

Carbon storage of Mediterranean grasslands

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Abstract

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Secondary grasslands are one of the most common vegetation types worldwide. In Europe, and in the Mediterranean basin, human activities have transformed many woodlands into secondary grasslands. Despite their recognized role in the global carbon cycle, very few data are available for estimating the biomass of Mediterranean grasslands. We developed linear regression models in order to predict the biomass of two native Mediterranean grasses (*Ampelodesmos mauritanicus* and *Hyparrhenia hirta*) and an invasive alien grass (*Pennisetum setaceum*). *Ampelodesmos mauritanicus* is very common throughout the Mediterranean basin, mostly on north-facing slopes, *H. hirta* characterizes thermo-xeric grasslands, while *P. setaceum* is an alien species that is rapidly spreading along coastal areas. The measured morphometric attributes of individual plants as potential predictors were considered. The validation results corroborate the ability of the established models to predict above ground and total biomass of *A. mauritanicus* and *P. setaceum*. We also evaluated the total biomass per hectare for each species. The highest biomass per hectare was found for *A. mauritanicus*, whereas biomass was higher for *H. hirta* than for *P. setaceum*. The replacement of *H. hirta* by *P. setaceum* may reduce the total carbon storage in the ecosystem; however, *P. setaceum* allocates more resources to the roots, thus increasing the more stable and durable pool of carbon in grasslands.

Keywords: *Ampelodesmos mauritanicus*, carbon storage, *Hyparrhenia hirta*, Mediterranean grasslands, *Pennisetum setaceum*.

INTRODUCTION

Grasslands are among the most widespread plant communities, being present on all continents except Antarctica, and covering about 24×10^6 km² or nearly one-fifth of the planetary land area (Parton & al., 1995; Scurlock & Hall, 1998). According to the UNESCO (1973), grasslands are those areas where the coverage of woody species does not exceed 10% of their surface. In some regions of the world, mainly in Asia and North America, grasslands are often mature communities where the absence or near absence of woody species is related to local limiting factors. Elsewhere, and especially in Europe, where humans have greatly modified the landscape and have used lands that originally had woody cover for raising cattle and cultivating crops, most grasslands are considered secondary communities (Pärtel & al., 2005; Zarovali & al., 2007).

In the enlarged European Union (EU-25, with 25 member states), grasslands cover an estimated area of 0.57×10^6 km² (15% of the whole territory, cf. Ciais & al., 2010). The FAO (2006), however, reported a reduction of almost 13% of the European grassland covering between 1990

Resumen

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Los pastizales secundarios son uno de los tipos de vegetación más comunes en todo el mundo. En Europa y en la cuenca mediterránea, las actividades humanas han transformado muchos bosques en pastizales secundarios. A pesar de su reconocido papel en el ciclo global del carbono, hay muy pocos datos disponibles para la estimación de la biomasa de los pastizales mediterráneos. Hemos desarrollado modelos de regresión lineal con el fin de predecir la biomasa de dos gramíneas nativas del Mediterráneo (*Ampelodesmos mauritanicus* e *Hyparrhenia hirta*) y otra exótica e invasora (*Pennisetum setaceum*). *Ampelodesmos mauritanicus* es muy común en toda la cuenca mediterránea, sobre todo en pendientes orientadas al norte, *Hyparrhenia hirta* es característica de pastizales termo-xerófilos, mientras que *Pennisetum setaceum* es una especie exótica que se está extendiendo rápidamente a lo largo de las zonas costeras. Se consideraron los caracteres morfométricos de plantas individuales como factores de predicción potenciales. Los resultados han corroborado la capacidad de los modelos establecidos para predecir la biomasa aérea total de *A. mauritanicus* y *P. setaceum*. También se ha medido y evaluado la biomasa total por hectárea de cada especie: la mayor fue la que correspondía a *A. mauritanicus*, mientras que la *H. hirta* fue mayor que la de *P. setaceum*. Así pues, la sustitución de *H. hirta* por *P. setaceum* puede reducir el carbono almacenado en el ecosistema, sin embargo, *P. setaceum* asigna más recursos a las raíces, lo que implica un almacenaje de carbono más estable y duradero.

Palabras clave: almacenamiento de carbono, *Ampelodesmos mauritanicus*, *Hyparrhenia hirta*, pastizales mediterráneos, *Pennisetum setaceum*.

and 2003. This trend is due to the adoption of more intensive cultivation techniques with relatively high environmental impact (Bonanomi & al., 2006) or, conversely, to the social and economic marginalization of the least accessible areas and the abandonment of traditional agro-pastoral activities, resulting in an encroachment by woody species. Woodlands, in contrast, have increased their covering in all European countries between 1960 and 2010 (Young & al., 2005; FRA, 2010) because of their increased protection resulting from conservation efforts and, as noted earlier, because of the spontaneous colonization (secondary succession) of abandoned pastures and grasslands. Similar trends have been recorded between 1990 and 2008 in Italy, where grassland covering decreased by 14%, while woodlands increased by 5.6% (Corona & al., 2012).

Grasslands contain a wide range of annual and perennial herbaceous species, and are among the most species-rich communities of semi-natural ecosystems. Because many plants and animals are exclusively linked to such habitats, grasslands have a prominent biogeographical and conservation value (Callis de Vries & al., 2002; Grill & al., 2005;

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Pärtel & al., 2005; Öckinger & Smith, 2007). Most temperate and Mediterranean European grasslands have a secondary origin, and the intensity and frequency of human disturbance, together with the heterogeneous pedoclimatic conditions of European countries, have generated local grassland communities that differ substantially in structure and species composition (Tuba & Kaligarič, 2008). Nevertheless, the recovery and long-term preservation of these precious semi-natural environments generally depend on regulated forms of human disturbance (e.g., controlled grazing and prescribed burning) that block succession and support a permanent herbaceous community at the expense of woody species (Barbaro & al., 2001; allis de Vries & al., 2002; Bonanomi & al., 2006). In other words, grassland management requires more than protection. In particular, extensive grazing is recommended for the long-term maintenance of grassland habitats and species (illems, 1983; Pykälä, 2003; Öckinger & Smith, 2007). According to Noy-Meir & Oron (2001), grazing is an essential tool for conserving the native flora of Mediterranean ecosystems. That grazing is feasible and desirable even within protected areas has been demonstrated in Spain (Verdú & al., 2000) and in the Czech Republic (Dostálek & Frantík, 2008). In addition to ensuring the preservation of habitats, moderate grazing of Alpine, temperate, and Mediterranean grasslands also benefits plant species richness (i.e., plant species richness is greater in moderately grazed grasslands than in abandoned areas or in grasslands that have not been grazed for several years; Puerto & al., 1990; Noy-Meir, 1995; Pucheta & al., 1998; Harrison & al., 2003; Pykälä, 2004; Bonanomi & al., 2006).

Grasslands also play an important role in the global carbon cycle (Parton & al., 1995), particularly as a consequence of carbon sequestration in soil (Ciais & al., 2010). The carbon stored in grassland soils represents a rather stable carbon pool (Hungate & al., 1997). Researchers have estimated that terrestrial ecosystems can absorb about one third of the anthropogenic emissions of greenhouse gases (Scurlock & Hall, 1998; Janssens & al., 2003) and may thus help mitigate ongoing climate change. The Earth's grasslands, including tropical savannas, represent approximately 20% of the total terrestrial biomass (Scurlock & Hall, 1998; Robinson, 2007) and contain in their soils at least 28% of the global stock of carbon (Robinson, 2007) and 12% of the soil organic matter (SOM; Jones, 2010). Even in the European Community in general, and in Italy in particular, grasslands are an important terrestrial carbon pool and, although they may be sources of

greenhouse gases (e.g., methane and nitrogen oxides), they generally represent a net carbon sink as important as that of forest ecosystems (Janssens & al., 2005; Gilmanov & al., 2007; Ciais & al., 2010).

The efforts to restore degraded and overexploited grasslands, which aim to recover biodiversity and ecosystem functions, also increase carbon sequestration in the soil and improve soil structure (De Deyn & al., 2011). The restoration and maintenance of degraded grassland by humans may reduce the potential for carbon sequestration that would come about should succession have been allowed to proceed.

In the first and experimental part of this study, we developed predictive models for the aboveground (ag) and belowground (bg) biomass of *Ampelodesmos mauritanicus* (Poir.) T. Durand & Schinz, Consp. Fl. Afric. 5: 874 (1894) [*Arundo mauritanica* Poir., Voy. Barbarie 2: 104 (1789), basion.], *Hyparrhenia birta* (L.) Stapf in Oliv., Fl. Trop. Afr. 9: 315 (1919) [*Andropogon birtus* L., Sp. Pl.: 1046 (1753), basion.], and *Pennisetum setaceum* (Forssk.) Chiov. in Boll. Soc. Bot. Ital. 1923: 113 (1923) [*Phalaris setacea* Forssk., Fl. Aegypt.-Arab.: 17 (1775), basion.].

While substantial data are available for estimating the biomass of trees and shrubs, very few data exist for Mediterranean herbaceous perennials. Filling this knowledge gap is an important objective of this research, in which those grasslands dominated by *A. mauritanicus* and *H. birta* on the island of Sicily (Italy) are considered a case study.

MATERIAL AND METHODS

Studied localities

The study was conducted in the two nature reserves of Cape Gallo and Mount Pellegrino in Palermo Province, and in the afforested area of Mount Inici in Trapani Province. These three places share the same bedrocks (which is mostly characterized by limestones and marls prone to karstic processes), the same soil associations, as well as the same natural landscapes (steep slopes with shallow soils mostly covered by perennial grasslands) (Table 1).

Grassland species

The main ecological and biological features of the three caespitose grasses considered in this study are described in the following paragraphs. Unless stated otherwise, the information is also provided by Pasta & al. (2010).

Table 1. Main characteristics of the three studied localities.

	Cape Gallo	Mount Pellegrino	Mount Inici
Altitude (m.a.s.l.)	40	85	500
Bedrock	limestones	limestones	limestones and marls
Soil association (USDA classification)	lithosoils-rock outcrops-terra rossa	lithosoils-rock outcrops-terra rossa	lithosoils-rock outcrops-terra rossa
Average mean annual temperature (°C)	20	20	16.5
Average annual rainfall (mm)	645	611	680
Bioclimate according to Rivas-Martínez's classification	thermo-mediterranean sub-humid	thermo-mediterranean sub-humid	meso-mediterranean upper-arid

Data on soils were obtained from Fierotti (1988), and information on local climate and bioclimate was obtained from Drago & al. (2002).

***Ampelodesmos mauritanicus* (Mediterranean tussock grass)**

It is a native C_3 tussock grass. It reaches 1 m in height and is very common throughout the coastal and hilly areas of the Mediterranean basin, from the Iberian Peninsula to Greece, including Northern Africa. Perennial grasslands that include *A. mauritanicus* are one of the most widespread vegetation types in Sicily. Although they generally represent a stage of degradation of the local forest communities, they should be considered as a stable and lasting “disclimax” (Minissale, 1995). The floristic richness of these grasslands may vary greatly among sites according to the frequency and intensity of human disturbance. They occupy most slopes from sea level up to 1,200 m.a.s.l. (Minissale, 1995) and are especially localized on steep and north-facing slopes within the meso-Mediterranean and also thermo-Mediterranean belt (Brullo & al., 2010). However, *A. mauritanicus* shows an effective drought resistance (Mingo & Mazzoleni, 1997). *Ampelodesmos mauritanicus* grasslands are considered important habitats in European countries and have therefore been included in the Council Directive 92/43/EEC (EC, 1992) on the conservation of natural habitats and of wild fauna and flora, hence requiring a special protection regime. This caespitose grass is commonly found in areas characterized by moderate and frequent grazing, and its considerable post-fire vegetative regrowth, coupled with its increased seed production in burned areas (Vilà & al., 2001), make it extremely well adapted to post-fire colonization and therefore important for control of water erosion.

***Hyparrhenia hirta* (Coolatai grass)**

It is a native C_4 perennial grass that normally grows up to 30-60 cm. Its wide natural distribution includes southern Africa and the Mediterranean region, but this perennial grass is now naturalized in many other countries and is considered a serious invader of native pastures in Australia (McArdle & al., 2004). In Sicily, thermo-xeric grasslands with *H. hirta* occur in coastal environments from sea level up to 600 m.a.s.l., mostly in extremely arid environments on poorly developed and shallow soils of the thermo-Mediterranean belt (Brullo & al., 2010). In particular, these grasslands represent a typical stage of degradation of the sclerophyllous scrub formations belonging to the phytosociological order *Quercetalia calliprini* Zohary. Because its seeds can germinate over a wide range of environmental conditions (Chejara & al., 2008), seedling emergence and establishment mainly depend on the number of seeds produced and on biotic and abiotic factors (Chejara & al., 2008). The progressive reduction of *H. hirta* on north-facing slopes and with increasing altitude has been attributed to the low germination rate and the limited resistance of its seedlings to low temperatures (Litav, 1972), especially to temperatures below 15 °C (McWilliam & al., 1970). Apart from facing summer drought, this native grass tolerates or is favoured by frequent and intense human disturbance (e.g., fire and grazing).

***Pennisetum setaceum* (Fountain grass)**

It is a non-native C_4 grass that grows up to 30-100 cm. Although it is native to Northern Africa and the Middle East, *P. setaceum* now naturally occurs on almost all continents.

It has long been recognized as a highly invasive species. Once introduced, *P. setaceum* can spread over large areas, thus modifying the characteristics and functioning of natural ecosystems, threatening local biodiversity, and also altering the carbon cycle, as documented in Hawaii and South Africa (Litton & al., 2006; Cordell & Sandquist, 2008; Rahlao & al., 2010). In Sicily, *P. setaceum* is one of the most aggressive and rapid invaders of coastal and hilly areas; during the 70 years following its first introduction in Sicily, it has established and spread over many coastal areas up to 600 m.a.s.l. and especially on south-facing slopes within the thermo-Mediterranean belt (Brullo & al., 2010). It frequently colonizes very disturbed and eutrophic habitats such as roadsides, railways, and urban wastelands. *Pennisetum setaceum* has also invaded *H. hirta* thermo-xeric grasslands and even the more mesophilous *A. mauritanicus* grasslands in some localities; in both cases, it has exhibited high competitive ability against native perennial species. *Pennisetum setaceum* has also a great phenotypic plasticity. While it is able to withstand summer drought (and has already spread into sub-desertic environments), it also appears able to take rapid advantage of rainfall during the warmer months (Williams & Black, 1993; Williams & al., 1995; Poulin & al., 2007). These traits, combined with a fast growth rate after a disturbance event (e.g., fire) and long-distance seed dispersal, indicate that *P. setaceum* is likely to continue to spread into many other suitable localities in Sicily, with significant and long-lasting ecological consequences.

Biomass prediction models for *A. mauritanicus*, *H. hirta*, and *P. setaceum*

Field surveys were carried out during the spring of 2009. In each of the three studied localities, 20 individuals of different sizes for each species were selected by a stratified random sampling scheme and were removed from the soil with a weeding hoe. The weeding hoe was used carefully to obtain the root system as undamaged and complete as possible. After the plants were dug from the soil, the roots were roughly cleaned of soil, rock particles, and other impurities. The maximum length of the roots (L_r), the diameter of the root collar (D), and the maximum height (H) were immediately measured in the field with a pair of calipers and a measuring rod. Then, each plant was labelled with an identification code (including the date and the place of collection) and transported to the laboratory, where the root systems were thoroughly cleaned, and roots and shoots were oven dried for 3-4 days at 60-65 °C. After drying, the roots were weighed to the nearest 0.01 g, and the shoots were weighed to the nearest 0.1 g.

Linear regression models that predict the aboveground (ag) and belowground (bg) biomass, and total biomass per individual for each species were developed using the measured morphometric attributes of individual plants (L_r , D , and H) as potential predictors (independent variables). The predictors of the total biomass model were selected by the conventional stepwise method (Draper & Smith, 1981), in which a critical value of F was adopted in the process of inclusion equal to that of the process of elimination. The level of significance of critical F was set at 0.9 to ensure the selection of few predictors; the value of tolerance, which measures the stability of the correlation matrix, was set at

0.001. The models for the prediction of ag and bg biomass included the same independent variables so that adding their predictions provides the same value predicted by the total biomass model.

The contribution of each of the three grassland species to biomass per hectare was estimated by assessing the coverage of each species within Sicilian grassland communities.

RESULTS AND DISCUSSION

Biomass prediction models for *A. mauritanicus*, *H. hirta*, and *P. setaceum*

The morphometric attributes measured for the selected individuals of the investigated species are all reported in Table 2. Because *A. mauritanicus* tufts are taller than those of the other two species, the higher values of biomass for *A. mauritanicus*, both above and belowground, were expected. Conversely, *H. hirta* plants were smaller than those of the other species. The mean root length of *P. setaceum* was comparable to that of *A. mauritanicus*, suggesting that an extensive root system may help to explain the invasion success of this alien species. The models for predicting the ag, bg, and total biomass per individual of the three species are presented in Table 3. For all models, the residuals did not show trends, and their average was, as expected, close to zero. The predictive potential of the models was validated by a “leave-one-out” procedure, *i.e.*, by the so-called deleted residuals (for each observation, a deleted residual was calculated by excluding the observation from the calculation of the regression coefficient; this procedure was repeated for each observation in turn).

The validation results (see Table 4) corroborate the ability of the established models to predict ag and total biomass of *A. mauritanicus* and *P. setaceum*; the models provided unbiased predictions (biases were less than 2% of the observed biomass means) and explained a high percentage of the variability of total biomass per individual of each species. The percent ratio between the mean of absolute deleted residuals and the mean of individual total biomass indicates the magnitude of the error when estimating the biomass of single individuals; this ratio was 33% for *A. mauritanicus* and 20% for *P. setaceum*. Although relatively high, these percentages are satisfactory if the biomass variability among the sampled individuals (biomass variation coefficient over 100%) is taken into account.

In contrast, the models developed for *H. hirta* did not provide useful predictions: The percent ratio between the mean of the absolute deleted residuals and the mean total biomass was 53%. No clear relationships were found between any measured morphometric attribute and the ag, bg, or total biomass per individual of this species. *Hyparrhenia hirta* develops roots early and seems to develop a greater ratio of bg to ag biomass than the other species, probably as a specific adaptation to the xeric environments.

Biomass values of grasslands

Within each of their respective communities, the average number of individuals per hectare was 15,000 for *A. mauritanicus*, 30,000 for *H. hirta* (the smallest species), and 20,000 for *P. setaceum*. The number of individuals per hectare was multiplied by the mean dry weight per individual to estimate ag, bg, and total biomass per hectare for each of the three species (Table 5).

Table 2. Attributes for individuals of the three grass species.

		Minimum	Maximum	Mean \pm std. dev.
<i>Ampelodesmos mauritanicus</i>	diameter at root collar (cm)	5	28	14.82 \pm 7.13
	root length (cm)	17	50	32.86 \pm 7.95
	height (cm)	60	165	99.64 \pm 31.15
	belowground biomass (g)	4.69	96.40	24.94 \pm 23.85
	aboveground biomass (g)	44.8	2772.4	773.44 \pm 916.35
	total biomass (g)	56.92	2853.80	798.39 \pm 936.96
<i>Hyparrhenia hirta</i>	diameter at root collar (cm)	2	21	12.50 \pm 6.20
	root length (cm)	9	40	27.00 \pm 7.25
	height (cm)	31	79	59.45 \pm 12.22
	belowground biomass (g)	0.43	11.55	5.29 \pm 3.29
	aboveground biomass (g)	13.0	504.1	158.73 \pm 121.47
	total biomass (g)	14.08	510.06	164.01 \pm 122.93
<i>Pennisetum setaceum</i>	diameter at root collar (cm)	3	21	11.07 \pm 5.46
	root length (cm)	20	48	34.33 \pm 7.301
	height (cm)	23	79	49.00 \pm 14.33
	belowground biomass (g)	1.51	33.04	16.21 \pm 10.16
	aboveground biomass (g)	4.6	967.7	191.87 \pm 256.03
	total biomass (g)	6.11	1000.74	208.09 \pm 263.85

Table 3. Results of the regression analysis carried out to estimate the numerical coefficients of the predictive models (r^2 = coefficient of determination; see = standard error of the estimate, in g).

Species – biomass component	Model	r^2	see
Am – ag	$Ab = 595.174 + 0.126373 * H^2$	0.906	293.1
Am – bg	$Bb = 5.107 + 0.002776 * H^2$	0.645	14.8
Am – total	$Bt = 600.281 + 0.129149 * H^2$	0.905	301.2
Hh – ag	$Ab = 125.486 + 4.781 * H$	0.231	109.4
Hh – bg	$Bb = 1.406 + 0.113 * H$	0.175	3.1
Hh – total	$Bt = 126.891 + 4.893 * H$	0.237	110.3
Ps – ag	$Ab = 6.415 + 0.0003395 * D^2 * H^2$	0.958	54.4
Ps – bg	$Bb = 10.324 + 0.0000108 * D^2 * H^2$	0.614	6.5
Ps – total	$Bt = 16.739 + 0.0003502 * D^2 * H^2$	0.960	54.5

Key: Am = *Ampelodesmos mauritanicus*; Hh = *Hyparrhenia hirta*; Ps = *Pennisetum setaceum*; ag = aboveground biomass (g) per individual plant; bg = belowground biomass (g) per individual plant; total = total biomass (g) per individual plant; H = maximum height in cm; D = diameter at root collar in cm. The units for the dependent variables are grams for every equation.

Table 4. Leave-one-out validation of the prediction models.

Species – biomass component	Mean of the deleted residuals (g)	Mean of the absolute deleted residuals (g)	Explained variance (%)
Am – ag	9.9	254.8	87
Am – bg	-0.8	11.8	17
Am – total	9.2	261.8	86
Hh – ag	-2.3	85.4	5
Hh – bg	-0.1	2.6	3
Hh – total	-2.4	86.6	7
Ps – ag	4.0	38.5	94
Ps – bg	-1.1	7.1	20
Ps – total	2.9	40	96

Key: Am = *Ampelodesmos mauritanicus*; Hh = *Hyparrhenia hirta*; Ps = *Pennisetum setaceum*; ag = aboveground biomass (g) per individual plant; bg = belowground biomass (g) per individual plant; total = total biomass (g) per individual plant.

Table 5. Phytosociological associations and mean biomass in grasslands on the study sites.

Locality	Phytosociological association	Biomass (Mg/ha)
Cape Gallo, Mt. Pellegrino, Mt. Inici	<i>Hyparrhenietum hirta-pubescentis</i> (Hb-dominated grasslands)	4.8 ag + 0.2 bg
Cape Gallo, Mt. Pellegrino	<i>Penniseto setacei-Hyparrhenietum hirtae</i> (Ps-dominated grasslands)	3.8-4.8 ag + 0.2-0.3 bg
Cape Gallo, Mt. Pellegrino, Mt. Inici	<i>Helictotricho convoluti-Ampelodesmetum mauritanici</i> (<i>A. mauritanicus</i> -dominated grasslands)	11.6 ag + 0.4 bg

Key: ag = aboveground biomass; bg = belowground biomass.

This approach, which uses phytosociological and biomass survey data, relies on the reasonable assumption that the total number of individuals of a species per hectare can be estimated by dividing its coverage per hectare (as indicated in the phytosociological relevés or plots) by its average crown area per individual. The estimated biomass per hectare was higher for *H. hirta* than for *P. setaceum* because the native grass compensates for its lower biomass per individual with a larger number of individuals per unit area. It might be deduced that replacement of *H. hirta* by *P. setaceum* reduces the total carbon storage in the ecosystem; however, the xenophyte allocates more

resources to the bg organs and therefore may contribute more than the native to a more stable and durable pool of carbon in these grasslands. The estimated *A. mauritanicus* biomass per hectare was substantially higher and was nearly as large as the lower value of biomass reported for Sicilian maquis (Costa & La Mantia, 2005). On the other hand, biomass evaluation seems to be strongly affected by community structure. For example, an investigation at the Garraf Natural Park in Spain (Grigulis & al., 2005) found relatively low values of ag biomass per hectare, ranging from 2 to 6 t/ha depending on the mean density of *A. mauritanicus* individuals and to the presence of a dense or a

scattered dominant shrub layer. The mean value of biomass per hectare estimated for both *H. hirta* and *P. setaceum* falls within the ranges previously reported for Mediterranean grasslands. Several studies concerning these grasses have reported ag biomasses that range from approximately 1 (or even less) to just over 7 t/ha (Puerto & al., 1990; Hector & al., 1999; Cleemput & al., 2004; Grigulis & al., 2005; Vallejo & al., 2006; Vázquez-de-Aldana & al., 2006; Zarovali & al., 2007; Golodets & al., 2010; Salis & al., 2010).

According to several sources, grasslands cover about 200,000 ha in Sicily (CLC 1990, 2000, 2006; AA. VV., 1996). If these data are combined with the biomass per hectare for each of the three perennial grass species, their total biomass in Sicily can be estimated to range from 0.98 to 2.40 Mt. Although this is clearly a rough assessment, it is useful and important because information on stand biomass of grasslands within the Mediterranean region is still scarce. Above all, this assessment indicates that such large-scale communities have a previously unrecognized potential to sequester carbon. Although biomass per hectare is considerable in the grassland communities, biomass per hectare is much greater in the pre-forest and forest formations, and was estimated to be about 19 Mt for the entire woodland area of Sicily (Hofmann & al., 2011).

CONCLUSIONS

This paper describes the first models that are able to predict the individual and community biomass of three perennial herbs that dominate central Mediterranean grasslands. The models should be useful for predicting the biomass of many other Mediterranean grasses with similar habit. Given the expected expansion of *C₄* grasses due to climatic warming (Mannetje, 2007), data concerning *H. hirta* and *P. setaceum* are very important for modelling the future carbon sequestration potential of Mediterranean xeric grasslands (Abberton & al., 2009).

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