Ecosystem services in smallholder coffee farming systems: a case study in Uganda using chemical soil indicators

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Abstract

Organic farming practices support ecosystem services at local, regional and global scales. It is crucial for organic smallholder farmers do understand linkages between the applied practices and their effects on the ecosystem. The soil parameters pH (H_2O), electrical conductivity (EC), total nitrogen of the solid phase (N_t), organic carbon (C_{org}), plant-available potassium (CAL-K), plant-available phosphorus (CAL-PO_4), total dissolved nitrogen (TDN), dissolved organic carbon (DOC), nitrate (NO_3), phosphate (PO_4), sulphate (SO_4), carbonate (CO_3) and cation exchange capacity (CEC) can be linked to soil-related ecosystem services derived through agricultural practices, and they highlight differences between organic and non-organic farming systems. The measured soil parameters in this study of organically managed systems and their quality exceed those of non-organically managed ones.

Introduction

Coffee experts from countries with a coffee-drinking culture are discovering that organic coffee beans have unique qualities unlike conventionally produced ones.

The bean quality needed for the perfect cup of coffee is for most farmers intangible, so economic incentives are the major reason to go organic. Farmers may not be aware of the economic, social and ecological benefits available through organic agriculture. At a local, regional or global scale, smallholder coffee farmers can discover that organic production methods are linked to provisioning, regulating, cultural and supporting ecosystem services (MEA, 2005). Figure 1 shows an overview of ecosystem services and their spatial dimension and agro-ecosystem impacts. Besides the quality of coffee beans, changes in soil chemical properties reveal advantages for coffee farmers.

The filtering, buffering, and transformation function of soils (Figure 2; Blum, 1998) regulates and supports ecosystem services like nitrogen fixation, erosion control, soil conservation, soil formation and nutrient cycling.

Figure 1: Ecosystem services, including their spatial scales and agro-ecosystem impact indicators (illustration: Pohl)

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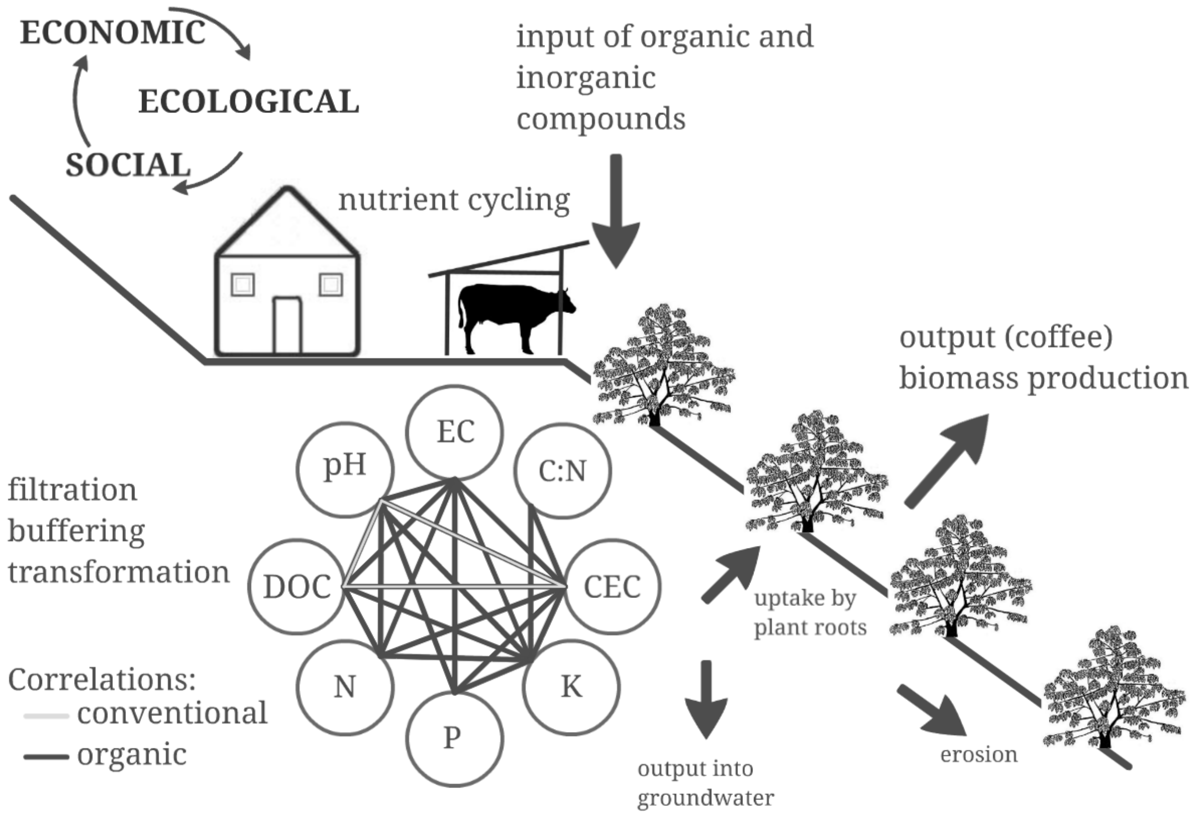

Figure 1: Schematic diagram of a typical coffee farming system with significant correlations between soil parameters and their ecosystem functions according to Blum (1998) (illustration: Pohl)

Material and methods

The study determined soil health indicators of 20 coffee (*Coffea arabica*) smallholder farms in four subcounties in the area of the Mbale, Mount Elgon region (1200 to 1900 m.a.s.l) in the southeast region of Uganda. Four groups, comprising five farmers each in the subcounties Bufumbo, Bukonde, Bubyango and Budwale, were researched. Farmers in the subcounties Bufumbo, Bukonde and Bubyango are working under the Bufumbo Organic Farmers Association (BOFA) and are certified organic. A non-organic control group in the subcounty Budwale was selected for comparison.

Most organic farms are agroforestry systems, whereas the non-organic coffee farms in Budwale have nearly no shade trees. They appear to operate with similar practices and production systems as those used by larger scale commercial coffee plantations, but they have limited access to additional fertilizer inputs into their system.

Soil samples (0-20 cm) were collected in August 2012 on each farm, one at the upper and one in lower areas of the coffee plantation. Soil characterization data from those samples are indicated as "upper" and "lower", respectively according to the sampling area. Samples were analysed in the laboratory according to OENORM standards from October 2012 to December 2012. Due to learning transfers between organic and non-organic farmers nearby, different subcounties were selected. The samples were air-dried and sieved through a 2mm sieve to determine pH (H_2O), electrical conductivity (EC), total nitrogen of the solid phase (N_t) and organic carbon (C_{org}). These upper soil samples were additionally analysed for plant-available potassium (CAL-K), plant-available phosphorus (CAL-PO_4), total dissolved nitrogen (TDN), dissolved organic carbon (DOC), nitrate (NO_3), phosphate (PO_4), sulphate (SO_4), carbonate (CO_3) and cation exchange capacity (CEC).

The values of the soil parameters were tested for correlations between the parameters. A one-way analysis of variance (ANOVA) was conducted using the statistical analytical software, SPSS Statistics Version 22.

Results

According to the Leven's test, the following soil parameters of the upper soil samples had homogeneous variances: pH, C:N ratio, K, DOC and CEC. The lower soil samples had homogeneous variances in pH, N_t and C:N ratio. The results of the one-way ANOVA showed a significant difference between pH, N_t, C:N ratio and DOC of upper soil samples. For the lower soil samples, significant differences were found for pH, N_t and C:N ratio. The characters (a,b) in Tables 1 and 2 indicate significant differences between the subcounties according to Duncan's multiple comparison test. The control group in the subcounty Budwale had significant differences compared to the organic operating subcounties in the soil parameters pH_{upper}, pH_{lower}, Nt upper, N_t lower, C:N $ratio_{upper}$, TDN and DOC. The higher C:N ratio of the organic systems' soils was probably due to a high input of acidic humus and organic matter from animal manure and litter of shading trees. In general, tropical soils with low organic matter (SOM) have a C:N ratio of <10, and a C:N ratio around 12 indicates "good" soils, and >20 signifies acid humus (Wintgens, 2004). All of the soil samples studied here had "good" soil C:N ratios, indicating the soil fertility of the Mbale region. The organic farms exceeded the commonly used pH range of 5.5 and 6.0 (Wintgens, 2004), but in natural coffee forests, the best quality coffee can be produced in the pH range 5.3 and 7 (Kufa, 2011) .

Table 1: Laboratory results of upper soil sample chemical properties in comparison (illustration: Pohl)

		soil chemical properties upper soil samples									
subcounty	n	pH	EC [mS]	Nt [g/kg]	Corg [g/kg]	C:N ratio	P [mg/kg]	K [mg/kg]	TDN [mg/kg]	DOC [mg DOC/l]	CEC [meq/kg]
Bufumbo (org.)	5	6,7 ±0,4 b	47,9 ±38,0 a	1,5 ±0,6 a	19,9 ±5,6 b	13,9 ±3,0 ab	95,8 ±162,6 a	314,5 ±244,5 a	42,8 ±20,4 b	23,8 ±11,3 b	151,0 ±55,6 a
Bukonde (org.)	5	6,3 ±0,4 b	26,0 ±10,3 a	0,8 ±0,2 b	11,7 ±2,2 a	16,2 ±3,4 b	34,7 ±45,5 a	290,6 ±322,3 a	30,1 ±2,9 ab	24,3 ±6,9 b	104,9 ±95,1 a
Bubyango (org.)	5	6,4 ±0,3 b	26,5 ±9,4 a	1,2 ±0,1 ab	15,7 ±2,2 ab	13,0 ±1,5 ab	35,3 ±26,4 a	117,0 ±52,3 a	33,3 ±9,2 ab	18,5 ±7,0 b	141,2 ±41,7 a
Budwale (con.)	5	5,7 ±0,2 a	20,5 ±9,2 a	1,8 ±0,7 a	19,5 ±6,6 b	10,7 ±0,4 a	9,1 ±7,4 a	189,1 ±116,5 a	24,1 ±4,6 a	6,7 ±4,4 a	83,3 ±43,4 a
Levene's test homogenity (sig.)		0,215	0,012	0,001	0,009	0,166	0,017	0,071	0,018	0,063	0,397
ANOVA		0,002	0,223	0,015	0,041	0,017	0,451	0,447	0,117	0,008	0,320

Means (± SD)
soil reaction (pH), electric conductivity (EC) ,organic carbon (Corg),total nitrogen (Nt), phosphorus (P), potassium (K), total dissolved nitrogen (TDN), dissolved organic carbon (DOC), cation exchange capacity (CEC)
level of significance $p < 0,05$ *

Table 2: Laboratory results of lower soil sample chemical properties in comparison (illustration: Pohl)

		soil chemical properties of lower soil samples				
subcounty	n	pH	EC [mS]	Nt [g/kg]	Corg [g/kg]	C:N ratio
Bufumbo (org.)	5	6,3 ±0,3 ab	31,4 ±16,5 a	1,5 ±0,7 ab	21,5 ±7,7 ab	14,5 ±1,3 b
Bukonde (org.)	5	6,3 ±0,4 b	26,9 ±16,1 a	0,8 ±0,4 b	13,4 ±3,8 b	17,7 ±3,2 a
Bubyango (org.)	5	6,0 ±0,2 ab	17,9 ±6,6 a	1,3 ±0,5 ab	17,3 ±6,5 ab	12,9 ±1,9 b
Budwale (con.)	5	5,9 ±0,3 a	26,1 ±4,6 a	2,1 ±0,9 a	24,1 ±9,8 a	11,9 ±2,5 b
Levene's test homogenity (sig.)		0,748	0,047	0,534	0,638	0,659
ANOVA		0,050	0,392	0,054	0,142	0,007

Means (± SD)

soil reaction (pH), electric conductivity (EC) ,organic carbon (Corg),total nitrogen (Nt), phosphorus (P), potassium (K), total dissolved nitrogen (TDN), dissolved organic carbon (DOC), cation exchange capacity (CEC)

level of significance $p < 0,05$ *

Indicators of higher biodiversity of soil microorganisms in organic systems are the increased mobilization of bonded soil nutrients through the release of organic compounds by microorganisms and plants. This was shown in the significant differences in dissolved organic carbon (DOC) between the organic farmers and the control group.

The distribution of N_t between upper and lower samples varied less in the organic systems than in the non-organic systems; probably reflecting less soil erosion of the organic soils. Due to high precipitation, especially between March and June, and due to the steep slopes at the foot of Mount Elgon; erosion control is a necessary management practice to prevent nutrient losses and landslides.

The higher amount of nutrients (P, TDN and K) in the soils from the organic farms indicated a better supply of soil nutrients to the coffee plants than in the non-organic soils. Organic matter in the soil is an important

reservoir of P, N and S. Consequently, organic farmers are enhancing nutrient cycling and the phosphorus level of the soil by the application of manure, compost and mulch. An increased interaction between organic matter and mineral components of soils characterizes soil fertility and is confirmed through higher cation exchange capacities (CEC) of organic farming systems. An additional aspect of an increased activity between various binding agents is the forming of aggregates and their stabilization.
The use of N_2-fixing trees, as well non N_2-fixing trees can enhance soil physical, chemical and biological properties through releasing and recycling nutrients from decomposing litter and the large annual inputs to soil organic matter (Beer et al., 1997; Jose, 2009).

Discussion

The multifunctional landscape of agroforestry is supporting organic farmers to maintain soil quality and profits through ecosystem services. Beneficial ecosystem services in organic coffee systems are higher inputs of organic matter, higher biodiversity of soil microorganisms, less soil erosion, and the potential for higher aggregate stability and superior nutrient circulation. The non-organic farmers lack inputs of organic and inorganic materials, and they miss the advantages of natural pest control, buffering capacity of water, reduction of temperature extremes, nutrient access through deep rooting trees and further beneficial ecosystem services of agroforestry systems. The health of the coffee plant is decreasing due to a low nutrient supply and natural regulating ecosystem services.
Organic farmers are able to create good growing conditions for coffee and foster the resilience of farming systems against risks such as climate change, while realizing long-term benefits from ecosystem services.

Future challenges to face in organic coffee production systems

Soil as a major resource within an agro-ecosystem, provides a number of functions, which support the health of other important pillars of a soil-plant-microbial system. The regulating and buffering service provided by soil will gain importance in tackling the challenges of climate change and nutrient availability, especially phosphorus. To integrate and develop methods into a simple soil field test kit to determine soil parameters relevant for organic farming will provide mutual understanding of natural processes by researchers and organic farmers.

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