Chapter 20
Measuring Agricultural Sustainability in Agroforestry Systems

P.K. Ramachandran Nair and Gregory G. Toth

Abstract Sustainability is an intuitively understandable but difficult-to-measure concept. Despite numerous efforts over the years to measure and integrate the ecological, economic, and social aspects of sustainability, a set of universally acceptable standards for measuring sustainability does not exist. The prevailing ecology–economy conflict, in which ecologists consider economics as a subset of environment, while economists view the environment and its benefits as part of the economy, adds to the difficulty. Agroforestry systems (AFSs), considered paradigms of sustainability, are faced with these difficulties when it comes to measuring and comparing various AFSs with one another or with other land-use systems. In ecological terms, the best criteria and indicators of AFS sustainability are ecosystem services, such as soil-fertility improvement, climate-change mitigation through carbon sequestration, and biodiversity conservation. As an example of the variability of one of these measures across studies, estimates of carbon (C) stored in AFSs range from 30 to 300 Mg C ha^{-1} up to 1 m soil depth; additionally, 0.29–15.21 Mg C ha^{-1} $year^{-1}$ is estimated to be accumulated in aboveground biomass although most of it may not contribute to long-term C storage. In terms of economic sustainability, the principles and procedures of ecological economics and valuation of ecosystem services are useful approaches. Measurement of social sustainability, perhaps more challenging than measurement of the ecological and economic components, entails assessment of such social factors as policy, culture, and other socioeconomic indicators; a single measure of the combined manifestation of all these indicators is the adoption of improved practices by targeted land users. Standard procedures are available for measuring many of these indicators; however, most of them entail measurements taken over relatively long periods of time. Even if measurements and assessments are made rigorously, the ultimate benefit will depend on how sustainability is perceived and valued at all levels, from land users to national and international policy makers.

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20.1 Introduction

At the outset, we acknowledge that the title of this chapter is somewhat presumptuous, because in a physical sense, the "measurement" of an entity implies that it can be measured and expressed in precise quantitative terms. But is sustainability measurable? Admittedly, this question has been asked many times before. The difficulty of measuring and expressing the ecological, economic, and social components of sustainability and thus capturing its scientific complexity has been taken as a challenge by various groups of academics, and numerous approaches have been suggested for measuring each of the three principal components of sustainability. These efforts have also contributed to the development of a new branch of science, appropriately termed "sustainability science." In this chapter, we focus on these developments in relation to measuring sustainability in agroforestry systems (AFSs) in developing countries.

20.2 Sustainability

Although the word "sustainable" has been used in European languages since the early Middle Ages, it was with the publication of the United Nations report *Our Common Future* (WCED 1987) that it was introduced into the agricultural and broader developmental vocabulary and became a commonly used term (de Vries 2012). In spite of the numerous definitions and explanations that have been proposed since that time, the World Commission on Environment and Development (WCED) definition of sustainability still encapsulates the concept and continues to be widely used: "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs" (WCED 1987). To help policy makers decide what actions should be taken to make society sustainable, assessments of sustainability provide them with evaluations of integrated nature–society systems at both global and local scales and from both short- and long-term perspectives (Ness et al. 2007).

One of the oldest and most common meanings of the verb "to sustain" is to keep a person, a community, or the spirit from failing or giving way, to keep it at the proper level or standard. An English equivalent of this verb is "to last," meaning to go on existing or to continue. Thus, the concept of sustainable development has traditionally been framed as the balancing of this objective of preservation with economic advancement and well-being, acknowledging that economic advancement typically comes at a cost to the environment (MEA 2005). These contradictions manifest themselves in the apt term "ecology–economy divide."

20.2.1 The Ecology–Economy Divide

From the ecologist's perspective, the economy is a subset of the environment; all economic activity, indeed life, depends on the Earth's ecosystem. Inherent in this view is a realization of limits, often described in terms of the first two laws of thermodynamics ("conservation of matter and energy" and "entropy increases") and exemplified with phenomena such as energy flows through the food chain. Accordingly, this view recognizes resources as finite: water, gases, nutrients, and the cycles thereof that keep us alive are bound by constraints, which means that takings beyond regenerative capabilities equate to future deficits (Weiss 1992). Upon these grounds, ecologists call for "intergenerational equity," seeking to protect nature and natural resources for the benefit of future generations.

Traditional economists, on the other hand, view the environment and its benefits as part of the economy. This has major ramifications. For example, benefits derived from the environment are considered infinite and substitutable (Neumayer 2000); this translates into the belief that future generations are not affected by current environmental degradation and into the present-day undervaluation and/or degradation of natural resources. The traditional economic view reflects an adherence to an outdated model that defines the environment in terms of its potential for development and fails to internalize externalities. Externalities are market imperfections resulting from impacts of production, extraction, or consumption processes that typically affect third parties and are not compensated. Although these impacts can be positive, negative outcomes are equally possible and are unrecognized in the costs of the transaction. A prime example of a negative externality is biodiversity loss resulting from agricultural development.

20.2.1.1 Historical Examples of the Ecological Cost of Development

Food shortages caused by environmental destruction undermined several ancient civilizations to the point of collapse. Most of these declines can be traced to one or two damaging environmental trends. During the Sumerian civilization (which occupied a region in the lower valley of the Euphrates River in the Near East, fifth to third millennium BCE), rising salt levels in soils due to a flaw in the irrigation practices led to crop failures. In the Mayan Empire (Mexico, 2000 BCE to 600 CE), forest clearing led to soil erosion and loss of soil fertility. These examples illustrate how settlement and agricultural development that fail to account for environmental degradation can contribute to societal failure. Initially, as agriculture advanced, more people were fed and human survival rates increased. However, with increased survival rates, demand for food grew and was met with further agricultural expansion—at increasing expense to the surrounding environment. This expense came in various forms.

In Sumer, where wheat and barley were grown under heavy irrigation, high temperatures and an overfed water table led to a soil-salinity level beyond the tolerance threshold of these primary crops. Water-table elevation raises salt from throughout the soil profile up to the zone occupied by plant roots, where it can be further concentrated by evaporation. Given that desalination is a long process that was likely not understood at the time, little could be done to counteract the effect: a drop in crop yields of 42 % between 2400 and 2100 BCE and a continued loss of up to 65 % by 1700 BCE (Ponting 2007). Once this tipping point was reached, starvation quickly destabilized and ultimately led to the demise of Sumerian society.

Likewise, as the Mayan Empire sought arable land and fuelwood, it decimated the productivity of its soils through ever-expanding deforestation. Losses of tree cover led to increased erosion susceptibility, especially given the mountainous terrain of what is now Guatemala. Tree cover prevents erosion through several means, most prominently the anchoring of soil by roots and the reduction of rain and wind exposure (Khalilnejad et al. 2012). Moreover, decomposition of leaf litter and other senescent parts of vegetation helps to replenish soil. When these environmental benefits were eliminated through deforestation, malnutrition quickly ensued, leaving the society weak and increasing warfare over limited resources (Turner and Sabloff 2012). Whereas the Maya and many other ancient civilizations were encumbered by relatively few damaging environmental trends, today we have to deal with several.

20.2.1.2 Costly Side Effects of the Green Revolution

The Green Revolution of the 1970s to the early 2000s, brought about by technological advances in plant genetics, pesticides, and fertilizers, produced increases in crop production that helped eradicate large-scale hunger in many parts of the developing world. Moreover, like the settlement phase of early civilizations, it was accompanied by a corresponding population boom (Ehrlich and Daily 1993). Although the resultant increase in well-being was good for the contemporary population, the accompanying environmental degradation has led to concerns about intergenerational equity (Daily and Ehrlich 1996). To name just a few of the detrimental effects of agricultural expansion, there are shrinking forests, eroding soils, deteriorating rangelands, expanding deserts, rising atmospheric carbon dioxide, unpredictable water-table fluctuations, melting glaciers, and rising sea levels, each alarming in its own right (or weight). Although the Green Revolution contributed greatly to development, some of its methods are now clearly understood to be unsustainable.

20.2.1.3 Ecological and Environmental Economics

One of the ways in which traditional economics has attempted to adjust to the difficulties associated with the multidimensionality of development contexts is to classify the perspectives from which sustainability is measured. That is, sustainability is categorized into two forms: strong and weak sustainability. Those who perform assessments from the perspective of strong sustainability essentially give greater credence to the centrality of natural capital in the context of development. Natural capital is the totality of nature (resources, plants, and ecosystems usable by the Earth's inhabitants), one of the forms of capital typically distinguished by economists, the other forms of capital being social, man-made, and human capital. Strong sustainability maintains that there are no substitutes for this natural capital (Davies 2013). Weak sustainability, on the other hand, is the belief that such assets can be replaced with man-made capital with minimal ramifications.

As noted, when traditional economics, with its focus on cost efficiency, is applied to environmental concerns, it fails to account for the holistic essence of natural capital (Gasparatos et al. 2008). The subfield of environmental economics attempts to account for this shortcoming by valuing natural resources through contingent valuation and hedonic pricing methods, but it maintains a cost-efficiency focus. Contingent valuation is a mainstay of traditional economics that has been applied to environmental concerns in situations where it is difficult to observe behavior directly, such as in "non-use" or public goods, like the existence of a park or water quality. "Stated preference" is the core concept of contingent valuation. Such techniques work well in a developed context to price nature for consumption, but they do not take into account continued reliance on the resource or its role in producing other benefits within an ecosystem (weak sustainability). It is left to regulation and enforcement to address this "market failure," but because these are difficult to implement in a rural-development context, they have failed at all levels.

Ecological economics, alternatively, recognizes the finiteness and irreplaceability of nature (strong sustainability). This translates into greater recognition of natural capital and ultimately higher valuation of ecosystem services. Ecological economics, although still criticized for monetizing nature, does a better job than conventional economics of recognizing the importance of sustainability and attempts to account for externalities. Most criticism of ecological economics is based on the idea that the monetization of a particular ecosystem function will lead to the exploitation or abandonment of corresponding natural elements based on market shifts (Gómez-Baggethun et al. 2010). However, this criticism fails to consider the holistic nature of ecological economics in that any one element undoubtedly plays several roles within ecosystems and cannot be fully valued based on only one use, as elaborated in the next paragraph; many interactions are beyond our current comprehension, calling for greater application of the precautionary principle (UNESCO 2005).

A prime example of situations where caution is warranted is ecosystem services. An AFS, for example, provides a habitat for pollinators, water purification, and carbon sequestration, among many other benefits (Sect. 20.3.2). A technological advance may remove the need for the water-purification service of a particular system, but the other benefits would still be needed. Removal of the trees/AFS would not only damage these functions but also result in other ecological costs (some of which we may not yet understand). However, a noteworthy feature of the criticism of ecological economics is that although the latter recognizes the importance of social systems (as opposed to the individual rational actor at the center of traditional economics), it is not well suited to the sociological aspects of rural-agriculture-based development, because its focus continues to be on monetization, not interdependency, and it takes for granted the roles of property rights and other public policies. Interactions and conflicts, therefore, are realms in which ecological economics may fall short when human and animal habitats overlap, indigenous rights and protected species meet, or two purported sustainability efforts interfere with one another. Sometimes the interests of both parties coincide, but sometimes the interests of one must give way (perhaps allowing a further analogy with thermodynamics: there are elastic and inelastic collisions). For example, those supporting an ecotourism model for sustainable development in Costa Rica are in conflict with those in the country seeking clean energy from hydroelectric dams (Fletcher 2011).

Answers to these questions may be difficult to find. Indeed, there is no "correct" answer; there are only differing levels of willingness to both sacrifice and capitalize on present resources and different perspectives on what should be left for later generations. Identifying the best means of accomplishing such goals, if in fact they can be agreed upon, awaits further debate. The application of environmental and ecological economics to such problems often ends in stalemates. However, the inability (or inflexibility) of these varying forms of economics to find common ground on these issues led to the evolution of the concept of dynamism in what has become sustainability science (Weinstein et al. 2012).

20.2.1.4 Sustainability Science

Sustainability science can perhaps be viewed as an extension of ecological economics. It deals with the interactions between natural and social systems (institutions) and the measurement thereof, and it is especially significant for developing countries, whose inhabitants seek to improve their well-being. Numerous authors have suggested that the failure to agree on a collective vision of how to attain sustainability lies in the limitations and disconnections among disciplines (Kaufman and Cleveland 1995). The emerging field of sustainability science is not confined to the borders of traditional disciplines, but draws from sociology, ecology, and economics, among other disciplines, allowing for a dynamic approach to meeting the "needs of present and future generations while substantially reducing poverty and conserving the planet's life support systems" (PNAS 2015). Sustainability science arose from the realization that sustainable development is an aspiration to improve quality of life (development) in an enduring (sustainable) manner and that it can be accomplished only by acting across several scales of time and space; that is, it is a transdisciplinary approach that integrates and synthesizes the theory and practice of these quantitative (natural) and qualitative (social) aspects (de Vries 2012).

The salient characteristics of sustainability science are that it is use inspired and place based, hierarchical, and multidimensional and transdisciplinary (Wu 2012); it does not seek a broadly applicable "correct" decision. As the historical examples above illustrate, the ineffectual balancing of economy and environment can have disastrous results. This makes sustainability science—specifically, sustainable agriculture and the corresponding measurement of that sustainability—especially important.

20.3 Agroforestry and Ecosystem Services

20.3.1 Agroforestry

Over the past 35 years, agroforestry has been transformed from a vague concept into a robust, science-based, land-use discipline. Today, agroforestry is at the forefront of numerous development agendas, particularly in developing countries (Garrity 2012). The potential of agroforestry to sustain crop yields, diversify farm production, and provide ecosystem services has been well demonstrated in both the scientific literature and practical applications.

Various forms of agroforestry systems, such as silvopasture, intercropping, shaded perennials, riparian buffers, and forest farming, to name a few, are estimated to be practiced on over 1.6 billion ha globally (Nair 2012a, 2014). The underlying concept of the various forms of agroforestry is the beneficial role of on-farm and off-farm tree production in providing numerous products and services to support sustainable land-use and natural-resource management. Whereas the aboveground and belowground diversity provides more stability and resilience for the system at the site level, the system provides connectivity with forests and other landscape features at the landscape and watershed levels. These systems provide the ecosystem services and life-supporting functions of nutrient cycling, water-quality enhancement, and, in a self-perpetuating fashion, continued biological diversity (Hammond et al. 1995), which are recognized for their relevance in agriculture, biodiversity conservation, and natural-resource management (Heimlich 2003) as well as in food security, medical inputs, infectious-disease regulation, and climate-change mitigation (COHAB 2010). Although these functions interact with and promote one another, they can be categorized into the primary scales at which they operate: local (soil-productivity improvement), landscape (water-quality enhancement), regional (biodiversity conservation), and global (climate-change mitigation). The biophysical and ecological measurement of the sustainability of the systems will, therefore, depend on how each of these ecosystem services can be measured and quantified at various spatial levels (plot/farm → watershed → regional → global).

20.3.2 *Major Ecosystem Services of Agroforestry*

20.3.2.1 *Soil Improvement*

One of the tree-mediated benefits of considerable advantage in the tropics is that trees and other vegetation improve the productivity of the soil beneath them. Over the past three decades, research results have shown that three main tree-mediated processes determine the extent and rate of soil improvement in agroforestry systems: (1) increased nitrogen (N) input from nitrogen-fixing trees (NFTs) trees, (2) enhanced availability of nutrients resulting from production and decomposition of tree biomass, and (3) greater uptake and utilization of nutrients from deeper layers of soils by trees, the roots of which extend much deeper into the soil than roots of common crops.

Nitrogen-fixing trees and other "fertilizer trees" are a valuable resource in agroforestry systems. Farmland in many parts of the developing world generally suffers from the continuous depletion of nutrients, because farmers often harvest without fertilizing adequately or fallowing the land. One promising method for overcoming the acute problem of the low-nutrient status of soils, such as African soils in general, is to enable smallholders to use fertilizer-tree systems that increase on-farm food production. Nitrogen-fixing trees and shrubs, a large number of which are available (Table 20.1), are interplanted with food crops, the trees and shrubs are pruned periodically, and the biomass is added to the crops. The nitrogen-rich biomass decomposes rapidly, making the mineralized N and other nutrients available to the growing crop (Fig. 20.1). Additionally, the atmospheric N fixed by NFTs becomes available in the soil. Numerous estimates are available on the extent to which N is fixed by different NFTs under different conditions (Dubeux et al. 2015). Some widely held assumptions about their benefits could, however, be wrong or incomplete. Because of methodological difficulties in quantifying N_2 fixation, especially in older trees, our understanding of the extent of N_2 fixation, and therefore of the benefit that is actually realized by using NFTs in agroforestry systems, is unsatisfactory. Furthermore, it is not clearly understood how much of the N_2 fixed by an NFT is actually utilized or potentially made available to an associated crop during its growth cycle and how much goes into the soil's N store for eventual use by subsequent crops.

Biomass-decomposition patterns and therefore nutrient-release patterns from the decomposing biomass vary greatly among agroforestry tree species. Several biomass (litter)-quality parameters, based on the chemical composition of plant tissues,

Table 20.1 Biological nitrogen fixation: the family Leguminosae (Fabaceae) includes several, mostly tropical, N_2-fixing woody shrubs and trees

Subfamily	Genera ([a]) Number of species	N_2 fixation % N_2 fixers	Examples of common genera
Papilionoideae (T, S, H, C)	677 ([a]165) 12,000 spp.	High 90 (%)	*Erythrina, Flemingia Gliricidia, Sesbania*
Mimosoideae (T, S; tropical)	66 ([a]15) 2800 spp.	High to moderate 90 (%)	*Acacia, Calliandra, Leucaena, Prosopis*
Caesalpinioideae	256 ([a]84) 2800 spp.	Low 35 (%)	*Bauhinia, Parkinsonia, Tamerindus*

Source Compiled from various sources

Note The amount of N fixed by different species will vary widely depending on a number of factors, such as plant characteristics (species and age of plant), soil and climatic factors, and management issues (plant density and arrangement). Moreover, the amount reported will vary according to the method of estimation. Therefore, it is unrealistic and misleading to give estimates of nitrogen fixation under field conditions

T tree, *S* shrub, *H* herb, *C* climber

[a]Numbers in parentheses indicate genera not examined for N_2 fixation

Fig. 20.1 Fertilizer trees: fast-growing, nitrogen-fixing shrubs and trees, grown in association with agricultural crops, are pruned periodically; the succulent and easily decomposable tree biomass is returned to the cropped alleys as a source of nutrient for crops. Photo shows *Gliricidia sepium* grown with maize (*Zea mays*), a practice followed by many farmers in Eastern and Southern Africa. *Photo credit* ICRAF, Nairobi, Kenya

have been developed to interpret these patterns: ratios of C to N, polyphenols to N, lignin to N, and (polyphenols + lignin) to N. Using this information, management strategies can be developed to manipulate the decomposition of plant biomass in AFSs, thereby regulating the rates of nutrient release in the short term and, in the long term, improving soil fertility via improved soil-organic-matter status (Nair et al. 1999; Palm et al. 2001). Roots of the crops and NFTs also contribute biomass build-up in AFSs. Our knowledge of the dynamics of belowground biomass in AFSs, however, is much poorer than that of the dynamics of aboveground biomass.

Soil conservation is another major avenue of soil improvement in agroforestry. When properly designed and managed, agroforestry techniques can contribute to reducing water erosion and wind erosion and enhancing soil productivity (Fig. 20.2). Furthermore, under agroforestry, the presence of deep-rooted trees in the system can contribute to improved soil physical conditions and higher soil microbiological activities. About 2 billion ha of land—a third of total farmland—in developing nations are estimated to be degraded through erosion, salinity, and

Fig. 20.2 Soil conservation: contour hedgerows of trees and shrubs planted across slopes help arrest soil erosion in gently sloping lands. Depending on the trees and shrubs used, they could provide various products, such as nutrient-rich biomass, fodder for animals, fruits, and small timber. Photo shows hedgerows of *Leucaena leucocephala* in a maturing cowpea (*Vigna unguiculata*) field in Ibadan, Nigeria. *Photo credit* B.T. Kang, IITA, Nigeria (deceased)

fertility depletion (UNEP 2004). The potential of agroforestry to reduce the hazards of erosion and desertification as well as to rehabilitate such degraded land and to conserve soil and water has been widely recognized. The soil ameliorative potential of agroforestry systems has been demonstrated in the temperate zone as well (Schoeneberger et al. 2015).

20.3.2.2 Water-Quality Enhancement

The so-called safety-net effect of tree roots—the ability of deep-rooted trees to absorb nutrients that have leached below the rooting zone of agronomic crops, recycle them via leaf litter and fine-root turnover, and thus improve nutrient-use efficiency in the system as a whole—could have an important application in the heavily fertilized, sandy soils that have low nutrient-retention capacities. The capacity of tree roots to capture nutrients from the deeper soil horizons can enhance nutrient storage in the plant-soil system and thereby reduce the amount of nutrients that might otherwise be transported to ground and surface water through runoff and leaching. Research over the past decade has shown that riparian forest buffers can remove significant amounts of sediment, nutrients, and pesticides from both surface and subsurface waters and thus reduce the non-point-source pollution of water bodies in industrialized regions (Jose et al. 2012).

20.3.2.3 Biodiversity Conservation

The number and diversity of trees and shrubs present in AFSs help increase the ecosystem's "hospitality" to a greater number of organisms, such as pollinators, decomposers, herbivores, predators, and pathogens, both above- and belowground, thereby improving the efficiency and functionality of ecosystem services and food chains. For example, in a 7-year experiment, Zak et al. (2003) found that greater species diversity increased plant production by increasing biomass and modifying the composition of soil microbial communities. In combination with the trees themselves, these ecosystem services help promote the hydrological services of water filtration/purification, habitat preservation, seasonal flow regulation, and sediment and erosion prevention (Daily et al. 2001). In a unique experiment to determine the influence of agroforestry practices on biodiversity in an agricultural mosaic, Francesconi et al. (2013) studied the distribution of fruit-feeding butterflies in six different land-use systems in two agricultural landscapes in Central-West Brazil. They found that shaded coffee practices that represent long-term mixed tree-and-crop stands had better potential for conserving forest butterfly species compared to monoculture practices.

In addition to maintaining a healthier and biodiverse ecosystem, mixed-species AFSs could provide greater landscape connectivity in areas where landscapes are increasingly being fragmented and remaining patches of natural vegetation are reduced to isolated habitat islands. This can occur in at least three ways: (1) an intensification of AFSs that leads to reduced exploitation of protected areas, (2) increasing biodiversity in working landscapes through the expansion of AFSs into traditional farmlands, and (3) increasing the species diversity of trees in farming systems (Nair 2013). Where croplands occupy most of the landscape, riparian forest buffers and field shelterbelts can be essential for maintaining plant and animal biodiversity, especially under a changing-climate scenario. The trade-offs between ecosystem conservation and agricultural production can convincingly be addressed by shifting the focus from the plot scale to the landscape scale and integrating biodiversity-friendly land-use systems such as agroforestry into development strategies.

20.3.2.4 Carbon Sequestration and Climate-Change Mitigation

Agroforestry systems are perceived to have higher potential to sequester carbon (C) than comparable single-species crop or pasture systems. The underlying premise of this perception is the niche complementarity hypothesis, which states that a larger array of species in a system leads to a broader spectrum of resource utilization, which in turn makes the system more productive (Tilman et al. 1997); this hypothesis implies that plant species in a mixed system use resources in a complementary way. The estimates of carbon (C) stored in AFSs range from 30 to 300 Mg C ha^{-1} up to 1 m soil depth; additionally, 0.29–15.21 Mg C ha^{-1} year^{-1} is estimated to be accumulated in aboveground biomass although most of it may not contribute to long-term C storage (Nair et al. 2010). Recent studies under various AFSs in diverse ecological conditions have shown that tree-based agricultural systems, compared to treeless systems, stored more C in deeper soil layers near the tree than away from the tree, and higher soil organic C content was associated with higher species richness and tree density. Furthermore, C3 plants (trees) have been found to contribute to more C in the silt + clay fractions (<53 μm diameter) that constitute more stable C than C4 plants (such as maize—*Zea mays*—and some other warm season grasses), in deeper soil profiles (Nair 2012a). The amount of C sequestered in an AFS depends to a great extent on environmental conditions and system management. Based on a comprehensive literature search, Nair and Nair (2014) estimated carbon sequestration rates for the different AFSs, as summarized in Table 20.2.

These are just a few examples of the ecosystem services provided by trees in general and AFSs in particular, on which some research data are available. Several other benefits have also been mentioned in the extant literature, and a great deal of undocumented information concerning such ecosystem services is said to exist in so-called indigenous/traditional knowledge.

Table 20.2 Estimates of carbon stocks and carbon-sequestration potential (CSP) in agroforestry systems in different ecological regions of the tropics

Agroforestry system subgroup	Major AF practices	Estimated C stock range (Mg ha^{-1})		CSP in new areas (Mg ha^{-1} $year^{-1}$)	
		Aboveground	Belowground (esp. soils)	Aboveground	Belowground (soils)
Multistrata systems	Home gardens	2–18	Up to 200	0.5–3	1.5–3.5
	Shaded perennials	5–15	Up to 300	1–4	1.0–5
Tree intercropping	Alleycropping	Up to 15	Very low to 150	0.5–4	1.5–3.5
	Multipurpose trees on farmlands	Up to 12	Very low to 150	0.2–2.5	1.5–3.5
Silvopasture	Tree fodder (Browsing, cut-and-carry)	1.8–3	Very low to 80	0.3–4	1.0–2.5
	Grazing under trees	1.5–8	Very low to 60	0.3–2	0.4–1.0
Protective systems	Windbreaks, shelterbelts, soil-conservation hedges, boundary planting	1.5–7	Very low to 60	0.7–2	0.4–1.0
Agroforestry tree woodlots	Woodlots for firewood, fodder, land reclamation	1.5–7	Very low to 60	1–5	1.0–6.0

Source Nair (2012a, b)

20.4 Policy and Institutional Aspects of Sustainability

20.4.1 Institutional Influence on Sustainability

Institutions are systems of established and prevalent social rules that structure social interactions (Hodgson 2006) and are formed through an iterative process involving a network of culture, policy, and socioeconomic factors (Holland 2007). As a network, all these factors influence one another as they interact to create an institutional environment. The resultant environment is in constant flux, and it serves as both a resource for (and constraint on) behavior in that it can mobilize information, social influence, resources, and social capital in highly differentiated ways (Ansell and Gash 2007). As would be expected, this flux situation influences the sustainability of agriculture; most importantly, it influences the perceived importance of ecosystem services and the incentives and ability to adopt the practices, such as agroforestry, that make possible the continued provision of those services.

Given that the biophysical underpinnings and impacts of agroforestry are well established, some may consider its adoption a measure of its perceived utility. Unfortunately, this alone does not translate into a measure of sustainability, because the financial and environmental incentives perceived by individual adopters cannot be distilled without closer scrutiny. Therefore, a large part of the sociological focus in the field currently revolves around determining perceived detriments and advantages to adoption—factors primarily controlled by the interaction of institutional influences and surrounding biophysical systems (Norgaard 1981). In ecological economic terms, technology availability and institutional structure determine the usefulness of any resource (Bromley 1991). Perceptions of practicality, in turn, are closely related to the knowledge potential adopters have about a technology (Meijer et al. 2014, 2015). The result of this causal chain is that culture, policy, and socioeconomic conditions are extensively explored in studies of technology (i.e., agroforestry) adoption and can be used to assess the environmental benefits of agroforestry in sustainable agriculture based on previous outcomes.

Identifying institutional factors is not difficult. Culture, and the social guidelines that define it, is easily ascertainable and for the most part well-defined for the majority of societies. Likewise, determining a particular household's socioeconomic status relies on indicators such as income, assets, and political position that require only cursory investigation. Moreover, even if policy is not clearly defined in writing, it can be identified through the rules it shapes and their effects. The difficulty lies in determining how these factors interact with one another to influence the adoption of agroforestry and thus the environmental sustainability of an agricultural setting. And this makes survey design and verification extremely important. Repetition has helped hone the quantification of these factors, and most agroforestry-adoption surveys today contain many of the same primary measures. Unfortunately, given the networked nature of these influences, it is inappropriate to use them individually for sustainability-assessment purposes. The existence of one factor may be ineffectual without the contributions of the other factors. Appraisals must be done holistically.

Given the appropriate cultural context and socioeconomic factors, accounting for all these influences can indicate the likelihood of the implementation of sustainable agriculture at the farm, or even community, level. In this sense, adoption rates and the policies that affect them can be used as part of the method for measuring potential agricultural sustainability. The clearest starting point for effecting change in an institutional environment is policy (Place et al. 2012). Policy measures include government programs instituted to support a particular technology (as this may contradict or complement agroforestry adoption), rules that govern markets for agroforestry products, extension programs, and land tenure. Policies can even affect culture, because incentives for certain genders and age groups can outweigh cultural motivations, and over time, the results can become solidified as norms (Stern 2000). Policies that reduce such risk and uncertainty, such as those that establish seed banks, nearby nurseries, and/or training, extension, and agroforestry subsidies, have positive effects on adoption (Pattanayak et al. 2002). Policies that raise awareness of the benefits of these technologies are also likely to instill optimistic perceptions regarding adoption (Ajayi et al. 2006).

Policy effects can also be extremely counterproductive to sustainable agriculture. The environmental impacts of poorly designed policy can be swift and long-lasting. For example, subsidies for inorganic fertilizers, common in southeast Africa, de-incentivize adoption of sustainable technologies and exacerbate the aforementioned downward cycle of environmental abuse. Although such policies benefit the politicians responsible for their propagation by temporarily increasing production, in combination with policies that neglect infrastructure, they lay the groundwork for perpetual food insecurity. This propensity stems from the fact that policy is often derived from economic concerns, making economic methodology determinative of environmental outcomes.

20.4.2 Influence of the Economic Perspective on Policy

To address the potential negative effects of policy, some economists have proposed the use of comprehensive institution-based analysis to assess policies concerning the sustainability of ecosystem function (Corbera et al. 2009). This relates closely to the many payment-for-ecosystem-service (PES) schemes that involve agroforestry, because sustainability assessment based on analysis of the institutional environment can be calibrated against the quality of the services produced by the corresponding ecosystem. In other words, indications regarding an institutional environment can be given by an assessment of whether the owners of a landscape who are purported to provide a hypothetical benefit have adopted practices intended to conserve this ability and whether this adoption has resulted in the continued provision of the benefit at an acceptable level of quality. If the benefit is not being produced and the ecological underpinnings remain constant, the sociological influences require closer scrutiny. Because the institutional context influences the coordination between policies that affect these influences, such as property rights, funding, and relationships between actors (Corbera et al. 2009), evaluating why the technology shown to create the ability was or was not adopted can then point to the relevant institutional issues. For example, failure to produce the hypothetical benefit could instigate a survey of current or potential PES participants that indicates that they chose not to adopt agroforestry because they did not feel secure in their property rights and, as such, could not justify the up-front investment costs in hopes of receiving a benefit in the long term.

Investigation of the institutional environment can potentially produce results that clarify the conservation issues that derive from sociological disconnections, for instance the causes of the differences between PES guidelines and implementation by land-use decision makers. Moreover, PES income effects, extension shortcomings, and influences that strengthen or weaken potential participants' interest in ecosystem conservation, as well as the underlying causes of deforestation that necessitated a PES program, can be identified. Such institutional measures can also be used to evaluate the collateral outcomes (both positive and negative) at the local level that result from PES (Corbera et al. 2009). Indeed, PES programs, such as Costa Rica's Programa de Pago por Servicios Ambientales (Payment for Environmental Services Program), often rely on land use for making program-enrollment and payment decisions. This relates back to the need for accurate measurement of the biophysical aspects of AFSs and other forms of sustainable agriculture as they are applied in the fields of economics. Of course, employing land use as a measurement is to rely on a proxy for an environmental service (i.e. it is not an actual output measurement). As such, a closer look at the concept of PES reveals a further opportunity for the advancement of sustainability science, because PES, along with the policies that must accompany it for successful functionality, encapsulates the difficulties involved in the measurement of ecological and sociological sustainability.

20.4.3 Difficulties in Sustainability Measurement of PES Schemes

A PES scheme is a "voluntary, conditional agreement between at least one 'seller' and one 'buyer' over a well-defined environmental service—or land use—presumed to produce that service" (Wunder 2007). Although this definition appears to be the most widely accepted, some researchers, such as Sommerville et al. (2009), have sought to "refine and refocus" the definition in order to highlight considerations of additionality, conditionality, and institutional contexts, while also contending that such agreements need not be voluntary. There is wide acknowledgement that because of the variety of local institutional contexts surrounding natural-resource management, pure PES approaches fulfilling all the criteria may not always be possible, or even preferable (Sommerville et al. 2009).

Additionality is a principal condition defined in the Kyoto Protocol that requires that benefits from proposed projects have real, measurable, and long-term effects in addition to any that would occur in the absence of the certified project activity (UNFCCC 1998). In short, in order for a project to be eligible to create a Certified Emission Reduction, the standardized and thus tradable unit under the Kyoto system, it must prove that the C being removed from the atmosphere is the result of an intentional effort by the project designers and not the by-product of another economically motivated activity (UNFCCC 1998). When applying this term to other PES situations, the focus shifts toward the "additional" environmental benefits (cobenefits) a PES scheme may provide and away from concepts of intentional design. Due to the difficulty in distinguishing between intended benefits and unintentional benefits resultant of some form of profit seeking Sommerville et al. (2009) feel additionality should be viewed as an aspiration and not a necessity of the Kyoto system.

Additionality and cobenefits, however, have led to considerable debate in the literature regarding how to treat "bundled" benefits (multiple services from the same system). The ramifications of "stacking" (being paid for more than one ecosystem service from an individual system) and "unbundling" (attempting to separate the intertwined services of an individual system in economic analysis) are being investigated from scientific and policy perspectives. Currently, the Wunder (2007) definition and much of the literature regard additionality simply as a PES-effectiveness indicator and not as a compensable construct, due to the difficulties associated with measurement and the possibility of the "leakage" or spatial shifting of an environmental pressure (Wunder 2008).

Although it appears straightforward, conditionality is open to interpretation, especially in light of additionality. The "conditions" for a PES scheme are as follows: the buyer pays the amount agreed upon at the agreed-upon interval, and the provider maintains practices that allow the environmental benefit to continue accruing to the buyer. Payment is "conditional" on provision of the service (Wunder 2005), not on intent. This basic understanding, however, can cause problems if all the terms are not clearly identified in the PES contract. For instance, what is to happen if the provider continues a practice that previously produced a particular result in the past but has ceased to produce that result despite continued effort, or the practice changes but the desired result remains the same, or the practice changes such that it discontinues a cobenefit but still provides the primary service. Designing institutions that address such issues while providing incentives for economic agents is an important part of the modern forms of economics discussed above (Laffont and Martimort 2002), and it is crucial to the appropriate recognition of environmental benefits through markets, reliable legal frameworks, and supporting governance.

PES schemes are constructed with the intention of providing incentives for conservation-oriented land-management practices. There is the added hope that these payments may eventually produce positive changes in attitudes toward conservation as participants experience the environmental benefits and the associated financial gains. Beyond the payment itself, participants using agroforestry could, for example, see financial gain from increased production and savings in inorganic-fertilizer and inorganic-pesticide costs. The intended effect on attitudes is necessary given that shifts in environmental conditions could require adjustments in the original provisions (e.g. a particular practice no longer producing the anticipated result or the possibility of buyers receiving facility from alternative sources). The ultimate goal is for these collective optimizations to heighten the recognition of ecosystem services at a macroscale (market). This relies on equal knowledge distribution for efficient functioning and continued existence, again attesting to the importance of appropriate social structures. Unfortunately, this recognition is not (yet) in place, nor does it seem to be forthcoming.

Low recognition of ecosystem services by markets is the result of three interrelated concepts: externalities, nonexcludability, and intangibility (Jindal and Kerr 2007). Proper valuation of the environment requires internalization of both external economies and diseconomies. The attainment of this condition is, however, complicated by the necessity of determining responsibility, which is inherently difficult due to the often abstract intangibility of such benefits and is complicated in places with weakly defined property rights. The term "intangibility" is used to signify either the current inability of science to identify the exact interactions that create specific environmental benefits or the degree to which such benefits can be realized through land-management practices such as agroforestry. Payments for ecosystem services, however, are primarily concerned with positive externalities. External economies are often not appropriately internalized because of the difficulty associated with excluding consumption by those who did not play a part in the production of the benefit (excludability—e.g., the oxygen produced by a tree plantation). A long history of such benefits being provided for free by nature has (in terms of incentive theory) dampened motivation: having received an external reward with minimal effort has conditioned an expectation that may be difficult to reverse (Singh 2015). With such conditions weighing against the possibility of attitude change regarding conservation, it is important that PES efforts be advanced carefully, with a focus on both the biophysical and institutional aspects of their implementation.

20.5 Measuring the Sustainability of Agroforestry Systems

20.5.1 Estimating Ecosystem Services of Agroforestry Systems

Having recognized what constitutes ecosystem services and the conservation potential of associated payment schemes (i.e., PES schemes), the next step in estimating the value of the service is to measure the parameters quantitatively using the most appropriate analytical procedures. Various analytical procedures can be used to measure the different parameters and entities of each of the ecosystem services discussed above. A discussion of the state of the knowledge regarding each of these is beyond the scope of this paper. A summary of the common procedures and methods available (Table 20.3) shows that, in general, the estimations/measurements are often unsatisfactory. This is due to one or a combination of several reasons, such as the lack of proper methods and rigorous procedures, the bias and errors in the assumptions based on which estimations are made, the extent of time and resources needed for long-term measurements of critical parameters, the lack of field validation of results generated by modeling, and so on. To illustrate this point, let us consider the situation regarding carbon-sequestration estimations under AFSs.

As mentioned above, numerous reports are available regarding the extent of carbon sequestration under AFSs. However, these studies exhibit enormous variability in terms of their nature, degree of rigor, and extent of detail, so that it becomes difficult to compare the datasets based on uniform criteria and hence to draw widely applicable conclusions. The reported values (Table 20.2) are mostly speculative, based on circumstantial and experiential rather than empirical and experimental evidence. The extreme site specificity of AFSs also contributes to the lack of uniformity in assessment methodologies. Even the systems in the same region vary considerably in structure (arrangements of components), function (expected outputs), species diversity (of crops and trees), management, and socioeconomics, such that no two agroforestry fields are identical. Consequently, the reports vary widely in the methods used and/or the extent of detail reported, making it difficult to subject such results to integrated analyses such as meta-analysis and other statistical tools. Furthermore, most published studies are of short duration and cannot be used to predict long-term consequences. The difficulty of modeling discontinuous multispecies stands adds to the problem. Most models used in forestry (for estimating stand volume, C content, growth patterns, etc.) have been developed for continuous, single-species stands, but agroforestry systems represent discrete stands of multiple species; therefore, applying available forestry models to AFSs results in a "round peg in a square hole" problem (Nair and Nair 2014). The extensive estimations of global forest biomass that are available are based on rough estimations, that is, measuring the volume of stem wood and multiplying it with species-specific wood density, and multiplying that number by 1.6 to get an estimation of whole-tree biomass. C content is assumed to be 50 % of the estimated whole-tree biomass, and root biomass is generally excluded (Nair 2012b; Malmer et al. 2010). Although the whole-tree harvesting method, which involves summing up the amount of harvested and standing biomass, has traditionally been used for more accurate estimations of tree biomass, the extremely tedious nature of the method limits its application to research purposes. Allometric equations developed based on biophysical properties of trees and validated by occasional measurements of destructive sampling are widely used in forestry for estimating volumes of standing forests. However, such allometric equations are seldom developed for trees common in AFSs. As far as soil carbon sequestration in

Table 20.3 Summary of procedures for estimating the ecological features of ecosystem services of agroforestry systems

Ecosystem service	Parameter	Commonly expressed as	Availability and clarity of methods
Soil improvement: soil fertility, soil conservation, soil properties	N_2 fixation by NFTs	N: kg ha^{-1} year^{-1}	Rigorous field-measurement-methods not available
	Nutrient cycling (nutrient release from biomass decomposition)	Biomass: Mg ha^{-1} year^{-1} Nutrient turnover (individual nutrients): Mg ha^{-1} year^{-1}	Good
	Deep uptake of nutrients	Nutrient uptake (individual nutrients): Mg ha^{-1} year^{-1}	Fair
	Soil properties: chemical, physical, and microbiological (pH, CEC, salinity, organic matter, nutrient store, bulk density, porosity, aggregate stability, water-holding capacity, soil microbial composition, etc.)	Change over a period of time under specific land-use regime: chronosequence studies	Good methods are available, but long-term studies are tedious and rare; modeling is used, but is seldom validated by field testing
	Soil erosion	Soil loss: Mg ha^{-1} year^{-1}	
	Soil degradation/regeneration	Soil degradation/regeneration expressed in defined parameters	Vague/poor
Water-quality improvement	Common chemical and microbiological quality parameters in water bodies including irrigation water	Change over a period of time under specific land-use regimes: chronosequence studies	Fair
Biodiversity conservation	Various biodiversity and indicators; indices for species richness, abundance, and evenness	Life-cycle analyses; alpha diversity; species richness; conservation values	Vague, poor; no single indicator*
Carbon sequestration (climate-change mitigation)	C storage in long-lived pools—in soils and aboveground reservoirs	C sequestration (Mg ha^{-1} year^{-1}); C storage (Mg ha^{-1}); CO_2 equivalent; change over a period of time	Analytical methods are good, but estimations lack rigor due to wrong assumptions

concerned, the estimated values in AFSs vary greatly depending on biophysical and socioeconomic characteristics of the system parameters and because of the lack of uniformity in study procedures such as depth of sampling and soil analytical procedures. Many reports lack even the essential information for comparison and extrapolation of data, such as soil bulk density. The uncertainties arising from the lack of uniform methods for describing area under agroforestry is another difficulty in gauging the importance of agroforestry in carbon sequestration. Furthermore, the reported studies on carbon sequestration under AFSs are of a short-term nature (fewer than five years), even when a so-called "chronosequence approach" is used for soil sampling (Demessie et al. 2013).

Because changes in C stock are unlikely to be linear across time (Fig. 20.3), understanding the nature of the curve of C storage over time is important for identifying the periods when the most C is being sequestered. In addition, it is difficult to know whether the residence time of C that is sequestered initially in a system differs from that of C that is sequestered later. Are the cycles undergone by the initial C and later C additions the same? As Nair and Nair (2014) noted, many such questions need to be answered in order to realistically assess the impact of agroforestry on carbon sequestration.

Many aspects of the above analysis of the carbon-sequestration (and climate-change-mitigation) potential of AFSs apply to other ecosystem services as well. The perceptions regarding the potential of AFSs to render ecosystem services at a higher level compared with single-species stands of croplands and grazing lands are based on solid scientific foundations. The methods and procedures adopted in collecting or estimating the data, however, are inconsistent, such that the data lack scientific rigor, often cannot be compared, and are often inconclusive. Even if/when reliable quantitative estimates become available, the bigger question of the value that the society assigns to or is willing to accept for such services will be a major issue.

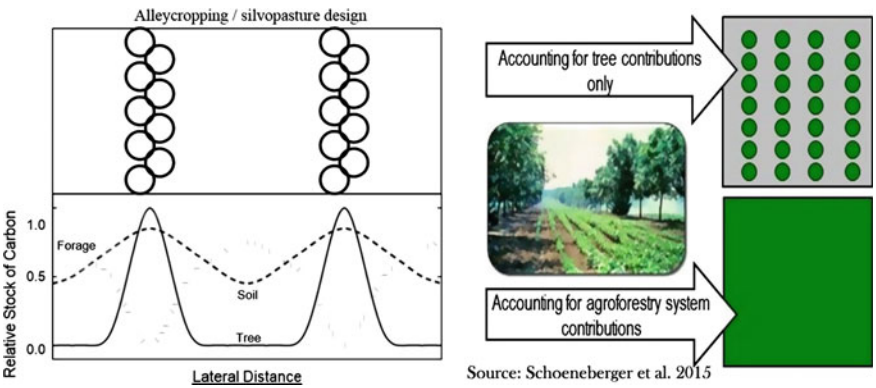

Fig. 20.3 Complexities of carbon-sequestration accounting in agroforestry systems. Agroforestry is not a "1 + 1 = 2" system, but rather a "1 + 1 maybe more, or less than 2" system. *Source* Schoeneberger et al. (2015)

20.5.2 Institutional Measures of Sustainability

As noted, an institutional environment is the interaction of culture, socioeconomic factors, and policy; the latter being the best entry point for stimulating change in an institutional environment. Given that policy's influence resonates through the casual chain that affects the use of sustainable agriculture, it can be utilized as an acceptable indicator of the potential for such use in a given community. This is because smallholder farmers view the influential factors of sustainable agriculture through the lens of an institutional environment, which policy helps to shape (Fig. 20.4). Applying this approach relies on an understanding of the connections between previous policy implementations and sustainability outcomes (Table 20.4). This understanding can then be compared with technology-adoption survey results and the functionality of schemes meant to incentivize sustainable-agriculture use, such as PES. A general sense of potential for sustainability can be gained if, in addition to policy, the cultural and socioeconomic elements described above are investigated properly, allowing for a summation of the manner in which drivers of sustainable agriculture are perceived by a community. Investigations of this nature are carried out through surveys, the results of which can then be calibrated against the results of the suggested biophysical-sustainability measurement technique in order to refine the process and produce a set of acceptable parameters.

Survey questions that focus on policy typically attempt to gauge participants' perceptions of policy effects rather than their knowledge of stated policies. For example, a policy that purports to solidify property rights for a given community may not result in its intended effect, and landowners could still feel uncomfortable about making long-term investments in their land. If a significant number of survey participants feel confident in their ownership, the stated policies are irrelevant from

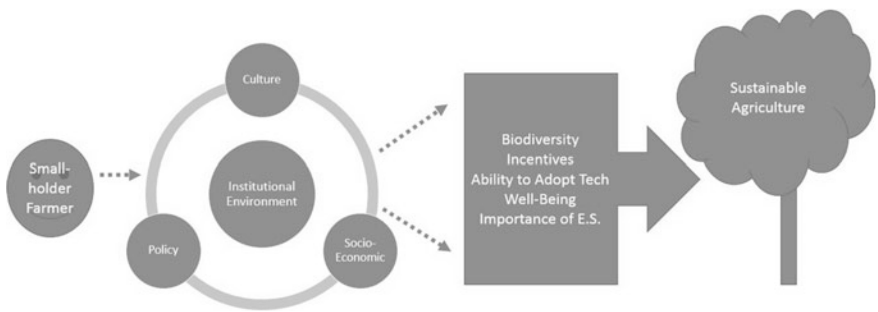

Fig. 20.4 Schematic presentation of how the institutional environment affects smallholder farmer perceptions. The institutional environment, which is the nexus of policy, culture, and socioeconomic conditions, affects farmers' perception (*dotted arrows*) of factors influencing adoption of sustainable agriculture (*solid arrow*), such as financial ability and incentives, benefits of biodiversity and ecosystem services, and their relationships to well-being

Table 20.4 Summary of measures for estimating adoption potential of agroforestry systems

Institutional environ.	Parameter	Influence on sustainability	Measurement/applicability	Ref.
Policy	Subsidies	Technology dependent, can be positive or negative	Typically not represented by stated policies but by perceptions (good b/c disconnect is common). Often quantified on a Likert scale using ordinal measures	11
	Property rights	Direct positive relationship		1
	Markets	Policies increasing access create blanket demand upturn		3
	Infrastructure	Provision of schools, medical, roads, etc., increase adoption		2
	Extension	Teaching and supporting tech use has large positive effect		9
	Tech available	Direct positive relationship		5
	Awareness	Direct positive relationship		2
Socioecon. factors	Resource access	Type of input acquirable can have positive/negative effect	Typically concrete, i.e., not perception. Often quantified through continuous measures denotable in intervals. This is good b/c it can highlight differences in population outcomes	13
	Property size	Often tied to soil quality; positive relationship		13
	Land tenure	Direct positive relationship		7
	Income/wealth	Direction of relationship often dependent on other factors		16
	Education	Mixed results; predominately positive esp. w/awareness		7
	Age	Inverse relationship		11
	Status	Mixes w/factors like subsidy creating positive effect		2

(continued)

Table 20.4 (continued)

Institutional environ.	Parameter	Influence on sustainability	Measurement/applicability	Ref.
Culture	Wealth meaning	If necessities met, value of added gain often still positive	No "typical" method. Difficult to quantify due to abstractness but has real effects. Responses can be represented through ordinal or interval measurement, making comparison across studies difficult	6
	Household roles	Stronger correlation with female household heads		12
	Communication	Direct positive relationship		8
	Marital residency	Variable depending on relation of resource manager to property owner, if one and the same influence is positive		12
	Family size	Often measure of available labor, with positive relationship		4
	Risk tolerance	Direct positive relationship		10
	Norm plasticity	Positive or negative relationship depends on other factors (e.g., policy)		15

(1) Ajayi and Place (2012), (2) Ajayi et al. (2006), (3) Bannister and Nair (2003), (4) Blatner et al. (2000), (5) Bromley (1991), (6) Fernandez and Fogli (2005), (7) German et al. (2009), (8) Kairuki and Place (2005), (9) Meijer et al. (2014), (10) Mercer (2004), (11) Pattanayak et al. (2002), (12) Place et al. (2009), (13) Sirrine et al. (2010), (15) Stern (2000), (16) Thangata and Alavapati (2003)

the perspective of sustainable-technology adoption. This is because it is the participants' perceptions that will ultimately determine their adoption decisions. Measuring these perceptions is typically accomplished by the use of ordinal measures quantified through a Likert scale (a five- or seven-point scale used in the social sciences to express the degree to which a survey respondent agrees or disagrees with a particular statement; Norman 2010). Continuing the property-rights example, participants might be asked to gauge their confidence that their land will remain under their control on a scale of 1–5, the larger numbers indicating greater confidence. This commonly used method accounts for disconnections between stated policies and their actual influence on adoptability, and it facilitates comparisons across adoption studies.

The quantification of socioeconomic factors is typically more straightforward than attempts at policy measurement, because most of these factors are represented by numbers, not perceptions. For example, property size can be physically measured, and in many societies a person's status is represented through clearly defined relationships with others in the community. The responses to questions gauging these factors are often collected as continuous measures and later assigned to intervals. For example, a question regarding age would yield ongoing varied responses that can then be placed into groupings. These groupings can then be used to uncover distinctions within the sample, such as the greater likelihood of participants in an age range of 18–25 years to adopt agroforestry. This measurement tendency has both good and bad attributes. Although it is good at revealing such features within a community, the intervals may appear in an inconsistent manner across studies. The effect of this potential inconsistency is not pronounced, however; the intervals and their related influences on sustainability align closely across the studies cited in this chapter.

Measurements of culture commonly used in technology-adoption studies have a low level of consistency, despite the strong influence of culture on adoption decisions. Techniques vary and can be based on the collection of nominal, ordinal, and interval data. Survey design, implementation, and interpretation rely heavily on anthropological considerations, necessitating the use of enumerators and consultants who belong to, or are very familiar with, the community being sampled. This reliance introduces another level of potential error in the measurement process, because the information is mediated by these persons' interpretations of the target community, most obviously when language translation is involved. In the same manner, a phrase can be translated from one language to another in multiple ways and with differing nuances, expression of the manner in which other cultural aspects appear can vary. For example, a culture-level propensity to tolerate risks (e.g. expenditures on a new sustainable technology) may not hold true for a consultant helping to design survey measures. Risk tolerance and the speed at which norms are prone to change within a community are highly influential (the prior having a positive relationship with propensity towards technology adoption and the latter functioning in conjunction with other considerations, such as policy). Therefore, inconsistencies in measurement design can have large effects on results.

The terms "typically" and "often" appear frequently in the descriptions of survey methodologies, because there is no standardized method for making such measurements, only common processes. Although this may appear to be a detriment, especially with respect to culture, such flexibility is required given the abstract nature of many of the concepts and the necessity of adapting to the complexities of different settings. When no standard exists for constructing indicators, issues of validity can arise. Validity is a fundamental property of good measurement that refers to the degree to which there is congruence between the operational definition and the concept the operational definition intends to measure. Because precise indicators of abstract concepts are especially important when measuring social phenomena, issues of validity require special attention. For example, when a study seeks to measure the influence of subsidies, there should be a precise understanding within the field about what constitutes a subsidy: is it a cash payment for a specific performance, the giving of implements conducive to the targeted technology, or something else? Although flexibility in measurement methods may help researchers capture difficult-to-define concepts, some of the distortion this creates can be compensated for with a concerted effort to improve validity.

Ultimately, analysis based on the influence of the varied aspects of policy, culture, and socioeconomic factors and how these affect sustainable agriculture can only provide a sense of the potential sustainability of an institutional environment at a macroscale. Despite some basic components identifiable as ubiquitous, "institutional contexts" that affect attitudes evolve over time and vary under the influence of a multitude of factors across societies (Corbera et al. 2009). Primarily, as motivation is shaped by the presence of incentives and disincentives, motivating behaviors (such as technology adoption) requires the creation of incentives and disincentives; this can be through law, monitoring, and financial frameworks that take form over iterative experiences in the development of a society (Weinstein and Turner 2012); and thus can vary widely. A review of the literature on ecosystem services found a consistent call for an improvement in the valuation of cultural ecosystem services, studies of culture in the context of bundling, and a better articulation of policy implications (Milcu et al. 2013); the review authors maintained that such a focus would help bridge gaps between academic disciplines, address real world problems, and foster new conceptual links between alternative logics relating to a variety of social and ecological issues.

20.6 Conclusions

For nearly the past four decades, the enigma of sustainability has appeared in almost all development agendas and paradigms as a leading item; yet, paradoxically, a clear definition of sustainability, let alone a well-defined set of criteria and indicators for measuring and expressing it quantitatively, has evaded researchers. The lack of such tools, however, has not dissuaded professionals from moving forward with a variety of sustainability-related programs, for which there is a growing demand. The American Society of Agronomy (www.agronomy.org; accessed 13 August 2015), for example, organizes and promotes webinars on measuring sustainability to help its "customers understand sustainability metrics and how to respond to downstream data requests for sustainable supply chain programs … and help farmers to measure environmental outcomes and provide opportunities to evaluate and adopt more sustainable practices." Thus, there is a contradiction between the lack of a clear set of criteria and indicators of sustainability measurements, on the one hand, and the demand for programs for educating practitioners on such measurements, on the other. The fact of the matter is that the demand for ensuring sustainability in agricultural operations is so overpowering that a combination of different measures and criteria, rather than any single one, is deemed acceptable as the measure of sustainability.

In agroforestry systems, as in other agricultural and natural-resource-management systems, these standards include measures of ecological, economic, and social sustainability. Among these three components, the one that stands out for agroforestry and sets it above other land-use disciplines is ecological sustainability, expressed in terms of ecosystem services. An important point in this context, however, is that the society at large must become more convinced and appreciative regarding the benefits of such ecosystem services for future generations, and norms and procedures (even legal mandates such as taxation) must be put in place. Until that happens, ecosystem services—and sustainability—will remain a mere talking point among academics.

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