2017 International Symposium on Cocoa Research (ISCR), Lima, Peru, 13-17 November 2017

Influence of Agroforestry Systems with Cacao on Soil Properties (Physical, Chemical and Microbiological) in Peruvian Amazon

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Abstract

Growing cacao in agroforestry system generates an intensive productive use of the land and maintaining and improving the properties of tropical soils, and which play an important role in improving cocoa production and fertility of degraded tropical soils. A long term study was established in the EE "El Choclino"/Instituto de Cultivos Tropicales – ICT, Tarapoto, San Martin - Peru, with the objective to evaluate the impact of improved natural agroforestry systems (INAS) and in improved traditional agroforestry system (ITAS) planted with cacao genotypes on soil physical, chemical and biological (fungus and nematodes) properties. Both systems of cacao production were installed on area with 30-years of secondary forest. Field experiment consist of 10 cacao genotypes (ICS-95, UF-613, CCN-51, ICT-1112, ICT-1026, ICT-2162, ICT-2171, ICT-2142, H-35, U-30) and one spontaneous hybrid. After removal of the surface organic layer, Samples for soil an soil microbiological community analysis were taken at 0-20 cm depth in 2004 before the installation of the management systems and in 2012, the samples for fungus and nematodes community analysis were preserved in frozen at -20 °C. Bulk density, porosity, and soil moisture content at field capacity and wilting point varied significantly during the years of assessment, under cocoa genotypes assessed. Soil pH, CEC, exchangeable Mg and sum of bases were highest in the INAS, than the ITAS. In both the systems, SOM contents, extractable P and K and exchangeable K, Mg and Cu and Al saturation, increased with years of cultivation. However, overall improvement of SOM and soil nutrient status was much higher in the ITAS than INAS. The levels of physical and chemical properties of soil under cocoa genotypes show a marked difference in both systems. The soil fungi and nematode diversity index varied significantly during the years of assessment under the systems assessed. The fungal communities showed significant changes due to soil disturbance influenced by the installation of INAS and ITAS with cacao genotypes. The population of soil nematodes associated to the Cacao was very varied, predominating the genus *Meloidogyne*, *Helicotylenchus* and *Pratylenchus*, while the population of non - phytopathogenic nematodes consisted of genera of the orders *Dorylaimida* and *Rhabditida*. Overall the edaphic conditions with a sandy loam texture, 60% sand, strongly acidic reaction, low organic matter (<1.5%), and annual average temperatures of 26.4 °C, played a significant role in the observed soil fungal diversity parameters and functional fungal groups and were favorable for development of nematode population.

Introduction

Peru is the third largest producer of organic cacao in the world (Willer and Lernout, 2017). In the last 10 years, the cultivated area under cacao in Peru has increased at the rate of 6,500 ha yr^{-1} (OEEE-MINAG, 2017).

The consequences of deforestation in the Amazon region are evident in the deterioration of natural resources with a loss of biodiversity, productive capacity of the soil and its consequential surrender to the natural regeneration of vegetation as compared to natural forest (Flores, 1998).

Success of sustainable production systems in the tropical areas is dependent on the proper management of the physical and chemical properties of these soils (Alegre et al., 1986). One way to mitigate these deforestation practices in the Peruvian jungle is to provide viable alternatives such as agroforestry systems of crop management for farmers who practice slash and burn crop production thereby accelerating deforestation and soil degradation and increasing rural poverty (Alegre et al., 2006).

The adoption of some typical farming practices for sustainable crop production include avoiding of cutting and burning or removing of the native vegetation, use of secondary forest trees as temporary and permanent shade, use of cover crops and reducing the use of synthetic fertilizers and pesticides, which cause fundamental differences in the quantitative and qualitative flow of soil nutrients. These changes affect the availability of nutrients for growing crops either directly by contributing to the availability of nutrients or indirectly by influencing the physical and chemical environment of the soil (Clark et al., 1998).

Most current cacao plantations depend on a traditional system of clearing areas for planting of crops such as maize, beans, and bananas and finally planting of cacao (Alegre et al., 1990; Watson et al., 2000.

The physical, chemical and biological properties of this habitat depend on time and space (Hedlund, 2002). "In a soil, the micro-habitats are different, eg: rhizoplane, rhizosphere, aggregates, etc. Typically the soils have stratified habitats, with different backgrounds; each of them can be treated as a separate entity. (Benedetti et al., 2003).

The biological properties of soil include the amount, activity and diversity of soil fauna (macro / micro / meso), micro flora and enzymes.

This work estimates the changes that occurred in the soil physical, chemical and biological properties in agroforestry system with cacao in the Peruvian Amazon.

Materials and methods

This study was carry out in the ICT-Experimental Station “El Choclino”, located in Tarapoto, Peru

A polyclonal plantation of cocoa was established in an agroforestry system under traditional management with slash and burn (ITAS), and other under forest without slash and burn (INAS) in 2004, inside of secondary forestry (SeF) of 30 years old

Soil samples near to the rhizosphere of cocoa were taken from 0-20 cm deep, making a zigzag path, prior to the installation of the cacao management systems. Litter was removed before soil sampling. A stainless steel tube with 2 cm diameter and 60 cm in length was driven at each sampling site to the desired depth to obtain a soil sample and these were mixed thoroughly and a 1 kg of composite sample was transported to the lab, air dried, ground and passed through a 2 mm sieve, them was divide in two sub samples, one for physical and chemical analysis and the other was stored at 5°C for biological analysis. The analysis was conducted in the laboratories of Soil and Plant Pathology of Instituto de Cultivos Tropicales (Tropical Crop Institute) (ICT).

Soil analyses followed protocols recommended by Anderson and Ingram, 1993. Soil texture with Bouyoucos densimeter; bulk density (BD) by the cylinder method, the BD porosity was computed [(1-BD/2.65) x 100]. Field capacity (FC) and wilting point (WP) were estimated based on texture and organic matter content according to the model proposed by Saxton and Rawls, 2006. The chemical properties determined were: pH (1:1) by the potentiometric method, electrical conductivity (EC) by conductivity meter, extractable ions (Ext. P, K, Fe, Cu, Zn, Mn) by Olsen modified method, exchangeable bases (Exch. K, Ca, Mg) for soils with pH $\leq$ 5.5 by 1 M ammonium acetate and for soils with pH > 5.5 by1 N KCl, exchangeable acidity (Exch. Al+H) by the Yuan method, and soil organic matter (SOM) by the Walkley and Black method. Ca, Mg, K, Fe, Cu, Mn, and Zn in the extractants were determined by atomic absorption spectrophotometry, P in the extractant by use of the ascorbic-Molybdate color development method and detected by colorimetry. CEC (Cation Exchange Capacity) was calculated as the sum of exchangeable bases (Exch, K, Ca, Mg) plus exchangeable Al+H.

For the soil fungus analysis, was by serial dilution (10^{-4}). Of final dilution an aliquot volume of 0.1 ml was incorporated in a petri dish, and then poured the culture medium potato sucrose agar (PSA). Then the plates were incubated at room temperature for seven days, at the end of this period was quantified the colony forming units per gram of soil (cfu g^{-1}). To identify colonies of fungi was used identification keys of Barron, 1968; Barnett & B. Hunter, 1998; Ellis, 1971 and Watanabe, 2002.

The extraction of soil nematodes was carried out using the method of screening (Cobb, 1914) and the tray (Canto, 2005). The number of nematodes per 100 cubic centimeters of soil (indiv.$100ccs^{-1}$) was quantified 48 hours after and was identified using taxonomic keys for nematodes (Mai et al., 1975, Jacob & Middelplats 1986, Canto, 2005).

All statistical analysis was carried out using InfoStat, 2013 version (Di Rienzo et al., 2014), to compare the soil physical, chemical and biological properties among two agroforestry systems.

Results and discussion

Soil physical and chemical properties

In the Table 1 we show the results the evaluation of soil physical and chemical properties of previous and eight years after the installation of agroforestry system with cacao (INAS e ITAS)

Table 1. Soil physical and chemical properties of previous the installation (2004) of agro forestry system with cacao (INAS e ITAS) and 2012

Soil properties	2004	2012		*P values*
	SeF	**INAS**	**ITAS**	
Physical				
Bulk density (BD) (g cm^{-3})	1.35 a	1.26 b	1.35 a	<0.0001
Porosity (Po) (%)	49.10 b	52.40 a	49.21 b	<0.0001
Field Capacity (FC) (%)	34.70 c	43.43 a	38.45 b	<0.0001
Wilting point (WP) (%)	20.80 c	32.89 a	27.20 b	<0.0001
Chemicals				
pH (1:1)	5.60 b	5.86 a	5.48 c	0.0007
EC (dS m^{-1})	0.58 a	0.21 b	0.12 c	<0.0001
SOM (%)	3.90	3.34	3.38	0.3542
Ext. P (µg g^{-1})	6.50 a	2.58 c	4.76 b	<0.0001
Ext. K (µg g^{-1})	130.0 a	47.00 b	53.09 b	0.0315
Ext. Fe (µg g^{-1})	69.50 a	37.18 c	51.05 b	<0.0001
Ext. Cu (µg g^{-1})	1.30 b	2.07 a	1.09 c	0.0074
Ext. Zn (µg g^{-1})	2.30 a	0.94 b	0.67 b	0.0078
Ext. Mn(µg g^{-1})	17.30 b	20.50 a	11.08 c	0.0173
Exch. K (cmol kg^{-1})	0.25 a	0.12 b	0.14 b	0.1678
Exch. Ca (cmol kg^{-1})	18.15 c	25.85 a	20.95 b	<0.0001
Exch. Mg (cmol kg^{-1})	2.39 a	2.36 a	1.83 b	<0.0001
Exch. Al (cmol kg^{-1})	0.30 a	0.13 b	0.18 b	0.0277
CEC (cmol kg^{-1})	21.09 b	28.46 a	23.09 b	<0.0001

EC=Electric conductivity, SOM= Soil organic matter, Ext.= Extractable, Exch.= Exchangeable, CEC= Cationic exchange capacity

The BD was improve in INAS while in ITAS is similar to SeF, The lower BD under INAS can have a positive effect on the development of roots, especially in tree plantations because when soil bulk density increases, soil strength increases and soil aeration decreases, leading to adverse effects on root growth (Nambiar and Sands, 1992)]. Unlike BD, the porosity, FC and WP, was higher in the INAS system and significantly different from ITAS. The soil physical soil properties can be altered over time by the management practices and nature of vegetative cover (Amusan et al, 2006).

FC and WP were linked to the soil moisture content as well as the clay content of the soil, so that a higher content of organic matter and clay will increase the field capacity. The wilting point refers to the moisture content of soil where the absorptive capacity of the root is less than the demand of the plant (Lambers et al., 2008).

The soil pH in INAS and ITAS were within the range of a medium to strongly acidic reaction. In INAS, soil pH values increased slightly by time. Overall, pH values in INAS were significantly higher than ITAS . The differences in soil pH between INAS and ITAS may be related to differences in the dynamics of the soil organic matter (Bell and Raczkowski, 2008) . Agroforestry systems adapted in the study have greater buffering capacity and that leads to increases in soil pH, and by having perennial vegetative cover with abundant foliage, which provides a permanent soil cover and abundant yearly addition of leaf litter that protects the soil from erosion and minimizes the nutrient loss by surface run-off and leaching. (Arevalo-Gardini et al. 2015).

All values of EC were low in both systems of management (<1 dS m-1) as compared to SF and given the high soil moisture content during rainy periods it is expected that such low EC will not be a problem because the EC values even though low but they are at adequate range (Soil Survey Staff, 1994).

In both systems of management, the SOM showed medium levels; overall, ITAS recorded higher SOM than INAS, but not significant to SeF. The organic matter positively influences nearly all important properties that contribute to the quality of soil (Bot and Benites, 2005)

In ITAS and INAS the available P decreased after the installation of agro forestry systems, in the time the values of Ext. P in ITAS was high than ITAS, could be the result of slash and burn in situ of SF, that produce strong mineralizing effect of fire on organic P (Gómez-Rey et al., 2013).

The level of Ext. K in both systems of management declined with the increase in years of assessment, this effect could be explained to the fact that the amount of K absorbed by plants is higher than the K present and replenished in the soil by slow transfer of K from primary minerals to soil exchange complexes, the soil solution and K released from mineralization of SOM (Havlin et al., 2005)

The agro forestry with cacao management had a significant influence on extractable Fe, Cu, Zn and Mn. Overall, INAS and ITAS recorded decline values for extractable Fe and Zn than SF. The decrease of extractable Fe might be associated with Fe losses from the eroding sediments (Gómez-Rey et al., 2013). In INAS the levels of extractable Fe and Zn have the overall tendency to decrease with time. The extractable Cu had a higher level of variability; this variation may be possibly influenced by the soil pH (Danoff et al., 2007). The extractable Mn showed a significant increase in INAS and decline in ITAS.

The soil exchangeable K, Ca and Mg were affected significantly for the agro forestry management. In ITAS exchangeable Mg decline significantly while Ca increase slightly significantly, however, exchangeable (Al+H) decreased significantly. Soils under the SF system were medium to strongly acidic in reaction.

The soil under management conditions in accordance with the balance of the ecosystem has better features than one under conventional management (Theodoro et al., 2003). Soils with high organic matter had higher pH and higher availability of Ca, Mg, K, P and Zn and a drop in exchangeable aluminum (Theodoro et al., 2003).

CEC values were significantly higher in INAS than in ITAS. In both systems of management, CEC increased with increasing years. Such increases in CEC could be attributed to the greater accumulation of organic matter in cacao production systems with time that promoted greater biodegradation and mineralization of surface biomass. (Arévalo-Gardini et al., 2015)

Soil biological properties

Soil Fungi

In the Table 2 we show the genera and functional groups of soil fungi in agro forestry system with cacao and the indicators of diversity found in a secondary forest previous to installation of INAS and ITAS

Tabla 2. Soil fungal genera and indicators of diversity in agro forestry system in 2004 and 2012

Genera	Functional Group	2004 SeF	2010 INAS	2010 ITAS
Clonostachys sp.	BCF	+		
Metarrhizium sp.	BCF		+	
Mycogone sp.	BCF	+	+	+
Paecilomyces sp.	BCF	+	+	+
Penicillium sp.	BCF	+	+	+
Trichoderma sp.	BCF	+	+	+
Bipolaris sp.	PPF	+		
Cephalosporium sp.	PPF	+	+	
Phytophthora sp.	PPF	+		
Rhizoctonia sp.	PPF	+		
Aureobasidium sp.	PSF	+		
Cladosporium sp.	PSF	+	+	+
Cylindrocarpon sp.	PSF			
Fusarium sp.	PSF	+	+	+
Hyalodendron sp.	PSF			
Nigrospora sp.	PSF			
Phialophora sp.	PSF			
Verticillium sp.	PSF	+		
Aspergillus sp.	SF	+	+	+
Chrysosporium sp.	SF	+		
Cunninghamella sp.	SF	+	+	
Didymostilbe sp.	SF		+	+
Eurotium sp.	SF		+	+
Gilmaniella sp.	SF			
Gliomastix sp.	SF		+	+
Mucor sp.	SF		+	+
Neosartorya sp.	SF		+	+
Rhizopus sp.	SF			+
Scolecobasidium sp	SF			
Sterile mycelia	SF		+	+
Abundance (thousand cfu g^{-1})		$2.2x10^4$ b	$2.8x10^4$ b	$4.4 x10^4$a
Richness (n)		6.67 a	4.76 b	4.36 b
Shannon-Wiener		1.42 a	1.30 b	1.17c
Simpson		0.33 b	0.34 b	0.40a

BCF=Potential biological control fungi, PPF= Potential plant pathogen fungi, PSF=Pathogen-saprophytic fungi, SF=Saprophytic fungi

We found in all system 30 genera (30% has potential biocontrol, 41% saprophytes , 17% pathogenic-saprophytic and 11% are pathogens), the most frequent were *Mycogone, Paecilomyces, Penicillium, Trichoderma, Cladosporium, Fusarium and Aspergillus.* The abundance was increase significantly in ITAS with $4.4x10^4$ cfu g^{-1} followed in INAS this result could be to sequences of different crops in the installation of this type of agro forestry system that include first, slash and burn, planting corns, beans, plantain, cocoa and forestry trees, but the Richness and the Shannon-Wiener index decline while in INAS this indicators were increased.

Soil nematodes

In the Table 3 we show the genera and trophics groups of soil nematodes in agro forestry system with cacao and the indicators of diversity found in a secondary forest previous to installation of INAS and ITAS

Genera or Family	c-p[a]	GT[b]	2004	2010	
			SF	INAS	ITAS
Rhabditidos	1	BF	+	+	+
Aphelenchoides sp.	2	FF	+	+	+
Aphelenchus sp.	2	FF	+	+	+
Ditylenchus sp.	2	FF			+
Dorylaimidos	4	O-P	+	+	+
Atylenchus sp.	2	PP			
Criconemoides sp.	3	PP	+		+
Crossonema sp.	3	PP		+	+
Dorylaimus sp.	4	PP			
Helicotylenchus sp.	3	PP	+	+	+
Hemicycliophora sp.	3	PP	+		
Meloidogyne sp.	3	PP	+	+	+
Paratylenchus sp.	2	PP	+	+	+
Pratylenchus sp.	3	PP	+		
Psilenchus sp.	2	PP			+
Rhadinaphelenchus sp.	2	PP			+
Rotylenchulus sp.	3	PP		+	+
Rotylenchus sp.	3	PP	+		
Scutellonema sp.	3	PP			+
Trichodorus sp.	4	PP		+	+
Tylenchorhynchus sp.	3	PP		+	
Tylenchulus sp.	2	PP			+
Tylenchus sp.	2	PP	+	+	+
Xiphinema sp.	5	PP	+	+	+
Mononchus sp.	4	PP	+	+	+
Abundance (individual/100ccs)			163	206	230
Richness (n)			8.67 a	3.56 b	3.86 b
Shannon-Wiener			1.28	0.81	0.81
Simpson			0.39	0.54	0.56

[a]c-p = colonizers and persistent, scale 1-5 where 1 is a colonizer of short generational period and 5 are persistent for a long generational period according to Borges, 1990. [b]GT = Trophic Group: BF = Bacteriophage, FF = Fungivore, PP = Phytophages or plant parasites, O-P = Ommivores-predators; according to Yeates et al. (1993).

We found in all system 23 genera (6.4% has bacteriophage, 14.9% fungivore, 6.4% Ommivores-predators, 72.3% Phytophages or plant parasites), the most frequent were *Rhabditidos, Aphelenchoides, Aphelenchus, Dorylaimidos, Helicotylenchus, Meloidogyne, Paratylenchus, Tylenchus, Xiphinema and Mononchus.* The abundance was increase in the time in INAS and ITAS from 163 in SeF to over 200 individual/100ccs, the Richness and the Shannon-Wiener index decline in both systems in comparison to SeF.
These results indicate that the diversity, richness and nematode population were affected by the increased activity in land use during the establishment of cocoa under the INAS and ITAS (Arévalo-Gardini et al., 2007).

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