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## Introduction

- 1 The lack of sustainability of agro-systems causes environmental degradation in the form of loss of the productive capacity of soil, reduction of biodiversity and damage to water supply and quality. Today the production of food is one of the greatest challenges facing humanity and demands multi-disciplinary study of environmental issues on climate change, limits to agricultural production caused by the degradation of soil and water resources as well as on social questions of food security, national sovereignty and social justice in the provision and distribution of food (Marsden, Morley, 2014). Consequently, the supply of food in the face of growing population and increasing consumer demand in the world means that there is an urgent need for the development of agro-ecosystems which promote environmental quality, agronomic sustainability and socio-economic viability (Andrews, Karlen & Mitchell, 2002).
- 2 One example of the global environmental crisis is the ongoing degradation of the Brazilian Atlantic Forest, a world 'hotspot' for forest and biodiversity conservation. The expansion of urban areas into the countryside and falling productivity and income in

unsustainable farming systems are considered to be the main factors causing soil and water degradation as well as rural exodus in this region (Negreiros, Araújo & Coreixas, 2002).

- 3 To reverse these trends, urgent changes are needed in productive systems, involving the introduction of the sustainable use of natural resources as well as planning and governance in which farmers also benefit from the services provided by agro-ecosystems (FAO, 2007). The perception and management of soil quality by farmers is an integral part of an agro-ecosystem that interferes with production decision making related to the use of natural resources. When allied to the concept of environmental services, agro-ecosystems can be considered to be the result of social structures and processes involved in farming interacting with the local ecosystem.
- 4 Based on interdisciplinary research uniting Social Geography and Soil Science, this article treats farmer perception of soil quality in the mountains of Rio de Janeiro State, in one of the few remaining areas of intact Atlantic Forest in Brazil. The focus is on how farmers identify and evaluate the soils that they cultivate and how the indicators they use compare to agronomic indicators. The aim of the article is to bridge farmer and scientific knowledge in order to devise sustainable agro-ecological systems in buffer zones of conservation units and so contribute to participatory local rural planning.

## Issues in bridging farmer and scientific knowledge

- 5 Science deals with universal and general knowledge while local realities are complex and heterogeneous so that a process of translation is necessary to apply general processes to the specific environmental and socio-economic realities in which farmers live. To do this, external and local actors have to interact successfully and reflect on how to maintain soil fertile and healthy through the use of environmentally appropriate agriculture, which includes mobilising farmer knowledge in a holistic perspective of sustainable agriculture.
- 6 Unfortunately, this is not what usually happens in Brazilian rural development practice. Communicative and cognitive dissonance exists between farmers and agricultural scientists concerning soil quality and sustainable agriculture and this is also a global problem rooted in sharp epistemological differences in worldview and perceived authority of Science over rural people's knowledge (Chambers, 2005). Farmer practice and knowledge are often disqualified by conventional agricultural scientists because the former lack knowledge of the subjacent ecosystem functions and processes which determine what is observed in landscapes. Consequently, farmer knowledge is simply ignored and farmers are seldom consulted about technical issues involved with farming.
- 7 However, this top-down approach has long been criticised in the international development literature because of the risk of introducing socially and environmentally inappropriate farm methods into local realities. Farmers are the ones who work specific landscapes first hand and understand the intricate diversity of local environments and ignoring this experience has been a fatal flaw in development strategies for decades. Agriculture is highly dependent on natural processes and local environments are not blank slates on which a general technology can be transcribed without local feedback from farmers who use it (Chambers, 1983, 2005; Scoones, Thompson, 1994).
- 8 On the other hand, the opposite approach, of uncritically lauding traditional local knowledge, can be socially naïve, i.e. not all rural knowledge is valid or even useful. The

literature on traditional farming presents examples showing that, for social reasons, loss of soil fertility and erosion can occur over time. Falling farm size reduces fallowing time and progressively degrades soil fertility and structure if not corrected with organic or synthetic fertilisers to compensate this and the result is a down-ward spiral of falling productivity (Boserup, 1965; Chambers, 1983; Ruthenberg, 1980).

- 9 This notwithstanding, the problems identified in traditional agriculture were often misconceived, concerning soil in particular. Reij, Scoones & Toulmin (1996) show how the practice of incorrectly extrapolating from plot-based measurements to whole regions exaggerated perceptions of the problems present in traditional agriculture. Then doomsday scenarios were constructed in development narratives to justify transferring modern agriculture disconnected from local socio-environmental realities and the consequent land degradation was predictable.
- 10 The lack of connection between modern agricultural science and poor rural people gave rise to an opposite approach to rural development that stressed environmentally and socially appropriate farm methods. Previous strategies were replaced by bottom-up farmer-first approaches that highlighted local innovation rooted in an active role for local farmers or even farmer-led rural extension (Chambers, 1983, 1994; Chambers, Pacey & Thrupp, 1989; Richards, 1985; Scarborough *et al.*, 1997). When this proved to be too specific and particular, a middle-scale, beyond-farmer-first approach was proposed involving participatory strategies, in which the contribution of both local and scientific knowledge is necessary and dialogue between farmers and agricultural scientists is fundamental (Chambers, 2005; Scoones, Thompson, 1994). However, real existing dialogue is still elusive due to fundamental differences in farmer and scientific worldviews, which is explored here.
- 11 Our study proposes possible ways of overcoming this basic problem by using an ecosystem framework applied to agriculture through the concept of agro-ecosystems. Soil quality is perhaps the most basic parameter of farming and it is also a key indicator of environmental quality within an agro-ecosystems approach. We try to bridge the epistemological divide between farmers and agricultural scientists by comparing how farmers identify and evaluate soil quality and how agricultural scientists do the same from a different perspective but arrive at similar conclusions, which could be a good start for tailoring sustainable farming practice in a critical area of the Brazilian Atlantic Forest.

## Theory and Method

### An agro-ecosystem theoretical framework

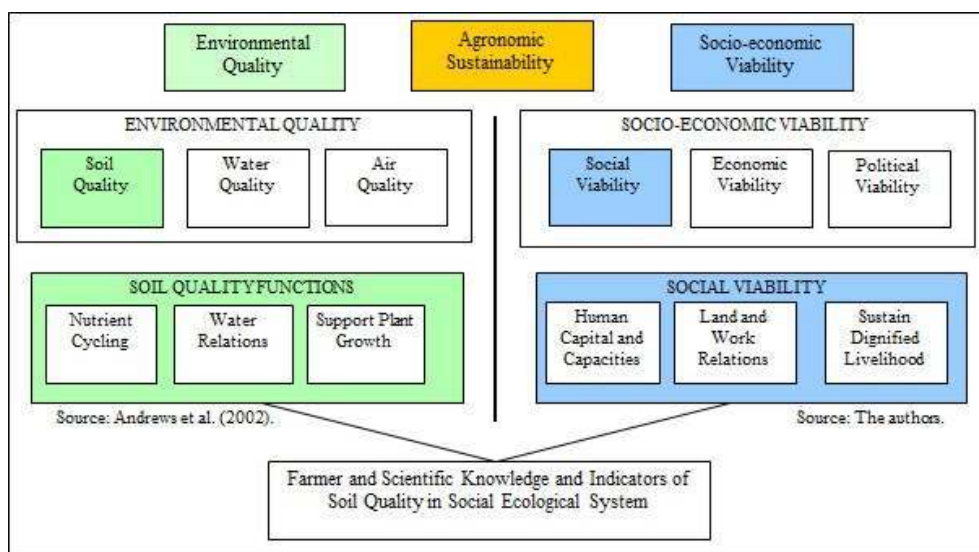
- 12 Soil quality is obviously important for basic agricultural productive functions of supplying food, raw materials and bio-fuel. Despite the diversity of the production ends, supplying food is still the main objective of agricultural production in the world. But soil also has wider ecological and socio-economic functions. Critical ecological functions are regulating hydrologic and bio-geochemical cycles, acting a natural conduit for recycling organic materials, mitigating global climatic change and being a genetic reservoir of biodiversity. Socio-economic functions include making a livelihood and hosting infrastructure and natural and cultural patrimony. With so many diverse functions for soil there is great need for participatory governance whereby local and regional actors decide which functions should receive priority in a given moment and specific space

(Blum, 2005). Participatory governance also means that basic agronomic research must incorporate farmer perspectives, i.e. agricultural scientists have to understand farmer worldviews, values, representations and performance in order to build a constructive dialogue between people who employ different languages and different ways of thinking (Chambers 1983, 2005; Scoones, Thompson, 1994).

- 13 Perception and knowledge concerning soil quality and governance of agricultural practice are basic components of agro-ecosystems and interfere directly in decision making that affects rural production and conservation of natural resources. This perspective combined with that of environmental quality yields the concept of agro-ecosystems which are the result of economic structures and social processes interacting with the ecosystem, producing what is recognised as socio-ecological systems in farming (CGIAR, 2014). Soil is part of the environmental subsystem and human decision-making and actions are part of the social subsystem. By comparing and contrasting scientific views with the views and practices of farmers and trying to jointly define soil quality and environmental services of soil in agriculture, socio-ecological systems can be devised which include the ecological system of soils in the form of natural capital (Clothier *et al.*, 2011).
- 14 As defined by Dominati (2013), natural capital is the stock of interrelated natural assets that provide ecosystems services for society. Soil natural capital is one such stock and consists of soil structure, formation and development involved in a dynamic process connecting inherent soil properties and human manageable properties. Soil quality depends on the state of these properties and soil processes. Manageable soil properties in an agro-ecosystem are related to rural land use and farmer management of cultivated fields, which in turn depends on farmer experience and understanding of soil quality. Farmer skills and knowledge are acquired over time and are the result of a cognitive learning process involving different means, such as formal education, life experience, exchange of information between farmers and communication with outsiders, such as agronomists. The whole process constitutes the human capital mobilised to improve abilities and capabilities to deal with production and work (Davenport, 1999; Armstrong, 2009).
- 15 Knowledge is central to the human capital brought to bear on the evaluation of soil quality and soil productive capacity. Technological decision making is dependent on how farmers judge soil quality in order to choose the appropriate agricultural practices to be used in cultivation. For Dominati (2013) soil natural capital stocks are usually replenished by farmers with nutrients, irrigation, etc. A wrong soil quality judgment leads to agricultural management that can cause soil degradation and so compromise soil quality and agricultural sustainability. So for this author "*a critical precondition for accessing the sustainability of land use is the need to identify where soil natural capital stocks are limiting and how they can be improved*" (2013, p.133).
- 16 Our aim here is to understand farmer knowledge concerning soil quality in order to improve communication with soil specialists and so promote better exchange of information between the two groups. Better communication can enhance farmer skills and practices and also improve agronomic extension practices promoting sustainable agro-ecosystems. Systems approaches are normally used to analyse the complexity and holistic character of natural environments. Social dimensions may be recognised as being important for agro-ecosystems but are rarely detailed in these studies, so that uniting ecological and social dynamics following a social-ecological system approach is still

allusive (Anderie, Janssen & Ostrom, 2004; Dominati, 2013). The study presented by Andrews, Karlen & Mitchell (2002) exemplifies this problem. These authors used an agro-ecosystem approach to the functions of soil quality in a study focussing on environmental quality (the left side of Figure 1). These authors focused on soil quality as related to the functions of providing nutrients, water and plant support but they did not develop the social side of the relationship (the right side of Figure 1), which we add to their original diagram. Here we look at this side of agro-ecosystems by exploring how soil quality as defined by scientific knowledge relates to social viability in the form of farmer human capital and capacities. More specifically, we evaluate the connection between scientific indicators of soil quality to those defined by local knowledge of specific farming environments. This is not a trivial issue. If the two groups can understand one another, both can benefit, if not, scientific research is not applied in practice and does not fulfil its function to society.

Figure 1. An agro-ecosystem approach to soil quality.



- 17 Indicators of soil quality are tools for monitoring positive and negative impacts of natural and human actions that can guide evaluating land use practice (Santana, 2002). Indicators are composed of physical, chemical and biological parameters, which have to be analysed together. The types of indicators chosen should include a number of properties related to the soil functions evaluated, which depending on the scale of the study, requires knowledge of landscape configuration, geomorphological features and constituent processes such as the influence of local climate (Arshad, Martin, 2002; Lima *et al.*, 2013). Soil quality represents an important indicator of the stock of natural capital and can be transformed in an anthropogenic time scale by examining the influence of land use and farming practices, increasing or decreasing stocks, and changing ways of servicing stocks (Dominati, 2013; Robinson *et al.*, 2013). An agro-ecosystems approach also includes strategies for land use planning directed toward social objectives of production and farmer wellbeing and at the same time toward objectives for maintaining biodiversity (Albert *et al.*, 2014).
- 18 Soil properties perceived by farmers are based on observation and life experience over time, which is accumulatively transmitted over generations. The parameters used by farmers for judging quality can use the senses of touch, sight, smell and taste. Cross-

cultural studies have yielded similar criteria used by farmers around the globe, such as soil colour and texture, slope position, soil-vegetation relationships, drainage, firmness and even flavour. Soil types are often distinguished by colour and texture related to different levels of fertility, while sweet, bitter or neutral taste reflects soil acidity (Chambers, 1983). It is also common for soils to be classed as cold or hot and hard or soft, which is associated to fertility (Scoones, Thompson, 1994).

- 19 This kind of comparison brings the two kinds of parameters together and enhances farming practice by uniting the natural capital of soils identified by agricultural scientists with the local human capital of farmers into integrated socio-ecological systems. Human capital consists of technical abilities, knowledge and individual and collective capacities built over time (Bourdieu, 1997; Coleman, 1988; Fine, 2001; Wilson, 2012). Farmer capacities are learned through formal and informal channels involving experience, educational and technical training, relations with agricultural extension officers and researchers and connections with other institutional players who work at the local level. The effectiveness of these relationships for developing and refining capacities depends on mutual understanding between the different actors involved, so that intercommunication at the agronomic sustainability interface between environmental quality and socio-economic viability is fundamental for overall agro-ecosystem sustainability.

## Research methods

- 20 CGIAR (2014) presents a methodology of how to research socio-ecological systems in farming. Agro-ecosystems are dynamic and involve different spatial and temporal scales (Table 1). In spatial terms, cultivated fields on farms are part of rural areas and places found within different regions. Temporal processes enter the analysis considering land use and landscape change, which, depending on the object and objectives of investigation, can embrace periods of days, years, decades and centuries. Socio-ecological actors also differ over space and time, which requires refinement of analytical methods to include inter-scalar relationships that mix actors, scales and time.

Table 1. Scales and level of integration in agro-ecosystems research.

Level	Scale			
	Spatial	Temporal	Ecological	Institutional
Particular	Cultivated field	Minutes-hours	Individual	Individual
↓	Farm	Days-months	Population	Family
	Community	Years	Community	Community
	Landscape	Decades	Ecosystem	National
General	Region	Centuries	Biome	International

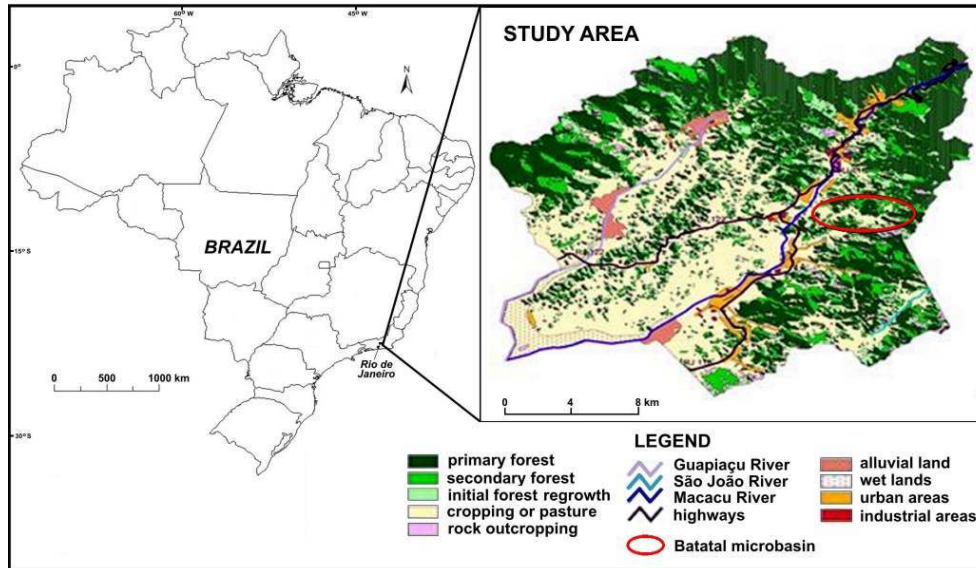
■ levels and scales of the study

SOURCE: CGIAR (2014, P. 8)

- 21 Using this framework, our study works at an *institutional scale* focused on individual farmers, each using specific agricultural methods in their respective fields and the farmers together are situated at the scale of a community or a named place, Faraó, located in the Batatal Valley. The *spatial scale* is the micro-basin of the Batatal River, a tributary of the Macacu River, located in Cachoeiras de Macacu Municipality, Rio de Janeiro State, Brazil (Figure 2). Faraó is situated on the steep escarpment of the Serra do

Mar coastal mountains in a buffer zone of the Three Peaks State Park, an important conservation unit of the *ecosystem* of the Atlantic Forest biome. A large portion of the area has declivity in the 45-75% class. Vegetation is Dense Ombrophylous Forest, which covers 51% of the area of the municipality. The climate is hot and humid and super humid with local precipitation of 2,000 to 2,500 mm a year.

Figure 2. The study area.



Source: Prefeitura Municipal de Cachoeiras de Macau (2012)

- 22 The Batatal micro basin covers 37 km<sup>2</sup> of the Macacu River basin. A mosaic of forest and crops exists throughout the micro basin where family farmers work on sloped fields subject to restrictions to land use and farming methods. Forest and bananas dominate the landscape, particularly on the slopes. Bananas are cropped in humid hollows surrounded by forest and some vegetables, maize and pasture are planted in bottom lands (Hoefle, Bicalho, 2012). Farming in forested and mountainous conditions of erosive susceptibility, risk of soil contamination and subject to deforestation requires promoting good agriculture practices as defined by FAO (Izquierdo, Fazzone & Duran, 2007; FAO, 2004) and EMBRAPA (2004). For this productive communication between farmers and agronomists is essential.
- 23 The *time span* of farmer observation is that of years farming in the valley, ranging from two to four decades, depending on the age of specific farmers and their empirical experience accumulated over time. During this time Brazil experienced the Green Revolution and a push to export commodity production involving agricultural methods and products inappropriate to the terrain of the Coastal Mountains and to the socio-economic situation of small farmers found there.
- 24 The *individual institution* is the farmer. Farmers in Faraó have low levels of formal education, are middle-aged or elderly, grow food crops for markets located within the state, especially for the Greater Rio de Janeiro Supply Centre (Bicalho, Machado, 2013). As the study area is located far from major agribusiness regions of the Brazil formal agricultural education is not available locally and farmers have little and sporadic



technical assistance. Most of their agricultural learning comes from their own life experience but they are open to outsiders and new information.

- 25 Field research involved direct contact with farmers and the use of qualitative methods developed in prior research on environment perception and farming in the same general area (Bicalho, Hoefle, 2002; Hoefle, 2009). Between 2010 and 2013, 23 small farmers in a universe of 136 farmers identified by EMATER (2011) in the Faraó community were interviewed a number of times. Themes researched were: land use, environment perception, ethno-agronomy and social characteristics of farmer families. A number of elderly farmers were interviewed concerning local historical change in land use and in farming methods during their lifetimes. Farmers were questioned about what constitutes good and bad soil and answers were related to agronomic indicators concerning soil properties expressed by colour, texture, humidity, organic material, mesofauna, vegetation cover, slope and productivity.
- 26 Great care was exercised in order to avoid inducing answers, but questions were directed toward agronomic indicators of soil quality, phrased in local colloquial language which farmers with low levels of formal education could understand. This language was maintained in organising the results for analysis, which were then compared and contrasted with agronomic terminology and evaluated according to a local soil survey carried out in the same place. This procedure is similar to that presented by Barrera-Bassols & Zinck (2003) as being the principal method used in Ethnopedology for avoiding distorting farmer viewpoints with a Western scientific model.
- 27 In our study a social ecological soil system approach focusing on agro-ecosystems is combined with comparative and integrated approaches of Ethnopedology. According to Barrera-Bassols & Zinck (2003), Ethnopedological studies usually are limited to comparing local soil knowledge with scientific information but do not take farmer perception and cognition processes in account. A more integrated approach would go beyond mere comparison and strive to link local and scientific knowledge in order to promote local development. To do this, research also must take into account the relationship between management, soil and land resources, which our agro-ecosystems line of enquiry investigates.

## Farmer and scientific criteria of soil quality in the social ecological system of the Brazilian Atlantic Forest

### The landscape as an expression of the socio-economic viability of an agro-ecosystem

- 28 The majority of studies of soil quality relate indicators to different kinds of agricultural activities (Arshad, Martin, 2002). Comparison is made to soil present in nearby areas of native land cover subject to the least amount of anthropogenic disturbance, where a state of equilibrium is thought to exist in the sub-forest systems present. Agricultural use alters this natural equilibrium and new equilibrium states are mediated by agro-ecosystems, which attain sustainable optimal production over time when soil quality is maintained. Landscapes suffer successive ruptures and re-adaptations through human

intervention involving a history of agricultural production and socio-economic viability of the different agro-ecosystems practised by social groups in specific places.

- 29 According to Özgen (2013), in addition to social background and assets, decision-making and attitudes within an agroecosystem also depend on the state of the environment itself and past experience, all of which influence perception. For Tacca, *“perception and cognition are tightly related. Perceptual information guides our decisions and actions, and shapes our beliefs. At the same time our knowledge influences the way we perceive the world”* (2011, p. 5). Farmer soil quality knowledge, choices and actions depend on individual cognitive processes interrelated with perception and at the same time are an active part of the agro-ecosystem. Individual abilities, knowledge and the way farmers perceive their working environment interfere with how players make decisions and choices within a work place (Davenport, 1999).
- 30 Farmer perception of soil quality has a direct relationship to their personal experience and the local history of land use associated with specific crops and production systems that altered the landscape over time. Until the 1980s the rural landscape in Faraó was relatively uniform throughout the Batatal Valley with crop land occupying the bottomlands and the slopes. A shifting-field system was used with five- to eight-year fallowing on the slopes and two-year fallowing in the bottomlands. Farming systems used no modern inputs. Little primary forest remained, soil loss was a problem and flooding occurred in the bottomlands during the rainy season. The area was noted for producing high-quality manioc and maize flour as well as bananas for the local markets.
- 31 In the middle of a general economic crisis in Brazil during the 1980s farming was transformed in the valley. Prices were poor for basic food crops and young people left the countryside causing a shortage of labour. The result was drastic reduction in crop land. Only bananas remained on the slopes. In the bottomlands of the lower valley, vegetables and fruit trees were introduced alongside previous crops. Environmental restrictions meant to reduce deforestation starting in the 1990s reinforced this pattern and the overall state of the agroecosystem changed radically.
- 32 Over the decades the abandonment of farm land led to widespread forest regeneration. This introduced greater landscape differentiation across the valley producing a mosaic pattern with grassy open areas in the middle of different-stage forests and bananas on the slopes. In the upper valley, new environmental restrictions banned opening fields in fallow areas so that today farmers only plant bananas in the gullies following traditional farmer knowledge with regard to soil quality. However, marketing strategies have changed and bananas are now sold to the Rio de Janeiro market. In the lower valley, with the rise of vegetable cropping in limited areas, some light mechanisation and use of agrochemicals were introduced but without the appropriate environmental and work safety guidelines. Modern methods are poorly understood and are not rooted in prior farmer experience so that farmer knowledge concerning soil quality is still based on past experience like farmers of the upper valley. Consequently, farmer perception of soil quality is rooted in the history of the socio-cultural landscape of Faraó, which reflects issues of long-term socio-economic viability of the local agro-ecosystem.

### Soil quality interrelating land use and relief

- 33 As the landscape in Faraó was constructed in a mountainous environment over time, it is only natural that accumulated farmer knowledge of soil quality is related to

topographical differences. Farmers distinguish soils according to relative position up and down slopes as well as across slopes, which is to be expected in land situated in a micro-basin shaped by first-order channels that flow into the Batatal main stream. According to this view, relative soil fertility and humidity vary according to slope position, the presence of rock outcroppings, vegetation type and exposure to sun light. Consequently, farmers possess an integrated view of the various elements that define soil quality.

- 34 Basic differences exist between how farmers and agricultural scientists identify soil quality according to how slopes are perceived, but in the end, they reach similar conclusions and this could be the basis for mutual understanding (Figure 3). Farmers look across the slopes identifying differences in soils present in concave hollows/gullies and on convex rolls located between and identify different soil characteristics in each. They also divide their land up and down the slope into hilltop, slope and bottomlands. With this grid they recognise great variety of soils. Agronomists for their part give greater emphasis to relative position up and down the slope because they see soil as a reflection of erosive processes, which results in a more fractured analytical view of landscape.

Figure 3. Scientific and farmer perception of soil quality according slope position.

SCIENTIFIC DESCRIPTION*	FARMER DESCRIPTION					
	Soil Quality	Colour	Texture	Humidity	Organic Material	Vegetation Cover
<b>Hilltop (hilly and craggy)</b> shallow soil on rocks; rock fragments in soil; usually young soils with weathering minerals Soil Types: Leptosol, Lithic + outcrop of rocks + Cambisol, Inceptisol	<ul style="list-style-type: none"> <li>• poor land</li> <li>• weak land</li> <li>• slab-stone</li> </ul>	---	<ul style="list-style-type: none"> <li>• rocky</li> <li>• sandy</li> <li>• red clay</li> </ul>	<ul style="list-style-type: none"> <li>• dry where grass</li> <li>• moist where forest</li> </ul>	---	<ul style="list-style-type: none"> <li>• forest</li> <li>• bamboo</li> <li>• native grass</li> <li>• thorn trees</li> </ul>
<b>Slope (strongly undulated and hilly)</b> soils of variable development and texture, usually young soils with weathering minerals, well-drained soil, although more weathering also occurs, acid and low nutrient content soils Soil Types: Cambisol, Inceptisol + Red-Yellow Ferralso; Oxisol + Yellow Ferralso; Oxisol	<ul style="list-style-type: none"> <li>• better land but mixed good &amp; bad</li> <li>• best land in gully</li> <li>• mixed on rolls</li> </ul>	<ul style="list-style-type: none"> <li>• black</li> <li>• dark</li> <li>• yellow</li> <li>• mixed</li> </ul>	<ul style="list-style-type: none"> <li>• clay</li> <li>• yellow clay</li> <li>• dark sandy</li> <li>• mixed</li> </ul>	<ul style="list-style-type: none"> <li>• moist</li> <li>• more humid in gully</li> <li>• dryer on rolls</li> </ul>	<ul style="list-style-type: none"> <li>• leaves</li> <li>• straw</li> <li>• worms</li> </ul>	<ul style="list-style-type: none"> <li>• forest</li> <li>• bananas</li> <li>• palms</li> <li>• manioc</li> </ul>
<b>Bottomland (flat and gently undulated)</b> soils of variable development and texture, soils with moderate drainage or even imperfectly drained, colluvial-alluvial sediments Soil Types: Yellow Ferralso; Oxisol + Acrisol; Ultisol + Gleysol, Entisol	<ul style="list-style-type: none"> <li>• fair land</li> <li>• variable land</li> </ul>	<ul style="list-style-type: none"> <li>• red</li> <li>• yellowish red</li> <li>• sandy</li> <li>• Grey</li> </ul>	<ul style="list-style-type: none"> <li>• heavy clay</li> <li>• mud</li> <li>• sandy</li> </ul>	<ul style="list-style-type: none"> <li>• wet</li> </ul>	---	<ul style="list-style-type: none"> <li>• manioc</li> <li>• yams</li> <li>• vegetables</li> <li>• pasture</li> </ul>

\*Based on soil research in the Batatal basin reported in Peixoto et al., (2012).  same or similar type of indicator or description

- 35 To compare both views, the description of soil quality of farmers was compared to a local soil survey undertaken by EMBRAPA in the Batatal micro-basin related to agro-environmental planning projects in the Serra do Mar Mountains of Rio de Janeiro state. As such, when scientific soil names and properties are cited here this information is based on the soil survey reported in Peixoto *et al.* (2012).
- 36 For farmers the hill tops have poor land because of the presence of stone slabs and rocks in the soil. This corresponds with the agronomic characterization of the soil on the local hill tops as shallow soil on rocks, rock fragments present in poor eroded young soils with weathering minerals typical of leptosols. As farmers point out, only poor native grass and thorn scrubs grow there. Cambisol is also present on hilltops and is where farmers say that forest grows.
- 37 Better land is found on the slopes, good farm land in gullies and variable land on rolls. Historically they planted different crops according to the presence of moisture and soil type, bananas in humid gullies with black soil and manioc and other crops on the drier rolls with drier mixed dark-yellow and clay-sandy soils. Two soil types were identified on slopes in the agronomic soil studies: cambisol and yellow ferralso. Cambisols are less weathered younger thin soils and because of this richer in nutrient minerals. Yellow and

red ferralsols are leached, contain fewer nutrients, are acidic and have high aluminium content. However, these soils have better physical characteristics and are deeper. The association of the two soils together compensates the deficiencies of each so that from an agronomic point of view, the slopes have the best characteristics for farming. The greater presence of vegetation on the slopes also produces biomass and organic material, which was one of the most important indicators of good soil for farmers.

- 38 Despite the fact that bottomlands are easier to plant than slopes, farmers say that the soil is worse because of the presence of heavy clays, sand and mud. Farmers point out that drainage works were undertaken in the 1960s which made matters worse in the lower Batatal valley resulting in an artificial mixture of river sand and rocks, which were deposited on the land located along the river. Soil research undertaken by agricultural scientists in bottomlands identified the presence of clays that can cause problems with soil compacting and raise water tables during rains so exposing plant roots to excessive moisture. Soils were found to have from moderate to imperfect drainage. The grey colour of the soil found in bottomlands is associated to the presence of gleysol, which is common in places subject to long periods of flooding.
- 39 Soil scientists are more concerned with erosion and the status of the natural fertility of soil as related to weathering processes over time, in which soil is lost or created, and these determine differences in soil quality up and down slopes. Soils present in different parts of the landscape are explained in terms of their process of geological formation although they were impacted more recently when forest cover was removed to open fields for the practice of slash-and-burn agriculture, causing the erosion of surface soil (A horizon) on steeply sloped land. Many of the same characteristics that farmers identify are explained in a scientific way. At first, the soil scientists were puzzled by the characteristics found in the bottomlands which should be of better alluvial quality but our research on oral history with the farmers cleared up the mystery: the bottomlands were swampy in the past and subject to flooding until the drainage works mixed soils and de-structured horizons by dumping dredged land on the river margins.
- 40 In sum, farmers and agronomists have a number of similar evaluations of soil quality, which are shaded in grey in Figure 2. This becomes more evident when the details of indicators of soil quality used by farmers and agricultural scientists are compared and contrasted.

## Farmer and scientific knowledge of soil quality indicators and functions

- 41 Following the agro-ecosystem theoretical framework previously discussed, farmer perception of indicators of soil quality is related to the soil quality functions of nutrient cycling, water relations and plant growth support as understood by soil scientists. Farmers have a holistic view of soil, which makes it difficult to clearly separate their way of thinking accordingly to each of the functions recognised by scientists. Even in the scientific view point soil quality functions are strongly interrelated. Farmer and soil scientist perception of soil quality indicators and their understanding of how soils work are presented qualitatively here. Measuring indicators analytically is not the purpose of this study.

## Nutrient cycling

- 42 When farmers are asked “What is good land?” the most frequent answer was land where there is black or dark soil present (Table 2). Poor land has white and light coloured soil, but also red soil and soil with red-yellow tones, commonly associated with problems with texture and dryness, such as in the case of white sand and red clay. Colours are used almost as symbols of soil quality, incorporating all of the other characteristics of soil, particularly in the opposition between dark and light coloured soils. Soil colour is also one of the first characteristics an agricultural scientist would look for. Darkness is related to organic matter in soil, whose presence is related to the expression of beneficial soil processes. Decrease in soil organic material is reflected in the colours of the type of soil minerals present. Quartz and kaolinite are white; hematite is red; gibbsite is yellow; iron oxides in reduction environment are grey when situated in a gley horizon.

Table 2. Farmer perception of soil quality.

Indicator	Good Land	Bad Land
Colour	black dark dark sand	red red clay white sand yellow light coloured
		heavy clay
Texture	clay dark sand clay sand mix	sand red clay with sand stone white grit
Humidity	humid	dry
Organic Material	black earth straw present leaves present decomposing pods	not present
Worms and Other Mesofauna	lots of worms in black earth big limp worms present bugs work in wet soil worms fertilise soil	depends on soil temperature worms not present ant nests in red clay bugs in the earth
Vegetation Cover	forest present where plant bananas where plant crops	grass pasture
Relief	hollow slope lower slope	hill top close to slate parts of bottomland
Production	where crops grow well where plant crops and harvest where produce well	where produce poorly

SOURCE: BICALHO, HOEFLE (2012)

- 43 For agricultural scientists the transformation of rocks by the action of climate, organisms and relief over time produce different kinds of soils that varies according to mineral composition and to the size of particles (sand, silt and clay) which produce different soil textures. The combination of these elements causes the natural soil fertility to vary in terms of the nutrient availability and other chemical elements as well as in terms of the organization of particles in aggregates which produce different soil structure (Peng, Horn & Hallett, 2015).
- 44 Agronomists also considered soil to be a natural medium for recycling organic materials. The proper management of soil fertility within an ecological framework is thought to

involve numerous variables, one of the most important for tropical and subtropical soils is the presence of organic material, which comprises a set of pools with multiple functions in the expression of chemical, physical and biological soil processes. Due to this, organic material is an indicator frequently used by soil scientists for evaluating soil quality and sustainability. Natural variation in soil type, climate, mineralization rates and farming systems all affect levels of fertility, which involve nutrient and water depletion or accumulation, and ultimately cropping system productivity. Organic material in soil includes microorganisms, animals and plant residues in different stages of decomposition that are intimately related to the minerals present in the soil. The stock of organic material depends on the intensity of processes involving plant residual input to soil and decomposition. A number of biological, chemical and physical factors also protect organic material from the attack of microorganisms (Feller *et al.*, 2006; Abbott, Manning, 2015; Bot, Benites, 2005; Lehmann, Kleber, 2015; Lynch, 2015; Maia, Parron, 2015).

45 Even if farmers in Faraó do not use such complex biological, chemical and physical explanations of soil quality they are well aware of the role of organic material in soil fertility. Most farmers do not know why soils have different colours and say that they are naturally the way they are, but some farmers say that dark soils are caused by the presence of organic material and nutrients. If pressed for details why the land is good or bad, farmers also associate the presence of organic material and earthworms. Leaves and straw are mixed in black and humid soil and contribute to the presence of worms and other 'small creatures' which soften the soil, with the net result being a process that fertilises it. As the farmers comment, "Worms eat the land, come up to the surface and release it in the form of manure", "Fertile land has worms and life" and "Worms soften the land". Therefore, good land has lots of worms present in dark soil, particularly a type identified as big limp worms. Farmers also note that certain little bugs are often found in humid soil and that the bugs fertilise the soil. Worms are absent in poor soils. The latter are located in hot land where there are numerous ant nests, particularly in red clay soils. From this we see that the presence of mesofauna is considered to be a sign of good land and fertile soil in local knowledge, and the presence of mesofauna depends on soil types which retain moisture. Farmers use their experience and power of observation using all of their senses to characterise soil quality. Good land has black humid soil rich in organic material, including plant residue, such as leaves, straw, roots and decomposing pods and fauna present such as the insects and worms cited above. From this we see that farmers have a clear notion of nutrient recycling used by agronomists to explain soil quality.

46 Agricultural scientists present similar views with regard to mesofauna. The transformation of organic material and fresh biomass by worms, insects and micro fauna directly contributes to nutrient recycling from organic material in this biomass as well as from the liberation of nutrients from the soil minerals. Through this transformation process organic material is fragmented into components which are grouped by particle size. Larger particles can serve as a short term labile nutrient reserve or can be stocked as a medium term reserve if organic material is protected inside soil aggregates. Finer and colloidal particles, such as the humid organic material is more stable and reactive, and serve to retain nutrients and act in soil aggregation formation (Zúñiga *et al.*, 2013). Earthworms transform organic material, help plants cycle nutrients, improve soil aggregation and porosity so that crops have access to adequate moisture. Higher biodiversity in soil acts as a biological control which maintains soil health and nutrient

cycling. Low biodiversity of organisms in soil indicates the presence of constraints for plant development and health. Tree species and remaining natural vegetation cover also contribute to soil biodiversity as well as to the development of deep root systems and soil porosity, adequate water infiltration and availability. Biomass production and organic material input are related to adequate soil fertility and biodiversity. The type and diversity of vegetation present and the aspect of plants may indicate soil and health constraints, such as low soil fertility, soil acidity and water availability restrictions. Unprotected soil surface without the protection of vegetation and mulch is subject to high sunstroke, soil erosion, compaction and dryness. Farmers also consider the type of wild vegetation present before opening a field to be a good indicator of soil quality. Land with robust forest cover is appropriate for cropping and land with grass and thorn scrubs is not, reflecting the role of vegetation as an indicator of soil fertility.

- 47 Agricultural scientists view the role of organic material from the bottom-up, in terms of the chemical, physical and biological processes that support plant productivity. They measure carbon accumulation and the presence of nitrogen and other plant nutrient cycling and then scale up to soil aggregation, moisture availability and organism activity (soil life). Farmers see these processes in terms of the final visible organic materials present in the soil. Straw, leaves and wild seed pods rot and fertilise the soil. These are absent in poor soils, which are not benefited by this process while soil science explains this in terms of depletion of chemical, physical and biological processes that support plant productivity.

## Water relations

- 48 Soil, water and humidity influence plant growth and interfere in flow, runoff and drainage. Soil structure and texture are important for water dynamics in the soil and can recharge local and regional water resources. The interaction of mineral particles and organic material promotes the formation and stabilization of soil aggregates as well as promotes the action of plant roots and soil organisms. The size and type of aggregates present are the building blocks of the soil porosity network that influences the expression of soil processes, such as water infiltration, storage and availability, gas exchange and aeration, root development, organism activity, among others.
- 49 Soil with medium texture has good physical soil properties and farmers identify this as mixed soil, which combines clay, mud and dark sandy characteristics. For scientists high clay content indicates excessive moisture, root damage and anaerobic processes while farmers identify the same problems in heavy clay and red clay with soap stone present in bottomlands. Soil with too much sand is also considered to be poor by farmers because it does not retain moisture. They point out local examples, such as sandy patches on slopes, white grit on hill tops and river sand in bottomlands. For agricultural scientists texture is related to soil mineralogy which indicates soil acidity and nutrient availability capacity and necessary soil management corrective action, while local farmers just leave problematic areas in undemanding native pasture for animals to graze on. Farmers associate colour to variation in soil texture according to the presence of more clay in better soil and more sand in poor soil but without referring to a matrix of mineral composition. In addition to colour, farmers observe that when soils are shallow and slate is present on the upper most part of slopes only grass grows there. These areas are not cropped and are only used to pasture animals that transport bananas down slopes.

50 After colour, humidity is the second most important indicator of soil quality for farmers. Good soils are humid and dry soils are poor. Researchers perceive this relationship in terms of adequate moisture that permits good plant development and crop production while inadequate moisture damages plant nutrition and biochemical processes. This can be seen in farmer attitudes toward many bottom lands which they consider to be too moist and damp to be suitable for crops. As most farmers have little bottomland they do not give the matter much thought. This utilitarian attitude is even stronger in how farmers rank indicators of soil quality. Indicators are important if they embrace a significant part of the landscape, such as the slope terrain type which is their principal area of production.

## Plant growth support

51 Production itself can be an indicator of soil quality for farmers. "Good land is where crops grow well, where you plant and harvest well". This view expresses an integrated evaluation of soil quality with the interplay of criteria such as colour, humidity, organic material and texture. For farmers soil quality has a strong relation with the notion of natural stocks of soil as discussed above. Researchers also explain crop production using integrated explanations such as high productivity reflecting the optimal conditions of chemical, physical and biological properties of soil for the development of specific crops. Low productivity is explained in terms of inadequate soil conditions for crop growth in terms of moisture, nutrients available, acidity, soil aeration, root depth, soil health, etc. All of these deal with soil stocks in the provision of environmental services for human use or for agriculture. Soil ecological functions identified are regulating hydrological and biogeochemical cycles that maintain ideal conditions of soil structure. Soil fertility is considered to be the natural base of agriculture which provides stability and support for plant growth.

52 Soil scientists consider the stability of organic material to be the result of the interaction of this material with soil minerals. Physical barriers to decomposition cause the occlusion of organic compounds by minerals present in clay and by the exclusion from specific soil pores of organisms that provoke decomposition. In addition, labile organic compositions, such as polysaccharides and proteins, which are subject to rapid decomposition, are protected when found inside soil aggregates which permits greater perennization of these substances in the soil.

53 Agricultural scientists have found that the preservation of organic material tends to be maximized in soil with a natural vegetation cover because the soil is not revolved. Consequently, the high production of biomass in forests permits greater entry of organic material in the soil than in cultivated soil. A vegetation cover with a robust and healthy appearance therefore is an indicator of adequate soil fertility. When land is cultivated levels of organic material generally diminish because revolving and de-structuring the soil exposes organic materials present to the attack of microorganisms. However, agronomists can recommend productive strategies using soil conservation techniques associated with permanent land cover and the management of organic material in no tillage systems and organic agriculture, all of which increase organic material in soil. This view attributes to soil a role in acting as a source and storage place or sink for carbon stocks, the amount of which depend on the relative rates of incorporation and decomposition of carbon by the organisms present in the soil. Soil with different layers of



arboreal vegetation and crops also protects surface soil from the impact of rain water and erosion. The depth and diversity of root systems also improves soil aggregation and porosity, which benefits water infiltration and accumulation in the soil.

- 54 Taking into account the different dimensions to soil quality it can be concluded that farmers and soils scientists make many of the same qualitative descriptions of soil properties that define good and poor soils. The difference between them is that while researchers are interested in evaluating soil potential for production, they are also interested in understanding the internal functioning of the indicators and how processes are caused. Farmers are mainly interested in identifying land which is good for production as well as in farming methods that maintain the land productive. In this sense, farmers are practical empiricists while conventional agricultural scientists are rationalists who dissect landscapes, identify constituent parts and measure physical and chemical properties situated at multiple scales of analysis. Farmers look across landscapes searching for good land while soil scientists look 'under' landscapes detecting geological and anthropogenic processes which gave rise to what is observed today.
- 55 Human action can cause soil degradation or improvement and contribute to sustainability, biodiversity, protection of natural resources and ecosystem services (Bouma, McBratney, 2013; Adhikari, Hartemink, 2016). In the case presented here, the substitution of maize and manioc by bananas and regenerated forest on most of the slopes improved the environment quality. Farmers are aware of this process which is reflected on the way they perceive soil properties and functions. In the bottom lands human intervention caused the opposite. In the past soil was de-structured by drainage works and today by the use of conventional agricultural practices in commercial vegetable cropping based on the use of machinery and agrochemicals. The socio-economic viability of the agro-ecosystem is undermined by the economic need to obtain a dignified livelihood because the farmers do not know how to produce vegetables with an alternative farming system. Consequently, developing good agriculture practice that is environmentally suitable would be crucial to cropping in an ecologically and socially sustainable way. The role of extension agents would be crucial for intermediating a technical transition toward organic and agroforestry methods that could benefit farmers cropping the slopes as well as the bottom lands. Access to such methods is particularly important for low income family farmers like those of Faraó. In sum, farmers of the study area were shown to possess relevant human capital and capacities in the form of local knowledge but they also need to combine this with new knowledge from soil scientists and extension agents.

## Conclusion

- 56 In the case presented here a number of points of agreement were identified between farmer and scientific perception of soil quality. Dialogue between scientific parameters and local parameters is possible and has the potential of uniting the natural capital of soils identified by agricultural scientists with the human capital of farmers who work them into integrated socio-ecological systems. Dialogue promotes agronomic sustainability which is a crucial dimension in an agro-ecosystems approach because it mediates local and scientific knowledge at the interface of environmental quality and socio-economic viability. However, the lexicon used by soil scientists can often be unintelligible to farmers and agricultural scientists confess that they have difficulty

translating their findings to the farmers. Scientific language is hermetic and many soil scientists remain cloistered in their research focussed solely on indicators of soil properties. Conclusions are inferred from laboratory analyses of samples collected in the field, often times by another person, so that a researcher may have no direct contact with the actual farmer whose agricultural practices are part of contemporary anthropogenic processes that have a strong influence on the results analysed in the laboratory. The results also may not even reach the farmer whose field was studied but when it does the message treats soil quality functions (part of environmental quality) out of touch with local human capital and capacities, so annulling social viability. What is missing is appropriate farm extension, fundamental for agronomic sustainability interfacing the two dimensions.

- 57 The farmers for their part are anxious to learn about the limitations of their soils and innovation which could improve production. They recognise and are aware that agricultural scientists possess important knowledge beyond what they know, particularly concerning the chemical composition of their land and they would like to have their soil analysed and receive technical assistance on how to correct problems. However, the farmers are relatively poor and do not have the means to pay for private soil analysis and diagnosis and depend on government farm extension.
- 58 Unfortunately, farm extension in Brazil no longer emphasizes technical assistance but instead governance: community and group organization and the relationship with government institutions. This important shift in the focus of rural extension was meant to promote farmer participation and to diminish dependency on top-down decision making. This strategy is fine for receiving community benefits like electricity and piped water, but technical assistance cannot be reduced to group organization and community development. Some technical and farm management issues can be solved collectively but not all of them. Land varies from farm to farm and even internally from plot to plot. As a social group farmers can have common interests but this does not mean that land resources and soil quality are identical and in many cases there is a need for farm-level assistance.
- 59 A widening gap has opened up between farmers and researchers because of the lack of technical assistance. This is unfortunate because degradation of the Brazilian Atlantic Forest will only be reverted when socially viable rural systems also provide relevant environmental services, and for this to happen farmer and scientific knowledge must be harnessed together in order to build good agricultural practices that truly integrate socio-economic and ecological functions. This study has strived to show how this can be achieved.

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## ABSTRACTS

This article focuses on how farmers identify and evaluate the quality of soils cultivated and how their indicators compare to those used by agricultural scientists. The aim is to bridge the gap between specific farmer knowledge and universal scientific knowledge by adopting an ecosystem framework applied to agriculture through the concept of agro-ecosystems. This approach was applied to farming in mountainous areas of the Brazilian Atlantic Forest, a global environmental hotspot that has been degraded over time. In order to reverse this trend, local actors have to build agro-ecological systems that maintain environmental quality, agronomic sustainability and

socio-economic viability. For this to happen, local and scientific knowledge must be bridged and mutually adapted in order to be successful. This study therefore concentrates on processes of inter-communication between farmers and agricultural scientists concerning the role of soil quality in farming and conservation.

Cet article met en lumière la façon dont les agriculteurs identifient et évaluent la qualité des sols cultivés et en quoi leurs indicateurs peuvent être comparés avec ceux utilisés par les sciences agraires. Il s'agit de combler le fossé entre la connaissance empirique des agriculteurs et les connaissances scientifiques universelles en adoptant un cadre écosystémique appliqué à l'agriculture à travers le concept d'agro-écosystèmes. Cette approche a été appliquée à l'agriculture dans les zones montagneuses de la forêt atlantique brésilienne, un hotspot environnemental qui s'est dégradé au fil du temps. Afin d'inverser cette tendance, les acteurs locaux doivent construire des systèmes agro-écologiques qui maintiennent la qualité de l'environnement, la durabilité agronomique et la viabilité socio-économique. Pour ce faire, les connaissances locales et scientifiques doivent être mises en commun et adaptées mutuellement. Cette étude se concentre donc sur les processus d'interconnexion entre agriculteurs et scientifiques et leur impact sur la qualité des sols dans les domaines de l'agriculture et de la conservation.

## INDEX

**Mots-clés:** savoir des agriculteurs, savoir scientifique, indicateurs de qualité des sols, agro-écosystèmes, biome de la forêt atlantique, Brésil

**Keywords:** farmer knowledge, scientific knowledge, soil quality indicators, agro-ecosystems, Atlantic Forest biome, Brazil

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