Economics NONE

10.6 Other observations (Nutrients by K. Shepherd?)

11. STATISTICAL ANALYSIS R. Coe for advice.

12. AVAILABILITY OF RESOURCES

		US$
1)	Cost of permeable root mesh for entire trial	320
2)	Cost of shade material	150
3)	Estimated man days for excavation	260
		730

4) Instrumentation required & available at ICRAF
   a) Light quantum sensor

b) Access tubes for soil moisture determination:
0.3 m length, 4 per plot x 5 treatments x 3 reps = 18 m
1.5 m length, 4 per plot x 5 treatments x 3 reps = 90 m

c) Heat balance technique for transpiration.

13. REFERENCES

Berendse F, 1981. Competition and equilibrium in grassland communities. PhD thesis, University of Wageningen.

Ong, C.K., Corlett, J.E., Singh, R.P. and Black, C.R. 1989. Above and below ground interactions in agroforestry systems. Presented at University of Edinburgh, Agroforestry, Practice and Principles. Forest, ecology and management (in press).

14. APPROVAL

Scientist(s)	Coordinator	Director(s)

Natural
Environment
Research
Council