Agroforestry with perennial crops: research ideas and methodologies

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Introduction

External and internal factors influenced formally recognized agroforestry research at its inception in CATIE in 1979. Paradigms in the international research and development community are among the most influential external factors: 1) high species diversity, structural complexity, closed nutrient cycles, little or no external inputs were considered highly desirable agroecosystem attributes; these had to be evaluated in existing and new production systems; 2) trees were a common feature in most tropical agricultural landscapes, and numerous "traditional" "agroforestry" systems existed, especially, on small tropical farms. A great effort had to be dedicated to document existing examples (Nair 1987).

Influential local factors included: 1) CATIE is a regional Center (Central America and the Caribbean) aimed at developing productive and ecologically sound land use technologies; research results must be applicable to identified problems; 2) most of Central America is tropical humid lowlands; 3) perennial crops have been (cacao) and are (coffee) of huge socio-economic importance in this region; 4) changes in the international market prices for coffee, cocoa, annual crops and meat resulted in changes of interests by national and international organizations; 5) many traditional agroforestry systems (AFS) include timber trees which have short production cycles on these humid, fertile sites; and 6) agroforestry research was lead by foresters (e.g. Department of Natural Renewable Resources, CATIE). These influences explain why CATIE focused on multi-strata AFS with perennials when most agroforestry research groups emphasized alley cropping with annuals.

In this paper we discuss the evolution of the main research ideas and methodologies in CATIE's agroforestry research with coffee and cocoa during the past 20 years, and the prospectus for the next five years. A critical analysis of the methods used is emphasized.

Qualitative and quantitative studies of traditional multi-strata systems in Costa Rica

Two research approaches dominated the study of traditional systems with coffee and cocoa: 1) characterization (often qualitative) of existing shaded coffee systems; and 2) quantification of coffee production and particularly timber growth. Studies concentrated on valuable timber species like *Cordia alliodora* and *Cedrela odorata*. Special attention was given to the estimation of tree density, tree growth, and to the enumeration of perceived advantages and disadvantages resulting from having the trees (Beer, 1987). These timber species regenerated naturally hence practical criteria to select both farmers and measurement plots in private farms had to be devised. Methods were borrowed from forestry, population ecology and simulation techniques (Somarriba 1990; Synnott 1979). The experimental determination of optimal shade tree densities over coffee was approached through regression analysis using a systematic spacing design, focusing on the quantification of

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competitive interactions between shade trees and crop plants (Beer 1992). Financial sensitivity analyses including effects of shade on coffee quality were also addressed.

Most research was conducted in commercial coffee plantations. Coffee production, soil erosion and biomass production of "service" shade trees such as *Erythrina poeppigiana* was determined using random complete block designs (RCB) which had the following problems: 1) plots were often too small; 2) blocks were not homogeneous and their designation arbitrary (and possibly unjustified); 3) studies were often of relatively short duration (≤ one year); 4) many uncontrolled factors (natural and human influences) affected the results; 5) stands (e.g. shade tree density) was not homogeneous in a plot; 6) information on the previous management, origen and age of the crop and tree components was unreliable.

The establishment of permanent sample plots in private farms was plagued by problems of scale and internal variability. Many AFS are managed as small units (≤ 1 ha) in which some components are large (e.g. timber trees). Excluding border areas, where these large components generally are more productive, will underestimate the productivity of the typical unit. The sample, when studying traditional shade-coffee systems, should be the whole plot and not some subjectively selected central area which supposedly represents unit area productivity. Variability is large, thus affecting precision of plot data. Several sources of variability can be identified: 1) the coffee bushes usually have variable spacing, ages and even different varieties are often mixed as replanting has occurred over a sufficiently long period for recommended germplasm to vary; 2) the timber component is usually a result of natural regeneration, which may not be permitted every year but rather at intervals, and there can also be a high variability in shade tree spacing, ages and sizes (result of both spacing and age differences); 3) site conditions are usually highly variable and the experimental requirement for within-block and even within-plot homogeneity, of for example soils, often can not be met; and 4) farmer participation will vary and may provoke intensified non-representative management of the plot under study.

Nutrient cycling studies in shaded coffee and cocoa

An increasing interest in process research, and in particular the need to quantify the ability of agroforestry systems to maintain nutrient reserves, was emphasized at an early stage. Studies were initiated in private farms with traditional shade management. However, in addition to the limitations mentioned in the previous section the need for controlled management, soil homogeneity, and safety ("clean" data, and security of expensive equipment) motivated a shift toward on-station research. "La Montaña", a large, replicated, researcher controlled experiment, including the comparison of leguminous *versus* timber tree species used for shade in coffee and cocoa plantations, became CATIE's "Central Experiment" for agroforestry research.

Biomass and nutrient accumulation in stems, branches, leaves, litter and soil was studied at the ages zero (soil only), five and ten years. Litterfall studies; crop and timber production, water and nutrient balances, organic matter decomposition, soil chemical changes, soil macrofauna, and financial performance were also studied. A wide array of methods were used. Descriptive, compartment models of biomass and nutrient stocks and fluxes were constructed. Allometric studies were used for non-destructive estimation of standing biomass. Tensiometers and ceramic lysimeters were used to quantify water movement through soil profiles and to sample soil water nutrient concentrations. Litterfall methods were borrowed from natural forest research. Soil organic matter and input-output ratios for nutrients were used as indicators of systems' ability (stability) to maintain nutrient budgets and hence of sustainability. Mesh-bag techniques and linear or non-linear regressions modeled litter

organic matter decomposition. Atmospheric N fixation by one shade tree species (*Erythrina poeppigiana*) was considered an important issue, but work was done on other nearby sites.

In the late 80's the need for larger plots, more replicates and interest in alternative shade species, more representative site conditions for coffee and cocoa production and the upsurge of interest by national organizations in the cultivation of cocoa, shifted research attention to the farmer's fields in the agricultural frontier in the humid lowlands of Costa Rica and Panama.

Shade management in cocoa plantations and the search for alternative SAF

On-farm research was initiated 1988-1990 in an attempt to develop shade management alternatives under several farm scenarios with cocoa as a main crop. Three leguminous shade tree species (*Gliricidia sepium, E. poeppigiana* or *Inga edulis*) and three timber tree species (*C. alliodora, Terminalia ivorensis* or *Tabebuia rosea*) and more complex systems, with plantains (*Musa* AAB) including only *C. alliodora* as the tree component, were tested on several farms. Canopy manipulation through pruning and thinning was monitored using hemispherical photography and other visual techniques. The effects of changes in shade levels on cocoa phenology and dispersal of *Moniliophthora roreri* spores were evaluated. Data analysis was largely based on analysis of variance. Financial analyses used standard techniques and risk analyses were based on econometric modeling of product prices (cocoa, plantains and timber) and simulation techniques. In the search for optimal management, shade species were managed (pruned, thinned) differentially according to crop needs. Individual factors (such as shade level or pruning frequency) could not be studied separately in on-farm trials due to their impracticality and negative effects on cacao yields. Systems and not individual factors were compared.

Selected technologies were then disseminated into several local Amerindian communities. Adoption and technology adaptation studies are currently under way using participatory research techniques. In addition to cocoa, agroforestry research also evaluated the use of living support stakes (*E. berteroana, E. fusca* and *G. sepium*) for black pepper (*Piper nigrum*) to provide a new commercial perennial crop alternative to cacao. However, severe soil fungal infestation and the use of highly susceptible black pepper genotypes resulted in a total failure of this research. Research with perennial crops also included studies of *Eugenia stipitata* (Myrtaceae), a shade-tolerant, Amazonian fruit tree under the shade of either *C. alliodora* or *Acacia mangium*. Despite promising productive and financial results, the absence of an established market for *E. stipitata* limited the potential of this permanent agrosilvicultural system.

Current and future research with coffee

Depressed international cocoa prices over more than ten years have lead to a drastic reduction in the area under cocoa cultivation in Central America and in a drop in the interest of governmental organizations and NGO's. The economic importance of coffee in Central American countries (Galloway and Beer, 1997), and CATIE's previous experience and available research infrastructure motivated a switch back to agroforestry research with coffee in 1996.

Research is now focused on: 1) biophysical and socioeconomic criteria used by farmers to determine shade design and crop management in the face of unstable environments, 2) the study and manipulation of key interactions between shade trees and crops. Several key interactions are given special research attention: 1) shade level – fertility-management (organic or not) – coffee yield; 2) shade management – microclimate modifications – pathogens - coffee yields; 3) tree – crop below ground competition for water and nutrients (root research); 4) canopy diversification – product diversification – financial stability and risk.

For the former, standard multivariate techniques (principal component, cluster and discriminant analyses), Anova and contingency tables are used to identify and rank the most important factors affecting shade canopy design. Decision models, game theory and artificial intelligence models are to be explored. Farmers' decisions and knowledge on shade and coffee management are also researched in "thought experiments": e.g. contrasting scenarios are formed by combinations of pre-selected key factors and farmers' responses to these theoretical situations are recorded.

An example for the later are studies of root competition, comparing fast growing timber trees, such as *Eucalyptus deglupta*, with traditional service trees, such as *Erythrina* spp. This work is already challenging standard claims for AFS such as "tree roots develop below crop roots, and hence recycle nutrients to the crop through above-ground litter fall (natural and pruning residues)". Methods of manipulating the spatial distribution of the tree roots by zoning of tree and crop components, directed fertilizer placement and the use of grass "root barriers" to reduce tree competition with the coffee, are presently being tested.

The two main research thrusts proposed for the next five years, for CATIE AF research with coffee are bio-physical process research on coffee responses to shade and competition with trees (growth, internal C-allocation, phenology, disease-pest tolerance, yields and quality effects) and socio-economic analyses of both traditional and new (or improved) shade coffee combinations compared to coffee mono-cultures.

Conclusions

CATIE's research agenda has been affected by external (paradigms in the international research and development community, commodity price fluctuations) and local factors (CATIE's mandate, availability of research sites nearby, the importance of coffee and cocoa in the region, available infrastructure and past experience with these crops, strong forestry department, etc.). Both on-farm and on-station research, applied and process research has been conducted using a wide array of methods. However, emphasis has been on biophysical research. More research effort is needed on dissemination, validation, adoption risks, and policy. Only researcher controlled studies have been done so far; participatory, farmers' operated research is required. The development of improved timber-perennial crop plantations did not follow the foreseen sequence of on-farm (characterization of farming systems, including traditional SAF and socio-economic studies), on-station (testing of innovations), and back to on-farm (validation).

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