Cadernos Lab. Xeolóxico de Laxe
Coruña. 2007. Vol. 32, pp. 139 - 150

ISSN: 0213 - 4497

Respiración basal en las zonas superior e inferior de una ladera cultivada con laboreo convencional

Soil basal respiration in the upper and lower slope of a conventional cultivated field

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Abstract

Soil basal respiration is an indicator of soil biological activity. In this study, the seasonal evolution of the biological activity was assessed on two different topographical positions of a hillslope representing erosion and deposition conditions. From April 2004 to April 2005, a total of 152 soil samples were taken, at two different depths, both on the erosion and deposition areas on 19 successive dates. Moreover, general soil properties, i.e. pH, water content, organic carbon and nitrogen contents were analyzed using routine methods. The soil basal respiration was found to be moderate, ranging from 0.01 to 0.15 mg C-CO_2 g^{-1} soil day^{-1}. Soil basal respiration was significantly higher in the erosional area compared to the depositional area. The seasonal oscillation of the biological activity was found to be dependent on soil water contents, so that its values were higher in the two wet seasons (spring and autumn) than in the summer, as expected. However, soil basal respiration was also high in the winter season, due to the fact of mild temperatures and high soil water contents.

Keywords: erosion, basal respiration, seasonal oscillation, soil water content.

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INTRODUCTION

Soil basal respiration rate, as assessed by carbon dioxide (CO_2) evolution, is an indicator of soil biological activity (MC FADYEN, 1970; ANDERSON & DOMSCH, 1975; WILD, 1992; DORAN *et al.*, 1994). Soil CO_2 evolution results from the decomposition of organic matter; thus, soil respiration rate is an indicator of the amount of decomposition that is occurring at a given time. Consequently, basal respiration is useful in assessing soil biological activity and soil organic matter reserves. This parameter makes it possible to learn about the biological status of the soil from the CO_2 emitted in a given time period and is also easy to measure. In fact, soil basal respiration is a measurement of background microbial respiration and is commonly regarded as a parameter giving information about the overall decomposition of organic material (HERNÁNDEZ & GARCÍA, 2003).

The term "soil quality" has been coined to describe the combination of chemical, physical, and biological characteristics that enables soils to perform a wide range of functions (DORAN *et al.*, 1994; KARLEN *et al.*, 1997). The assessment of soil quality requires quantification of critical soil attributes. Initial measurements of soil quality attributes should be made in high and low productivity areas to establish ranges of values that are site specific. Changes occurring over time can then be measured to evaluate effects of different practices, land uses or degradation stages (SARRANTONIO *et al.*, 1996).

Mainly, CO_2-loss is originated by soil biological activity even though it can be originated, also, by abiotic processes. Thus, soil basal respiration has been used as an indicator of soil quality (GARCÍA & HERNÁNDEZ, 1997; LEIRÓS *et al.*, 2000; HERNÁNDEZ & GARCÍA, 2003).

Soil microorganisms (fungi and bacteria) and other fauna (e.g., earthworms, insects, arthropods) influence the availability of nutrients for crop growth by decomposing soil organic matter and releasing or immobilizing plant nutrients (ANDERSON & DOMSCH, 1975). Biological activity improves soil aggregation through the secretion of soil binding mucilages and hyphal growth. Improved aggregation, in turn, increases water infiltration and the ease of plant root penetration. Soil biological activity is considered an integral attribute of a healthy soil (DORAN & JONES, 1996; SARRANTONIO *et al.*, 1996).

Soil respiration can be limited by moisture, temperature, oxygen, soil reaction (i.e., pH), and the availability of decomposable organic substrates. Optimum respiration usually occurs around 60% of water filled pore space. Soil respiration will decrease under saturated or dry conditions. Biological activity doubles for every 10°C rise in temperature until the optimum temperature is reached (varies for different organisms). Activity declines as temperature rises above optimum. The most efficient soil organic matter decomposers are aerobic; thus, soil respiration rates decline as soil oxygen concentration decreases. Oxygen is most limiting in soils that are saturated with water. Greater oxygen flow occurs in well-aggregated soils that have many macropores (WILD, 1992).

Temporal oscillations of soil respiration should reflect the impact of climate and season, whereas spatial oscillations may be due to soil factors, i.e., physical-chemical properties. In agricultural land, temporal and spatial oscillations are also related to management practices leading to changes in soil organic matter content and changes in nutrient recycling. Higher basal respiration values are positive if combined with high biomass content and decreased values can indicate physical or chemical degradation and deterioration of the functions a soil should fulfil.

Soil erosion is a degradation process so that some functions of the soil, especially storage and filtering, are damaged by the loss of the surface layer. When a soil is exposed to degradation, its biological state is the first to be affected, diminishing its productive capacity. Soil organic matter and nutrients eroded from a field area may contribute to resource accumulation in another area. Removal of organic matter and nutrients from the soil surface by erosion reduces populations of soil organisms, with consequent reductions in biological activity and fertility, thus aggregation and rooting depth. Soil erosion usually degrades soil quality and a potential effect of soil erosion is declining microbiological activity (KLIK *et al.*, 2002).

In our study area, it has been shown that concentrated flow erosion by rill and/or ephemeral gully transport large amounts of sediments to streams (VALCÁRCEL *et al.*, 2003; SANDE FOUZ, 2005). Conventional tillage practices and seedbed preparation enhanced concentrated flow erosion. Until now, the influence of soil degradation by erosion has not been assessed. The aim of this work was to compare soil basal respiration, at the upper and lower slope of a small field conventionally tilled which corresponded to zones of erosion and deposition, respectively.

MATERIALS AND METHODS

The studied site is located at A Zapateira, a periurban area of La Coruña (Spain). The experimental field, over granite is highly sloping (16.81%) and it is conventionally tilled following the common rotation system in the region. Since 1997, erosion has been monitored to be effective in this hillslope (VALCÁRCEL *et al.*, 2003). Long term mean annual temperature and rainfall figures are 14.4 ºC and 1008 mm, respectively. Yearly rainfall distribution is uneven with water surplus in the winter months and water deficits in summer.

Duplicate soil samples were taken on 19 successive dates between April 2004 and April 2005. Two different depths were sampled (0-5 and 5-10 cm) in the upper and lower side of the hillslope. Thus, a total of 152 individual samples were analyzed over the study period.

Soil wet samples were sieved through a 2 mm sieve. The general properties of the soil such as pH (H_2O), pH (KCl), organic carbon and nitrogen contents and texture were determined by routine methods (GUITIÁN OJEA & CARBALLAS FERNÁNDEZ, 1976). The pH of the soil was measured in water (1:2.5 v/v) and in a 0.1N KCl solution (1:2.5 v/v). Particle size distribution was determined by the pipette method (MAPA, 1994). Soil water content was measured gravimetrically.

Organic carbon contents were measured using the elementary analysis method. This technique is based on the complete oxidation of the sample by an instantaneous combustion. Combustion resultant gases are transported by a gas (helium) through a reduction oven and through a cromatographic column where their separation is produced, using a thermic conductivity detector for their quantification.

Soil basal respiration was estimated in laboratory conditions as described by GUITIÁN OJEA & CARBALLAS FERNÁNDEZ (1976) and HERNÁNDEZ & GARCÍA (2003). Soil sample (50 g) was put into hermetic lock jars with flasks containing 10 ml of 0.1N NaOH to react with the CO_2 produced by microbial respiration, in a culture chamber for a four-day incubation period at 28 ºC. The biological activity was determined with three repetitions per sample. Once the incubation was complete, a volumetric analysis with 0.1N HCl was performed. Results are expressed as mg C-CO_2 g^{-1} soil day^{-1}.

Significant differences between soil basal respiration as a function of topography and depth were analyzed using the ANOVA test. Linear regression analysis was carried out to assess significance of correlations between variables.

RESULTS AND DISCUSSION

The studied topsoil horizon is sandy-loam textured; the sand content varied from 56.33% to 64.72%; the silt content fluctuated from

17.30% to 21.01% and the clay content ranged from 15.44% to 21.91%.

Mean temperature and rainfall during the study period is shown in Table 1. Mild temperatures were measured during the whole study period; even minimum temperatures were mild during the winter months (from December to March).

	Rainfall (mm)	Mean Temperature (ºC)	Mean Minimum Temperature (ºC)	Mean Maximum Temperature (ºC)
April 04	66.10	11.43	7.24	15.62
May 04	65.50	14.53	10.04	19.02
June 04	22.80	19.06	14.80	23.32
July 04	19.90	18.86	14.48	23.25
August 04	71.20	19.53	15.78	23.28
September 04	26.90	18.31	13.78	22.85
October 04	249.50	14.65	11.40	17.89
November 04	52.20	10.56	6.51	14.62
December 04	68.00	9.00	5.20	12.80
January 05	34.00	10.05	7.11	12.98
February 05	50.90	7.00	3.02	10.99
March 05	53.40	11.56	6.70	16.41
April 05	95.40	12.82	9.19	16.46

Table 1. Mean climatic values registered during the study period.

The summary of the statistics of the studied variables is shown in Tables 2 and 3, regardless of the sampling date and soil depth. The pH (H_2O) values in the erosion zone (mean = 4.82) were slightly lower than those observed in the deposition zone (mean = 4.89). Deposition zone pH values presented a wider range of fluctuation than those of the erosion zone, as the coefficient of variation showed.

A wide range of soil water content was observed during the study period (MIRÁS *et al.*, 2005). In the erosion zone, soil water content ranged from 3.17 to 24.12 g/100g (Table 2), whereas in the deposition zone it varied from 6.06 to 32.45 g/100g (Table 3); these contents depended on the daily rainfall, mainly. Mean soil water content was slightly higher in the deposition zone (mean = 15.62 g/100g) than in the erosion zone (mean = 14.19 g/100g).

Variable	N	Mean	Median	SD	CV	Minimum	Maximum
pH (H_2O)	38	4.824	4.853	0.221	0.046	4.420	5.27
pH (KCl)	38	4.060	4.073	0.170	0.042	3.665	4.375
Soil Water Content (g/100g)	38	14.193	15.461	5.328	0.357	3.169	24.124
C (%)	38	2.092	2.083	0.673	0.322	1.215	3.340
N (%)	38	0.176	0.181	0.056	0.319	0.098	0.285
C/N	38	11.997	11.675	0.849	0.071	10.790	14.250
Respiration (mg C-CO_2 g^{-1} soil day^{-1})	38	0.071	0.069	0.027	0.387	0.015	0.125

Table 2. Statistical summary of the different analyzed variables in the erosion zone (SD = Standard Deviation; CV = Coefficient of Variation).

Variable	N	Mean	Median	SD	CV	Minimum	Maximum
pH (H_2O)	38	4.893	4.893	0.267	0.055	4.395	5.430
pH (KCl)	38	4.311	4.303	0.210	0.049	3.905	4.840
Soil Water Content (g/100g)	38	15.624	15.660	5.400	0.346	6.061	32.448
C (%)	38	2.596	2.555	0.581	0.224	1.693	4.515
N (%)	38	0.218	0.210	0.054	0.250	0.140	0.385
C/N	38	12.030	11.883	0.987	0.082	10.830	16.252
Respiration (mg C-CO_2 g^{-1} soil day^{-1})	38	0.062	0.059	0.026	0.424	0.022	0.124

Table 3. Statistical summary of the different analyzed variables in the deposition zone (SD = Standard Deviation; CV = Coefficient of Variation).

The carbon and nitrogen contents as well as the carbon/nitrogen ratios also showed significant fluctuations when all the 152 soil samples were considered. In the upper hillslope zone or erosion zone, the organic carbon content fluctuated from 1.21 to 3.34% (mean = 2.09%), whereas in the deposition zone it varied from 1.69 to 4.51% (mean = 2.60%) (Tables 2 and 3).

The mean values of the basal respiration on a yearly basis as a function of depth, topography and season of the year are given in Table 4. The significance of the mean differences was assessed by the ANOVA test (Table 5) where soil respiration was set as a dependent variable against factors such as season of the year, sample location on the hillslope and depth.

Season of the year	Erosion area	Deposition area
Mean annual	0.070	0.062
Mean annual 0 – 5 cm	0.071	0.064
Mean annual 5 – 10 cm	0.070	0.060
Spring	0.071	0.059
Summer	0.058	0.045
Autumn	0.076	0.073
Winter	0.081	0.076

Table 4. Mean soil respiration values (in mg C-CO_2 g^{-1} soil day^{-1}) for each season of the year.

Soil basal respiration was slightly higher at 0-5 than 5-10 cm depth in both the upper and the lower hillslope (Table 4). This is an expected result due to better aeration and high temperatures in the surface layer. However, differences in depth were not significant according to the ANOVA test as shown by the results of this analysis (Table 5). Nevertheless, the mean differences of the investigated parameters were significantly higher at the uppermost part of the hillslope than at its deposition zone (Table 4 and Table 5) with values of 0.070 and 0.062 mg C-CO_2 g^{-1} soil day^{-1}, respectively. Furthermore, significant differences between basal respiration mean values along seasons of the year were found (Table 5). However, interaction between season and soil depth was found non-significant for soil basal respiration. On the other hand, significantly higher values of soil respiration were found in the erosion zone for every season of the year (Table 4). Mean soil basal respiration values were higher in winter than in any other season due to the fact of mild temperatures during this time period and high soil water contents.

Font	Square Sum Type III	Df	Square Mean	F	p-value
Season	1.109 _ 10^{-2}	2	5.547 _ 10^{-3}	7.712	0.001
Location	6.213 _ 10^{-3}	3	2.071 _ 10^{-3}	2.879	0.040
Depth	1.843 _ 10^{-5}	1	1.843 _ 10^{-5}	0.026	0.873
Season * Location	1.949 _ 10^{-3}	6	3.249 _ 10^{-4}	0.452	0.842
Season * Depth	4.460 _ 10^{-4}	2	2.230 _ 10^{-4}	0.310	0.734
Location * Depth	5.779 _ 10^{-4}	3	1.926 _ 10^{-4}	0.268	0.848
Season * Location * Depth	7.458 _ 10-4	6	1.243 _ 10-4	0.173	0.984
Error	6.905 _ 10-2	96	7.193 _ 10-4		
Total	0.552	120			
Corrected Total	9.009 _ 10-2	119			

Table 5. ANOVA results for soil basal respiration (Df = degrees of freedom).

The mean values of basal respiration measured in the studied hillslope were lower than the figures for this parameter reported in soils supporting natural vegetation of the region (LEIRÓS *et al.*, 2000). On the other hand, the basal respiration assessed by GARCÍA & HERNÁNDEZ (1997) on degraded soils for arid climatic conditions varied from 0.023 to 0.055 mg C-CO$_2$ g^{-1} soil day^{-1}. This is a consistent outcome which considers that the soil organic matter content in our temperate climate conditions is higher that those in the arid climate conditions of GARCÍA & HERNÁNDEZ (1997). Soil respiration was studied in Austria during the period between March and October 2001 by KLIK *et al.* (2002) in the topsoil of three plots with different tillage systems; namely, conventional tillage, conservation tillage and no till. Soil respiration values ranged from 0.07 to 0.26 mg C-CO$_2$ g^{-1} soil day^{-1} depending mainly on the soil type. No significant differences between treatments compared to conventional tillage were found.

MIRÁS AVALOS (2005) observed a higher respiration activity in a forest soil nearby this tilled plot; this soil was degraded as well. Forest soil respiration mean value for the same period was 0.265 mg C-CO$_2$ g^{-1} soil day^{-1}. In addition, soil respiration in this forest showed significant differences between depths which were attributed to the higher organic matter content found in the 0 to 5 cm depth compared to that found in the 5 to 10 cm depth layer.

Furthermore, the ANOVA analysis was performed for the closely related soil respiration variables, such as carbon contents and carbon-nitrogen ratios, revealing similar results to those found for soil respiration, i.e., significant differences were observed between topographical locations but none between depths. The lack of significant differences in organic carbon contents between the two studied depths revealed similar soil respiration rates.

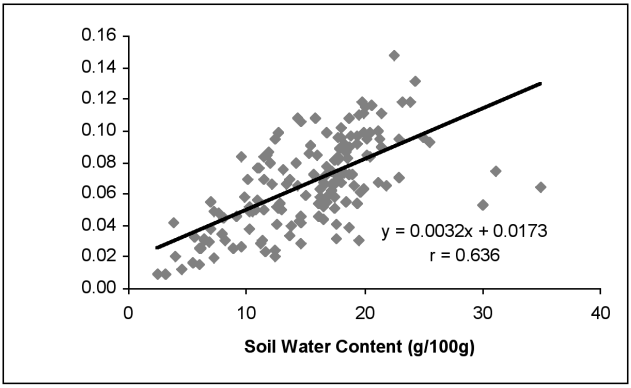
Results of correlation analysis regarding the total number of individual samples are shown in Table 6. It is observed that soil respiration is significantly correlated with pH (H_2O) of the soil and with its humidity content, showing a higher correlation coefficient for the latter parameter ($p < 0.01$).

PH (H_2O)	**PH (KCl)**	**Soil Water Content**	**C**	**N**	**C/N**
0.31 **	0.16 NS	0.64 **	0.07 NS	0.05 NS	0.09 NS

NS = non-significant
** = highly significant (p<0.001)

Table 6.Correlation coefficient values between soil basal respiration and other variables.

The relationship between soil water contents and soil respiration is shown in Figure 1. An increase of soil respiration as a function of soil water content can be observed.



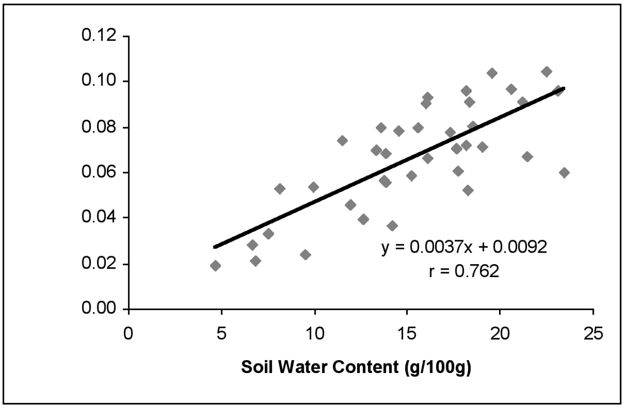


Figure 1. Relationship between soil respiration and soil water content for the 152 individual samples (upper side) and for the 38 grouped samples, i.e., 19 samples per zone (lower side).

The high correlation between the water content and soil respiration shows that the amount of emitted CO_2 was higher in spring and autumn than in summer. This relationship was observed when data were grouped by topographical position. In fact, highly significant correlations among soil respiration and soil water content were found in both erosion (r = 0.711) and deposition (r = 0.696) areas. Moreover, significant correlations among soil respiration and pH were found in the deposition zone.

Table 7 shows the coefficient of correlation observed among the soil basal respiration values and the soil water contents during the seasons of the year on both erosional and depositional areas.

Season of the year	Erosion area	Deposition area
Spring	0.67*	0.29
Summer	0.69*	0.85**
Autumn	0.80**	0.87**
Winter	-0.35	0.90*

* Significant (p<0.05)
** Highly significant (p<0.01)

Table 7. Coefficients of correlation for soil basal respiration and soil water content on a seasonal basis.

Significant correlations between soil basal respiration and soil water content were observed in every season of the year (Table 7); however, no correlation was found between these variables in the erosion zone in winter and in the deposition area in spring maybe due to the fact that soil basal respiration was relatively high and temperatures were mild during both periods. Higher correlation coefficients between both attributes were found in the deposition area than in the erosion area (Table 7).

Figure 2 shows a trend of soil basal respiration values to decrease as soil water deficits developed. The lowest soil basal respiration values, below 0.040 mg $C\text{-}CO_2$ g^{-1} soil day^{-1} were recorded on 24 May, 26 July and 5 October 2004. The highest soil basal respiration was measured by the end of October and early November 2004. Relatively high values of soil basal respiration were recorded between December and February, the coldest study months (Figure 2). In fact, a parallelism among soil respiration and soil water content is found on both the erosion and the deposition zones.

Figure 3 shows the evolution of soil respiration along the study period related to the maximum and minimum temperatures for the same period.

The lowest values of soil basal respiration in spring, summer and autumn 2004 are related to low soil water contents. In fact, total precipitation along the study period was 875.8 mm, much lower than the long-term average for the study site. An increase in soil water content during summer leads to increasing soil basal respiration. On the other hand, relatively high respiration values during winter months are the consequence of soil water content near saturation and mild temperatures, which is illustrated by the fact that mean temperatures between December and February were above 10 ºC and averaged minimum monthly temperatures were above 7 ºC (Figure 3). A significant correlation between maximum temperature and soil respiration values was found in the

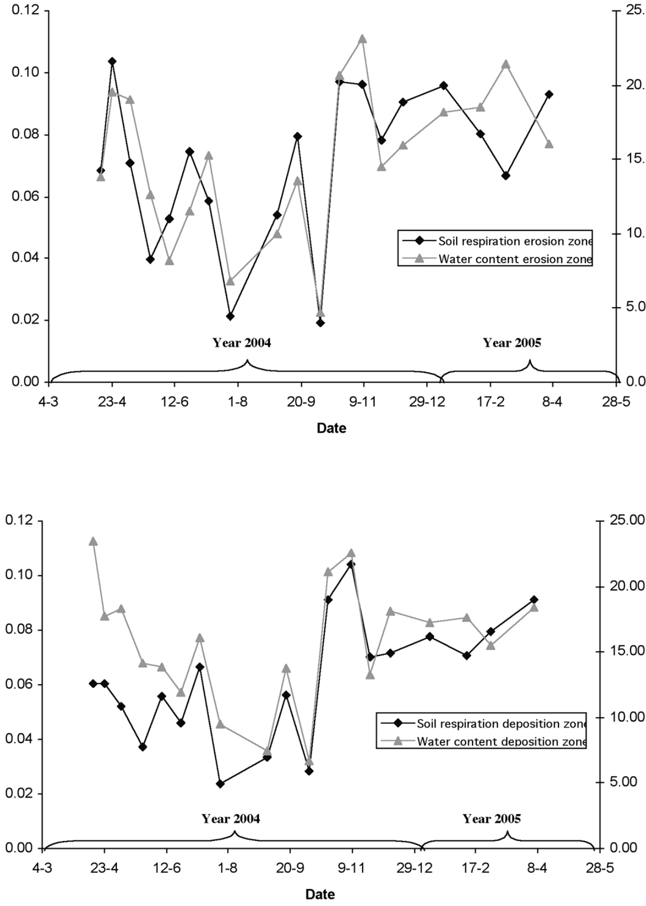


Figure 2. Yearly evolution of soil basal respiration on a hillslope at 0-10 cm depth in the erosion zone (upper side) and in the deposition zone (lower side) related to soil water content.

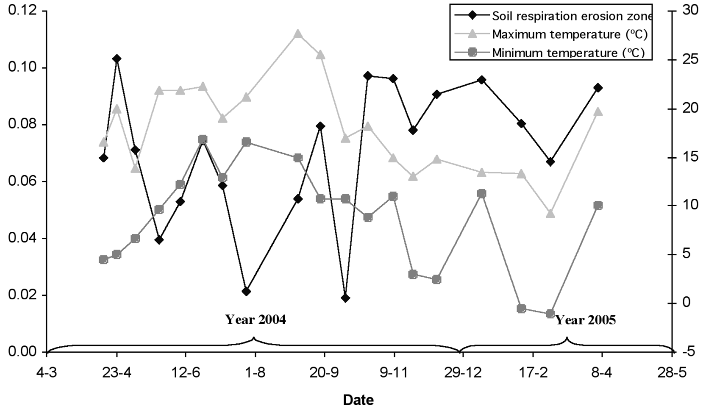
deposition zone; however, this correlation was not observed for the erosion zone.

Significant correlations between soil respiration values and soil water contents were found on both erosion (r =0.8) and deposition (r = 0.82) areas.

CONCLUSIONS

The soil basal respiration was significantly higher in the erosion than in the deposition zone of a conventionally tilled slope. It was strongly influenced by the soil water content, thus positively correlating with this parameter. Significant differences in soil basal respiration values along the seasons of the year were found, in accordance with temperature and soil water contents.

The study site was rated as a field with moderate to low soil biological activity. Thus, conventional tillage leads to a biological degradation of the study soil and soil conservation practices are recommended to protect and restore soil quality.



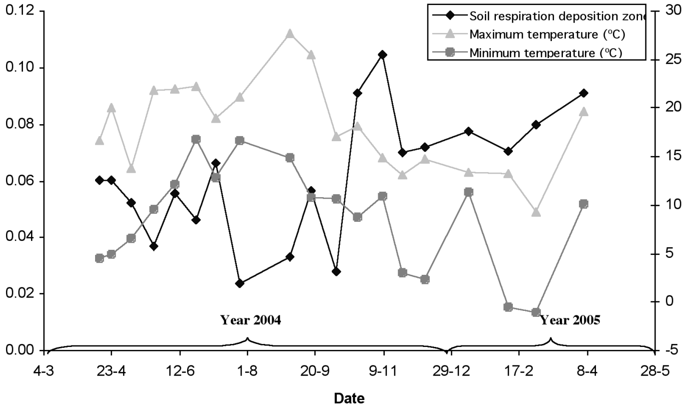


Figure 3. Yearly evolution of soil basal respiration on a hillslope at 0-10 cm depth in the erosion zone (upper side) and in the deposition zone (lower side) related to maximum and minimum temperatures.

ACKNOWLEDGEMENTS

This work was funded by MEC (project AGR2003-09284-CO2-01)) and by Xunta de Galicia (projects PGIDIT05PXI16201RT and PGIDIT05RAG10302PR). The authors also acknowledge Mr. Carlos Carballeira Díaz for the laboratory analysis.

Recibido: 03 / 04 / 2007
Aceptado: 02 / 10 / 2007

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