Georg Cadisch, Edwin Rowe and Meine van Noordwijk

Nutrient harvesting - the tree-root safety net

The hypothesis that deep rooting trees intercept nutrients which have leached below the crop rooting zone and compete for nutrients less strongly than trees rooting mainly within the crop root zone was tested in a mixed alley-cropping system on an Ultisol in North Lampung, Sumatra by measuring uptake of ^{15}N placed at varying soil depths. *Gliricidia sepium,* with its predominantly shallow root system, competed strongly for N with the crop and took up little ^{15}N from lower soil depths. In contrast *Peltophorum dasyrrachis* roots exhibited a higher nutrient uptake activity at lower soil depth thus providing an active 'safety-net'. Root activity as well as root length density has to be taken into account when assessing the efficiency of the safety-net. Preliminary modelling results using WaNuLCAS suggested that *Peltophorum* roots in the 40-60 cm soil layer could reduce leaching by 5-10% over the course of a maize crop cycle in the rainy season.

Introduction

In alley cropping systems in the humid tropics major leaching potentials arise when crop demand is low and nutrient release from decomposing pruning mulches is fast. Such an asynchrony is common at and after crop planting when trees have been pruned and for several days (or weeks) nutrient demand of both crop and tree are low. The potential for nutrient leaching increases when the tree pruning material is of high quality and thus a large amount of N is mineralized within the first four weeks. Leaching could be reduced if trees have a relatively dense root system beneath the crop root zone (a safety-net). For such a safety-net to be effective, roots must be active at the time major leaching events occur.

Until recently few methods were available to test the activity of such a safety-net, and most were static methods such as evaluation of root profiles or measurement of nutrient levels down the soil profile. More dynamic observations using minirhizotrons to evaluate root turnover are now used. We explored a new method to test the efficiency of roots in aquiring nutrients from different soil layers by measuring uptake of labelled ^{15}N placed at specific depths. ^{15}N is not radioactive, unlike other isotopes used in root activity studies, such as ^{32}P. Negative attributes are the lower detection sensitivity (although this has improved with the arrival of highly sensitive mass-spectrometers) and the higher mobility of mineral N isotopes compared with ^{32}P.

Methods

The hypotheses that deep rooting trees intercept nutrients which have leached below the crop rooting zone, and compete for nutrients less strongly than trees rooting mainly within the crop root zone, are being tested on an Ultisol in North Lampung, Sumatra, in which crop rooting depth is severely restricted by the aluminium toxicity of the subsoil. Hedgerows of *Gliricidia sepium* and *Peltophorum dasyrrachis* were established in 1991 in an *Imperata cylindrica* grassland and have been intercropped with maize, upland rice and groundnut for the past three years. In the current study, ^{15}N-labelled ammonium sulphate was applied to the soil at varying depths (5 cm = main crop rooting zone; 35 cm = shared zone; and 55 cm = below most crop roots). Labelled nitrogen was applied with a carbon source to stimulate microbial immobilization and so avoid rapid movement from the injection site. ^{15}N enrichment in the tree and the crop was monitored by weekly sampling of young shoots.

***Peltophorum* has proportionally more roots in deeper soil layers than Gliricidia, and shows greater N uptake activity in these layers**

Results

Initial results indicate that *Peltophorum* at first took up little ^{15}N from shallow (5 cm) applications in comparison to *Gliricidia* and the crop, thus competing less strongly for N with the crop than *Gliricidia.* Both the crop and *Gliricidia* showed little uptake from deeply placed isotopes, in contrast to *Peltophorum* which maintained an active root safety-net at 55 cm (Figure 1). Uptake of ^{15}N by *Peltophorum* from this soil layer increased over time as plant N demand increased after the initial pruning event. These results seem to support the 'safety-net' hypothesis whereby adapted, deep rooting tree species can utilize leached N efficiently, particularly when tree N demand is high.

The relationship of root N uptake to root length density is not straight-forward

Subsequent root length density measurements showed that *Gliricidia* had a higher root length density than *Peltophorum* in the top soil layer, which corresponds with its initial higher ^{15}N uptake from the 5 cm placement. However root length densities of *Gliricidia* and *Peltophorum* in the 50-60 cm layer were similar, in contrast to the measured differences in ^{15}N uptake activity (Figure 1). Thus there was not a direct relationship between root length density and activity when comparing the two species. In the above case it can be hypothesised that *Gliricidia* has a lower N uptake per unit root length (because it has a much greater total root length) and its

Modelling provides an essential complement to field experimentation in complex systems such as simultaneous agroforestry

Roots of an ideotype tree for intercropping would avoid the nutrient rich topsoil and instead explore the often more hostile deeper soil layers

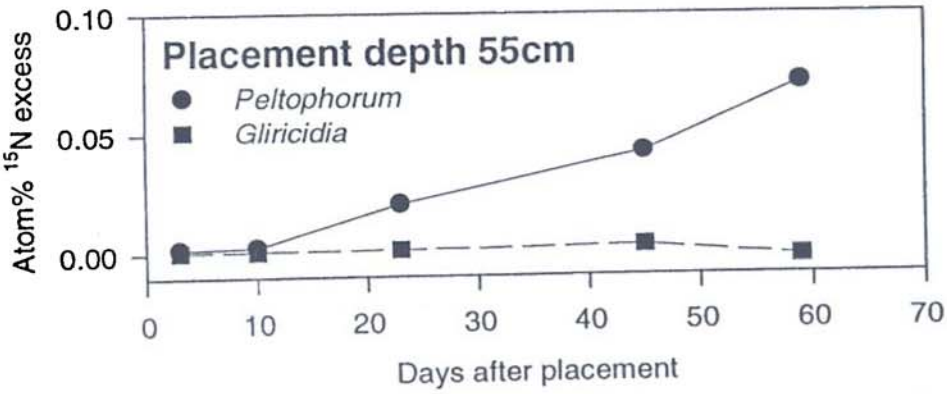

Figure 1. ^{15}N *enrichment of young tree leaf samples derived from isotopes placed at 55 cm soil depth.*

obtaining a higher proportion of the N it needs from the shallower layers, or that *Gliridia* obtained a significant proportion of its N from N_2 fixation (as suggested by its low natural ^{15}N value) and deeper roots served mainly for water uptake. In contrast the non-fixing legume *Peltophorum* relied much more on an efficient capture of N and maintained a highly active root system at lower soil depth.

Modelling approach

To analyse where and how agroforestry systems work experimental approaches are not sufficient and an integrated modelling approach is needed. We used WaNuLCAS, a model of Water, Nutrient and Light Capture in Agroforestry Systems, to test the effectiveness of roots to act as a safety-net. In WaNuLCAS emphasis is placed on belowground interactions. It can be applied to spatially zoned agroforestry systems and/or rotational systems. The model is formulated in the STELLA IV modeling environment and thus remains opén to modifications. A key feature of the model is the description of uptake of water and nutrients (at this stage only N) on the basis of root length densities, plant demand, and soil characteristics.

Potential nutrient uptake, U_{ijk}, from each cell ij (i=soil layer and j=spatial zone) by each plant component k is calculated from a general equation for zero-sink uptake (de Willigen and van Noordwijk, 1994) on the basis of the total root length in that cell, and allocated to each component proportional to its effective root length as equation 1:

$$U|_{ijk} = \frac{L_{rvijk}}{\sum_k L_{rvijk}} \frac{\pi D_0 (a_1 \Theta_{ij} + a_0) \Theta_{ij} H_{ij} N_{stock\,ij}}{(K_a + \Theta_{ij}) [-\frac{3}{8} + \frac{1}{2} \ln \frac{1}{R_0 \sqrt{\pi \sum_k L_{rvijk}}}]} \qquad (1)$$

where L_{rv} is root length density (cm cm^{-3}), D_0 is the diffusion constant for the nutrient in water, Θ is the volumetric soil water content, a_1 and a_0 are parameters relating effective diffusion constant to Θ, H is the depth of the soil layer, N_{stock} is the current amount of mineral N per volume of soil, K_a is the apparent adsorption constant and R_0 is the root radius.

Actual uptake, S_{ijk}, is derived after summing all potential uptake rates for component k for all cells ij in which it has roots. Total uptake will not exceed plant demand. The definition of 'demand$_k$' is based on the current biomass and a target nutrient concentration appropriate for that biomass (van Noordwijk and van der Geijn, 1996), *minus* a fraction derived from atmospheric N_2 fixation.

We used WaNuLCAS to determine how efficiently roots in the safety-net zone intercept leaching nitrogen in the case study in Lampung. The runs we made were during the December-March high rainfall period, without N fertilizer application. The crop was started on day 10 and the trees were pruned on the same day, prunings being added to the soil. The safety-net zone in the simulation was defined as the 40-60 cm soil layer, to reflect restricted root subsoil exploration in this soil. The safety-net efficiency was defined as:

Safety-net efficiency (%) = TN_{upt} / ($Leach_{out}$ + TN_{upt}) * 100

where TN_{upt} is the tree N uptake from the safety-net zone (40-60 cm soil layer) and $Leach_{out}$ is the amount of N leached out of the safety-net zone. The simulations are based on cumulative averages for an 80 day crop period. Preliminary results suggested that *Peltophorum* roots in the 40-60 cm soil layer would reduce potential N leaching by around 5-10% over a period of 60 days (Figure 2).

To significantly increase the safety-net efficiency much larger root length densities would be required. Also the more deeply the trees root, the greater is the chance of interception. The average safety-net efficiency flattened to a maximum of around 80% at high root length densities. This may be because of asynchrony, with N passing through the safety-net layer at a time when tree N demand was saturated, or because fast leaching events prevented N uptake. Factors such as rainfall intensity and amount, pruning quality and management options (timing of pruning, fertilizer applications) will further influence safety-net efficiency. Thus a whole range of such safety-net efficiency curves would emerge for particular situations. The challenge is to identify adapted tree species with a high safety-net efficiency and with complementary rather than competitive resource capture strategies. The effects of management interventions (e.g of pruning on root activity) also need to be understood in order to optimize tree-crop interactions.

Georg Cadisch and Edwin Rowe
Department of Biological Sciences
Wye College
University of London
Wye
Kent TN25 5AH
fax 01233 813140
e-mail: g.cadisch@wye.ac.uk

Meine van Noordwijk
ICRAF
P.O. Box 161
Bogor 16001
Indonesia
fax +62 251 315567
e-mail: icraf-indonesia@cgnet.com

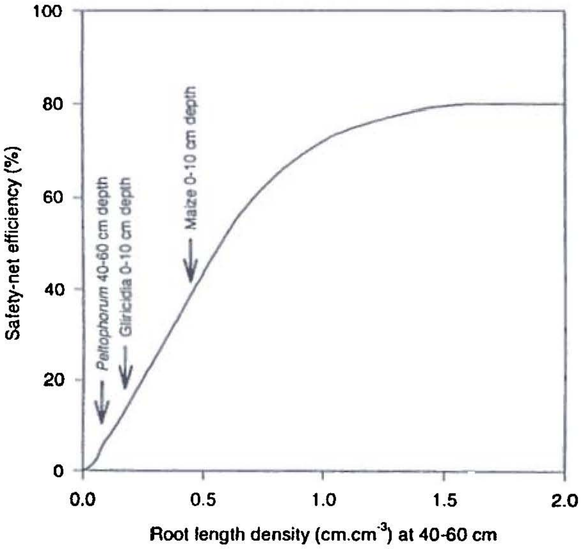

Figure 2. WaNuLCAS simulations testing the relationship between tree root length density and safety-net efficiency in the 40-60 cm soil layer at Lampung, Indonesia during the rainy season. Measured root length densities are shown for comparison.

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Resource use and growth in semi-arid agroforestry systems

Agroforestry models require comprehensive experimental datasets to validate both the underlying assumptions and the output they produce. This study aimed to compile a comprehensive dataset describing resource capture and tree and crop growth over an extended period within a semi-arid agroforestry system. The data collected are sufficiently sensitive to demonstrate the extent of spatial variation in crop growth and development resulting from microclimatic changes induced by the trees.

Background

Agroforestry offers one of the most promising land-use systems for semi-arid regions since mixtures of annual and perennial species may increase the capture of limited resources and/or the efficiency with which they are used. In particular, residual water often remains in the soil after harvesting annual crops and off-season rainfall may go unused. The trees within agroforestry systems may be capable of capturing these untapped resources and providing microclimatic benefits for associated crops. However, the success or failure of such systems is critically dependent on the extent to which the component species are complementary rather than competitive in their use of water, light and nutrients. A detailed understanding of the changing patterns of resource capture as the trees mature is therefore essential for successful system design.

A key objective was to compile a comprehensive database spanning an extended period to support the development and validation of integrated tree and crop growth models. This was achieved by adapting established techniques to quantify the capture and use of water and light by trees and crops in *Grevillea robusta*-based agroforestry systems.

The research was carried out at ICRAF's Machakos Field Research Station, 80 km south-east of Nairobi, Kenya. Rainfall at the