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Seasonal dynamics for Organic Carbon in Andosols and volcanic Aridisols of the Canary Islands (Spain) and in related enzymatic activities

B. Santana, C.D. Arbelo, A. Rodríguez-Rodríguez, C.M. Armas, J.L. Mora, and J.S. Notario
Department of Soil Science and Geology, University of La Laguna, Canary Islands, Spain (antororo@ull.es)

Resumé

Le principal objectif de cette étude a été de caractériser la variation saisonnière de l'activité enzymatique (dehydrogenase, glucosidase et cellulase) et des fractions de carbone dans des andosols et des aridisols volcaniques des Îles Canaries. Les andosols étudiés présentent une haute contenu de carbone microbien, qui coïncide avec les maximaux apports de feuilles au sol. La biomasse microbienne la plus active apparaît dans les andosols umbriques, caractérisés par des processus de minéralisation intenses, démontrés par les hautes activités enzymatique mesurées. Dans les aridisols volcaniques au contraire, les niveaux de carbone organique total, carbone microbien et activité enzymatique sont beaucoup plus faibles, en indiquant un plus petit dynamisme biologique dans ces derniers.

Introduction

Soil biochemical parameters such as soil enzyme activities are sensitive indicators of the activities of soil organisms (fungi, bacteria). Of the extracellular enzymes in soils, those involved in the degradation of soil organic matter are of particular interest. Andosols, are characterized by a high SOC content, atributted to the fact that in these soils the organic matter is stabilized by short-range ordered minerals or by Al-humus complexes. In both cases, SOC becomes highly resistant to microbial attack (Boudot, 1992).

Very few studies related to enzymatic activities in volcanic soils and their seasonal changes as related to those soil organic C forms predominating in every season have been carried out so far (Kawahigashi *et al.*, 2003; Hopkins and Bartoli, 2004). The aim of this study is to characterize the seasonal pattern of the enzyme activity and organic carbon in Andosols and volcanic Aridisols of the Canary Islands.

Materials and Methods

In Andosols, the study was performed at three plots, two of them on Aluandic Andosols (Fulvudands) under laurel forest, and another one on Umbric Andosols (Hapludands) under degraded Erica-Myrica heather. The soils overlie deeply weathered ferrallithic saprolite derived from Pliocene basalts. Annual precipitations (850-1100 mmyr^{-1}) give rise to an Udic soil moisture regime. Mean annual temperature is 14ºC, whereas potential evapotranspiration has been estimated to be around 600 mmyr^{-1}. In volcanic Aridisols, the study was performed at two plots on Skeletic, Sodic Cambisols (Haplocambids), one under Tabaiba scrub, and the other one under shrub steppe. Annual precipitations (100-150 mmyr^{-1}) give rise to an Aridic soil moisture regime. Mean annual temperature is 21ºC, whereas potential evapotranspiration has been estimated to be around 1010 mmyr^{-1}.

The seasonal (july, october, january and april) pattern of several biochemical parameters was assessed in surface (15 cm) soil samples, on a one-year term basis, including: dehydrogenase (Camiña *et al.*, 1997), -glucosidase (Eivazi and Tabatabai, 1988) and

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cellulase (Schinner and Von Mersi, 1990) activities, microbial-carbon biomass (Vance *et al.*, 1987), total OC (Nelson and Sommers,1982), pyrophosphate-extractable OC (Van Reeuwijk, 1993), K_2SO_4-extractable OC (Horwarth and Paul, 1994) and hot-water soluble OC (Ghani *et al.*, 2003).

Results and Discussion

Seasonal dynamics in organic carbon forms

Results show that the Andosols have high total organic carbon (166-231 g C kg^{-1}) as well as high microbial-C biomass (2.49-6.11 g C kg^{-1}) contents (Table 1). These values are higher than those reported by other authors in volcanic ash-derived soils (Kawahigashi *et al.*, 2003). Pyrophosphate-extractable OC represents 26-36% of the total OC content. The mean biomass C to soil C ratio is 1.8-2.4%, much higher than those found by Hopkins and Bartoli (2004) in the COST622 reference volcanic soils of Europe (1.3-1.7%). Moreover, microbial biomass C correlates poorly with total soil organic C (r=0.44) (Table 3). Hot water has been shown to extract more organic C than K_2SO_4, and their values relate fairly with total SOC (r=0.87**). Aridisols show lower total SOC and microbial-C biomass contents (2.1-4.6 g kg^{-1} and 0.26-0.93 g kg^{-1}, respectively), although the mean biomass C to soil C ratio was 10.6-17.0%, much higher than in Andosols, suggesting that their organic matter is less recalcitrant. Ghani et al. (2003) have found that hot water-soluble organic C exceeds biomass C in Andosols from NewZealand. It also happens in Canarian Andosols (mean ratio = 1.2), but not in Aridisols (mean ratio = 0.76), which confirms that microbial biomass in Aridisols can only be partially extracted with boiling water. Such a differential behaviour suggests that the organic C forms that regulate the microbial biomass, as well as the availability of C substrates, are different in both soil types.

In Andosols the highest total soil organic C values have been measured in winter and spring, together with the highest values for soil moisture, whereas the microbial biomass, hot-water- and K_2SO_4-extractable organic C contents have been determined during spring and summer. No significant seasonal fluctuations have been found for pyrophoshate-extractable organic C. In Aridisols, only a slight increase of the microbial biomass, hot-water- and K_2SO_4-extractable organic C contents have been found in winter.

	Aluandic andosol Valley *Laurus* forest	**Aluandic andosol** Slope *Laurus* forest	**Umbric andosol** Degraded *Erica-Myrica* heather	**Sodic cambisol** Xerophitic *Tabaiba* Scrub	**Sodic cambisol** Xerophitic shrub steppe
Total OC (g.100g^{-1})					
Spring	16.6 ± 0.17	21.3 ± 1.54	20.3 ± 0.61	0.46 ± 0.04	0.36 ± 0.00
Summer	21.3 ± 0.68	17.7 ± 0.14	19.5 ± 0.01	0.44 ± 0.03	0.33 ± 0.02
Autumm	23.1 ± 0.28	18.9 ± 0.54	18.4 ± 0.09	0.32 ± 0.00	0.24 ± 0.00
Winter	19.8 ± 0.33	20.6 ± 0.83	20.4 ± 0.67	0.58 ± 0.05	0.21 ± 0.02
Annual mean	*20.2 ± 2.75*	*19.6 ± 1.64*	*19.7 ± 0.93*	*0.45 ± 0.10*	*0.28 ± 0.07*
Microbial OC (mg.kg^{-1})					
Spring	4320 ± 80	3754 ± 82	3362 ± 76	355 ± 8	420 ± 7
Summer	4816 ± 90	2493 ± 21	6115 ± 23	256 ± 3	380 ± 5
Autumm	3898 ± 85	4417 ± 81	4107 ± 12	416 ± 1	393 ± 6
Winter	6012 ± 72	3218 ± 78	4372 ± 72	929 ± 7	580 ± 9
Annual mean	*4762 ± 914*	*3471 ± 815*	*4564 ± 1075*	*489 ± 301*	*443 ± 93*
PyroP OC (g.100g^{-1})					
Spring	5.4 ± 0.04	6.8 ± 0.07	7.2 ± 0.09	nd	nd
Summer	5.0 ± 0.02	5.8 ± 0.23	6.9 ± 0.04		
Autumm	5.2 ± 0.13	5.6 ± 0.16	7.1 ± 0.04		
Winter	5.4 ± 0.13	6.4 ± 0.12	7.5 ± 0.22		
Annual mean	*5.3 ± 0.20*	*6.1 ± 0.50*	*7.2 ± 0.30*		
K_2SO_4 OC (mg.kg^{-1})					
Spring	832 ± 10	1281 ± 11	1312 ± 13	229 ± 3	210 ± 2
Summer	781 ± 9	1699 ± 13	1280 ± 10	397 ± 6	229 ± 5
Autumm	1208 ± 10	1542 ± 9	1210 ± 10	208 ± 5	208 ± 2
Winter	1064 ± 7	1418 ± 9	1286 ± 11	294 ± 8	118 ± 3
Annual mean	*971 ± 200*	*1485 ± 178*	*1272 ± 43*	*282 ± 85*	*191 ± 50*
HW-soluble OC (mg.kg^{-1})					

Spring	2699 ± 17	7606 ± 45	5016 ± 16	329 ± 4	433 ± 9
Summer	4200 ± 21	3679 ± 32	5464 ± 12	269 ± 3	270 ± 3
Autumm	5867 ± 15	4512 ± 12	5680 ± 12	447 ± 11	213 ± 3
Winter	4892 ± 9	4764 ± 18	5284 ± 13	675 ± 9	201 ± 2
Annual mean	*4414 ± 1332*	*5140 ± 1708*	*5361 ± 281*	*430 ± 179*	*280 ± 107*
Microbial-OC/Total-OC (%)					
Annual mean	2.40 ± 0.57	1.77 ± 0.41	2.33 ± 0.57	10.6 ± 4.7	17.0 ± 7.7
PyroP OC/Total-OC (%)					
Annual mean	26.0 ± 5.0	31.0 ± 1.0	36.0 ± 1.0	--	--

Table 1.- Organic carbon forms. Annual average values (mean ± S.D.) nd: Not determined. PyroP: Pyrophosphate. HW: Hot water. All concentrations expressed as mass of elemental C. mass of soil^{-1}.

Seasonal dynamics in enzymatic activities

Enzymatic activities reach maximum values on Umbric Andosols (Hapludands). Cellulase activity ranges between 8 and 620 mmol glucose g^{-1}.h^{-1}, being higher in fall, but with a low seasonal variability (Table 2). Cellulase activity was strongly correlated with all the C fractions, save the hot-water extractable OC (r = 0.50, p>0.1) (Table 3). -glucosidase activity is also higher on Umbric Andosols (7200 mmol PNP g^{-1} h^{-1}), with maximum peaks in fall (maximum litterfall and biomass proportion). Dehydrogenase activity reaches maximum values on Umbric Andosols (Hapludands) (1360 mmol INTF g^{-1} h^{-1}). Seasonal variation is generally small, being maximum in spring.

In volcanic Aridisols, the enzyme activity is lower than in Andosols and their seasonal variation is generally small, with maximun peaks on summer (-glucosidase) or spring (dehydrogenase). Positive correlations are observed only with total organic carbon (Table 4). No cellulase activity is found in any case, probably because of a low accumulation of fresh plant debris.

	Aluandic andosol Valley Laurus forest	**Aluandic andosol** Slope Laurus forest	**Umbric andosol** Degraded Erica-Myrica heather	**Sodic cambisol** Xerophitic Tabaiba scrub	**Sodic cambisol** Xerophitic shrub steppe
Cellulase activity (mmol glucose.g^{-1}h^{-1})					
Spring	64 ± 3	159 ± 5	593 ± 11	0.0	0.0
Summer	45 ± 3	316 ± 7	620 ± 10	0.0	0.0
Autumm	33 ± 2	440 ± 6	497 ± 8	0.0	0.0
Winter	8 ± 2	330 ± 6	468 ± 5	0.0	0.0
Annual mean	*38 ± 23*	*311 ± 116*	*545 ± 73*	*0.0*	*0.0*
-glucosidase activity (mmol PNP g^{-1}h^{-1})					
Spring	4464 ± 23	5920 ± 45	10362 ± 49	251 ± 9	264 ± 6
Summer	5259 ± 27	2918 ± 32	8149 ± 21	275 ± 11	133 ± 6
Autumm	5903 ± 46	6326 ± 39	5124 ± 30	174 ± 4	80 ± 4
Winter	6048 ± 38	9050 ± 40	5124 ± 68	291 ± 7	90 ± 5
Annual mean	*5418 ± 723*	*6053 ± 2510*	*7190 ± 2551*	*248 ± 52*	*142 ± 85*
Dehydrogenase activity (mmol INTF g^{-1}h^{-1})					
Spring	510 ± 3	1100 ± 10	1360 ± 11	190 ± 2	150 ± 5
Summer	830 ± 8	320 ± 8	370 ± 9	150 ± 5	110 ± 3
Autumm	1090 ± 11	690 ± 12	930 ± 15	60 ± 3	80 ± 2
Winter	1090 ± 8	540 ± 5	650 ± 4	60 ± 1	40 ± 3
Annual mean	*880 ± 280*	*660 ± 330*	*830 ± 420*	*120 ± 60*	*100 ± 40*

Table 2.- Enzymatic activities in soils. Annual average values (Mean ± S.D.)

	Total OC	**Microb OC**	**PyroP OC**	**K_2SO_4 OC**	**HW OC**	**Cellulase**	**-gluc.**	**Dehydr.**
Total OC								
Microbial OC	0.44 *							
PyroP OC	0.91***	0.53 *						

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K_2SO_4 OC	0.86***	NS	0.81***					
HW OC	0.87***	0.51 *	0.82***	0.62**				
Cellulase	0.68***	0.65**	0.83***	0.69**	0.50 *			
-glucosidase	0.69***	0.49 *	0.64**	0.49 *	0.54 *	0.67**		
Dehydrogenase	NS	NS	NS	NS	NS	NS	NS	
Soil moisture	NS	NS	-0.60**	-0.62**	NS	-0.72***	NS	NS
Soil pH	-0.90***	NS	-0.88**	-0.83**	-0.84**	NS	NS	NS
C-litter supply	NS	NS	NS	NS	NS	NS	NS	NS
C/N ratio	0.60***	NS	0.59**	0.71***	NS	0.58**	NS	NS

Table 3.- Correlation coefficients between organic carbon fractions, soil enzyme activity and some abiotic variables in Andosols. HW: Hot water. PyroP: Pyrophosphate. NS: Not significant,* p<0.1; **p<0.05; ***p<0.01.

	Total OC	**Microbial OC**	**K_2SO_4 OC**	**HW-OC**	**-glucosidase**	**Dehydrogen.**
Total-OC						
Microbial OC	NS					
K_2SO_4 OC	0.57*	NS				
HW-OC	0.68*	0.57*	NS			
-glucosidase	0.86***	NS	0.52*	0.63*		
Dehydrogenase	NS	-0.65*	NS	NS	NS	
C/N ratio	0.73**	0.71**	NS	0.74**	NS	NS

Table 4.- Correlation coefficients between organic carbon fractions, soil enzymatic activities and some abiotic variables in volcanic Aridisols. Notations as in Table 3.

Conclusions

The Andosols studied show a high microbial biomass carbon content, which coincides with the maximum litter supplies to soil. The most active microbial biomass occurs at Umbric Andosols, characterized by intense mineralization processes, as shown by the enzymatic activities measured. On the opposite, the organic C levels, microbial C and enzymatic activities are much lower in Aridisols, pointing to a lesser biological dynamism. Seasonal differences in enzymatic levels have been observed, and they must be related to factors such as: aeration, soil moisture, organic carbon content and availability, etc.

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