Trees on farms: agroforestry

Agroforestry involves a wide range of trees that are protected, regenerated, planted or managed in agricultural landscapes as they interact with annual crops, livestock, wildlife and humans.

Photo: Brawijaya University/Kurniatun Hairiah

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CHAPTER ONE

Agroforestry paradigms

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Highlights

- Agroforestry as a word enters its fifth decade, as a practice it is as old as agriculture
- Definitions of agroforestry have evolved during the first four decades from plot- to landscape- and policy-level concepts
- Agroforestry can be understood at these three scales as interactions, interfaces and synergy between agricultural and forestry components
- Agroforestry has its roots in farmer-focused learning loops supported by formal science

1.1 Introduction

> *"The existence of large numbers of people in the fragile ecosystems of the developing world, and the fact that these ecosystems occupy the greater proportion of the land of the developing economies suggest that means must be devised which will assist in increasing the productivity of these ecosystems while at the same time either rehabilitating them or arresting the process of degradation. Agroforestry is a system of land management which seems to be suitable for these ecologically brittle areas. It combines the protective characteristics of forestry with the productive attributes of both forestry and agriculture. It conserves and produces."*
>
> ____*(King 1978)*[1].

In the four decades of its existence[2], agroforestry as a concept has been understood and defined in multiple ways, often referring to a specific system scale of interest[3,4,5,6,7]. Its potential contribution to 'restoration' and 'conservation' alongside 'productivity' of land has been expressed in many ways, emphasizing soil conservation[8], land degradation[9], food security[10], land use for integrated natural resource management[11,12], or biodiversity conservation[13]. The range of studies include trees and their domestication[14], tree–soil–crop interactions at plot level[15], the interactions between land, labour, knowledge and risk at farm level[16], human livelihoods at landscape scale[7], dynamics of tree-cover change in space and time[17], social-ecological systems at landscape scale[12], the multiple value chains that start with tree, crop and livestock production in landscapes[18], and the policy domains[19] of forestry and agriculture in the context of sustainable development goals[20], global change and multi-species agroecosystems21, the role of trees in agro-ecology[22], responsible trade in globalizing markets[23] and global climate change[24]. The inclusion of all these aspects under a single term may indicate a need for greater clarity on the different system scales involved and their connections. Figure 1.1 provides a four-level typology of what can be seen as nested paradigms: mutually compatible but distinct in concepts, methods and implications for practice and policy. The various definitions that have over time been given for agroforestry reflect these concepts[25,26].

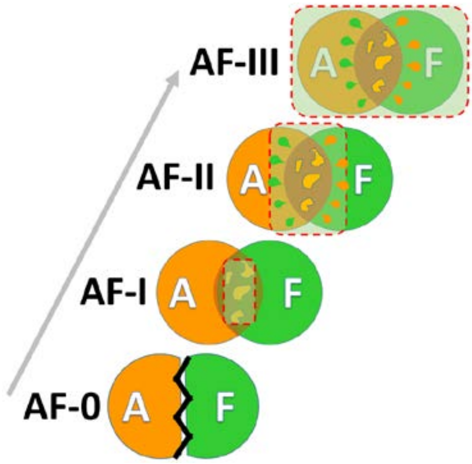

Figure 1.1 Evolution of what agroforestry is understood to be in relation to agriculture (A) and forestry (F): exclusion, by definition, of any interface (AF0), a collective name for specific practices involving farmers and trees (AF1), multifunctional landscapes (AF2) and a domain for coherent policies for all land uses (AF3)

We will describe the way these concepts evolved in this introduction to a book that in three sections takes stock of ***thematic aspects*** (focussed on understanding components, systems and their processes of change and feedback), ***change in context*** (focussed on 'theory of place' or the ways that contextual factors shape current efforts in 'land restoration') and on policies as part of ***theories of induced change***. The latter summarize experience and evidence of the way constraints at the level of knowledge, understanding, motivation, regulation and investment can be overcome (in their specific contexts) to let the full spectrum of agroforestry solutions contribute to rural livelihoods, to sustainable multifunctional landscapes and to attainment of the Sustainable Development Goals[27] at (inter-) national scales.

1.2 Definitions

Before the term 'agroforestry' emerged, agriculture and forestry had been on very different institutional pathways even though 'farmers' and 'forests' interacted in the real world in multiple ways for as long as agriculture existed (ten thousand years or so)[28]. From a farmer's perspective, forests were both a resource (source of firewood, utility and construction timber, hunting, fishing and grazing opportunity, protecting water quality, regenerating soil fertility in swidden/fallow rotations[29]) and a threat (wild animals, robbers and, in some environments, fire). 'Forest' as a word and as a concept originated in exclusion, in boundaries and in claims by sovereigns to reserve access to part of a landscape's resources. Use of forests for hunting preceded the relevance of forests for shipbuilding and navies[30]. Management of the regeneration of forests gradually led to plantation forestry controlled by forest authorities who inherited an ambivalent relationship with farmers, perceived as the major threat to forests. Schools for training professional foresters to work as resource managers on behalf of those in power were set up separate from schools of agriculture, training professionals to support commercialization and intensification of agriculture through business development, extension and research. Where agricultural and forestry training became united under a common umbrella, this difference in culture, science and relationship with rural communities persisted. As a formal concept, definitions of agriculture tended not to exclude trees and farmer-managed forests or plantations, but 'forest' definitions tried a combination of criteria based on tree cover and control by forest authorities to set apart some of the area. Statistics and spatial databases related to this distinction between agriculture and forestry were (and still are) maintained at national levels and compiled internationally by the Food and Agriculture Organization of the United Nations (FAO), with challenges to consistency and comparability that became problematic where international policy instruments emerged[31].

At the start of 'agroforestry' as a concept in the late 1970s, critique of the focus of the 'green revolution' on intensified monocultural forms of agriculture added to the recognized failure of forest authorities to interact with farmers. Existing combinations of trees, crops and livestock on farms could benefit from a more systems-oriented understanding under a new umbrella term while social contracts between forest authorities and farmers that had emerged in the plantation establishment as 'taungya' in Myanmar or 'tumpangsari' in Indonesia offered hope for widespread use in restoring deforested and degraded lands. In the first decade of agroforestry, definitions emphasized that it was a 'collective name for…', with specifications of the components and the 'deliberate' management of the combinations. The degree of 'deliberateness' was not easily assessed, however, challenging answers to simple questions on how much agroforestry existed where. The first agenda for agroforestry, indeed, was to prove that **agroforestry exists** and that the many practices and land-use systems described under the umbrella term had properties in common as well as a functional typology and terminology to differentiate them[32,33].

The definition of agroforestry (Box 1.1) that evolved in the first decade[34] is still the most widely quoted[35,36].

Box 1.1 AF1 DEFINITION[22]

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

When the 'honeymoon' period of discovery of the many forms of agroforestry was over, a more critical phase emerged in which research became a relevant complement to what was established as an information-sharing body in a first incarnation as the International Council for Research in Agroforestry (ICRAF). The close interactions between trees and crops that involved competition as well as opportunities for complementarity became a focus of biophysical research[37,38], with associated economic evaluation of trade-offs and risk analysis[39,40,41]. This resulted in hypotheses about the functioning of tree-crop combinations such as 'Benefits of growing trees with crops will occur only when the trees are able to acquire resources of water, light and nutrients that the crops would not otherwise acquire'[42]. Active involvement in genetic selection and improvement of trees with desirable properties became one of the emphases of agroforestry research[43] although the diversity of trees and circumstances made it hard to emulate the successes achieved with research into the major food crops or industrial timber plantations. A balance was sought between compiling information on any tree of potential relevance anywhere[44] and specific efforts in 'domestication' of species of particular value, with science-based support for farmer-driven efforts[45]. Deliberate introduction of alien species became known for its risk of invasiveness[46].

Expectations on benefits of agroforestry practices involving close tree-soil-crop interactions at plot scale were tempered, despite evidence for many of the hypotheses on positive functions of trees. Meanwhile, the landscape and livelihood scale gradually emerged, in the early 1990's, as a relevant scale for understanding agroforestry, in the AF2 concept. A new definition, proposed by Leakey[47] emphasized the benefits that can be achieved, but did not make the term operational in a world where segregated agriculture and forestry concept remained dominant. He proposed a new definition (Box 1.2).

Box 1.2 AF2 DEFINITION[35]

Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in agricultural landscapes, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels.

The lack of recognition of the active interface of agriculture and forestry became the basis for the AF3 focus, in the late 2000s–early 2010s, on harmonization of regulations and incentives in order to achieve the higher-level Sustainable Development Goals. Rather than defining 'agroforestry' as a separate land-use category that had complex borders with 'pure agriculture' and 'pure forestry', the central idea became removing bottlenecks to change, which were the result of the artificial segregation of policy domains. The fuzzy boundary between 'agriculture' and 'forestry' reflects a continuum that cannot be satisfactorily sliced into two (or three) parts but needs to be understood and managed as a continuum of functions. Recent analyses of global tree cover on farms provide a new tool to quantify agroforestry, with a key finding that more than 40% of agricultural land has at least 10% tree cover[48]. Ten percent is the lower limit of tree cover that countries can, according to international agreements, use in their definition of 'forest', so the overlap of the two sectors is much larger than what is commonly recognized. In the AF3 paradigm, the definition of 'agroforestry' can be simple (Box 1.3) and refer to the roots of the word. In doing so, it inherits all the complexity of 'agriculture' and 'forestry', without having to spell them out.

Box 1.3 AF3 DEFINITION[14]

Agroforestry, a combination of agriculture and forestry, is land use that combines aspects of both, including the agricultural use of trees.

The three definitions have direct consequences for answers to the simple questions, 'How much agroforestry is there in the world?' and 'Is it increasing or decreasing?'. To earn a place at international negotiation tables, the simplest definition (1.3), which shows the largest relevance, may be preferable[49]. To motivate programs to promote agroforestry, the aspirational aspects of the second definition can open minds and doors. Empirical work on comparing and improving 'agroforestry practices' will likely stay within the first definition (1.1).

1.3. Researchable hypotheses, performance metrics and methods

In the first decade of research, the 'Diagnose and Design' framework[50,51] was formulated in support of regional development planning (Fig. 1.2). However, in the practice of its application it seemed to have standard answers rather than an 'evidence-based' portfolio of potential solutions on offer. It was short-lived as a method, but the idea of 'learning loops' came back in multiple forms[52].

The gradual development of 'agroforestry' as a concept with the need for operational definitions that allowed agroforestry to be distinguished from non-agroforestry interacted with efforts to involve the full spectrum of scientific disciplines (biophysical, socio-economic, integrative geographical, integrative development studies, legal and policy-oriented) in a wider and wider set of questions (Figure 1.3). The early formulation of 'hypotheses' on resource use in agroforestry did not distinguish between contexts and targeted general statements that were presumably valid for

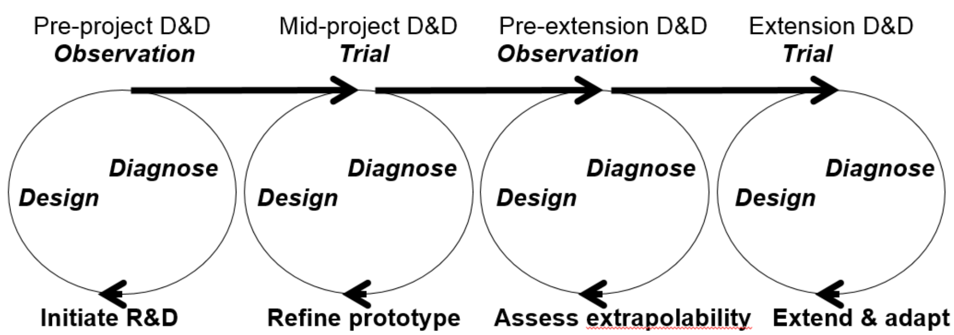

Figure 1.2 Representation in 1982 of multi-phase "diagnose and design" (D&D) learning loops and project cycles[38]

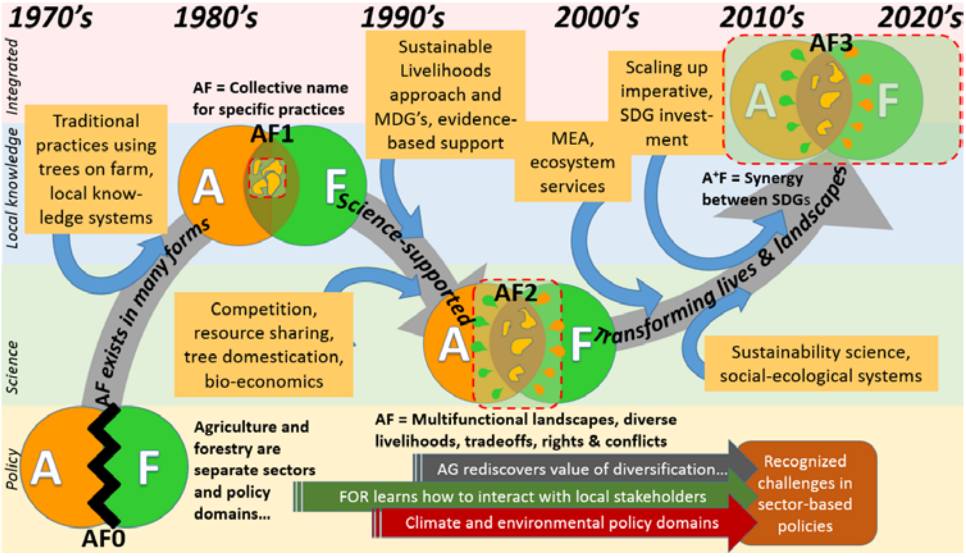

Figure 1.3 Summary of the evolution of agroforestry concepts and definitions over the last 40 years (MDG = Millennium Development Goals[6]; MEA = Millennium Ecosystem Assessment; SDG = Sustainable Development Goals)

all forms of agroforestry. Examples of validity could be found for each hypothesis in specific locations but not as generic truths[53,54].

Overall, research methods were derived from this wide range of disciplinary traditions, but the temporal and spatial scales of trees and landscape-wide interactions called for adjustments. The initial studies largely described existing land-use practices but in the interpretation the basic assumption of 'chronosequences'—that all land had the same initial properties and that changes were due to land use—became increasingly challenged. Soil science became one of the fundaments of agroforestry research[55].

The early use of replicated field trials was built on agronomic research traditions but ran into problems with the lateral expansion of tree roots that defied the treatments imposed and complicated the analysis. Use of larger plots and active root trenching were seen as answers but increased the cost and created a need to bring excluded interactions back into consideration of what happens on small farm plots[56]. Explicit attention to 'lateral flows' allowed empirical scale transitions by specifying what happens to a variable expressed per unit area when the scale of observation changes[57,58].

Many of the methods for characterization of tree diversity[59] and landscape functions[60,] built on established ecological rather than agronomic research methods. Agroforestry productivity estimates should refer to the whole plot, including the border areas, and not some subjectively selected central area that supposedly represents unit area productivity[61]. It became clear that uncontrolled crop, tree and management heterogeneity limited extrapolation of early on-farm research results to other farmers' fields while replicated case studies of 'best-bet' technologies (traditional or experimental) on different farms were preferable to the use of formal experimental designs.

Although landscape-scale planning of agroforestry in Kenya had been initiated in the 1980s from a landscape architecture 'research through designing' perspective[62,63], the interdisciplinary study of land-use change—its actors, drivers, consequences and feedback options—only emerged slowly in the agroforestry world[64], requiring the AF3 conceptualization to take shape alongside efforts to engage at policy level. Methods for co-location of research across disciplines in a pantropical comparison led to the Alternatives to Slash and Burn program of research on active tropical forest margins[65,66]. The focus on multi-scale, policy-relevant issues made this into a prime example of 'boundary work'[67]. Key to this type of boundary work was the recognition that science was only one of several knowledge systems and that clarifying contrasts and overlaps between knowledge systems could contribute to negotiated solutions in natural resource management conflicts involving the interface of agriculture and forestry[68].

System research traditions brought to agroforestry a shift from 'components' and 'cause–effect' relations to one of feedbacks, buffering and filtering[69]. The way 'process-based models' and 'empirical evidence' informed each other's progress in agroforestry was constrained by the disciplinary traditions from which agroforestry researchers continued to be recruited[70].

Performance metrics for agroforestry have evolved over time. Table 1.1 provides some examples of metrics for each of the three AF paradigms (scales of evaluation). Further details of these will be discussed in subsequent chapters of this book.

Silvo-pastoral system with native trees - Pacobamba, Apurimac-Peru. Photo: University of Bern, Switzerland/Sarah-Lan Mathez-Stiefel

Table 1.1 Performance metrics for agroforestry in the contexts of the three AF paradigms

AF1 (plot and farm level)[42,43,44]
Efficiency in productive use of land: Land Equivalent Ratio (LER) or the sum of relative yields of all components (with unsatisfied demand) compared to a 'current practice' monocultural production mode (LER values below 1 indicate that specialized (segregated) land use is more efficient than integrated ones) Efficiency in use of labour: wage rate at which a Net Present Value calculation for total input and output accounting of a land-use system yields zero (wage rates below what is considered to be 'minimum wage' indicate a drive out of agriculture) Efficiency in use of capital: Net Present Value (discounted flow of financial equivalents of all inputs and outputs of a land-use system; dependent on discount rate used) (relevant for capital investment and creditworthiness) Flexibility and risk management: maintenance of multiple options in the face of variation in weather, prices, labour availability, pests and diseases (percent of the years that performance is satisfactory) Resource conservation: avoidance of degradation of the resource base beyond the natural recovery capacity
AF2 (landscape and livelihoods' level)[56,71,72]
Landscapes in context of the Sustainable Development Goals: Multifunctionality Land Equivalent Ratio, sum of relative contributions to all Goals (relative to current shortfalls for each goal) compared to land uses specialized in a specific function Above- and belowground terrestrial carbon stocks and net greenhouse-gas emissions Water flow buffering metrics, such as Flow Persistence, and water quality of streams and lakes Procedural and distributive equity (over gender, age, social and wealth strata) of landscape-level resources Nutritional diversity: fraction of population (or specifically vulnerable groups) with access (physical, economic) to all key food groups, and relevance of all landscape elements in providing these
AF3 (policy level)[40,73,74]
Perception of agriculture as threat to forests and of forestry rules as threat to on-farm production of 'forest' resources Coinvestment and cooperation between traditional agriculture and forestry/conservation agents in enhancing multifunctionality Public recognition of 'trees outside forests' as providers of regulatory and productive functions Footprints: area equivalent of all consumption associated with a given lifestyle at current production efficiencies Carbon footprint: sum of attributable emissions per unit product or per capita (given lifestyles)

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