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Litter decomposition and soil CO_2 efflux on the Mediterranean island of Pianosa

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Abstract

Mediterranean ecosystems are particularly vulnerable to changes in climate and land use forecasted for the near future, with likely perturbations of the carbon cycle. The aim of our study was to quantify particular aspects of the carbon cycle in typical Mediterranean ecosystems, in particular (1) the decay rates of litter from common tree and shrub species, (2) the efflux of CO_2 from the soil and its relation to soil and litter moisture, and (3) the dynamics of the stable isotope ^{13}C during litter decomposition. Filed work was conducted on the island Pianosa, which comprises a range of common Mediterranean ecosystem types. Litter decay rates of three selected species (*Cistus monspenliensis*, *Pistacia lentiscus* and *Juniperus phoenicia*) were found to be low with an average of 70 % of initial mass remaining after 2 years of field incubation. Over the same period, all litter types showed only a slight (<10 %) net loss of N. Despite relatively high initial N contents, litter decay rates were comparable to those reported in the literature, suggesting that C and N dynamics are decoupled during litter decomposition. Over the two years of incubation, ^{13}C dynamics were not unanimous between the three litter types, with only a slight enrichment in one species. Continuation of this ongoing experiment is likely to resolve the long term effects of decomposition on ^{13}C enrichment on litter.
Soil CO_2 efflux was found to be unusually high (peak rates of over 9 μmol m^{-2} s^{-1}), owing to both high soil water content and soil temperature during an intensive measuring campaign in October 2003. Mean daily fluxes in woodland ecosystems were significantly higher than in either macchia or ex agricultural ecosystems, exceeding the latter about twofold. However, when scaled to the relative surface representation on Pianosa, the highest contribution of daily soil CO_2 efflux stems from Macchia type vegetation, followed by abandoned agricultural sites and woodland ecosystems (around 20, 22, and 8.5 t C d^{-1}, respectively). With the exception of one site, soil CO_2 efflux correlated positively with litter content at different sites across the island. Rather than causing the higher fluxes directly, higher litter contents are likely to indicate higher site productivity rates, resulting in higher CO_2 turnover dynamics and hence higher overall soil CO_2 efflux rates. Owing to the only small range of soil moisture conditions during the measuring campaign, no dependence of soil CO_2 efflux on soil moisture could be detected. However, a range of moisture conditions between sites was noted, indicating the significance of site specific conditions also within the same ecosystem types.

Introduction

The global Carbon cycle is presently unbalanced, with larger incoming fluxes to terrestrial ecosystem C pools than outgoing to the atmosphere, resulting in a mitigation of the increase in atmospheric CO_2 concentration induced by anthropogenic CO_2 emissions (IPCC, 2001). However, the length of time this "extra-C" will remain fixed in terrestrial stores and the extent to which these unbalanced fluxes will be maintained is still to be clarified, and its understanding is crucial to the regulation of future ecosystem management. Soils store the largest C pool in terrestrial ecosystems (Schlesinger, 1997), and its fate depend ultimately upon the balance between processes controlling soil C input (i.e. primary production, C allocation, land use and soil management) and output (i.e. litter decomposition, soil CO_2 efflux, leaching of dissolved C).

Among terrestrial ecosystem, Mediterranean ecosystems are considered highly vulnerable to global climate change (IPCC, 2001), with fires, soil erosion, salinization and aridification affecting a continuously growing area of the Mediterranean basin (Mazzoleni et al., 2004). Additionally, both climate change and land-use change are predicted to have

profound impacts on the biota of the Mediterranean basin, with changes in plant community composition, loss of endemic species and an increase of invasive species (Mooney et al., 2001) all contributing to further changes in C flux dynamics in this ecosystem type. Despite this, the number of studies devoted to the understanding of decomposition processes and soil C fluxes in Mediterranean macchia ecosystems is still limited (Fioretto et al., 2001; Reichstein et al., 2002). The characteristic climate conditions with mild wet winters and dry summers, appear to be the main controlling factors of ecosystems processes in these environments, limiting productivity and nutrient mineralization (Davis & Richardson, 1995). Mediterranean vegetation is characterized by adaptations to summer water stress (i.e. sclerophylly, hairy leaves, etc.) and often live in N poor environments, thus, generally resulting in leaf litter material that is physically resistant to microbial attack. High C/N ratios and higher concentrations of secondary C compounds are characteristic features of these litter types, and are all factors known to limit decomposition rates (Swift et al., 1979). Similarly, the interaction between soil moisture and temperature regimes is the key controlling factor of respiration processes in Mediterranean soils (Reichstein et al., 2002).

Owing to its favourable environmental conditions, the Mediterranean region has long been colonized by man, and today it is among the most densely populated and most intensively managed regions of the world (Grove & Rackham, 2001). Over the last centuries large areas of natural vegetation have been converted into arable lands, and pastures. A more recent process involves significant agricultural land abandonment and more or less rapid re-colonization by shrubland. The understanding and quantification of changes in soil C stores and fluxes linked to land use changes and vegetation succession will help to clarify future C dynamics in the Mediterranean region.

The Pianosa-lab project (Baraldi et al., same issue) is the perfect framework to address these questions. Here we report the results of a two year leaf litter decomposition experiment and of soil CO_2 efflux monitoring, designed with the following specific aims:

1) To quantify leaf litter decay rates of *Cistus monspenliensis*, *Pistacia lentiscus* and *Juniperus phoenicia,* three of the most common species at the study site (Colom et al., same issue).
2) To quantify soil CO_2 efflux in different Mediterranean ecosystem-type (i.e. macchia, woodland and abandoned agro-ecosystems), and their relation to soil moisture.

Additionally, since within the Pianosa-Lab project interest is devoted to the isotopic characterization of the main C pools on the island (Scartazza et al., 2000) and given the still poor understanding of isotopic discrimination during decomposition processes (Ågren, et al., 1996; Ehleringer et al., 2000; Fernandez et al., 2003), the dynamic of ^{13}C during litter decomposition was assessed.

Material and Methods

The study sites are on the island of Pianosa, and a detailed description of it is given in Baraldi et al. (same issue).

Leaf litter decomposition study

The leaf litter decomposition study was conducted on *Cistus monspeliensis* L., *Pistacia lentiscus* L. and *Juniperus phoenicia* L. leaf litter. In October 2000, litter was collected directly from the plants by gently shaking senesced branches, and collecting the falling leaves in a net. Several plants located in different parts of the island were sampled, litter was pooled by species, air dried and stored in paper bags, until used for the decomposition study and chemical analyses.

Litter decomposition was studied using the litter bag technique. To allow access to mesofauna (< 2mm) but minimizing loss of litter fragments, bags (10 cm x 10 cm) were made of two layers: on the outside a sealed HD polyethylene net with a mesh size of 2 mm, allowed access of mesofauna; while an unsealed HD polyethylene net with a mesh size of 770 x 220 μm contained in the outer bag impeded loss of litter fragments. Four grams of air dried litter was place in each bag, individually identified by a Dymotape label. For correction of dry weights, litter water content was measured on three sub-samples of each litter type during the time of bag preparation. In June 2001, bags where incubated in the field under a mixed macchia vegetation canopy, where bushes of the three species were represented, and fixed by metal pegs on the floor, within the freshly fallen litter. A block design was used for the incubation, with 10 bags for each species in each of three blocks. At yearly interval, 2 bags per species and block (n=6 per species) were sampled, cleaned of soil and dried in an oven (70°C) for the determination of remaining litter mass.

For each species, litter chemistry (i.e. N, C and ^{13}C concentrations) was assessed on a sub sample of the fresh litter as well as on the decomposing litter retrieved from each individual bag. Dried material was ground to a fine powder, and aliquots of litter powder were weighed in tin cups and analysed, for C and N, in a CHN-Elemental Analyser (NA1500, Carlo Erba Instruments, Rodano, Italy), and for ^{13}C, in a CHN-Elemental Analyser coupled to a mass spectrometer (MS-Delta plus, Finnigan , MAT) via an open split interface (Conflo II, Finnigan, MAT).

Soil respiration

Twelve sites located in the three representative ecosystem types on Pianosa were selected for soil respiration measurements (3 macchia, 3 woodland, and 6 abandoned agricultural, here on called ex-agricultural sites). The ex agricultural sites are further distinguished into former pasture (3 sites) and former agricultural use (3 sites). One former agricultural site is located at the foot of an eddy covariance tower (see Vaccari et al., same issue; from now referred to as the "eddy site"), and was used for intensive monitoring. At the eddy site, continuous data on air temperature, air humidity, net ecosystem CO_2 flux, and soil temperature and moisture were available. At each measuring site, we installed three PVC collars (10.4 cm diameter, 4.5 or 8 cm high) within an area of about 40 x 40 cm to a depth of 2 to 3 cm, with the exception of the eddy site, where 4 collars were installed. Soil CO_2 efflux measurements were carried out at least 24 h after collar installation to avoid any disturbance effects on the natural efflux. Measurements were carried out from the 1st to the 4th October 2003, during which time each site was measured three or four times. Intensive monitoring at the eddy site involved repeated measurements (7 times over 36 h) on the first two days of the measuring period to obtain the daily pattern of CO_2 efflux.

Soil CO_2 efflux was measured using the Li-Cor 6400

(Li-Cor, Lincoln, Nebraska) gas analysis console with the Li6400-09 soil chamber. Soil CO_2 efflux rates were calculated by the instrument from the rate of increase in CO_2 concentration around a target value determined prior to measurements by measuring the CO_2 concentration above the soil, and from chamber area and volume. The CO_2 concentration within the chamber was modulated automatically by the instrument by circulating air through a soda lime column between measurements. The interval around the target value was set to 10 μmol CO_2 mol^{-1} air (15 μmol CO_2 mol^{-1} air if efflux values exceeded 10 μmol m^{-2} s^{-1}). Normally, three consecutive measurements were carried out on one collar without removing the chamber, and more (up to 6) if a trend was detected between measurements. All three measurements made on each collar (or the last three, when more measurements were made) were averaged, and the standard deviation was calculated. To check the repeatability of the measurements, the coefficient of variation (CV=sd/avg) was calculated for each collar. The CV never exceeded 0.11, and all measurements were included for flux calculations. In order to capture the spatial variability, the efflux values measured on the three (or four) collars of each site were averaged to give the mean soil CO_2 efflux rate of each site.

Mean daily soil efflux rates

All the measurements made at the eddy site in the first two days of our measuring campaign, were plotted against the hour of day, to capture a mean daily trend. A one way ANOVA with subsequent Tukey test showed a significant difference between the efflux rates measured in the morning and the efflux rate measured between late afternoon and night time. In order to correct for the differences between measurements made at different times of the day, all efflux rates were corrected on the basis of the daily trend obtained at the eddy site. This correction assumes that the relative variation in soil CO_2 efflux observed at the eddy site occurs at all sites on the island. Linear interpolation for daytime hours between measurements at the eddy site gave a reasonable efflux value for every hour of the day. Since the highest efflux value was observed around 11 am, all the efflux rates measured at different hours of the day were expressed as fractions of the 11 am efflux rate. All efflux rates measured in the other sites were divided by the respective fraction obtained at the eddy site for a given hour of the day, to scale all efflux values to conditions at 11 am, and site averages were calculated on the basis of these "11 am" flux values.

In order to obtain daily soil CO_2 efflux estimates, a correction coefficient (α) was calculated by averaging the efflux rates of all hours at the eddy site (measured and interpolated), and dividing by the 11 am efflux rate.

$$\alpha = \frac{\textit{mean daily efflux rate}}{\textit{efflux rate at 11 am}} = 0.895$$

The efflux rates of each site (corrected for 11 am conditions) were multiplied by α to obtain daily efflux rates, and mean ecosystem efflux rates were calculated by averaging the daily efflux rates of all sites of within an ecosystem type. Since the variation in efflux rates within sites was smaller than between sites of the same ecosystem type, to calculate mean ecosystem soil CO_2 efflux we consider only the error originating from the between site variability, and consider each site's mean efflux rate as a single measurement. The daily average quantity of CO_2 released from the entire island during the measuring period was obtained by summation of the mean daily flux rates of each ecosystem multiplied by its area, and scaled to an entire day.

Following the efflux measurements, soil samples were collected from all sites where respiration measurements had been made on the 5th October 2003. Surface litter from within one of the collars was collected by hand, and where present, dead grass stems were cut at surface level and added to the litter sample. The collar was then inserted into the ground for its entire length and the intact soil core collected. Both litter and soil samples were stored fresh in plastic bags, until taken to the laboratory for analysis. Water content was assessed by gravimetric determination, with fresh and dry mass (80°C) of the litter samples and of a sub-sample (5 g) of each soil core being recorded.

Data analyses

A two-way ANOVA (species x day of incubation) was applied to test for differences in the dynamics of litter decomposition and N and ^{13}C concentrations, between species. The *a posteriori* Tukey's test was applied to identify the differences. Decay rates were calculated by species, fitting the values of percentage mass loss over time with a singular exponential model ($y = e^{-kt}$, where y is the mass loss (%), t is time in days and k is the decay constant), both for the first and second year of incubation, independently and continuously. Regressions over the two years of experimental data were performed, and R^2 values were 0.99, 0.87 and 0.99 for *C. monspeliensis*, *P.lentiscus* and *J. phoenicia* litter, respectively.

A one-way ANOVA with subsequent Tukey-test was applied to the calculated mean ecosystem CO_2 efflux to test for differences between ecosystem types. The relationship between values of soil CO_2 efflux and standing litter as well as between soil and litter water content were tested for linearity. All statistics and data fits were conducted using the Microcal Origin software (version 6).

Results

Leaf litter quality and decomposition

Prior to decomposition, the *J. phoenicia* litter showed significantly lower values of N concentrations, when compared to *C. monspeliensis* and *P. lentiscus*, whereas no significant differences were observed between the other two litter types (Table 1). The juniper litter was also distinguished for its high $\delta^{13}C$ value of -24‰ (Table 1).

In the two years of field incubation, litter lost only a small fraction of its original mass, with *C. monspeliensis* showing the highest mass loss (29%), and lower values for *P.lentiscus* and *J. phoenicia* leaf litter (both around 22%). These differences were statistically significant ($p<0.01$) but no correlation with the initial N concentration of the leaf litter material was observed (data not shown). Litter from the different species showed markedly different decay dynamics, indicated by the significant interaction ($p< 0.01$) observed between species and day of incubation. In fact, *J. phoenicia* litter decomposed at a nearly constant rate throughout the 2 years of field incubation, with yearly decay rates of 0.14 a^{-1} and 0.11 a^{-1} respectively for the first and second year of incubation; *P. lentiscus*, decomposed at a fast rate in the first year of incubation ($k= 0.20$ a^{-1}),

Table 1. *Leaf litter chemical composition. Values are means with standard deviations (n=6; except for day 0 when n=3). Results of the two way ANOVA are also reported.*

Species	Day of incubation	N (%)	C (%)	$\delta^{13}C$ (‰)
C. monspeliensis	0	1.48 ± 0.01	50.1 ± 0.2	-27.61 ± 0.17
	338	1.66 ± 0.13	49.0 ± 0.9	-27.41 ± 0.20
	731	1.98 ± 0.15	46.6 ± 1.2	-27.37 ± 0.17
P. lentiscus	0	1.59 ± 0.04	51.1 ± 0.3	-27.27 ± 0.09
	338	1.82 ± 0.09	50.6 ± 0.8	- 27.79 ± 0.11
	731	1.91 ± 0.03	47.6 ± 1.6	-28.03 ± 0.12
J. phoenicia	0	1.37 ± 0.16	51.0 ± 0.1	-23.94 ± 0.49
	338	1.47 ± 0.16	52.8 ± 0.8	-24.38 ± 0.14
	731	1.91 ± 0.03	47.8 ± 1.4	-24.22 ± 0.16
Source of variation				
Species		P < 0.0001	P < 0.0001	P < 0.0001
Day of incubation		P < 0.0001	P < 0.0001	P < 0.05
Species x Day of incubation		n.s.	P < 0.01	P < 0.0001

reaching almost 18% of mass loss, to slow down in the second year (k= 0.05 a^{-1}). The opposite behaviour was observed for *C. monspeliensis* leaf litter which decomposed at a faster rate in the second year of incubation, with an yearly decay rate of 0.20 a^{-1}, compared with a k value of 0.14 a^{-1} measured in the first year (Figure 1). Fit over the two years of experimental data gave decay rates of 0.16, 0.14 and 0.13 a^{-1} for *C. monspeliensis, P. lentiscus* and *J. phoenicia* litter respectively. During decomposition, N concentrations increased significantly in all litter types, and no significant differences were observed between species (Table 1). However a clear N dynamic during litter decay was not observed, with both net N immobilization and mineralization processes being measured with progressing C mineralization (Figure 2). Litter $\delta^{13}C$ values significantly changed with time of incubation (Table 1). A trend, still not significant, was observed for ^{13}C accumulating in litter tissue with accumulating C loss (Figure 3).

Soil CO_2 efflux

During the entire period of the intense soil CO_2 efflux measuring campaign, climatic conditions stayed relatively stable, with a mean daily air temperature of 22.4 ± 0.3°C and a mean daily relative humidity of 88.2 ± 4.1%. Only minor variations in mean daily temperature and a small increase in relative humidity were registered (Figure 4). One rain event occurred during this period, on the 4th October, and it was after

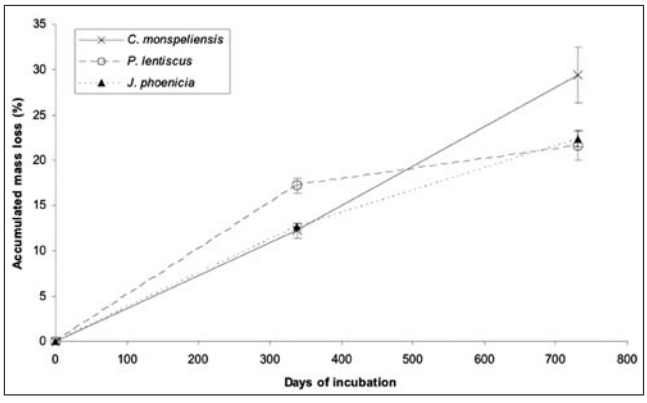

Figure 1 Dynamics of accumulated mass loss for the *C.monspeliensis*, *P.lentiscus* and *J. phoenicia* leaf litter during two years of field incubation. Vertical bars indicate standard errors (n=6).

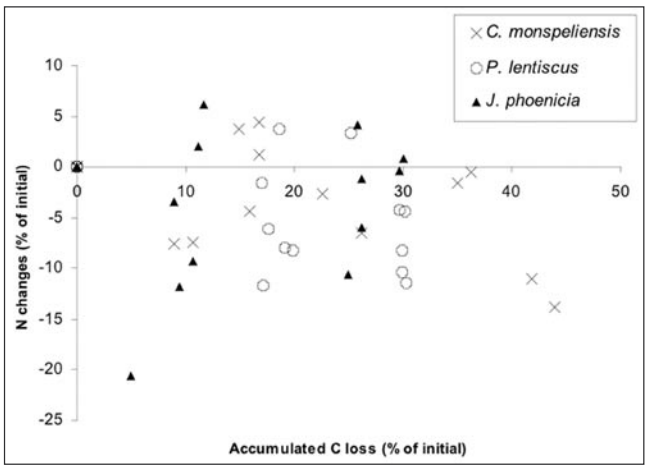

Figure 2 Changes in litter N content proportional to the initial values in relation to accumulated C loss during the first two year of decay for the *C.monspeliensis*, *P.lentiscus* and *J. phoenicia* leaf litter. Data for individual litter bags are shown.

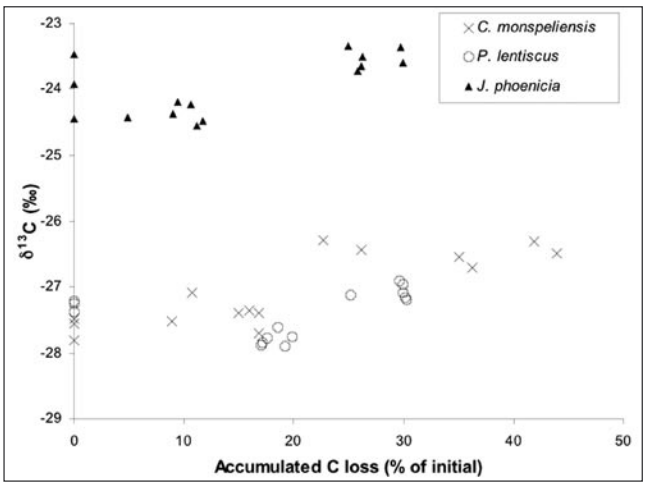

Figure 3 Litter $\delta^{13}C$ in relation to accumulated C loss during the first two years of decay for *C. monspeliensis*, *P. lentiscus* and *J. phoenicia* leaf litter. Data for individual litter bags are shown.

flux measurements had been completed. The water content (expressed as mean H_2O in percentage of sample dry weight, ± standard error) of the litter layer varied between 42.9 ± 7.6 % at the ex-agroecosystems and 78.3 ± 20.8 % of the macchia litter, with an intermediate value of 59.6 ± 6.5 % for the woodland litter. Soils were dryer than corresponding litter with water content values ranging from 13.9 % ± 1.1 at the ex-agroecosystems, to 23.7 ± 7.5 % for woodland soils. In the macchia soil water content was 19.7 ± 3.4 %. As expected there was a positive correlation between soil and litter water content, but a linear fit of both water contents proved not significant (p = 0.10; Figure 5)

Soil CO_2 efflux at the eddy site varied only little around a value of 5 μmol m^{-2} s^{-1} during the entire day of measurements, picking at 11 o'clock to slow down gradually in the evening (Figure 6). When comparing respiration rates across the three main ecosystem types of the island, mean daily soil CO_2 efflux rates in woodlands were significantly higher than those in the other two ecosystem types, exceeding those of the ex-agricultural ecosystems about twofold (Figure 7). However, both the macchia and the ex-agricultural systems contribute significantly larger amounts of CO_2 to the total soil respiratory flux of the island, owing to their greater spatial representation (Table 2). Based on these extrapolations, the

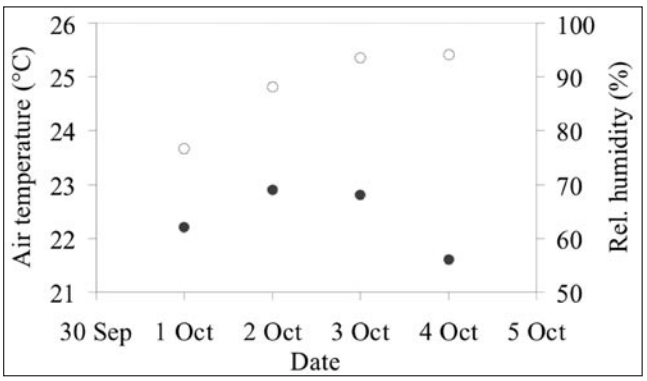

Figure 4 Mean air temperature (solid symbols) and humidity (open symbols) during the measuring campaign (dates in 2003).

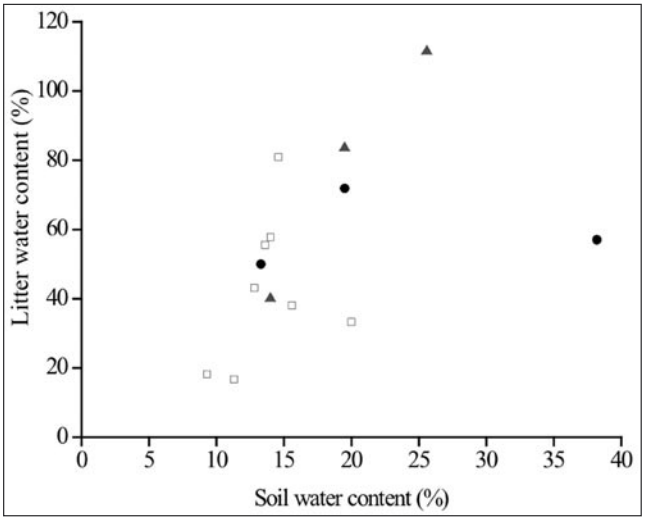

Figure 5 Soil and litter water contents of samples collected on 5th October at all respiration measurement sites (● woodland, ▲ macchia, □ ex-agroecosystem). The correlation between both water contents was not significant (linear fit: p = 0.10).

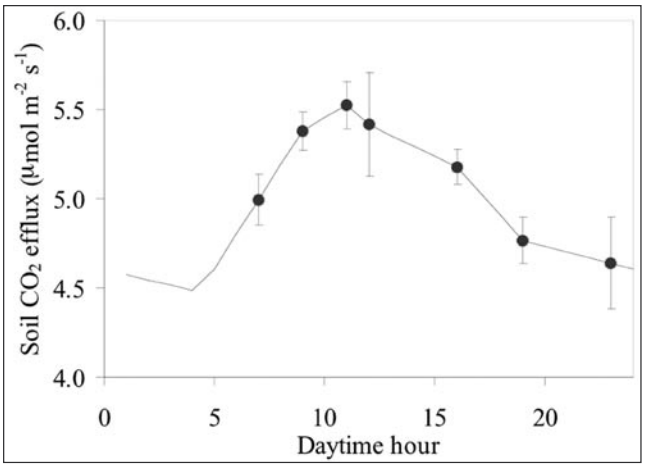

Figure 6 Daily trend of soil CO_2 efflux measured at the eddy site between 9:00 on the 1st Oct. and 19:00 on the 2nd Oct. 2003. Soil CO_2 efflux rates are plotted against the hours of the day. Error bars are standard errors (n = 4).

total soil CO_2 efflux from Pianosa during the study period could be estimated to ca. 50 ± 5 t C d^{-1}.

In order to identify possible factors contributing to the difference in respiration rates across the different ecosystem types, the standing litter mass, sampled from one collar at each site, were plotted against mean daily soil CO_2 efflux rates measured on the same collars (Figure 8). With the exception of one macchia site dominated by *J. phoenicia* (labelled "a" in Figure. 8), soil CO_2 efflux correlated positively with litter mass across all ecosystems.

Table 2 *Mean daily soil efflux rates and total daily soil C flux contributions for the three dominant ecosystem types on the island of Pianosa for the study period.*

Ecosystem type	Area ha	Soil efflux rate µmol CO_2 m^{-2} s^{-1}	Daily soil emission t C d^{-1}
Macchia	357.3	5.34 ± 0.80	19.7 ± 2.9
Woodland	93.7	8.80 ± 0.61	8.5 ± 0.6
Ex agriculture	505.6	4.41 ± 0.50	22.4 ± 2.6
total	956.6	n.a.	50.5 ± 4.8

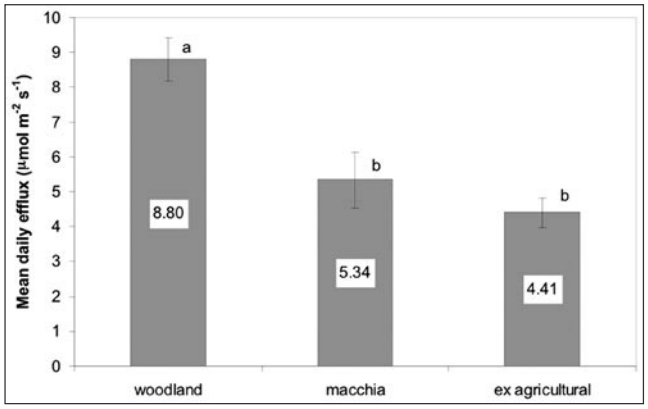

Figure 7 Mean daily soil CO_2 efflux rate for the three main ecosystem types on Pianosa. Error bars are standard errors of site averages (n=3 for woodlands and macchia, and n=6 for ex-agricultural). Different letters indicate significant differences (p<0.005) between means (one-way ANOVA with Tukey test).

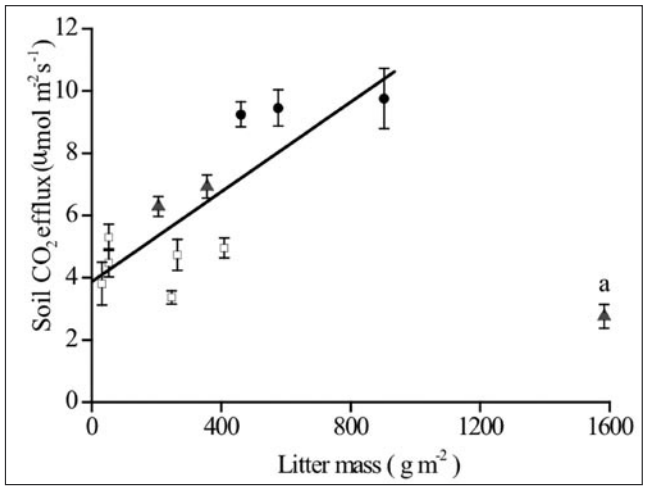

Figure 8 Mean daily soil CO_2 efflux measured on one collar at each measuring site (● woodland, ▲ macchia, □ ex-agroecosystem), plotted against litter mass of the same collar. The linear regression line indicates a significant positive correlation ($p < 0.005$) between litter mass and soil CO_2 efflux rate. Note, however, that the data from a macchia site with highest litter mass and lowest efflux values (marked "a") are not included in the regression (see text).

Discussion

The three leaf litter types used in this study showed relatively high values of N concentration, ranging from 1.4 % to 1.6 % for *J. phoenicia* and *P. lentiscus*, respectively, if compared to values in leaf litter of similar species collected in Mediterranean environments (i.e. less than 1%; Moro and Domingo, 2000, Fioretto et al., 2001). Surprisingly, N concentration

values were also substantially grater than those measured in a previous study conducted on the island of Pianosa on the same litter species, which varied from 0.35 % to 0.46 % for *C. monspeliensis* and *P. lentiscus*, respectively, while *J. phonenicia* was not investigated in that study (Cotrufo, 2000). Such a discrepancy could be the result of incomplete N retranslocation in the litter collected in the current study. In fact, although it had the appearance of senesced litter, litter was collected before natural abscission, directly from the plant by gentle shaking. The withdrawal of N is an efficient mechanism through which plants diminish the dependency on the soil N pool, thus it is frequently adopted in Mediterranean environments poor in available soil mineral N (Del Arco et al., 1991).

Litter decomposed at low rates (i.e. k= 0.13 – 0.16 a^{-1}), and across all species an average 70% of the initial mass remained after the two years of field incubation. Similar low decay rates appear to be common for litter decomposition in Mediterranean environments. In a study of leaf litter decomposition of woody species in a Mediterranean climate, Moro and Domingo (2000) measured decay rates ranging from 0.1 for *Pinus pinaster* to 0.5 for *Adenocarpus decorticans*, with a decay rate of 0.2 for *C. laurifolius*. As a consequence of the slow decay, litter accumulates on the forest floor and may contribute significantly to soil C pools and fluxes. The dynamics of litter decomposition differed among the three species investigated in this study but differences did not appear to be driven by the initial N content of litter. In fact, no clear pattern of C *vs* N mineralization was found (Figure 2).

Despite the observed increase in litter N concentrations with time of incubation at the end of the studied period net N mineralization had occurred in all litter bags, with less than 10% of the initial N being lost on average. Similar N mineralization values were measured during decomposition of *Cistus incanus* leaf litter, with an initial N concentration of 1.04% (Fioretto et al., 2001), whereas in a study of *Cistus laurifolium* litter decay, with an initial N concentration of 0.3%, N immobilization occurred during the entire period of incubation (Moro and Domingo, 2000). Since in all three studies litter reached similar values of mass loss, litter N mineralization in Mediterranean environments appears to be decoupled from C mineralization, and mostly dependent on available N for the decomposer community.

The $\delta^{13}C$ values of C_3 plant tissues is strongly dependent on the plant's ability to use water resources, and ^{13}C concentration increases in plant tissues with high water use efficiency (Farquar et al., 1989). Across the three Mediterranean species investigated in this study, *J. phoenicia* showed the highest values of $\delta^{13}C$, confirming the results of Scartazza et al. (2000), who also measured values of around -24 ‰ for this species, the highest value measured across a wide range of species on Pianosa.

During the two years of incubation litter isotopic composition was only slightly modified with a tendency for ^{13}C to accumulate. There is an open debate on C isotope discrimination processes during litter decomposition (Ehleringer et al., 2000; Fernandez et al., 2003). Recent studies suggest that different discrimination processes take place during litter decomposition, with ^{13}C accumulating in litter residue during the initial stages as a result of degradation of very labile compounds. Following this stage, an intermediate phase would occur when ^{13}C-CO_2 is preferentially respired due to intramolecular microbial discrimination (Fernandez et al., 2003). At a final stage, ^{13}C would accumulate in the SOM, resulting in the commonly observed increase of ^{13}C along the soil profile (Nadeloffer & Fry (1988). Our results appear to confirm that ^{13}C accumulates at the initial stage of litter decay. Since this study will proceed for another four years, we will be able to better understand the long term dynamic of ^{13}C during litter decay, and further test the Fernandez-hypothesis in the field.

Soil temperature and water content are known to be the most important abiotic drivers of soil CO_2 efflux. The soil respiration measurements were carried out in a period when substantial rainfall in the previous week had led to relatively high soil water contents. During the campaign, climatic conditions were relatively stable with moderate temperatures and relatively high air humidity (Fig. 4), which means that only very small differences in the drivers of soil respiration persisted between different days in this period. It can therefore be reasonably assumed that the mean daily efflux of CO_2 from the soil did not differ significantly over this period. Accordingly, no systematic differences between measurements (corrected for 11 am efflux values) from any given site could be observed during the length of the campaign. The timing of the campaign, following extensive precipitation after a prolonged dry period, is likely to be the reason for the high efflux values throughout all ecosystem types. Other studies in Mediterranean type ecosystems have reported "flushes" of CO_2 from soils following rain events after drought conditions (e.g. Xu & Baldocchi, 2004). Under these conditions, sufficient substrate for heterotrophic respiration has accumulated, and autotrophic (i.e. root-) respiration also increases due to the increase in aboveground plant activity following rainfall. The efflux estimates for the three ecosystem types as well as for the entire island are therefore likely to be amongst the maximum rates to occur throughout the year. Despite the higher efflux rates from woodland ecosystems, the contributions from areas covered by ex- agricultural and macchia type vegetations dominate the overall soil CO_2 efflux sum of the island (Table 2). Depending on future land management, the spatial extent of the different vegetation types may shift towards more woodland, following a succession from abandoned agricultural and pasture sites via macchia vegetation towards more woodland areas.

The soil CO_2 efflux results show a positive correlation with the litter content present at the sites (Figure 8). However, the variation in soil CO_2 efflux is not likely to be caused by decomposition of the varying amounts of litter directly, but rather reflects different site productivities, for which the litter content is a surrogate. Woodland sites with high LAIs and a more complex 3-dimensional structure compared to the other ecosystem types have higher input rates of organic matter to the soil (both above- and below ground) as well as higher rates of C allocation to roots, resulting in higher root respiration. The obvious exception from correlation between soil CO_2 efflux and litter content in figure 7 is a Juniper (*J. phoenicia*) stand (a), where considerable amounts of litter have build up. Our decomposition study results indicate that for the first two years at least, *J. phoenicia* decomposes relatively slowly. The longer term evaluation of this study will show if this particular type of litter is more resistant to decay compared to the other types under investigation, thus explaining the higher litter

content at the site and for the low magnitude of soil CO_2 efflux. Soil water content of soil and litter samples taken on the same day showed considerable variation between sites (Fig. 5). In contrast to the variation in litter mass, this variation occurred throughout all ecosystem types, and could not explain the variation observed in soil CO_2 efflux. A positive (but not significant) relationship between soil and litter water content prevails, which is likely to be due to site specific conditions of soil drainage, exposure to solar radiation, plant water use, and rainfall interception by the canopy.

For a more detailed understanding of the carbon cycle on Pianosa, more intensive monitoring of soil CO_2 efflux from different ecosystem types would be desirable. If measurements cover the ranges of temperature and soil moisture conditions that occur during one year, a better dependency on these drivers could be established, allowing the calculation of the yearly soil CO_2 efflux budget for the entire island. Comparison to the ecosystem flux at the "eddy" site, which is already continuously monitored, a flux separation into assimilation, aboveground respiration and soil respiration flux would be possible at least for the ex-agricultural sites measured by the eddy tower.

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