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Agroforestry Research at a Crossroads

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Abstract: Organized research in agroforestry was initiated nearly 25 years ago. At that time, the expectations were high on the potential of agroforestry as a development vehicle and the role of research in realizing that potential. Many of these expectations remain largely unfulfilled. Although agroforestry is becoming a rigorous science, the research focus has mostly been on biophysical issues at plot or field level; social, economic, and policy issues, as well as broader-scale and long-term issues have received little attention. Furthermore, in many developing countries, agroforestry research is mainly of an observational and exploratory nature, with little emphasis on process-oriented investigations to understand the reasons of the observed behavior. Therefore, the results lack scientific rigor and reproducibility. In order to overcome this, it is essential that agroforestry research is re-evaluated and refocused. A matrix of temporal (short-, medium-, and long-term) objectives and spatial (local, regional, and global) focus is suggested as a guide for natural resource management in agroforestry research. The matrix could be applied at different levels and institutional hierarchies. Research agenda at the institutional levels should be broadened to include such items as agronomic components of agroforestry, domestication of indigenous trees, development of appropriate research methodologies, socio-economic studies, and impact assessment. Broader-scale research issues of a long-term nature should include carbon sequestration, environmental amelioration including water quality enhancement, and biodiversity conservation. Research strategies should eschew the dichotomy of the "versus" syndrome (such as on-farm vs. on-station, socio-economic vs. biophysical, and local vs. global), and replace *versus* with *and* so that future research will involve a proper balance between on-farm *and* on-station studies on socio-economic *and* biophysical issues of local *and* global importance.

Key words: Carbon sequestration, nutrient cycling, research directions, research methodologies, socio-economic issues.

About 25 years after its initiation, agroforestry research is at a crossroads today. Its direction is unclear. This is not because all the expectations with which we started agroforestry research have been fulfilled; not because the scientists and other research practitioners of agroforestry are unconvinced about the excitement of agroforestry; not because farmers have abandoned agroforestry as a land-use approach; not because development agencies and policy makers are disinterested in agroforestry; and not even because agroforestry research is slowing down. What, then, is the problem?

The problem needs some explanation. Agroforestry research was initiated on a global scale when ICRAF (International Council – now Centre – for Research in Agroforestry) was established in 1977 following nearly two years of deliberations by a group of individuals (including this author). It happened in the wake of frustrations arising from the Green Revolution's failure to benefit poor farmers, and from escalating land-management problems such as tropical deforestation, fuelwood shortage, and soil degradation. The expectation then was that investments in research to support development of integrated land-management systems involving trees, crops, and animals would contribute substantially to decrease of deforestation, increase of food production, enhancement of biodiversity, and protection of environment. Subsequent modest investments in agroforestry research focused on enhancing the understanding about indigenous agroforestry systems and devising methodologies for research in this new activity. But soon (by mid- to late 1980s) agroforestry started to be trumpeted as a panacea. It meant different things to different groups, and naturally their expectations were quite diverse. The development community embraced the new concept with unprecedented enthusiasm as a magical approach, with a perceived relevance to "difficult" or "fragile" environments and resource-poor conditions (Steppler and Nair, 1987; Nair, 1993). Many of these expectations were not fulfilled – certainly not to the expected scale – within the targeted time frame.

In the meanwhile, the direction of agroforestry research has changed considerably. The early research initiatives that consisted of mostly descriptive and empirical studies gave way to more rigorous process-oriented studies (Sanchez, 1995; Nair, 1998; Buck *et al.*, 1999). Today agroforestry is recognized as an applied science and integrating discipline, based on the principles of natural resource management (TAC, 1998). It cuts across the strict disciplinary boundaries of traditional land-use disciplines such as agriculture and forestry, and draws upon data and hypotheses derived from research in related areas such as agronomy, forestry, soil science, ecology, economics, and anthropology. Acting as an interface between agriculture and forestry, agroforestry is now accepted as a viable approach to land management, particularly in resource-poor small holdings of the developing countries, and an important part of ecosystem management and environmental protection in the industrialized nations (Garrett and Reitveld, 1999; Izac and Sanchez, 1999).

Although these scientific gains are impressive, the bureaucrats and policy makers of governments and donor institutions cannot be blamed if they demand "impact-oriented" research: perhaps they are right when they lament that agroforestry research has not delivered the expected results. The scientific community, in spite of the often contradictory views according to its various disciplinary orientations, is also perhaps right when it argues that agroforestry research needs long-term investment and the results should not be judged based on short-term benefits and valuations that are mandatory of common funding cycles. The answer to the question "have the original expectations been not fulfilled at least to some extent?" depends on how the problems are perceived and results analyzed. Maybe the magnitude and enormity of problems we have set out to tackle have increased beyond expectations; maybe, the rewards of agroforestry research are not clearly quantifiable; maybe, the benefits of agroforestry are inseparable from those of other related activities; and maybe, agroforestry research has simply not delivered the expected outputs. Maybe, all of the above are true. Whatever it is, accountability is of paramount importance today, be it in research, development, or anything else. In the case of agroforestry research community, it means, the result of our efforts should produce measurable results: measurable not only in terms of our own criteria such as research publications, but in terms of benefits and impacts that are considered "tangible" in the eyes of the taxpayers and donors who keep investing in agroforestry. Therefore, the time has come for us to take a hard look at the way in which agroforestry research has gone and ought to be going.

Thus, the "problem" is that we need a reevaluation of the future and direction of agroforestry research. Several options are available. It is extremely important as well as challenging to choose the right one. Perhaps the right choice itself could be a mixture of several strategies. The objective of this paper is to reflect on some of these ideas, based on the author's unique experience in this field right from its early stages, in order to facilitate an introspective appraisal of agroforestry research and help initiate a discussion on the directions of agroforestry research.

Myths and Misconceptions in Agroforestry Research

Some of the reasons for the perceived concerns (about the failure of agroforestry to deliver expected benefits) can be related to the prevailing myths about the science of agroforestry, and misconceptions about the practice of conducting agroforestry research. A major myth centers around the popular perception that agroforestry involves "miracle" tree species that can deliver wonders. The "miracle" varieties of the green revolution became successful only after the scientific bases of the higher yield-potential of dwarf cereals were established, only after the soil conditions and management requirements for facilitating them to attain their potential were understood and provided, and only after enabling social and political policies were put in place to help farmers adopt them. None of these has happened in the case of agroforestry. Some trees and shrubs have been branded as multipurpose species. Their potential to deliver the multiple products and services have not been understood fully; perhaps because of that, the scientific mechanisms involved in those "miracle" abilities have not been explored. The research that has gone into even the most "miraculous" among the so-called miracle trees, say the genus *Leucaena*, pales when compared to what has gone into research on food crops such as rice (*Oryza*) and maize (*Zea*).

Another popular myth is concerning the "magic" of soil improvement in agroforestry systems. Quite a lot of ambiguity and misconceptions are involved around the supposedly magical ability of trees and tree-based systems in terms of nutrient cycling, soil conservation, and soil fertility improvement. The benefits of agroforestry (and for that matter, any system) cannot surpass the principles. Reviewing the results of nutrient cycling studies in tropical agroforestry systems during the past two decades, Nair *et al.* (1999) concluded that the main tree-mediated processes that determined the extent and rate of nutrient cycling in agroforestry systems were three: (1) increased N input through biological nitrogen fixation by nitrogen-fixing trees, (2) enhanced availability of nutrients resulting from production and decomposition of substantial quantities of tree biomass, and (3) greater uptake and utilization of nutrients from deeper layers of soils by deep-rooted trees. The review also cautioned that our understanding about these mechanisms were far from satisfactory so that some of the widely held assumptions about their benefits could be wrong or incomplete.

Misconceptions also abound in agroforestry research. A major one is about research methodologies. In agroforestry research, be they of biophysical or socio-economic nature, we rely on methodologies that have been developed in specific disciplines, often for conditions that are simpler (or, different) than those of agroforestry. Such methodologies may not encompass the special conditions and requirements of agroforestry. To cite a specific example, quite a lot of reports are available on nutrient cycling studies in homegardens and multistrata systems of agroforestry. They all start with the assumption that homegardens are ecologically stable and sustainable systems characterized by highly efficient nutrient cycling, and then create nutrient budgets with the "conventional" mass balance approach with estimates of inputs and outputs. Invariably all such estimates show high rates of nutrient outputs from the systems implying that they in the long run will deplete the soil of its nutrient store and make the systems ecologically unsustainable (Beer *et al.*, 1998; Nair, 2000). They caution that nutrient (especially N) removal rates in harvested products from these systems are so high that N deficiency would eventually limit system's productivity. Yet, home-gardens have flourished for a long time without any apparent symptom of soil-nutrient-depletion. Following these evaluations, Nair (2000) suggests that there might be inherent anomalies in applying the methodologies that have been developed for monocultural systems for the study of mixed-species systems. Although the homegardens are found predominantly in the humid tropics, this issue of research methodology is equally relevant to other ecological regions as well.

Agroforestry systems are a puzzle to the economists too. Since the basic-needs approach of classical political economics (goods have value because people find them useful in satisfying needs for food, shelter, or clothing) has been replaced by the market superiority premises of neo-classical economics (it is only for the sake of profit that any man employs his capital in the support of an enterprise, and he will therefore endeavor to employ it in the support of value or to exchange for the greatest quantity of goods or money), economic efficiencies of farm enterprises are calculated based on their profit generation. Agroforestry systems that are primarily subsistence systems, which fulfil the basic needs of farm families (mostly food), rank very low in the value premises and theoretical assumptions that underline the neo-classical analysis (Current *et al.*, 1995). Yet, agroforestry systems have flourished for a long time. Thus, agroforestry systems are a sort of "mystery" to the ecologists and the economists alike.

Many of the other misconceptions about research in agroforestry are not necessarily unique to agroforestry, but are characteristic of most such application-oriented research on low-input, integrated land-use systems to support the evasive and ill-defined goals of rural development. The literature is replete with arguments and counter-arguments supporting (or disputing) the merits (or demerits) of one type or strategy of research versus another, even if both are two sides of the same coin and cannot be mutually exclusive (more about this is discussed later in the paper).

Natural Resource Management - The Key Element of Agroforestry Research

A fundamental aspect of research in agroforestry is the understanding of the linkages between land use and natural resource management (NRM). The objective of NRM is the sustainable use of the resource base such as soil, water, plant and animal germplasm, and solar energy for production goals and environmental preservation. It involves the idea of designing land-use systems based on the judicious use of natural resources, incorporating the structural and functional attributes of natural ecosystems. The concept of NRM has both temporal and spatial dimensions. The temporal dimension refers to the needs and aspirations of the current as well as future users. For most practitioners of agroforestry, satisfying immediate basic needs such as food, fodder, fuelwood, and small timber, and possibly obtaining some cash, may be the immediate need; at the same time, they are also concerned that the production base is maintained or even improved so that future generations are not deprived of its use and enjoyment. The spatial dimension relates to ecosystem hierarchy at different levels ranging from the farm to the village (or watershed) and region (or country) and the globe. The various ecosystem functions of agroforestry at these spatial and temporal scales can be presented as a matrix as in Fig. 1.

Let us briefly consider the specific situation of NRM in the dry areas, the main target area of this journal. It is common knowledge that water is the most crucial component of NRM in dry areas, and the drier the climate, the more the water required to meet demands of evapotranspiration. And, the more the water used for irrigation to support agriculture, the more the chances of soil salinization. Raising short duration crops and scheduling their cropping season to synchronize with rains is a strategy that has been used since time immemorial in dryland agriculture. Traditionally, several of such low-rainfall areas, such as the extensive savannahs of Africa, also support large herds of herbivores in pastoral and grazing systems. In the ecological sense, the mammals harvest and convert the primary production of vegetation whether grass or tree and store biomass, and the humans live trophically downstream from the grazers and browsers eating the animals or their metabolites such as milk and blood (Ewel, 1999).

As repeatedly emphasized in agroforestry literature, the challenge in agroforestry is to manipulate such well established ecological principles and other laws of nature to fulfil the production objective of crops and other plants without depleting the

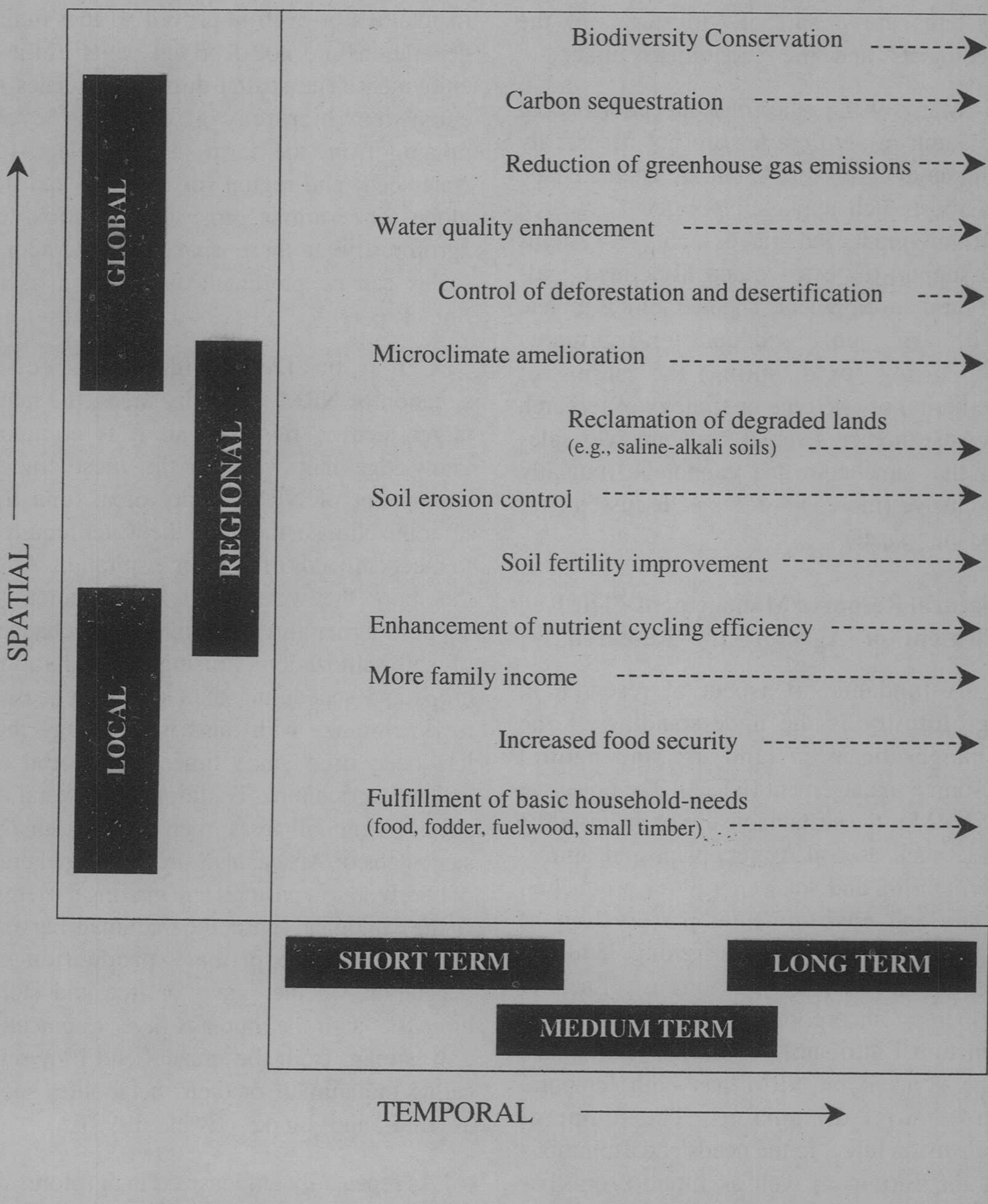

Fig. 1. Objectives of natural resource management strategies in agroforestry at various temporal and spatial levels.

resource base. Recent studies of some natural ecosystems, especially tropical grasslands, have shown that they can be highly productive (Solbirg *et al*., 1996). Indeed, a large number of grasses and tree species are known to allocate a high proportion of their photosynthate and nutrient reserves to roots and below-ground organs, largely as an adaptation to herbivory and fire. Analyzing the ecosystem-mimic hypotheses (Lefroy *et al.*, 1999) in the context of the drylands of sub-Saharan Africa, van Noordwijk and Ong (1999) hypothesize that where annual food crops replace the natural grass understorey of the savannah systems, water use will decrease and stream and groundwater flow change unless tree densities increase relative to the natural situation. These predictions are based on a number of assumptions, some of which are unsubstantiated and some others are not relevant to managed agroforestry production systems. Moreover, it is common knowledge from a large number of dryland situations that increasing tree density over crops will decrease crop yields (Breman and Kessler, 1995). Although the understorey species may benefit from temperature reduction under tree canopies, the water use by trees providing the shade may far outweigh that advantage in terms of the crop's productivity (Ong and Leakey, 1999). This may not be too much of a problem in traditional systems involving indigenous trees that are long adapted to local conditions including intercropping. But introduction of fast-growing trees may tilt this equilibrium to the negative side of overall productivity and total benefit to the farmer.

Next to water, soil resources are the important component of NRM in drylands. Although management of the two major resources (soil and water) cannot be considered in isolation, in dryland systems, soil management issues such as fertility maintenance and erosion control receive comparatively lesser attention than water-related issues such as irrigation (and, related to that, salinity control). But soil fertility decline consequent to continuous cropping is a major problem even in semi-arid agriculture. Following a comprehensive review of the role of trees and fallows in soil fertility maintenance in the traditional farming systems of Sub-Saharan Africa (SSA), Kaya (2000) concluded that depending on the management of resources, there were possibilities for soil fertility depletion or replenishment, indicating, in turn, NRM possibilities and directions for capitalizing on the benefits and minimizing the adverse effects in the dry areas. The effects of some of the prominent arid-zone trees of India such as *Prosopis cineraria* on soil fertility and yield of undersown crops have been well documented (Mann and Saxena, 1980; Shankarnarayan *et al.*, 1987). Several other reports indicating the beneficial effects of trees on soils are also available from various semi-arid and dry parts of India. The effect of trees and agroforestry systems in saline-land reclamation is another area, where management recommendations based on convincing research results are now available from India. These are just a few examples to illustrate the realm of possibilities for natural resource management through agroforestry in the arid zone.

Moving Forward

The gains and developments of more than two decades of agroforestry research are certainly impressive. In particular, the second half of 1990s has witnessed a large number of top-quality research and specialized publications: for example, tree-crop interactions (Ong and Huxley, 1996; Rao *et al.*, 1998), plant litter quality and decomposition (Cadish and Giller, 1997), soil conservation (Young, 1997), and directions in agroforestry research (Nair and Latt, 1998). Efforts to address specific land-management problems have resulted in some application-oriented agroforestry publications on subjects such as the management of imperata-infested grasslands in south-east Asia (Garrity, 1997), and improved fallow systems (Buresh and Cooper, 1999). Computer-based models and other quantitative approaches have become a major part of research in many situations: for example, Auclair and Dupraz (1999).

Undoubtedly agroforestry is now on a firm scientific footing. Today agroforestry is no longer a mysterious enigma that defies science and scientific principles, as it was perceived two decades ago. Today we do not just speculate on the advantages of trees and crop and/or animal associations, nor do we fantasize about their magical or imaginary virtues; we now have scientifically rigorous data to prove/disprove several of the assumptions and speculations that used to be characteristic of discussions on agroforestry. Agroforestry is well on its way to becoming a specialized science at a level similar to that of crop science and forestry science.

The question, now, is what next? We cannot expect to continue to do agroforestry research in the "business-as-usual" nor the "one-size-fits-all-and-for-ever" modes. The hard-earned scientific gains need to be put to practice for solving the problems we had set out to address when we started research 25 years ago. In order to accomplish that, a two-pronged approach seems to be the best strategy. First, process-oriented research should be extended to hitherto under-researched aspects of agroforestry, and secondly, a rethinking is needed on the overall research directions of institutions at all levels (local, regional, and global). The former category of research can be undertaken by individual researchers or institutions, whereas the latter needs a longer-term commitment by country-wide, regional, or international efforts.

Some New Thematic Areas of Agroforestry Research

The 'Agro' part of agroforestry

In spite of any semantic shortcomings of the word agroforestry (Nair, 1993), it is obvious that it literally entails two parts: "agro" and "forestry". In most discussions, agroforestry is perceived as a part of forestry than of agriculture. In reality, agroforestry is an aspect of neither agriculture nor forestry. Agroforestry has (or, should have) an identity of its own. In any case, the herbaceous component of agroforestry systems is equally important as the woody (tree) component. However, all discussions on component improvement or research tend to center around trees – multipurpose trees, nitrogen-fixing trees, indigenous fruit trees, and so on – to the total exclusion of agronomic components. The reasons are several: trees are the "central" components of all agroforestry systems; the greatest opportunities and needs in agroforestry are, or were, in the area of trees; trees provide production and service functions; the emphasis in agroforestry is on exploiting the trees and their attributes for enhancing productivity and sustainability of farming systems, and so on. However, the "agro" components of agroforestry are important too, certainly from the production point of view. Usually, in agroforestry experiments, the crop component is considered as "given". In most cases, the varieties used are improved genotypes that have been developed for high performance under conditions of optimum supply of light, nutrients, and water, and freedom from pests and diseases. Paradoxically, one of the compelling reasons for the development of agroforestry is the lack of such optimum conditions in many cases; indeed, agroforestry is expected to do well under conditions that are far from optimal for the performance of agronomic crops (Nair, 1998). Suffice it to say, crop varieties and cultivars that are adapted to less-than-optimal growth conditions are essential in agroforestry. Varieties of crop plants have been developed for some special conditions (water shortage, lower and higher pH ranges, and even nutrient deficiency), but breeding/selection of varieties adapted to low light conditions has perhaps never been attempted. There is a wide range of other issues related to crop selection and management in agroforestry systems. Agroforestry research in the 21st century should embrace agronomic components as enthusiastically as the tree components.

Domestication of indigenous trees

It has long been recognized that one of the greatest opportunities in agroforestry lies in the domestication and improvement of the large number of indigenous plants that are used in a number of traditional agroforestry systems all over the tropics (Nair, 1993). Yet, research has been sorely lacking in this vital area. Domestication, which involves accelerated human-induced evolution to bring species into wider cultivation (Simmonds, 1976), is an iterative procedure involving the identification, production, management, and adoption of desirable germplasm. It can occur at any point along the continuum from the wild to the genetically-transformed state, and it has both biological and socio-economic dimensions (Leakey and Simons, 1998; Leakey and Tomich, 1999). Income (cash) generation and food value are the two most important motivations that promote domestication efforts.

Judging from the examples of the benefits accrued from some of the successful domestication efforts such as the "ber" or desert apple (*Zizyphus nummularia*) as a cash spinner in the arid zone of India, fruit trees such as *Irvingia gabonensis* and *Dacroydes edulis* in Nigeria (Okafor, 1980; Okafor and Lamb, 1994), and the various palm trees such as peach palm (*Bactris gasipaes*) and aguaje palm (*Mauritia flexuosa*) in South America (FAO, 1995), the opportunities offered in the domestication and marketing of indigenous fruit trees in agroforestry systems seem unlimited. Trees and shrubs of value in pharmaceutical and cosmetic industry are another major group of species that offer much scope for improvement and exploitation in the agroforestry context. In addition to the commercially well known species such as vanilla (*Vanilla* sp.) and cardamom (*Eletteria cardamomum*) that are grown traditionally in the "typical" agroforestry pattern (under tree shade), there are a large number of indigenous species that are used for a variety of medicinal purposes in many indigenous cultures, and opportunities for their exploitation for commercial purposes are enormous. A case in point is that of *Prunus africana*, an indigenous "wild" tree, threatened by extinction. Its bark is used to treat prostrate disorders. The bark of a single tree is reported to fetch \$ 200 to \$ 2,000 to a collector and \$ 6,500 to \$ 65,000 in the pharmaceutical market (Dawson and Powell, 1999).

Research methodologies

As has already been noted, in most agroforestry research, we are seriously constrained by the lack of methodologies that are appropriate, or are misguided by the use of methodologies that we consider appropriate but in reality are inappropriate, to the systems we are studying. As Nair (2000) states, the conventional nutrient cycling studies and economic analyses that have proven to be inappropriate for agroforestry should give way to innovative and appropriate methods that have the scientific rigor as well as the required depth and breadth to truly "handle" the situation.

Socio-economic issues

Development of appropriate biological technologies forms only one, perhaps the first, step in the promotion of agroforestry; provision of public policies and institutions that support program implementation is an equally important requirement. Analysis of the experience of several countries in Latin America has shown that rapid and dramatic expansion of agriculture and plantation forestry occurred when supportive public policy was put in place through appropriate subsidies, national investment, and adequate extension programs (Southgate, 1992). The Green Revolution in Asia was similar: it too occurred in places where national policies supported and facilitated the availability and adoption of the technologies.

In a recent analysis of the socio-economic and institutional issues of agroforestry, Alavalapati and Nair (2000) observe that agroforestry is lacking in a number of such issues. They articulate that target-specific agroforestry policy formulations are needed to ensure distributional equity of agroforestry benefits within the society. Non-market benefits such as protective and environmental values, option values, value-added opportunities, and spin-off values must be considered in agroforestry-system valuation. Innovative incentive mechanisms that internalize non-market benefits are sorely needed to ensure their optimum production. This further articulates that well defined property rights and their effective enforcement will ensure long-term investment, improve economic efficiency, and promote distributional equity. Appropriate monetary policies and market integration also influence the widespread adoption of agroforestry. Practically no research has been done on any of these aspects of agroforestry.

Impact assessment

A major issue concerning agroforestry is the lack of a comprehensive, robust, and widely applicable methodology for realistically assessing the benefits and impacts of agroforestry. Traditional agroforestry systems have evolved under site-specific conditions for meeting the land users' basic needs. Our information about them is mostly experiential rather than experimental. In experimental systems, the objectives are specific, and the results are therefore quantifiable according to the accepted criteria for assessing those objectives. Studies of this nature have been much less common in the socio-economic than in the biophysical arena. Although some notable initiatives have been made – calculation of a whole farm efficiency index (Johnson, 1994), bioeconomic modeling (Menz and Grist, 1996), and socio-economic impact assessment of some agroforestry interventions (Current *et al.*, 1995; Mercer and Miller, 1997) are among the few such examples – these, unfortunately, have not been vigorously pursued. The analyses of single factors (or a small cluster of them) cannot be used for realistic assessment of the impact of agroforestry. Assessments that focus on only one or a few of the factors that affect agroforestry systems will be partial and inadequate. The problem is further compounded by the temporal (short- vs. long-term) nature of the benefits. We need a measure of the combined value of all products and services at various time scales. Although a formidable task, the development of appropriate methodologies that embody economic, social, and environmental costs and benefits of agroforestry should be a priority item in the agroforestry research agenda for the 21st century.

Some Broader-Scale Issues in Agroforestry Research

Spatial issues: The need for larger-scale perspectives

Agroforestry field research has so far focused on smaller spatial scales or research plots in experiment stations or farmers' fields. Less than 5% of the publications in agroforestry are based on global, regional, or even watershed scales (Nair, 1998). Publications that appear to take a broader perspective usually address the issues in a conceptual generalized manner, with little data from empirical investigations. As a consequence, the importance of agroforestry in issues that need to be assessed on a much larger scale than individual fields or plots – for example, carbon sequestration, water-quality improvement, biological conservation and biodiversity, and extraction of nontimber forest products – has been neglected.

Carbon sequestration in terrestrial ecosystems is a good example of such issues. Agroforestry systems such as fuelwood plantations, shelterbelt/windbreak systems and woodlots may have the potential to sequester C, or offset fossil fuel emissions by substituting sustainably produced fuelwood and fodder (Brown *et al.*, 1993; Schroeder, 1993). Based on a preliminary assessment of national and global terrestrial C sinks, Dixon (1995) suggests that there are two primary beneficial attributes of agroforestry systems in this regard: (1) direct near-term C storage (decades to centuries) in trees and soils, and (2) potential to offset immediate greenhouse gas emissions associated with deforestation and subsequent shifting cultivation. Schroeder (1994) estimated that median carbon storage by agroforestry practices was 9, 21, and 50 Mg C ha^{-1} in semi-arid, subhumid, and humid ecozones, respectively. Dixon (1995) estimated that within tropical latitudes, one hectare of sustainable agroforestry could provide goods and services with the potential to offset 5 to 20 ha of deforestation. The impact of agroforestry on terrestrial C budget is an area that needs to be researched in more depth.

Other environmental benefits such as water-quality improvement through agroforestry have received no attention in agroforestry research in the tropics. Results from temperate-zone agroforestry point to the beneficial effects of riparian buffer strips in reducing sedimentation load and nutrient pollution in agricultural landscapes (Schultz *et al.*, 1995). These may not be relevant to most of the tropics, at least for now. However, other potential benefits such as amelioration of salt-affected soils through agroforestry have been amply demonstrated (Tejwani, 1994), but not adequately promoted.

Conservation of biodiversity is another issue in which agroforestry may have a major role to play but which has received scant attention. It is obvious that agroforestry systems are far more diverse than crop or tree monocultures. It may not be prudent, however, to expect that having a high number of economically useful plants per hectare would lead to biodiversity conservation. Similarly, in commercial prospecting among natural sources for new products (such as the biodiversity prospecting, which is usually promoted not because of the realization of the value of nature's diversity for ecological, aesthetic, or spiritual reasons, but by the lure for the discovery of the miracle plant or animal that contains the cure for such human diseases as cancer or AIDS), the value of biodiversity is not as high as some conservationists might suppose (Simpson, 1997). Apart from a few attempts to list the number of economically useful plants that are found in some indigenous agroforestry systems (for example, Nair, 1989; Tejwani, 1994; De Jong, 1996; Lawrence, 1996), or isolated studies such as mammalian diversity in coffee agroforestry systems (Gallina *et al.*, 1996), agroforestry research has seldom attempted to establish the importance of agroforestry as a viable option for biodiversity conservation.

The "Versus" syndrome

As mentioned briefly in the early part of this paper, research in agroforestry and similar other low-input, integrated land-use systems is faced with what can be called the "versus" syndrome. The reference here is to the tendency to perceive two (or more) closely related, complementary phases of research, as contradictory and mutually exclusive. For example, we hear constant controversies as biophysical versus socio-economic focus, "on-station" versus "on-farm" research, market versus non-market values, short-term versus long-term benefits, farm-level versus regional- or ecosystem-level applications, and so on. It is inconceivable that any one of these pairs (or clusters) can progress at the exclusion of the other. In agroforestry, progress in biophysical research will be meaningless and even impossible without simultaneous progress in socio-economic research, and vice versa; on-station research has no meaning without on-farm research; and so on. Resource limitations and professional chauvinism could be the reasons for the "versus" syndrome. The sooner we realize that it is not a question of "either-or," but it is one of both (or all) in a meaningful, judicious combination, the better it will be in agroforestry research. However, since research institutions, protocols, and guidelines are compartmentalized along strict lines of discipline, focus, and other bases, crossing those lines would be an unaccomplishable – yet noble – enigma.

Quality of Research and Research Infrastructure

In most national settings, agroforestry research is confined mostly to what can be termed as observational trials: undertaking field trials of various multipurpose tree (MPT) germplasm at different management regimes (such as pruning schedules, planting arrangement, and so on) and observing the effect of these on intercropped herbaceous species; examining – albeit superficially – the effect of planting MPTs on soil fertility or soil amelioration; and computing the economics (labor utilization, "net gains" from the sale of products), and so on. For example, the author's computer search of the recently (since 1985) published reports on agroforestry research in dry parts of India yielded dozens of such reports; but most of them belong to what can be called "what" type of research: what happens when something is done in a particular manner. These studies are conducted with the objective of mostly testing some "new" or "improved" technologies at specific locations. The assumption is that the results could be applicable in the region of the study and similar other regions. The reality, however, is that such results may not be repeated if the same trials are conducted again even in the same region, let alone in other places. There are several reasons for that. The most important is that such observational studies seldom reveal any information on the reasons – "why" and "how" – of the observed results. Unless the underlying reasons and principles are understood, the chances are the results may not be reproducible. That is the main problem with most of the ongoing research in agroforestry in a number of national settings. Admittedly, agroforestry research is location-specific, and some amount of specificity to the location where a study is conducted is to be expected. However, unless research is process-oriented, the results will be of "hit-or-miss" nature.

The importance of the right type of political leadership and the creation of enabling policies should not be forgotten in this discussion although these are not the themes of discussion here. Research agenda of any institution or country has to be cognizant of and compatible with the prevailing economic conditions and institutional infrastructure. Because of the low priority given to research – especially agroforestry research – in many developing countries, the gap between developed countries (and international research centers that are replicates of developed-country institutions) and the developing nations is widening in science and scientific activities as in almost any economic or academic activity. In a recent analysis of science in the future of India, Rao (1999) aptly states "it is becoming increasingly difficult for Indian researchers who work at the cutting edge of science and technology to do their jobs well because of the poor infrastructure and facilities at most institutions, particularly universities." His observation that "oppressive administrative practices, political interference, and personal animosities tend to impede creativity and innovation, as in most other developing countries" is right on target. The bottom line is that, in order to make progress in agroforestry research or any other beneficially creative activity, progressive political leadership and enabling national policies are absolutely essential.

Conclusions

Agroforestry research of the past more than two decades has contributed substantially to our understanding of the scientific basis of agroforestry and therefore the contribution it can make to rural development in the tropics. However, all expectations about the potential role of agroforestry have not been fulfilled. Although this is not unique to agroforestry, these frustrations should not be allowed to undermine our enthusiasm. Agroforestry is in the threshold of a leap forward. Any slackening of efforts at this stage could scuttle the potential gains of two decades of efforts, and would thus be a serious blow. However, as we enter the new millennium, we need a re-evaluation of the directions and strategies in agroforestry. Considering the location specificity, diverse objectives and expectations, and shrinking research funding in agroforestry, a logical strategy should involve a judicious blending of research at local, regional, and global levels, with short-, medium-, and long-term goals. The matrix of Fig.1 can be a guideline for research planning in a wide range of spatial and temporal context. For example, planners and policy makers at different levels of organization (farm, watershed or village, province, country, and so on) could decide on objectives of their research for immediate or longer-term benefits. While solving local problems of immediate nature is an important target, all efforts should not be concentrated on such "fire-fighting" issues at the exclusion of broader ones. Disappointingly, such a comprehensive strategy for agroforestry research is lacking in most developing countries where agroforestry could play a vital role in the national economic development. As for the developed countries, the role and promise of agroforestry are quite different from those of the developing nations. Therefore, unlike in many other aspects of land-use research, the developing countries may not be in a situation to benefit much, or look for examples and experience, from developed countries in agroforestry research.

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