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CONSIDERATIONS FOR THE PLANNING, IMPLEMENTATION AND EVALUATION OF ON-FARM EXPERIMENTATION IN AGROFORESTRY FARMING SYSTEMS

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INTRODUCTION

While agricultural research has developed over the last century with a concomittant increase in the sophistication of techniques and specialization of research personnel, agroforestry is a recent arrival on the applied science scene. Furthermore, although agricultural research has considerably increased agricultural production in some areas and for certain groups of farmers, the small farmers in the tropics have benefited much less.

A major criticism of over-reliance on on-station agricultural research is that in many cases, conditions on such stations bear little resemblance to those under which the majority of farmers operate. Consequently, the relevance of the results to the needs and circumstances of small farmers is questionable. In this context, agroforestry researchers are in a unique position to incorporate relevant lessons from agricultural research into the very foundations of their approach to technology-generating research. This involves a shift from the conventional 'top down', heavy-handed methods that assume the researcher knows best and the farmer must do everything he is told, to one in which the farmer's opinions matter and he has an active role at all stages of technology generation and testing - a 'bottom up' approach.

WHAT IS AGROFORESTRY?

'Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboo) are deliberately used on the same land management unit as agricultural crops and/or animals, either in some form of spatial arrangement or temporal sequence. In agroforestry systems, there are both ecological and economic interactions between the different components' (Lundgren and Raintree, 1983).

Thus, the key characteristics of any agroforestry system are:

- generally involves two or more species of plants (or plants and animals), of which at least one is woody

- always has two or more outputs

- mostly has a cycle in excess of one year

- is more complex ecologically (in structure and function) and economically than a monocropping system.

The promise of agroforestry lies in the fact that it has the potential to address some of the key ecological and socio-economic problems of land use, e.g. soil fertility decline and erosion, food and fuelwood scarcity. The aim is to maximise positive interaction between the woody spp., crops and/or animals so as to achieve, at the very least, a more sustainable and diversified production from the land (Lundgren, 1982). It should hence be possible to achieve present requirements of food and wood while conserving the soil resources required for future production (King and Chandler, 1978). Under certain ecological and socio-economic conditions, it is feasible that a higher total production, than is possible with other forms of land use, can be obtained.

It is important to stress that agroforestry is not a panacea for all land-use problems. In each case, it will also be necessary to consider the opportunity cost of other land-use systems (Hoekstra, 1983). Thus, an agroforestry system/practice is justifiable if it makes efficient use of available resources (land, labour, capital) with respect to sustainable production.

THE OBJECTIVES AND ROLE OF ON-FARM EXPERIMENTATION (OFE) IN AGROFORESTRY RESEARCH

The objectives of OFE in agricultural or agroforestry farming systems (AFS) are essentially the same:

1. To improve understanding of an existing farming system vis-a-vis farmers' expectations and priorities and identify the constraints limiting productivity and efficiency.

2. To identify, with the aid of farmer participation, new technical relationships, farmer-originated innovations, constraints and evaluation criteria and feed them back for use on research stations.

3. To test technology development on research stations under more representative agro-ecological and socio-economic conditions.

The overall objective of OFE is to gain a clear picture of the agroforestry farming system and draw conclusions that are relevant to the farmers' circumstances. It is important to realise that while agriculturists have a large range of tested technology options at their disposal, agroforestry shelves are rather bare of tried and tested technologies. This is the major difference between OFE in agriculture and agroforestry. It is hence vital that the farmer plays an active role at all stages of OFE in agroforestry - a true 'bottom up' approach. The alternative could be grim - to wait at least ten years till on-station agroforestry research results become available and then find that the technology is not really suitable! The second objective listed above spells out the farmer's role in ensuring the suitability and future adoptability of virtually untried technologies - the case with most agroforestry technologies today.

PLANNING, IMPLEMENTATION AND EVALUATION OF OFE IN AGROFORESTRY

For effective planning, implementation and evaluation of OFE in agroforestry, it will be crucial to have a multi-disciplinary team working in an inter-disciplinary manner. Representatives from agricultural science, forestry, social science and disciplines related to land resource survey would be most appropriate (Raintree, 1983). It is important that in addition to having compatible personalities, team-members appreciate the limitations of their own disciplines in solving the problems of AFS without the inputs from other disciplines. Unfortunately, it is likely that this "multi-disciplinary maturity" comes mainly from longevity in the field rather than through formal training programmes or ad hoc conglomerations of specialists.

Extension personnel from the target area must also be closely involved with the multi-disciplinary team through the stages of the diagnosis of existing AFS and the testing and evaluation of OFE. The multi-disciplinary team thus has the benefit of the extension team's intimate local knowledge while the extension team gain a good understanding of the managerial and technical implications of a new intervention and will be better able to disseminate it if it is successful.

Planning

It is assumed that OFE is contemplated only after an AFS is well understood subsequent to description and diagnostic analysis, formulation of appropriate hypotheses and identification of promising alternative technologies. To this end ICRAF has developed a "Diagnostic and Design" methodology as an FSR tool (Raintree, 1982).

The preference for a diagnostic and problem-solving approach is based on the assumption (and some experience) that technologies aimed at solving perceived problems in the existing land-use systems are more likely to be adopted should they prove successful (Raintree, 1982). Such an approach contrasts strongly with the more common method that seeks to realise biological or bio-economical potentials within a system which, when or if they exist, may or may not be a priority from the farmer's point of view.

Defining the target group for OFE is very important and must be carried out in the early stages of planning. Rogers and Shoemaker (1971) point out that in any farming system, a small percentage of farmers will be innovators, the great majority will have a "sit-on-the-fence" approach and a few will have a negative attitude towards change or new technologies. Various sampling strategies may be employed to ensure an objective selection of a target group that is representative of the farming system. A good strategy would be to use a stratified sampling technique weighted towards the "sit-on-the-fence" group, i.e. the great majority of farmers in any farming system. Raintree (1983) argues that such a conservative strategy is often necessary since technologies that prove successful with the innovator group may not be as readily adopted by the rest.

Nevertheless, innovators can play a very important role in OFE. They can be used for screening or early demonstrations of new interventions prior to dissemination within a farming system. Certain agroforestry technologies may require screening prior to OFE in order to reduce the risk of negative results, for example, technologies involving interaction between livestock and fodder trees/shrubs where pods, etc., may contain certain toxic substances.

Technology Selection Criteria for OFE in Agroforestry

Because of the increased time, cost and complexity (relative to crop or livestock systems), of conducting agroforestry OFE, it will be necessary to be extremely selective in choosing interventions for testing. Sustainable productivity is the major characteristic of any agroforestry technology. However, such a technology would be useless unless it is adopted by a significant proportion of the farmers (Raintree, 1983). Consequently, the criteria listed below highlight mainly the adoptability issues (productivity and sustainability being implicit):

- Technologies that are expected to have a sustainable impact on productivity that is both intensive and extensive. Thus, a technology should be applicable over a wide geographical area within the boundaries of an existing AFS.

- Technologies that are revealed through ex-ante evaluations by researchers and farmers to have a good chance of adoption if proved successful. A good bet are those technologies that maximise returns to the most scarce production factor.

- Improvement of existing technologies that can be achieved within the farmer's objectives and without major increases in inputs, such as labour, land and capital (Zandstra, 1983). In most cases, an incremental modification approach is likely to be more easily assimilated than one which aims at total transformation.

- Technologies that do not expose the farmers to undue levels of risk. A major concern of small farmers, living at the very margins of existence, is considerations of risk. There is a tendency to avoid change which, though it might improve his situation if it functions as expected, could leave him worse off than he is now if it does not.

- Technologies that do not require complex technical/management inputs (at experimental or post-adoption stages) by researchers and farmers and can be effectively monitored by available staff.

Characteristics of Experimental Units in Agroforestry

A major source of difficulty in conducting OFE in agroforestry has to do with the characteristics of resulting experimental units. The multicomponent nature of AFS, the characteristics of and interaction between components impose certain constraints on the design, testing and evaluation of on-farm experiments. It is important that these

TABLE 1. COMPARISON OF CHARACTERISTICS OF CROPS, LIVESTOCK AND TREES AND IMPLICATIONS FOR ON FARM TESTING IN AGROFORESTRY PRODUCTION SYSTEMS (Modified from Bernsten et al, 1983)

Factor	Situations with respect to: Crop	Livestock	Trees/shrubs	Implications
Component arrangement	Generally standardised	Mobile/stall-fed	Generally haphazard in traditional systems	Difficult to measure and control non-experimental factors
Life cycle	Generally less than 4 months	Generally over one year	Nearly always more than one year	Increases costs, likelihood of losing experimental units
Production phases	All units synchronized	Units seldom synchronized	Units seldom synchronized	Difficult to find comparable units
Outputs	Only grain/tuber	Multiple outputs, meat, hides, milk, manure, power	Multiple outputs, firewood, fodder, fruit, timber, poles	Difficult to measure/value treatment effect
Non-market inputs/outputs	Few	Many	Many	Difficult to value input/output
Experimental unit size	Small, divisible	Large, non-divisible	Large, divisible	Increases cost, risk to cooperator
Location traditions/customs	Some social/ritual uses	Various taboos	Often complex owner/user rights	Limits treatments
Management variability	Relatively low	High	High	Difficult to isolate treatment effect
Observation units	Many	Few	Few	Large statistical variability
Genetic makeup	Relatively homogeneous (domesticated)	Relatively homogeneous (domesticated)	Very heterogeneous (largely wild)	Large statistical variability
Interaction	Crop residue feed	Manure for crops	Fodder for animals green manure for crops shelter for animals and crops	Increased cost of more complex statistical design

constraints are considered at the planning stage. Table 1 identifies the major component factors and their implications for OFE in AFS:

- Arrangement of components. It is not possible to find identical arrangements of trees with respect to crops on different farms. The alternative is to plant the trees in the same pattern and wait 10-20 years for them to grow. In nomadic silvopastoral systems, livestock mobility makes it difficult to describe livestock-environment interactions. In some cases individual ownership but communal herding makes control of non-experimental variables virtually impossible.

- Life cycle duration. The life cycle duration of most food crops is 3-5 months; ruminants' reproductive cycle is over a year; and the gestation period of tree products can extend over several years. This increases not only the cost of an experiment but also the risk that an experimental unit or a major part of it may be lost, e.g., if a tree is cut for fuelwood or sold to generate cash in an emergency or if an animal dies.

- Production phases. While crops are planted and harvested at set times, production of animal and tree products is not synchronized and occurs at different times or time intervals. Tree phenology can vary not only between species but also within species. Tree fodder quality is known to vary between seasons and with stage of growth. To find enough animals of the same age category and in the same production phase is difficult. Such a lack of comparable experimental units can introduce unacceptably high levels of bias, thereby invalidating statistical models to be used during the evaluation phase.

- Outputs. Crops generally produce a primary output such, as grain or tubers, and a secondary output, e.g., crop residue. Trees and livestock, however, may provide several outputs/services, e.g. fuelwood, fodder, timber, green manure, fruit, shelter, soil conservation and meat, manure, milk, hides and draft power.

It is not easy to attach a value to some of the above-mentioned outputs/services, and this makes it difficult to measure the impact of treatments and evaluate the economic effect of an intervention.

- Size of experimental units. In an agrosilvipastoral system, for example, crop plants which are generally small could be manipulated in field trials that affect only a small proportion of the farmer's field. In contrast, because animals are large, on small farms few in number, OFE involving farmer-owned livestock may expose the farmer to high levels of risk.

- Traditions/customs. In some AFS, tree rights or ownership may be very complex and in some cases linked to land tenure, e.g., in the case of tenant farmers. Such attitudes or customs may severely constrain experimental design. Also, religious customs and taboos may make it difficult to cull, castrate or ear-mark livestock.

- Management variability. Crop management practices are a major source of variability in on-farm crop trials. However, this is a much greater problem with agroforestry trials due to the longer life cycle (of trees and/or livestock) over which a greater number of critical management decisions must be made. This makes it difficult to observe the effect of an experimental treatment. The effects of any management bias are compounded over the increased time span and can seriously affect the results.

- Number of observation units: Crop trial results are measured in yield production per hectare. Thus, even in a small trial plot, the yield estimate is an average of many individual plants. In the case of small farmers in an agrosilvopastoral or a silvopastoral system, the numbers of livestock and trees of any one species are relatively small. Consequently, statistical variability of treatments between groups increases markedly.

Statistical models

The experimental constraints described above and various other non-experimental interferences, such as pest attack and bad weather, require that any statistical designs used allow for:

1. Estimation of treatment effects with a high level of precision.

2. Precise comparisons between equally important treatments.

3. Necessary adjustments between treatments or farms without loss of validity of the model.

The most commonly used designs rely on inferential statistics. This often results in problems because the parameters used are subject to strict assumptions in order to assess probabilities. For example, randomised blocks, latin squares and factorial designs require that each treatment occur at least once in each block, column or row. These designs also imply that experimental units are grouped into sets that are expected to behave in a similar manner.

In the above-mentioned designs, an important assumption is that any non-experimental interference affects all the treatments equally, leaving the treatment means unaffected. This is seldom the case in OFE since, for example, pest attack can affect some plots and leave others unaffected; soil variations can occur over short distances and planting all plots at the same time may not be possible. Because of the above limitations, non-parametric methods are becoming more popular. The major disadvantage of non-parametric statistics, however, is the lack of a specified probability distribution which weakens statistical inferences with regard to hypothesis testing.

IMPLEMENTATION

Category of On-farm Experiments

As in other farming systems, management and execution of OFE in AFS can be shared between the researcher and the farmer;

- Researcher managed and researcher executed;
- Researcher managed and farmer executed;
- Farmer managed and farmer executed.

The choice of the category will depend on the type and the complexity of the experiment, how much is already known about the technology being tested and the skill or management capability of the target group. In the first category, the researcher manages and executes the trial to attempt to eliminate or minimise variation in non-experimental variables. In the third category, farmer management itself can be a test factor (Matlon, 1982). Where confidence is high that a technology found elsewhere will be applicable locally, the new technology may be immediately compared with a currently existing technology with intensive farmer involvement. Conversely, technologies needing modification or pre-screening will require greater researcher involvement (Collinson, 1984).

OFE in agroforestry will involve observations on trees, crops and/or animals. It is hence important that all parties involved are fully aware of their responsibilities and know at what stage their inputs are required. Researchers and/or farmers should know at what stage of animal, crop or tree growth to make observations and be aware of the duration of the experiment. For example, labour inputs need to be recorded weekly; crop and animal development, pest and disease incidence monthly and tree/shrub yields may be recorded every two or three months. Simple, well-designed tools can be used to obtain rapid but reasonably accurate animal/tree growth estimates, for example, regression equations relating animal live weight to an easily measured parameter, such as body girth or forage biomass related to stem diameter and height.

Where farmer execution in involved, researcher schedules should, as far as possible, fit those of the farmer. For example, farmers should not be expected to be lopping and processing fodder and fuelwood from trees on the experimental plots when they would normally be weeding the rest of their fields. Attention to such details can go a long way in making the farmers feel that the experiment is their own and not that the land is on loan to the researcher. In the former case, the farmer is more likely to appreciate the importance of applying his normal management decisions to the experiment. This can be very important in AFS where such decisions will have to be applied over a longer time period than with agricultural or livestock systems.

EVALUATION

The time scale over which most agroforestry technologies reach an equilibrium within a farming system is much longer than for crop and, to some extent, livestock systems. Consequently, OFE in AFS should be thoroughly evaluated for short- and long-term effects. This is important since most agroforestry technologies commit farmers to a selected course for decades rather than for a few years. Where differences between new and standard technology are small, researchers should look for consistency in performance over several seasons/years before making recommendations. For example, the use of leguminous trees for N-fixation and green manure on croplands may not show a marked response in crop yields but may be sufficient to enable sustained crop yield which would not normally have been possible without fertilisers.

Any evaluation of OFE in AFS must consider the following aspects:

1. Technical feasibility

2. Economic viability and

3. Social acceptability

Technical Feasibility

Technical evaluation can be carried out via assessment of various criteria, e.g. sustainability of crop yields, stability of animal performance, yield of technology components and compatibility with existing systems. For example, the effects of planting hedgerows of Leucaena leucocephala or Calliandra calothyrsus on slopes for soil conservation and green manure production can be evaluated by the biomass of green manure produced, the change in soil structure, infiltration, soil erosion, organic matter content of the soil, changes in soil organism populations and/or yield of crops grown between the hedgerows.

Economic Vaiability

Criteria for economic evaluation include profitability, stability of returns and better use of the available resource base. The simplest and most common approaches to the economic evaluation of a farming system and its component technologies are various forms of budgeting. However, the multicomponent nature, seasonal variability and long life span of agroforestry technologies introduces complications (Etherington, 1981; Etherington and Matthews, 1983):

1. The cost of time as represented by a discount rate needs to be considered. Although there are well-defined discounting techniques available, choosing an appropriate discount rate is not easy in practice and can depend on several factors, e.g. ability/opportunity to borrow money, use of equity capital, future perception of the farmer, etc. (Hoekstra, 1983). Since individual farmer circumstances will vary, it will be necessary to differentiate between farmers.

2. The performance of a given technology will depend on the time of its introduction and will vary with time after its introduction. This is due mainly to the effect of the woody perennials on environment (microclimate, soil nutrients, soil water balance) into which the technology is introduced.

3. An agroforestry budget needs to take into account annual crops as well as woody perennials and/or livestock. Seasonal variations in yield and labour requirements are important with woody perennials.

Budgeting is essentially an iterative procedure. The relatively recent arrival of the microcomputer has placed the power of rapid computation, and hence realistic partial budgeting for AFS, within the reach of most agricultural research institutes in the tropics. ICRAF, in conjunction with the Australian National University, has developed a "multicomponent, multi-time period budgeting package for use on microcomputers. The package has the acronym "MULBUD" (Etherington and Matthews, 1981). Its features include:

- considerations of land, labour, capital and time cost

- summary criteria, such as the sum of net present values (SNPV), returns to labour and internal rates of return

- sensitivity analyses and effects on summary criteria of variations in revenues, costs and discount rates. The integrity of each analysis may be ensured by linking it to a clearly defined set of environmental variables and/or biological constraints.

MULBUD gives alternatives, not solutions. Because of the complexity of the systems that the approach seeks to describe, judgements regarding the relative merits and realism of alternatives will best be made by a multi-disciplinary team.

It must be admitted, however, that precise information on biological interactions in AFS is largely lacking. Where the effects of interactions are known, they are rarely in precise mathematical form. In addition, it is not yet possible to derive general interaction equations valid for all possible component combinations in different environments. Experience, "gut-feelings" and "guesstimates" will, at least in the foreseeable future, be the most likely source of information on biological interactions. This is the reason for the weakness of presently available tools for the technical and economic evaluation of AFS.

Social Acceptability

Criteria for evaluating social acceptability include farmers' assessments/reactions, adoption rate and social distribution of benefits and liabilities of the new intervention. Farmer assessments of agroforestry interventions are a valuable, rapidly available, but often overlooked evaluation tool of OFE. There are two major reasons for using farmer assessments of OFE in agroforestry:

1. The evaluation of agroforestry technologies by conventional statistical and economic tools is limited by the complex nature of AFS.

2. Because of the anticipated high variability that can be expected when unreplicated trials are conducted on single small farms, conventional analyses may show that there is no significant statistical difference between treatments. However, such a treatment that is rejected by researchers may, in the view of a farmer, be quite impressive. This is often because he evaluates a technology not in terms of inter-farm results, but in terms of his life-long farming experiences (Bernsten et al., 1983).

This is not to suggest that farmer assessments should be the only evaluation of agroforestry on-farm experiments, rather they should supplement conventional researcher evaluation tools and indices. It is important that agroforestry researchers appreciate that at present levels of precise knowledge of agroforestry, it may be necessary, in some cases, to depend heavily upon the intuitive insight of participating farmers for identification of constraints and evaluation of agroforestry interventions. Too many researchers discard a treatment just because it was not significant at the 'biblical' 95% level without consideration of farmer opinions. The fact that the statistical model may have been invalidated, due to contravention of the important assumptions inherent in the model, is conveniently ignored. The final decision on the desirability of a technology should reflect the sum total of all the evaluations - technical, economic and social (farmers' assessments).

CONCLUSIONS

An early indicator to agroforestry researchers of the need for OFE to complement on-station research is the work in recent years on the potential of Leucaena leucocephala as livestock fodder. On-station research into Leucaena fodder in Australia revealed that it was toxic to goats when it constituted more than 30 percent of the feed ration. Accordingly, recommendations were made and widely accepted in the tropics that Leucaena fodder should not exceed 30 percent of the diet of ruminant livestock.

Although Leucaena toxicity is true for some ruminants, field experiments several years later in Hawaii, Indonesia, Thailand and India have shown that some goats are capable of existing on a diet of 100 percent Leucaena with no ill effects. Apparently, the goats used in Australia did not have the appropriate gut micro-organisms capable of degrading the toxic by-products of Leucaena digestion, i.e., mimosine and its breakdown product 3-Hydroxy-4(1H)pyridone. This finding has resulted in a drastic shift in the focus of research from the long-term breeding programmes for lowered mimosine content of Leucaena to the relatively short-term culture and testing of appropriate gut micro-organisms.

Because of the long-term nature of agroforestry trials and the paucity of tested agroforestry technologies, the relevance of such research to the conditions of small farmers and the active participation of such farmers in OFE in agroforestry becomes very important. Thus, on-station research in agroforestry should be complemented by a farming systems approach and OFE in order to yield a more refined understanding of existing systems and opportunities both through treatment results and through tapping farmers' knowledge - a "bottom up" approach.

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