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GAMINI KEERTHISINGHE
(Scientific Secretary)

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1. Introduction

This is the third Research Co-ordination Meeting (RCM) of the Co-ordinated Research Project (CRP) on “The Use of Nuclear Techniques for Developing Integrated Nutrient and Water Management Practices for Agroforestry Systems”, which was initiated in 1998 based on the recommendation of a Consultants’ Meeting held in Vienna at the IAEA Headquarters in September 1997. The first RCM was held in Vienna from 19 - 23 April 1999 and the second RCM in Kuala Lumpur from 7 – 11 May 2001. The main purpose of this meeting is to evaluate the progress and achievements made so far in line with the project objectives and to plan future activities. The specific objectives of the project are:

(i) To understand how trees contribute to N, C and P cycling and the availability of nutrients and water to crops;
(ii) To identify how tree-crop systems can be manipulated for improved nutrient and water use;
(iii) To identify relationships between N and C fractions of soil organic matter and capacity for long-term productivity.

The Meeting was held at the Mount Lavinia Hotel, Colombo, Sri Lanka from 2 – 6 June 2003 and it was attended by all the contract and agreement holders except for the contract holders from Benin (thesis defence examination) and China (travel restrictions due to SARS). The local organiser of the meeting was Dr. Sarath Nissanka, University of Peradeniya, Sri Lanka.

The meeting was officially opened by the Chairperson of the Atomic Energy Authority (AEA), Prof. H. Hewamanne. She welcomed the participants on behalf of the Atomic Energy Authority, Sri Lanka and highlighted the importance of the project to Sri Lanka and to the region. The local organizer explained the programme of the meeting and provided the details of the field trip. The scientific secretary, Dr. Gamini Keerthisinghe, informed the main purpose of the meeting, and the procedure of evaluating the progress of the project. The first three days of the meeting consisted of Technical Sessions where participants presented the results of their on-going activities in relation to the CRP. The last two days of the meeting was devoted for general discussion on experimental protocols and implementation of the project.
2. Programme

Monday, 2 June

09:00 - 09:30 **Official Opening**

Sarath P. Nissanka (Local Organizer)

Gamini Keerthisinghe (Scientific Secretary)

Prof. R. Hewamanne, Chairperson, Atomic Energy Authority, Sri Lanka

09:30 - 10:00 G. Keerthisinghe

Remarks by the Scientific Secretary

10:00 - 10:30 Coffee Break

**Session I**  
Chairperson: Mark Adams

10:30 - 11:30 S. Recous (France)

“Integrated nutrient and water management in agroforestry systems in sustained food production”

11:30 - 12:30 C. Ovalle-Molina (Chile)

“Nutrient and water contributions of *Fraxinius excelsior* and *Chamaecytisus proliferus* to annual crop nutrition in an agroforestry system in Mediterranean Chile”

12:30 - 12:45 Discussion on presented papers

12:45 - 14:00 Lunch break

**Session II**  
Chairperson: Sylvie Recous

14:00 – 15:00 M. Smith (UK)

“Effects of trees on availability of soil water and water uptake and partitioning between trees and crops”

15:00 - 16:00 C. Cervantes (Costa Rica)

“Dynamics of nutrients in agroforestry systems”

16:00 - 16:30 Coffee Break

16:30 - 17:30 Discussion on presented papers
Tuesday, 3 June

Session III  Chairperson:  Roel Merckx

08:30 - 09:30  M. Adams (Australia)
“Application of stable isotopes at natural abundance to agroforestry”

09:30 - 10:30  J. M. Ndufa (Kenya)
“Nutrient sourcing and soil organic matter dynamics in mixed-species fallow with legume trees”

10:30 - 11:00  Coffee Break

11:00 - 12:00  R. Chintu (Zambia)
“Integrated nutrient and water management in agroforestry systems for sustainable food production”

12:00 - 12:30  Discussion on presented papers

12:30 - 14:00  Lunch Break

Session IV  Chairperson:  Zaharah Rahman

14:00 - 15:00  P. Ebanyat (Uganda)
“Nitrogen dynamics and physical properties in two best bet sequential fallows in the highlands of South Western Uganda”

15:00 - 16:00  S. Nissanka (Sri Lanka)
“An evaluation of agroforestry systems for sustainable crop production through integrated nutrient and water management”

16:00 - 16:30  Coffee Break

16:30 - 17:00  Discussion on presented papers

19:00  Reception
Wednesday, 4 June  | Field trip

Thursday, 5 June

**Session V**  
**Chairperson:** Mark Smith

- **09:00 – 10:00**  
  R. Merckx (Belgium)  
  “Long-term soil organic carbon dynamics in a sub-humid tropical climate: $^{13}$C data and modelling with ROTHC”

- **10:00 – 10:30**  
  Coffee break

- **10:30 – 11:30**  
  Bin Zhang (China)  
  “Synergy or competition for nitrogen and water use between *choerospondias axillaris* and intercropped sweet potato sequenced by rape and in alley cropping systems estimated by nuclear techniques”

- **11:30 – 12:00**  
  Discussion on presented papers

- **12:00 – 14:00**  
  Lunch break

**Session VI**  
**Chairperson:** G. Keerthisinghe

- **14:00 – 15:00**  
  Z. Rahman (Malaysia)  
  “Nitrogen and phosphorus cycling in a *P. falcataria* food crop alley cropping system on an ultisol”

- **15:00 - 15:30**  
  Discussion on presented papers  
  Formulation and function of working groups

- **15:30 - 16:00**  
  Coffee Break

- **16:00 – 17:00**  
  Presentations from working groups

**Friday, 06 June**

- **09:00 – 10:00**  
  Overall progress of the project  
  G. Keerthisinghe

- **10:00 – 10:30**  
  Coffee break

- **10:30 – 11:30**  
  Final editing of reports

- **11:30 – 12:00**  
  Final discussion

- **12:00**  
  **Closing remarks**  
  G. Keerthisinghe
3. Abstracts of Presentations

3.1 Dual analysis of oxygen and carbon isotopes at natural abundance examples from agriculture and natural ecosystems illustrate short and long-term acclimation to environment

Stefan Arndt, Sebastian Pfautsch, Chris Weston, Heinz Rennenberg, and Mark Adams

1Forest Science Centre, Water St., Creswick, Victoria 3363, Australia, e-mail: adamsma@unimelb.edu.au
2Albert Ludwigs University, Institut für Forstbotanik und Baumphysiologie, Georges-Köhler Allee, Geb. 053/054, 79110 Freiburg, Germany

Publication of both (i) a theoretical basis for the likely fractionation of oxygen isotopes in plant foliage, and (ii) simple models describing the relationship between the abundances of carbon isotopes and those of oxygen, have created new opportunities to use these isotopes to quantify and examine a range of ecophysiological processes. Using selected examples from Australian agriculture and native vegetation in Australia and China, we illustrate some of the sources of variability in oxygen and carbon isotopes in plant foliage. In glasshouse studies, the agricultural legume *Lupinus angustifolius* acclimated quickly to shortages of water and to varying humidity and oxygen and carbon isotope composition of organic matter also changed quickly. Under continued well-watered conditions, $\delta^{13}C$ and $\delta^{18}O$ were poorly related but were strongly and positively related if water was withdrawn. These data reflect strong genetic control of development and physiological acclimation (strong stomatal response to shortages of water) to a Mediterranean climate and sandy soils. In a field study in a wet sclerophyll forest in Australia, the oxygen isotope composition of rainfall, streamwater and soilwater varied little over a large range in altitude and landscape position – a necessary precondition for comparing foliar $\delta^{18}O$ over such a range. Carbon and oxygen isotopes were negatively related in foliage, and matched the known and likely variation in photosynthetic capacity and stomatal conductance and were broadly supportive of the conceptual model of Scheidegger et al. (*Oecologia* 125, 350-357). The relationship between $\delta^{13}C$ and $\delta^{18}O$ in vegetation growing around an oasis in the Taklamakan desert could be interpreted as being indicative of well-watered conditions suggesting the plants were behaving as phreatophytes, drawing their water consistently and reliably from groundwater.

The analysis of both $\delta^{13}C$ and $\delta^{18}O$ in foliage will seldom be sufficient, of their own, to be used to test hypotheses about the environmental control of gas exchange or water loss. Nonetheless, analysis of $\delta^{18}O$ will greatly inform interpretation of $\delta^{13}C$ data that is now widely used to interpret both short- and long-term acclimation to environmental conditions.
3.2 Soil factors limiting growth and establishment of pigeon pea (*Cajanus cajan* (L.) Mill sp.) in farmers’ fields in the derived savannah of Benin Republic

Kouessi Aihou
Centre de Recherche Agricole de Niaouli, Cotonou, Benin, e-mail: k.aihou@yahoo.fr

During the last two decades (mainly in the 1980-1990’s) there has been a shift of paradigm in soil fertility management in West Africa: the use of agroforestry systems (alley cropping) and herbaceous legumes (e.g. *Mucuna pruriens*). Once both technologies were exposed to farmers, they did not pass the test of adoption because of lack of an economical product such as grain. Therefore, these technologies are now being replaced or combined with optimum rates of mineral fertilizers. Systems including dual-purpose grain such as soybean, cowpea and pigeon pea (*Cajanus cajan* (L.) Millsp.) are currently of interest to farmers because of their ability to restore soil fertility while providing nutritive grains for food and cash. This has a potential in the Benin Republic, but it is often limited by different soil factors including nutrient deficiency and soil borne diseases. In order to see the impact of biological fixation, diseases as well as of soil N and P, a greenhouse study was conducted with sterilized (SS) as well as non-sterilized (NSS) soil collected from different farmers' fields in two villages of the derived savannah of the Benin Republic.

Growth of *Cajanus cajan* differs among farmers' fields (ranging from 3.36 to 9.90 g/plant) and was on average higher in the Zouzouvou soils than in the Eglimé soils. There were significant interactions between sterilization and *Cajanus cajan* growth. Shoot dry weight per plant in the non-sterilized soil was higher than in the sterilized soil. Three types of soils from farmers' fields could be identified according to the response of *Cajanus cajan* to soil sterilization: (i) 42 to 58% of soils from Eglimé and Zouzouvou had a shoot dry weight higher in the NSS than in the SS, (ii) 33% of soils had a shoot dry weight higher in the SS than in the NSS, and (iii) 25 to 42% of soils showed a non significant difference of the shoot dry weight between the NSS and the SS. These results imply that either the symbiotic properties or the root soil borne diseases affected the growth of the plants in the different soils. The role of soil N and P on plant growth and their interactions with the symbiotic parameters such as nodulation and the arbuscular mycorrhizal fungi (AMF) supports the presence of suppressive and/or stimulatory effects of *Cajanus cajan* grown in sterilized or non-sterilized soils.

3.3 Cropping systems with pigeon pea (*Cajanus cajan* (L.) Mill sp.) in the derived savannah of Benin Republic: Recovery of $^{15}$N from a mixture of urea and plant residues

Kouessi Aihou
Centre de Recherche Agricole de Niaouli, Cotonou, Benin, e-mail: k.aihou@yahoo.fr

The synchronization of nutrient release from plant residues and uptake by plants has become a central paradigm in applied soil research in the tropics. Combination of both inorganic and organic inputs has been recommended as a mean of alleviating soil constraints and increasing
food production in the derived savannah of Benin. For proper management of these sources of N, it is necessary to quantify how much of the applied N is contributed by each component of the mixture. The fate of a single application of \(^{15}\)N labelled urea-N or labelled residue of \textit{Cajanus cajan} and their mixture at different rates of N application on maize was followed at two different sites (Sekou I and Niaouli) in the derived savannah in southern Benin. The results show that N response was significant at Sekou I, while at Niaouli it was not, most probably because of the different status of soil fertility.

It was observed that the N content of maize in the treatments that received 120 N kg\(^{-1}\) (as urea) was higher than when 120 kg N ha\(^{-1}\) was given as \textit{Cajanus cajan}. The maize crop recovered 10.5 and 6% of the applied N (average values of urea and \textit{Cajanus cajan} residues) at Niaouli and Sekou I, respectively. The partitioning of N was similar in the different plant parts (grain, pods and stover). The highest proportion of applied N recovered by the maize occurred at the highest rates of applied N as urea or \textit{Cajanus cajan} residues at Sekou I. The differences between the two N sources were, however, not significant at Niaouli. The interaction between the organic and inorganic N source was not significant on maize N recovery despite the large differences in maize grain yields especially at Sekou I. These results indicate that the interactions between organic and inorganic inputs cannot be explained by effects on nitrogen availability and that there are other factors such as moisture regime and other nutrients such as P and S not studied here which may be responsible for the interaction found between the grain and biomass production.

3.4 Nutrient balances in coffee \textit{Gliricidia} and coffee \textit{Eritrina} agroforestry systems in Costa Rica

Carlos Cervantes  
National University Foundation, Universidad Nacional, Laboratorio de Suelos, Heredia, Costa Rica. e-mail: ccervant@una.ac.cr

Two alternative management systems were tested against the full light system of Coffee production in Costa Rica. The effects of two legume trees, \textit{Erythrina poeppigiana} and \textit{Gliricidia sepium}, on growth of coffee were tested in an agroforestry system. The experiment also included a coffee plantation without legumes trees as control. The experimental site is located at the Costa Rican central plateau in BARVA, province of Heredia, Costa Rica. The altitude is 1250 meters above sea level. The mean temperature is 26.8 C and the mean annual precipitation is 2277.7 mm. The highest rainfall is in October (413.3 mm). The dry season is from December to March and lowest rainfall is in January (10.3 mm). The shade trees were planted in May 1999 in a square of 6 x 7 m at a density of 238 trees/ha. The spacing of coffee plants was 1 m and the row spacing was 1.5 to 2 m with a population of about 6700 plants/ha. The shade trees are pruned twice a year at the beginning of June and in August of each year. Coffee management also includes pruning of the coffee plants.

On July 5 2002, Gliricidia and Erythrina legumes trees were labelled with \(^{15}\)N using tree injection technique to follow the transfer of N from trees to coffee. Shade trees were pruned ten days after injection and the coffee trees around the legume trees were sampled on July 30 2002 for the first time and then sampled every two weeks. The results showed a relatively fast decomposition and a good recovery of nitrogen by the coffee tree. The highest recovery of N from legume was obtained from Gliricidia providing as much as 4.5 % of the total coffee plant N. Management practices are proposed to increase the amount of N entering the system.
through the atmospheric N fixation by increasing the amount of legume biomass. One approach is to increase the number of trees/ha to about 350. In considering the low levels of nitrogen recovery by coffee from fertilizers under local conditions, N could be supplied to the crop using the legume tree agroforestry systems. Besides N, recuperation of other nutrients showed the capacity of the system to recycle nutrients, assuming that most of this elements were captured from deeper soil layers moved by leaching in volcanic ash soils. Phosphorus is not used in high amounts in coffee because of low responses to P applications. Even with the low returns, the amount of phosphorus returned to system is of importance specially because is in organic form. This form of P is more available to plants in volcanic soils with a high P fixation capacity.

3.5 Soil nitrogen and physical properties in coppicing and non-coppicing planted tree fallows in Zambia

Richard Chintu
Department of Research and Specialist Services, Ministry of Agriculture, Food and Fisheries, Msekera Agriculture Research Station, P.O. Box 510089, Chipata, Zambia, e-mail: zamicraf@zamnet.zm

Improving food production and soil resources in the smallholder farm sector of southern Africa is an enormous challenge. Soil degradation and nutrient depletion have become serious threats to agricultural productivity in southern Africa. Declining of soil fertility due to continuous cultivation without using fertilizers is a major cause of low crop yields in the entire sub-Saharan Africa. Presently, nitrogen (N) is cited as the most limiting nutrient to crop production in the region. We hypothesized that planted tree fallows can potentially increase available N for subsequent crops, thus enhancing crop yields. Field studies were conducted on depleted sandy clay loam at Msekera and Kagoro, Zambia, to determine the effect of contrasting fallows (natural fallow, non-coppicing and coppicing planted tree fallows) and no-tree no-fallow ((maize (Zea mays L.) with and without fertilizer)) systems on soil fertility and maize yield.

Planted fallsows significantly \((P<0.01)\) increased topsoil inorganic N and maize yields over the no-tree, unfertilized controls. Maize yields in planted fallows of Gliricidia sepium (gliricidia) and Leucaena leucocephala (leucaena) were consistently high and comparable \((P<0.01)\) to those in fertilized controls \((3.5\ t\ ha^{-1}\) on average) over 8 cropping seasons. Maize productivity in non-coppicing Sesbania sesban (sesbania) fallows dwindled significantly after three post fallow seasons indicating decreased soil fertility. Preseason topsoil \((0-20\ cm)\) N positively correlated \((r = 0.83; P<0.05)\) with maize grain yield, implying that preseason topsoil N can be used to predict post fallow crop yields in planted fallsows. Nitrogen significantly accumulated in the subsoil \((at\ 200\ cm)\) under the non-coppicing sesbania fallsows (in post fallow phase) and in no-tree fertilized and unfertilized plots. This could be due to lack of live functioning post fallow roots in case of sesbania and lack of deep and profuse root system in maize mono-cropping systems, thus lack of root safety-net to effectively intercept leaching nutrients. Significant topsoil N accumulation was attributed to foliage biomass addition in the planted fallow systems and, to inorganic fertilizer addition in fertilized control. Coppicing leucaena, gliricidia fallsows and the mixed fallow of gliricidia and sesbania, were found more suitable for long-term N amendment than sole sesbania fallsows which improved yield of only 3 post fallow maize crops under semiarid conditions of Zambia. Mixing
sesbania and gliricidia was found to be a strategy to reduce subsoil N accumulation that is associated with sole sesbania post fallow phase. This system significantly ($P < 0.05$) enhanced post fallow coppice biomass yield, 1.6-4.0 t ha$^{-1}$ compared to 1.7-2.4 t ha$^{-1}$ in sole gliricidia and nil in sole sesbania it (sesbania) being non-coppicing. This study shows that soil fertility replenishment in Sub-Saharan Africa in its totality should go beyond N availability alone. Soil physical properties such as soil storage, infiltration rate and compaction combined with crop nutrient requirements and other factors, may reduce or improve soil fertility and subsequent crop yields.

### 3.6 Nitrogen dynamics and soil physical properties in best bet sequential fallows in the highlands of South-western Uganda

**P. Ebanyat**  
Department of Soil Science, Makerere University, P.O. Box 7062, Kampala, Uganda.  
e-mail: ebanyat@yahoo.com

Small-scale farmers in Kigezi highlands of South-western Uganda are faced with the constraints of declining soil fertility and insufficient wood production. Crop yields across the terraces follow a trend; upper<middle<lower position. Relative yields in the upper and mid terrace positions are usually about 40% or less. Previous work (limiting nutrient trials and soil profile characterisations) has indicated that the yield trends are associated with nitrogen and soil physical limitations. In a complete randomised block experiment with four replicates set up by AFRENA/ICRAF in October 1999, the effects on soil productivity of three prospective fallow species *Alnus acuminata*, *Calliandra calothyrsus* and *Sesbania sesban* planted to the upper 2/3 of degraded terrace sections are being assessed as compared to continuous cropping. A maize/wheat rotation was implemented while the trees were establishing. Data collected from the experiment include; tree growth (monthly), crop yields and particulate organic matter (POM) and its N and P contents (seasonally), infiltration rates (Is) and saturated hydraulic conductivity (Ksat) annually. Growth rates differed significantly between the tree fallows. The rates of height increase were 1.32, 1.24 and 0.91 cm per month for *Sesbania*, *Alnus* and *Calliandra* respectively. The corresponding crown diameter and root collar diameter increases were approximately half of this rate for *Sesbania* and *Alnus* and 1/50 for *Calliandra*. No significant effect of fallow species on maize yields was observed across terrace positions in neither of the three seasons during establishment. However, significant differences between treatments were obtained with the wheat crop in the upper terrace positions. Wheat performed similarly in the *Sesbania* plots (904 kg ha$^{-1}$) and the *Calliandra* plots (537 kg ha$^{-1}$) but significantly better than in the *Alnus* plots (457 kg ha$^{-1}$) in the upper terrace position. In all the three seasons the yields responded to a fertility gradient as the trees did not yet significantly improve soil physical properties (Is, Ksat and BD) nor the nitrogen contents of soils. Data collected for 2 seasons after fallowing (maize – wheat) show that tree falls can increase crop yields in the degraded terrace positions (up to 200%) presumably through a mulching effect indicated by particulate organic matter contents. Yield increases are however not very high and appear to be short lived (limited to one season) due to modest biomass yields of the fallows and the underlying reasons for this i.e. likely deficiencies and nutrient imbalances in the degraded terrace sections. So far over the two seasons, *Sesbania* proved to be the best tree fallow towards increasing crop yields. It also increased soil infiltration rates with up to a factor of two to three, but the effect declined after
the first crop. Investigations of fallow effects on yield and soil properties will be continued for two more seasons. Through the field micro plot $^{15}$N studies that are currently running, actual amounts of N cycled from tree biomass to subsequent maize – wheat crops will be obtained.

3.7 Long-term soil organic carbon dynamics in a sub-humid tropical climate: $^{13}$C data and modelling with ROTHC

J. Diels$^1$, B. Vanlauwe$^{1,2}$, M.K. Van der Meersch$^{3,4}$, N. Sanginga$^{1,2}$, R. Merckx$^3$

$^1$IITA, Ibadan, Nigeria, c/o Lambourn & Co., 26 Dingwall Rd., Croydon CR9 3EE, UK
$^2$present address: Tropical Soil Biology and Fertility Institute of CIAT, PO Box 30677, Nairobi, Kenya; $^3$Laboratory for Soil and Water Management, Faculty of Agricultural and Applied Biological Sciences, K.U.Leuven, Kasteelpark Arenberg 20, 3001 Heverlee, Belgium
$^4$Present address: Kerkstraat 11, 3870 Heers, Belgium.
e-mail: roel.merckx@agr.kuleuven.ac.be

Information on long-term soil organic matter (SOM) dynamics in the tropics is scanty and this hampers validation of SOM models for such conditions. We observed SOM content changes in a 16-year continuously cropped agroforestry experiment in Ibadan, south-western Nigeria. The objectives were to quantify the effect of the cropping system and fertilizer additions on SOM contents, to investigate if $^{13}$C abundance measurements could provide useful information in such complex system involving mixtures of C$_3$ and C$_4$ plant species, and to use the experimental data to test the ROTHC soil organic carbon (SOC) model. It was found that two alley cropping systems, one with *Leucaena leucocephala* and one with *Senna siamea* hedgerows, sequestered an additional 5.0 Mg C ha$^{-1}$ in the 15-cm topsoil after 11 years compared to the control treatment without trees. After 16 years, 5.2 Mg C ha$^{-1}$ was sequestered. The addition of NPK fertilizer had little effect on the quantities of plant residues returned to the soil, and there was no evidence that the fertilizer affected the rate of SOC decomposition. The fact that both C$_3$ and C$_4$ plants returned organic matter to the soil in all cropping systems, but in contrasting proportions, led to clear contrasts in the $^{13}$C abundance in the topsoil SOM. This $^{13}$C information, together with the measured SOC contents, was used to test the ROTHC model. Decomposition was very fast in this experiment, illustrated by the fact that we had to double all decomposition rate constants in the model in order to reproduce the measured contrasts in SOC contents and $\delta^{13}$C values. We hypothesized (1) that the pruning materials from the legume trees and/or the extra rhizodeposition from the tree roots in the AC treatments accelerated the decomposition of the SOC present at the start of the experiment (true C-priming), and (2) that the physical protection of microbial biomass and metabolites by the clay fraction on this site, having a sandy top soil in which clay minerals are mainly of the 1:1 type, was lower than assumed by the model.
3.8 Quantifying the contribution of legumes above- and belowground N to soil N pools and subsequent crop in improved fallow system using \textit{in situ} $^{15}$N labelling techniques in Western Kenya

Ndufa, J.K.$^{1,}$, Cadisch, G.$^{2,}$ and Albrecht, A.$^{3}$

$^{1}$Kenya Forestry Research Institute (KEFRI), P.O.Box 20412, Nairobi, Kenya
e-mail: Jndufa@africaonline.co.ke
$^{2}$Department of Agricultural Sciences, Imperial College at Wye, University of London, Wye, Kent TN25 5AH, UK; gcadisch@ic.ac.uk
$^{3}$Soil Science Laboratories, ICRAF/IRD, P.O. Box 30677, Nairobi, Kenya

Significant increase in crop yields have been reported following short duration leguminous fallows (9-18 months) with substantial residual benefits following maize crop for at least two cropping seasons. However, despite such large yield increases, the amount of legume belowground biomass, nitrogen content and utilization by the subsequent crop is less understood under field condition. We hypothesized roots can contribute a substantial amount N to soil N pool through root turnover and root decomposition after the fallow, immobilize N released from aboveground biomass at the initial stages of decomposition but immobilized N is released at the later stages and root decay and turnover can supply a substantial amount of SOM to the soil as well as nitrogen to the subsequent crops after the fallow. The $^{15}$N-labelling of aboveground plant components has been proposed as a method for estimating amount and turnover of N in root systems as N is rapidly distributed throughout the plant.

A field experiment was undertaken in western Kenya to (i) determine the amount of legume above- and belowground biomass N at a given time without physically disturbing the soil, (ii) study $^{15}$N recovery by maize from decomposing labelled roots of legumes fallows and assess interactions occurring when mixed with the above-ground fallow biomass and (iii) determine the distribution of assess the of $^{15}$N in water stable aggregates, free organic matter and clay+silt fraction. One year old \textit{Sesbania sesban}, \textit{calliandra calothyrsus}, \textit{Senna spectabilis}, \textit{Cajanus cajan}, \textit{Crotalaria grahamiana} were enriched \textit{in situ} with labelled ammonium sulphate ($^{15}$NH$_4$)$_2$SO$_4$ through stem injection techniques.

The total aboveground dry matter (DM) of the various tested legumes varied between 589 g/tree for senna and 1572 g/tree for calliandra. The Shoot to root ratio ranged from 1.2 for senna to 3.1 for calliandra. Total aboveground N ranged from 8.6 to 23.1 g/tree and was highest for calliandra and lowest for senna. Cajanus, calliandra, crotalaria and tephrosia exhibited similar proportion $^{15}$N enrichment in the leaves and wood, but senna allocated more $^{15}$N to wood as compared to leaves. Total aboveground $^{15}$N recovery in the aboveground ranged from 49% for crotalaria to 69% for tephrosia indicating that 27 to 50 % is potentially allocated to the roots. About 2.5 to 7.4 % of $^{15}$N is potentially recovered from roots less than 5 mm. Our results indicated that in improved fallow tree based systems a large proportion (39%) of belowground N became protected in water stable meso- and macro-aggregates while around 20% was associated with the clay-silt sized fraction. This contrasts with the fate of $^{15}$N labelled foliage litter from which only 31% was found in aggregates but a larger proportion remained in the free organic fraction, suggesting an important role of roots in aggregate formation. $^{15}$N recoveries of belowground N in the catch crop were small suggesting that these inputs play a more important role in soil structure rather than in nutrient supply.
3.9 Cycling of $^{15}$N and soil properties of alley cropping systems in the Mid-Country Intermediate Zone of Sri Lanka

Nissanka, S. P. and U. R. Sangakkara
Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Sri Lanka. e-mail: spn@pdn.ac.lk

The objectives of this research were to study the potential of alley cropping agroforestry systems to improve degraded lands in the Mid-Country Intermediate Zone of Sri Lanka. The specific objectives of the project are to assess and quantify

- nutrient (mainly nitrogen) and water use by tree and crop components
- the use efficiency of nutrients added in organic matter by tree and crop components
- growth and physiological variation of the crop as influenced by hedgerows
- improvement of soil properties due to the continuous addition of organic matter.

The field experiment was established at the experimental station of the University of Peradeniya. Gliricidia was used as the hedgerow species (with in row spacing of 0.75 m and between row spacing of 7 m) with 8 m long rows. Labelled $^{15}$N Ammonium sulphate (60 kg/ha) was applied to a micro plot consisting of 3 Gliricidia trees (2.25 m x 7 m plot area). Labelled plant material was added for different portions of micro plots as crop alone, gliricidia loppings alone, crop and gliricidia lopping, and no residues. Soil chemical and physical properties and plant nutrient content was recorded regularly for every growing season.

Soil analysis and profile descriptions at the beginning of the experiment clearly indicated that the site is degraded. The organic matter and nitrogen content of the soil is low compared to other agricultural fields in the country. The soil at the site is shallow and prone to heavy erosion and nutrient leaching.

Results for last three years showed that the addition of organic matter has improved soil chemical and physical properties. There was no significant impact of hedgerows on soil fertility level compared to sole cropping. Similarly, the distance from the hedgerow had no effect on soil fertility.

Measured physiological parameters suggest competition for resources close to the hedgerows. Leaf photosynthesis of alley cropped maize was greater than when maize was grown as a sole crop. Leaf chlorophyll content of maize plants near the hedgerows was less than those in the middle of the alleys. This may be an indication of competition for nitrogen between the crop and the tree components. Slightly higher stomatal resistance and lower transpiration may be an adaptation to water limited conditions near the hedgerows. These measurements are being continued.

There was large variability in yield among seasons mainly due to variation in rainfall. However, the total addition of carbon (organic matter) to the soil from both maize and alley tress increased over the seasons. Compared to sole crop of maize, the yield was greater for all treatments where organic matter was added to the soil.

More information on nitrogen cycling, competition for nitrogen between tree and crop components, and dynamics of C and N in different types of organic matter will be available, once evaluation of all isotopic results are completed. Isotope analyses are being currently conducted at the Agency.
Continuation of this study for several seasons (about 3 years more) will provide a clear understanding of nutrient dynamics, the nature of competition for growth resources, and the productive and protective contributions of tree components in alley cropping systems.

3.10 Nutrient cycling and water balance in agroforestry systems with legume trees in Mediterranean Central Chile.

Carlos Ovalle-Molina
Instituto de Investigaciones Agropecuarias (INIA), Centro Regional de Investigacion Quilamapu, Chillan, Chile. e-mail: covalle@quilamapu.inia.ch

The main objectives of the project are to a) evaluate the influence of the fast-growing tree, Tagasaste (*Chamaexytisus proliferus* subsp. *palmensis*), on N availability for an associated cereal crop or mixed, legume-rich pasture. b) evaluate the combined influence of Tagasaste trees and of an associated legume-rich pasture on N availability for a cereal crop in a field rotation incorporated in an agroforestry system, c) determine the influence of the presence of Tagasaste and *Acacia caven* trees, on the availability of water in the overall agroforestry system, d) to determine the sources and origin of the water used by each component of the system (trees, annual pasture, annual crop) to establish whether competition or complementarity best describes the interactions among the components.

**Description of treatments:** Traditional system (TS): Dispersed trees (*Acacia caven*); rotation scheme - 3 years natural pasture, followed by 1 year of wheat. 2) Traditional system + Tagasaste (TST): Agroforestry system associating the TS with Tagasaste plantation. 3) Improved system without trees (IS): Sown pasture of annual medics (*Medicago polymorpha*), for 3 years, followed by 1 year of wheat. 4) Improved system + Tagasaste (IST): Agroforestry system associating IS with Tagasaste planted in alleys; this treatment has 2 sub treatments (*15*N labelled tree and *15*N labelled legume pasture).

The *15*N tree injection technique was used to measure the tree contribution to the crop. Completed the first cycle of the crop rotation, (three years of annual legume pasture (*Medicago polymorpha*), followed by one annual crop of wheat). The rotation effectively increased soil fertility through biological nitrogen fixation, which showed a significant effect on yield of the otherwise unfertilised cereal crop. A similar effect was produced when the annual legume was associated with alley cropping of the legume tree Tagasaste. However, when Tagasaste was the only introduced legume, the increased input of N and the yield of the annual wheat crop, were not significantly different from the control plots (same crop rotation, without legumes).

Results from nitrogen recovery from legumes indicated that percentage of N recovered varied from 2 to 23%, which was equivalent to 1 and 20 kg N/ha. In all cases, the annual legume pasture (*Medicago polymorpha*) had the highest contribution, because of low biomass production by the Tagasaste during that season.

Soil water varied significantly with presence or absence of trees (Tagasaste or *Acacia caven*). Presence of trees had a large effect, with important differences between tree species. In Tagasaste, regardless of the herbaceous stratum associated with the trees (natural pasture or legume pasture), the water content of soil was always lower under the tree canopy than between tree rows, away from the influence of tree canopies. This indicates lower availability of water under the tree canopy, which in turn suggests that competition for water between the trees and the associated herbaceous strata existed in the upper soil profile. However, in the
case of Acacia caven, water content was consistently higher throughout the year under the tree canopies than in the open. These results suggest the existence of an important effect of the tree on the water content of the soil. Two possible explanations of this effect are: (1) less evapotranspiration under trees because of shade; or (2) re-distribution of water into the surface layer of soil (hydraulic lift). Comparative and more detailed studies of water dynamics in these systems will be needed to understand the water dynamics under different tree species. Variation in δ18O was measured in rain and well water between January to December each year. Seasonal differences in δ18O between rain and groundwater (from the well) were observed. These variations showed no relationship to water in plant tissues. Several measures will be adopted to improve sampling and analyses of water for 18O and the experiments are continuing.

3.11 Nitrogen and phosphorus cycling in a P. falcataaria food crop alley cropping system in an ultisol

Zaharah, A.R. 1, Chintu, R. 2, and Wan Rashidah, W.A.K. 3

1Department of Soil Management, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia. e-mail: zaharah@agri.upm.edu.my
2Department of Research and Specialist Services, Ministry of Agriculture, Food and Fisheries, Msekera Agriculture Research Station, P.O. Box 510089, Chipata, Zambia,
3Forest Research Institute of Malaysia, Kepong, 52109 Kuala Lumpur, Malaysia

Laboratory and field experiments during the period February 2001 to March 2003 were used to study the dynamics of C and N in an alley cropping system. We quantified the rate of decomposition, nutrient release and nitrogen contribution from P. falcataaria and G. sepium above- and below-ground biomass to grain corn planted in association with these N-fixing trees.

The quality of P. falcataaria residues followed the order; P. falcataaria leaves > P. falcataaria mixture > P. falcataaria roots. C and N mineralization from P. falcataaria residues in an acidic Ultisol under controlled conditions followed the same order. P. falcataaria leaves, when mixed with roots, reduced acidity of an acid Ultisol while, roots alone did not. P. falcataaria residues are a potentially cost-effective input for crop production in acid soils.

Below ground biomass from P. falcataaria contributed more N to corn production than did the leaves from which recovery of N was low (4%). The rapid mineralization of leaf-N, coupled with low demand from the corn at that stage of growth, may promote leaching and gaseous losses of N.

Integration of P. falcataaria leaves with either an inorganic N source (Urea) or the P. falcataaria hedgerow, did not improve N recovery by the corn, further evidence that leaf mineralization might not be matched to crop demand. The use of P. falcataaria residues, especially below ground biomass, in combination with minimal rates of inorganic N rather than the use of either of them separately, seemed a better management strategy to improve soil N availability and use efficiency.

G. sepium is a good source of nutrients for associated crops. G. sepium trees did not contribute nitrogen to the corn crop, but surface application of fresh leaves improved soil
chemical properties such as pH, exchangeable Al, Ca, Mg and K. Its use in combination with P fertilizers improved P derived from fertilizers and yield of crops.

3.12 Effect of crop residue quality and localisation on C and N dynamics in soils

Sylvie Recous\textsuperscript{1}, Samuel Abiven\textsuperscript{1,2}, Filip Coppens\textsuperscript{1,3}, Patricia Garnier\textsuperscript{1}, Roel Merckx\textsuperscript{3}

\textsuperscript{1}INRA, Unité d’Agronomie, 02007 Laon cedex, France. e-mail: (recous@laon.inra.fr), \textsuperscript{2}UMR SAS (INRA/ENSAR), 65, rue de Saint Brieuc, CS 84215, 35042 Rennes, Cedex, France and \textsuperscript{3}K.U.Leuven, Department of Land Management, Kasteelpark Arenberg 20, 3001 Heverlee, Belgium

The decomposition of crop residues is controlled by numerous factors, among which biochemical composition of the plant material is particularly important (Heal et al., 1997). High variability exist between plants of the same species, depending on growth conditions and even on a same plant, depending on ratio between the different plant organs. Depending on cropping systems, different parts are harvested and so proportions of plant parts returning to the soil as residues are different. In most of the cases, roots stayed buried into the soil and also could represent an important part of the fresh organic matter that is available for microbial decomposers.

Tillage systems affect crop residue management and location (mulch vs. incorporated) that influence physical conditions in soil (aggregation, hydrodynamic properties) that by turn modify short and long term C- and N-dynamics.

During the years 2001-2003, two projects were run on these topics. The first project aimed at investigating under controlled conditions, the relationship between crop residue quality and C and N mineralisation for several plant species and different plant organs. A special emphasis was put on the comparison between decomposition of roots and other plant parts (leaves and stems) in order to better evaluate the contribution of root systems to soil C sequestration. This experiment is part of a larger program which objectives is predicting C and N dynamics in Rice and Soya rotations with or without cover crops (brachiaria and sorghum) in Brazil, and improving the management of no-tilled systems in the tropics (Reyes et al., 2002). The second project aims at understanding the interactions between soil cultivation and crop residue management and the consequences on C and N dynamics in the soil. The work reported here examined the combined influence of the initial crop residue localisation in soil on water fluxes and on the biotransformations of carbon and nitrogen.
3.13 Developing commercial agroforestry for tropical Australia

D.M. Smith
CSIRO Sustainable Ecosystems, PMB Aitkenvale, Queensland 4814, Australia
e-mail: mark.smith@csiro.au

As elsewhere in the tropical world, new or modified agricultural systems are needed in North Queensland to combat environmental degradation. Sustainability requires maintenance of productive capacity in agriculture, but restoration of biophysical function and ecosystem processes is also critical. Without the latter, there will be continued aggravation of threats to water quality and biodiversity in the ecosystems of the region, which include the ‘Wet Tropics’ rainforest and Great Barrier Reef. However, in significant respects Australia lags behind other regions in developing systems of agricultural and natural resource management for the tropics, which integrate multiple economic, environmental and social benefits. In part at least, this results from the requirement that any systems innovation is compatible with commercial-scale agriculture dominated by the sugar industry. Large areas are ‘locked-in’ to monoculture sugarcane production because of the need to protect financial capital in sugar mills, creating seemingly insurmountable barriers to diversification options such as agroforestry which would re-introduce functional diversity to the landscape. One pathway forward may therefore be to use diversification of the sugar mill to drive diversification of the landscape. A set of concepts have been developed in which infrastructure for processing and value-adding to fibre, timber and fruit, for example, are clustered around the conventional sugar mill, with components of the cluster sharing energy and trading by-products. New farming systems to provide the mix of raw materials needed by such facilities are proposed, based on land-use mosaics and, potentially, integrated tree-crop systems. Diversification of sugar mills could thus have positive feedbacks on the landscape and the livelihoods, communities and ecosystems it supports. Significant scope for new R&D would flow from such innovation, including measurement and modelling of agro-ecosystem function, including water and nutrient cycling, at scales from the plot to catchment.

3.14 Synergy or competition for nitrogen and water use between peanut (Archis hypogaea) and Choerospondias axillaris in alley cropping systems estimated by nuclear techniques in subtropical China

Zhang Bin, Wang Xingxiang, Wang Mingzhu, Institute of Soil Science, Chinese Academy of Soil Science, P.O. Box 821. Nanjing 210008, P.R. China
e-mail: bzhang@issas.ac.cn

One of the main benefits of alley cropping is the ability of tree roots to mobilize water and nutrients from deeper soil layers and transport to surface layers. Trees also minimize soil erosion. However, trees and crops in the alley cropping systems may compete for nutrients and water, causing reduction in crop yield. The overall objective of this study was to investigate the synergy or competition for water and nitrogen between Choerospondias axillaris and peanut grown as an alley cropping system.
Monitoring soil water regimes in space and soil erosion and runoff were carried out from 1999 to 2002 to determine effects of soil water use and soil and water conservation. $^{18}$O in well water and rainwater was determined from 2000 to 2002. $^{15}$N labelled fertilization experiment were carried out in microplots in 2000 and 2001 to determine N fertilizer use. $^{15}$N injection was carried out to research the recycling effect of N. In addition we monitored the diurnal and spatial photosynthetic available radiation (PAR) of intercropped peanut in 2000. Peanut straw and peanut yield and tree growth performance were also monitored each year. The alley cropping of peanut and Choerospondias axillaris decreased the yield and biomass of peanut by 20 to 50% as compared to a mono-cropping of peanut. Tree growth performances, measured by tree height and trunk diameter, in the alley cropping systems were better than in the tree alone systems. The spatial variation of photosynthetic available radiation (PAR) in 1999 showed a reduction of PAR in the alley cropping systems, indicating that the competition for light was the most determining factor for the reduction in peanut yield. The spatial variation of soil water regimes showed that the trees used water up to a depth of 120 cm in the dry season and competed for water with intercropped peanut. The peanut used soil water up to a depth of 70 cm. $\delta^{18}$O indicated that the ground water in the region was slightly different from the rainwater especially in dry season. The alley cropping system reduced nutrient losses due to soil erosion and runoff and increased the use efficiency of applied nitrogen. $^{15}$N studies showed an accumulation of nitrogen at 40-60 cm soil layers in the mono-crop peanut and small trees intercropped with peanut system. The nitrogen left in soil profile was reduced to about 60 % in alley cropping system compared to mono-crop of peanut.

The results of $^{15}$N recovery showed that peanut used applied nitrogen up to a depth of 35 cm and well-grown trees up to a depth of 55 cm. The $^{15}$N recovery by peanut was about 25% in the mono-crop peanut system, 13-15% in the small tree / peanut system and 10-12% in the big tree / peanut system, when nitrogen was applied at 10 cm soil depth. When nitrogen was applied at 35 and 55 cm soil depth, the recovery of nitrogen by peanut was less than 8% and 2%, respectively. The $^{15}$N recovery by trees was 10-30% and 30-53% for small tree and big trees in the alley cropping systems when nitrogen was applied at 10 cm soil depth. When nitrogen was applied at 35 and 55 cm soil depth, the recovery of nitrogen by small and big trees was 3-15.5% and 34-53% and >7% and 15-18%, respectively. From a system point of view, the alley cropping systems have greater $^{15}$N recovery than the mono-crop peanut system.

These results indicated a competition for nitrogen, water and light between trees and peanut in alley cropping systems. However, overall efficiency of applied nitrogen was significantly better in alley cropping system than mono-crop, minimizing the adverse effects on environment due to loss of applied nitrogen.
4. Review of Progress

The following working groups were established to discuss the achievements made so far and to report at the final session of the meeting. The Group Leaders are marked in bold.

**M. Adams** (Australia)
S. Nissanka (Sri Lanka)
Z. Rahman (Malaysia)

**S. Recous** (France)
R. Chintu (Zambia)
J. K. Ndufa (Kenya)

**R. Merckx** (Belgium)
K. Aihou (Benin)
P. Ebanyat (Uganda)

**M. Smith** (Australia)
C. Cervantes (Costa Rica)
C. Ovalle-Molina (Chile)

Evaluation of progress of the project activities was mainly based on (i) Presentations of the participants and their reports (ii) Review of results (Group discussions) and (iii) Presentations of Group Leaders. The results obtained were compared against the main objectives and the following reports were prepared in consultation with the agreement holders:
4.1 WORKING GROUP REPORT

Group: Zaharah Rahman, Sarath Nissanka and Mark Adams
Report prepared by: Mark Adams

Summary of progress and future work in relation to objectives:

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Malaysia</th>
<th>Sri Lanka</th>
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</table>
| **Objective 1**  
Understanding how trees contribute to C, N and P cycling and nutrient and water availability | Experimental basis established prior to CRP. Completed for N and P, studies of decomposition completed – water to be done 03/04. Further discussion between contract and agreement holders. | New experiment established for CRP. Mass transfer data available – nutrient analysis on-going (N, P, K, Ca?, Mg?) and needs to be completed (03/04) Water availability studied using physiological parameters – some evidence of reduced competition for water in alley cropping system. Is photo inhibition partially responsible? First isotopic analysis for $^{18}O$ in soil and groundwater completed – data being analysed – decision about continuation once data assessed (subject to discussion between agreement and contract holders) |
| **Objective 2**  
Can we manipulate systems to improve nutrient and water availability? | Alley cropping system in place. AC plus fertilizer tested. Tree labelling completed. | Alley cropping system in place. Fertilizer not part of experimental design Tree labelling to be done in 03/04 (design will be discussed between agreement and contract holders). |
| **Objective 3**  
Long term productivity and soil organic matter – C and N fractions esp. | Examine potential to use Roth-C or other models – dependent on previous soil samples and on analysis of vegetation. Possible in 03-05. | New experiment needs to be maintained and ‘protected’. Soil sampling at regular intervals, soil properties need to be re-assessed and checked against other sites in region. Organic materials analysed for C fractions? |
Objective 1: Understand how trees contribute to N, C & P cycling and the availability of nutrients and water to crops.

Carlos Cervantes

Progress to date:
- percentage values for N derived from the atmosphere obtained for *Erythrina peoppigiana*; technique was not successful for *Gliricidia sepium*, but will try again.
- data obtained for total amounts of N, C, P, Ca, Mg and K returned to the soil surface.
- time to maximum uptake by coffee of N derived from tree prunings determined using $^{15}$N labelled *Erythrina* and *Gliricidia*.
- efficiencies of N delivery to coffee determined for urea, ammonium and nitrate fertilisers, showing rapid movement through profile and very low recovery.
- was interested in using $^{13}$C to determine contribution of legume trees to soil organic matter, but differences in $\delta^{13}$C were not found between coffee and legume trees and so this approach was abandoned.

Water availability is not a priority issue in the Costa Rica project as it is not a limiting factor for coffee production. However, nutrient management to reduce leaching of nutrients into groundwater is an important consideration in the development of new cropping systems and offers a means of linking nutrient and water issues in the project.

Carlos Ovalle-Molina

Progress to date:
- quantification of N fixation by tagasaste and *Acacia caven* completed, in terms of percentage and annual total quantities derived from the atmosphere.
- determination of amounts of N transferred from trees to animals to crop is ongoing, with results showing low quantities (<5%) of N recovered in wheat crops derived from trees.
- amounts of N from annual legume pastures transferred to wheat is much higher, whether or not trees present.
- differences in soil water dynamics adjacent to tagasaste and *A. caven* measured using a neutron probe.
- use of $^{18}$O to identify sources of water used by *A. caven* and tagasaste has progressed, with seasonal differences between groundwater and rainwater shown; next step is to revise distillation procedure for recovery of water from soil and tissue samples to ensure valid data are obtained and comparison of $\delta$ values for groundwater, soil water and xylem water is possible.
- $^{13}$C data not collected as all plants in system are C$_3$. 

Report prepared by: Mark Smith
Objective 2: identify how tree-crop systems can be manipulated to improve nutrient and water use.

Carlos Cervantes

Progress to date:
- have used results from dynamics of N mineralisation from legume mulches to design a prototype for a new shaded-coffee system with a pruning cycle applied to a higher density of trees, to obtain more annual biomass input without additional potential for competition.
- quantification of N input is still required, to determine whether provision of whole N supply is possible in the new system using mulches from legume trees.
- if substantial reduction or elimination of mineral N fertiliser input is possible using the new system, an added potential benefit is higher N retention in the system and lower risk to water quality from coffee production.

Carlos Ovalle-Molina

Progress to date:
- quantification of additional N and C input to degraded systems obtained from the introduction of tagasaste.
- a potential cost from using tagasaste is competition with the pasture for water, as unlike *A. caven*, tagasaste does not exhibit reverse phenology; a key question for management is therefore the optimal density of tagasaste during rehabilitation.
- data from the current project on N cycling and water sources and uptake dynamics is enabling improved understanding of the trade-offs implicit in system change and will contribute to an eventual mathematical/modelling solution to the optimisation problem.


This objective has not been a priority for either project. Carlos Cervantes holds C:N data the legume residues used in his project. Carlos Ovalle has data for changes in total soil C over time.

4.2.1 Future Needs and Workplans

Carlos Cervantes

Priority issues are (1) system management; (2) quantification of N recovery from residues; and (3) N movement in the soil profile.

Workplan:
(i) Trial of prototype for a new shaded-coffee system in 2 ha commercial scale plots. System aims to increase biomass input from legume trees by increasing tree density and to use a pruning cycle to avoid additional competition with coffee. Two fertiliser treatments will be used, one with no mineral N fertiliser input and
the other with a 50% reduction relative to commercial practice.

(ii) Quantify recovery of N from legume residues by coffee, using the methodology demonstrated by James Ndufa, with 15N labelled prunings added to large containers containing coffee plants.

(iii) Some consideration given to comparing N movement in soil columns with 15N labelled legume residues or fertilisers added, to provide an initial assessment of the effects of the new management system on leaching.

Future needs:
  (i) 15N labelled fertiliser.
  (ii) Analytical services for 15N determination.

Carlos Ovalle-Molina

Priority issues are (1) N recovery from trees and cycling through system; (2) comparison of water sources used by A. caven and tagasaste; and (3) experimental testing of hypotheses relating pasture growth under trees to water dynamics.

Workplan:
  (i) Completion of experiment currently underway which is testing effects of system options and crop rotation on N cycling. Scheduled for completion in 2005.
  (ii) Completion of study of water sources and competition in tagasaste/pasture and A. caven/pasture systems. This requires analysis of 18O in soil, plant tissue and groundwater. Consideration should also be given to analysis for 2H to enable application and further testing of the dual isotope methodology for assessing water sources. This would require identification of a lab able to provide the 2H analysis and the necessary resourcing.
  (iii) Testing of hypotheses relating pasture growth response under trees to mechanisms involving higher soil water content because of either (1) shading of the soil by the tree canopy; or (2) re-distribution of soil water to the surface layer by hydraulic lift. An extract from the End of Mission Report prepared by Mark Smith after his visit to Chile in April 2003 outlining the proposed experiment is attached. Under this CRP, measurement of soil water content and 18O (and 2H if possible) at natural abundance would be undertaken. Use of an enriched 2H source is also proposed, but assessment is required of costs involved and quantities needed.

Future needs:
  (i) 15N labelled fertiliser (check?).
  (ii) Analytical services for 15N and 18O determination.
  (iii) Analytical services for 2H at natural abundance and atom excess if possible.

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4.2.2 Preparation of Outputs

Carlos Cervantes

Outputs to date:
- 2 papers presented to Costa Rican Agronomy Congress
- MSc thesis (Andalucia)

Outputs in preparation:
- paper on N cycling with legume trees in coffee plantations, ready to submit to Agronomy Journal.

Paper for special issue:
- paper on systems development based on synthesis of results from project

Carlos Ovalle

Outputs to date:
- paper published in Agroforestry Systems in 2002 on N fixation in legume trees

Papers for special issue:
- paper on N cycling with tree legumes and annual legumes
- paper on water sources, depending on results
**4.3 WORKING GROUP REPORT**

**Group:** R. Merckx, K. Aihou and P. Ebanyat  
**Report prepared by:** R. Merckx

**Kouessi Aihou, Benin**  
- Cajanus cajan biomass production and urea interactions

<table>
<thead>
<tr>
<th>Objectives</th>
<th>State</th>
<th>Future</th>
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| Objective 1  
To understand how trees contribute to N & C cycling and availability of nutrients | AF trials trials studying interactions between organic (Cajanus cajan) and inorganic (urea) sources of N established and analysed, using labelled urea and/or labelled Cajanus biomass. Soil biological factors related to variable performance of Cajanus in different soils unravelled to some extent. (Within context of PhD thesis, forth coming June 2003) | Socio-economic analysis of I/O interactions to be done. Yields are low, whatever the treatment, finding out the underlying reasons is recommended, or repeating the experiment along a soil fertility gradient may be advised. Strategies where inputs are concentrated on the legume may be more emphasized. |
| Objective 2  
To identify how tree crop system can be manipulated | Emphasis on nitrogen so far, water relation not studied. | Tentative studies aiming at testing the water stress hypothesis planned |
| Objective 3  
To identify relationships between N & C fractions of organic matter and capacity for long-term productivity | No action taken | Nothing planned |
Peter Ebanyat, Uganda  
- Sesbania, Gliricidia on degraded terraces

<table>
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<tr>
<th>Objectives</th>
<th>State</th>
<th>Future</th>
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</table>
| Objective 1  
To understand how trees contribute to N & C cycling and availability of nutrients | AF trials established targeting N and soil physical factors  
Data on infiltration rate with AF obtained  
Anaerobic N mineralisation data available  
Biomass data on trees available after two years, crop yields of three seasons available.  
$^{15}$N injection on-going | Alnus and Calliandra regrowing Sesbania to be replanted  
Analysis of distribution of $^{15}$N over tree components (lignin, etc.) |
| Objective 2  
To identify how tree crop system can be manipulated | Establishment phase for now | Split plots into +/- NPK to have more biomass, and to study interactions residue/fertilizers |
| Objective 3  
To identify relationships between N & C fractions of organic matter and capacity for long-term productivity | POM analysed seasonally | Soil fractions and $^{15}$N contents in them measured, to investigate the process of rebuilding organic N stocks across the terrace. |
4.4 Working Group Report

**Group:** S. Recous, R. Chintu and J. K. Ndufa

**Report prepared by:** S. Recous

**Richard Chintu, Zambia**

Soil nitrogen and physical properties in coppicing and non-coppicing planted tree fallows in Zambia.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Experiments</th>
<th>Achievements</th>
<th>Perspectives</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective 1:</strong> To understand how trees contribute to N &amp; C cycling and availability of nutrients</td>
<td><strong>Done:</strong> Fields experiments with tree fallows and maize</td>
<td>Effect of tree N uptake on N dynamics in soil, and return to soil through foliage</td>
<td>Modelling N and C dynamics, trees and maize growth. Objectives are (i) to identify gaps in knowledge, (ii) to analyse impacts of other scenarios</td>
</tr>
<tr>
<td><strong>Start:</strong> Tree $^{15}$N injection experiment: Estimating leaves and roots contribution of Sesbania, Gliricidia, Tephrosia, Acacia to N nutrition of following maize crop, by injecting $^{15}$N into trees.</td>
<td></td>
<td>Cumulative effects of biomass addition to soil on soils properties (compaction, infiltration rate)</td>
<td>Plan to contact James Ndufa’s group (WANULCAS model)</td>
</tr>
<tr>
<td><strong>Objective 2:</strong> To identify how tree crop system can be manipulated.</td>
<td><strong>Done:</strong> comparison of various systems studies: maize crops and planted legume tree fallow (coppicing, non-coppicing), natural fallow, and no-fallow (continuous maize ± fertiliser): 2 experiments at Msekera and Kagoro</td>
<td>Selection of systems that provide higher maize productivity: Coppicing fallows and/or mixing of non-coppicing fallow</td>
<td>Following long-term sustainability Economic analysis of the various systems (collaboration with Economist)</td>
</tr>
<tr>
<td><strong>Objective 3:</strong> To identify relationships between N &amp; C fractions of organic matter and capacity for long-term productivity</td>
<td>Not done yet</td>
<td></td>
<td>To assess carbon dynamics in parallel to nitrogen: - characterise residual C in trees pot experiment - identify respective links of roots N and leaves N within soil aggregates (contact to be kept with JM Ndufa) - may be running incubations with tree residues</td>
</tr>
</tbody>
</table>
Quantifying the contribution of legumes above- and below-ground N to soil N pools and subsequent crop in improved fallow system using *in situ* $^{15}$N labelling techniques in western Kenya.

<table>
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<tr>
<th>Objectives</th>
<th>Experiments</th>
<th>Achievements</th>
<th>Perspectives</th>
</tr>
</thead>
</table>
| **Objective 1:**
To understand how trees contribute to N & C cycling and availability of nutrients | **Done:** Tree $^{15}$N injection experiment with several tree species: Sesbania, Crotalaria, Cajanus, Tephrosia, Senna, Calliandra  
**following contribution of:**  
$^{15}$N shoot + $^{15}$N root  
$^{15}$N shoot + $^{14}$N root  
$^{14}$N shoot + $^{15}$N root | Nitrogen recovery by maize of $^{15}$N labelled shoot >>> $^{15}$N labelled roots (which remained small)  
High variability in contribution according to litter quality (4% Calliandra -> 22.5% for Sesbania) | On-going experiment: to analyse medium-term contribution of labelled material (data to be obtained)  
Publications  
Training (incubations & modelling)? |
| **Objective 2:**
To identify how tree crop system can be manipulated | Same experiment as above: comparison of tree performance (biomass production) and decomposition | Biomass production by different species, their quality (nitrogen content) and distribution in various parts (leaves, wood, litter fall)  
Quantification of root N for each species | ?design optimal tree-maize system to optimise short-term (availability of nutrients) and long-term fertility (prevent decrease in soil organic matter)  
=>MODELLING |
| **Objective 3:**
To identify relationships between N & C fractions of organic matter and capacity for long-term productivity | Same experiment as above: $^{15}$N injection experiments with trees.  
Recovery of $^{15}$N in water stable aggregates and POM. | Higher contribution of roots N to the formation of water stable meso- and macro-aggregates, less mineralisation (due to poor quality)  
=>role in building up the soil structure and protecting C&N >> role in nutrient supply. | Combining C and N studies, by labelling trees with pulses of $^{13}$C. |
Some additional suggestions/questions that should/could be examined:

- Establish N balances in plant or soil+plant systems, before using $^{15}$N information.
  - in all experiments, adopting common way to present N and $^{15}$N data: total biomass, total N content, %N, total $^{15}$N, % recovery, %Ndff
  - first interpret biomass and N data

- How much of the total tree-N, the injected $^{15}$N is the tracer? (*to what extent are the residues (leaves & roots) homogeneously labelled*)
  - improving understanding of short-term fate of injected $^{15}$N in plant and soil (if knowledge available…)
  - injecting several times $^{15}$N during the foliage development of the tree

Some additional suggestions/questions that should/could be addressed in the project:

- Experimental designs: Problems with confining trees in containers:
  - few maize plants: high variability in plant biomass between replicates
  - changes in root biomass production, morphology and distribution in the soil

- Do we/you need additional incubations to quantify specific processes/fluxes?
  - data regarding chemical quality of crop and tree residues are numerous, and data base may be used already? (N is required, however)
  - net N mineralisation from soil is often a missing data. It is necessary to get it, in order to calculate the N balance, and to understand the respective contribution of the various N pools (including the residues)

Some additional suggestions/questions that should/could be addressed in the project:

- Analyse short-term vs. long-term impacts of agroforestry management
  - priority to above ground tree production and easily decomposable material? (short-term availability of nutrient)
  - priority to high production of roots and/or low quality of above ground biomass (long-term storage of OM)
  - Use of modelling to obtain useful information.
4.5 Review of Water-Related Issues in the CRP

Mark Smith

1. Data collected to date
Values for δ¹⁸O in groundwater and rainwater have been collected for the projects in Chile, Malaysia, Sri Lanka, Zambia and Kenya. Analysis of samples for Benin and China needs to be confirmed. The necessary samples have not be collected for Uganda and Costa Rica, as these are upland sites where groundwater is not a relevant issue.

Time series of soil water content have also been collected in Chile using a neutron probe.

2. Collation of data
The original intent of gathering data on ¹⁸O in the CRP was to identify those sites where it might be possible to assess sources of water use by trees and crops on the basis of δ¹⁸O values. The methodology requires that differences in δ¹⁸O exist between groundwater and other sources of water in the soil. Analysis of the size and seasonal patterns of differences in δ¹⁸O between groundwater and rainwater was intended as a simple pre-screening step to identify where the necessary gradients in δ¹⁸O were most likely to be found and therefore where resources available for ¹⁸O analysis should be targeted.

The data currently available from the Contract Holders indicate that gradients in δ¹⁸O occur with some consistency at the sites in Chile and Malaysia. However, data from all the sites has yet to be collated. This should be done at the earliest opportunity to enable comparison of patterns in δ¹⁸O variation among the CRP sites. Published data and data held by Agreement Holders for other sites could be included (eg. for sites in the UK, Niger, Zimbabwe, Western Australia, SE Australia) to see if differentials in ¹⁸O are most common in particular climatic zones for example. Some categorisation might then be possible for the types of sites where the water-source methodology should and should not be attempted.

3. Next steps
Two or possibly three sites should be identified where competition for water is a likely constraint on agroforestry and where it is felt meaningful results on water sources might be obtained. Values of δ¹⁸O should then be compared for groundwater, soil water and plant tissue at relevant intervals over the year. This has already been initiated in Chile. These analyses (if successful) will enable characterisation of the contribution of groundwater to tree water use and therefore the importance of competition for water in the functioning of each system. This will help to ensure that mistakes are not made by extrapolation of results from locations where complementarity for water dominates to sites where competition dominates, or vice versa. Such mistakes have been made in the past and work in the CRP with ¹⁸O offers a means of avoiding repetition of this error.

Recent publications have shown that uptake from different soil layers can in some circumstances be more readily distinguished using two isotopes rather than just one. For this reason, consideration should be given to obtaining both ¹⁸O and ²H data for one or two of the sites.

There is a need at the site in Chile to test the hypothesis that hydraulic lift provides a mechanism for improved pasture growth near trees. One means of doing this involves
placement of an enriched $^2$H source below the pasture root zone. Deuterium-enriched water and access to the necessary analytical services would be necessary for this to be done.

4. Future considerations
It may be worthwhile for the Agency to investigate use of the ‘equilibration’ method for $^{18}$O analysis of water in soil and tissue for future projects. This technique entails equilibration of samples with CO$_2$, analysis of $\delta^{18}$O in CO$_2$ and then back calculation of $\delta^{18}$O for water in the sample. The method is described by Scrimgeour (1993 – need to check reference). The major advantage of the method is elimination of the distillation step and thereby removal of a labour intensive procedure and a significant source of error. Use of the method at the Vienna laboratories would require international shipment of soil and plant tissue, which is potentially a constraint. It might be possible, however, to develop and test a method for containment and shipment of the CO$_2$ gas samples for analysis.

Another development worth investigating for application to agroforestry is use of $\delta^{18}$O for discrimination between baseflow (groundwater) and surface runoff in stream discharge. A review of the literature is needed to verify the relevance of the technique, but potentially it would enable analysis of changes in catchment hydrology resulting from large-scale rehabilitation impacts from agroforestry in degraded catchments.
4.6 Extract from End-of-Mission Report to IAEA Expert and Training Section after Mission to Chile by M. Smith in April 2003

Soil water dynamics and hydraulic lift in espinal
Available evidence suggests that promotion of pasture growth by *A. caven* in espinal stands is at least partly a result of the effects of the trees on availability of water to the understorey plants. The research team has determined that pasture productivity is higher near trees than in the open and that pasture remains green for one to two months longer in the spring under tree crowns than in unsheltered patches. Additionally, the extension of the pasture growth season under trees tends to be longer in valley bottom locations, where groundwater is more likely to be close to the surface. During discussion throughout the week, two hypothetical mechanisms for this phenomenon were identified:

1. shading of pasture below (the leafless) tree crowns causes reduced cumulative uptake of water by pasture over the winter and therefore higher soil water storage below trees than in the open; and
2. facilitation of pasture growth by hydraulic lift in the root systems of *A. caven* during the spring (after re-growth of tree leaves) and consequent re-distribution of groundwater to the drier surface soil layers.

An experiment was devised to test these hypotheses. Five possible treatments were identified. These would be applied during the spring dry down:

- T1. Tree + pasture, with tree roots intact;
- T2. Tree + pasture, with lateral roots of trees severed;
- T3. Pasture only;
- T4. Tree only (pasture mowed or killed) + mulch;
- T5. Pasture only + artificial shade.

In addition to pasture yield, four possible sets of measurements were identified:

1. soil water content measured using a neutron probe (or alternative method);
2. isotopic composition of water at natural abundance (18O, 2H or both);
3. placement of 2H enriched water below the pasture root zone and monitoring of uptake;
4. sap flow in lateral tree roots.

A table of contrasting outcomes for the experiment under each proposed measure is given in Table 1 for alternate hypotheses.

There was discussion during the mission of applying the treatments to both *A. caven* and *tagasaste*, to enable identification of contrasts in tree-pasture interactions between traditional espinal and a promising option for system improvement. The experiment would thus provide knowledge of differences between system options in mechanisms of competition or complementarity for water and possible facilitation of pasture growth. Such knowledge is needed for assessment of whether the benefits of system improvement, through higher rates of nitrogen fixation in the case of *tagasaste*, outweigh the cost of any change in hydrological function.

The experiment would also have relevance to general ecological questions about plant-soil-water relations in ecosystems and agroecosystems in seasonally dry environments where the phenology of trees and the understorey is reversed. Another prominent example of reverse phenology in agroforestry is *Faidherbia albida* in parkland agroforestry in West and Southern
Africa. As with espinal, crop growth under the leafless crowns of F. albida in the wet season is higher than in open patches. It has been found that a complex set of interacting mechanisms is likely responsible for this phenomenon, but the role of water and possible effects of hydraulic lift have not been adequately assessed. Thus, results from the experiment in espinal will raise suggestions of mechanisms that may be applicable to savannah or savannah-like systems in other regions of the world where trees exhibit reverse phenology.

**Table 1:** Contrasting outcomes of measurements applied to treatments T1 – T5 (see text) for the hypothetical ‘shading’ and ‘facilitation’ mechanisms for promotion of pasture growth under tree crowns in espinal. (Notation: gw=groundwater; t=tree; p=pasture; θ = soil water content).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Hypothesis</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>θ</td>
<td>shading</td>
<td>T1≤T2</td>
</tr>
<tr>
<td></td>
<td>facilitation</td>
<td>T1&gt;T2</td>
</tr>
<tr>
<td>Δ18O / Δ2H</td>
<td>shading</td>
<td>t → gw</td>
</tr>
<tr>
<td></td>
<td>facilitation</td>
<td>t → gw</td>
</tr>
<tr>
<td>enriched 2H</td>
<td>shading</td>
<td>2H in t</td>
</tr>
<tr>
<td></td>
<td>facilitation</td>
<td>2H in t</td>
</tr>
<tr>
<td>sap flow in</td>
<td>shading</td>
<td>+ve flow</td>
</tr>
<tr>
<td>lateral roots</td>
<td>facilitation</td>
<td>-ve flow at night</td>
</tr>
</tbody>
</table>
5. Conclusions and Recommendations from Meeting

The implementation of the CRP is progressing satisfactorily. Linkages with CGIAR centres (IITA, ICRAF), international funding institutes (IFS, DFID, USAID) and a range of national institutes has been established for effective implementation of the project activities. Through these linkages the counterparts have been able to obtain considerable financial and human resources in addition to the inputs from the Agency.

The reports presented by the working groups showed that the experimental work is progressing well in line with the main objectives and the project is well positioned for significant contributions in understanding the role of trees in agricultural systems and in contributing to the development of improved agroforestry systems. The project has also provided the counterparts the knowledge and skills on the use of nuclear techniques for obtaining valuable information on nutrients and water dynamics in different agroforestry systems. The information obtained will be useful for identifying promising agroforestry management practices for sustainable crop production. It is encouraging to note that the contract holders are actively involved in dissemination of information emanating from this project to end-users through presentations at national and international meetings and publications in scientific journals (published: 03; in press 06 and in preparation: 05).

Recommendations:

- The recommendations and suggestion made at this RCM should be taken into consideration in continuing the project activities.

- All counterparts should continue to collect data according to the minimum data set discussed and agreed at the first RCM.

- Water samples should be collected as per instructions provided and sent to the Soil Science Unit, Seibersdorf for $^{18}$O analysis.

- All counterparts are encouraged to continue in publishing in scientific journals, make presentations at national and international meetings and discuss with extension workers and farmers for effective dissemination of promising technologies emanating form the project.

- The links established with other national and international institutions should be maintained and enhanced for exchanging information and obtaining further support in implementation of project activities.

- Tree induced changes in addition to nutrients and water availability to crops should be considered in evaluating the overall benefits of agroforestry systems.

- The next RCM of this CRP will be held in April 2005. The exact dates and the venue will be decided later.
THIRD RESEARCH CO-ORDINATION MEETING
of the FAO/IAEA Co-ordinated Research Project
on “The Use of Nuclear Techniques for Developing Integrated Nutrient
and Water Management Practices for Agroforestry Systems”

Colombo, Sri Lanka

02 - 06 June 2003

Scientific Secretary: Mr. Gamini Keerthisinghe
Local Co-ordinator: Mr. Sarath P. Nissanka

LIST OF PARTICIPANTS

Contract Holders

Mr. Carlos Ovalle-Molina (CHI-10405/RB)
INIA, Centro Regional de Investigacion Quilamapu Producción Animal
Av. Vicente Mendez 515
Casilla 426
Chillán
Chile
Tel.: 0056 42 211177
Fax: 0056 42 217852
Email: covalle@quilamapu.inia.ch

Mr. Carlos Cervantes (COS-10406/RB)
National University Foundation
Universidad Nacional
Laboratorio de Suelos
Heredia
Costa Rica
Tel.: 00506 2773303
Fax: 00506 2610035
Email: ccervant@una.ac.cr
ccervant@samara.una.ac.cr

Mr. James Kamiri Ndufa (KEN-10408/RB)
Kenya Forestry Research Institute (KEFRI)
Regional Agroforestry Research Centre, Maseno
P.O. Box 25199
Kisumu
Kenya
Tel.: 00254 35 51163 or 00254 35 51164
Fax: 00254 35 51592
Email: jndufa@africaonline.co.ke
Ms. Zaharah Rahman (MAL-10560/RB)
Department of Soil Management
Universiti Putra Malaysia
43400 UPM
Serdang, Selangor
Malaysia
Tel.: 00603 89486101 ext 2655
Fax: 0060 3 89434419
Email: zaharah@agri.upm.edu.my

Mr. Sarath P. Nissanka (SRL-10411/RB)
Department of Crop Science
Faculty of Agriculture
University of Peradeniya
Peradeniya
Sri Lanka
Tel.: 0094 8 388239
Fax: 0094 8 388239 or 388041
e-mail: spn@pdn.ac.lk

Mr. Peter Ebanyat (UGA-10412/RB)
Department of Soil Science
Makerere University
P.O. Box 7062
Kampala
Uganda
Tel.: 00256 41-540707
Fax: 256-41-531641
Email: ebanyat@agric.mak.ac.ug
acs@starcom.co.ug
ebanyat@yahoo.com

Mr. Richard Chintu (ZAM-10414/RB)
Department of Research and Specialist Services
Min. of Agric., Food and Fisheries
Msekera Agriculture Research Station
P.O. Box 510089
Chipata
Zambia
Fax/Tel: 00260 062 21404
Email: zamicraf@zamnet.zm
mfongoya@zamnet.am
Agreement Holders

Mr. Mark Adams (AUL-10686/CF)
School of Forestry
University of Melbourne/Natural Resources and Environment
Water St.
Creswick, Vic 3363
Australia
Tel.: +61 353 214165
Email: adamsma@unimelb.edu.au
Fax: +61 353 214166

Mr. Mark Smith (AUL-11670/CF)
CSIRO Sustainable Ecosystems
Davies Laboratory
PMB
Aitkenvale, Queensland 4814
Australia
Tel: 0061 7 4753-8567
Email: mark.smith@csiro.au
Fax: 0061-7-4753-8600

Mr. Sylvie Recous (FRA-10654/CF)
INRA - Unité d’agronomie
02007 Laon
France
Tel. +33 3 23 23 64 79
Fax: +33 3 23 79 36 15
Email: recous@laon.inra.fr

Mr. Roel Merckx (in lieu of Dr. N. Sanginga NIR-10410/CF)
Lab. of Soil Fertility and Soil Biology
Catholic University of Leuven
Faculty of Agricel. and Applied Biol. Sciences
Kardinaal Mercierlaan 92
3001 Heverlee
Belgium
Tel.: +32 (16) 321605
Fax: +32 (16) 321997
E-mail: roel.merckx@agr.kuleuven.ac.be
SCIENTIFIC SECRETARY:

Mr. Gamini Keerthisinghe
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture
Soil and Water Management & Crop Nutrition Section
Wagramer Strasse 5, P.O. Box 100
A-1400 Vienna
Austria
Fax: (+43 1) 26007
Tel.: (+43 1) 2600 ext. 21649
Email: G.Keerthisinghe@iaea.org
Internet: http://www.iaea.org

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