Estimated Net Ecosystem Exchange (NEE) of Turfgrass at Different Management Intensities in a Golf Course in the Province of Verona

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Abstract: The carbon (C) sequestration potential of turfgrass systems has been investigated and demonstrated from several studies. The role of these ecosystems in continental and Mediterranean climates though, is not yet clearly understood because environmental limiting factors and management intensities can strongly influence the overall C budget. The aim of the present study is to improve the understanding of the mechanisms underlying C fluxes in a turfgrass ecosystem and to assess its C sequestration potential by estimating the annual C budget. NEE (Net Ecosystem Exchange) of turfgrass was calculated in its seasonal variation over one year, and compared between areas characterized by different degrees of maintenance. The C sequestration potential of the turfgrass was investigated in a golf course near Verona (Italy), adopting a small-chamber enclosure approach. The measurements of gas exchanges between biosphere and atmosphere, permitted to estimate the NEE, as a function of different management intensities. The intensity of management seems to have influence on its C balance. This study needs further research to understand which maintenance variables are determinant on turfgrass C sequestration.

Key words: Carbon balance, carbon dioxide, golf course, net ecosystem exchange, small chambers enclosure, turfgrass.

1. Introduction

1.1 Carbon Fluxes and Productivity of Ecosystem: Definitions and Mechanism

The exchange of CO₂ between the ecosystem and the atmosphere reflects on the balance between photosynthesis (by plants) and respiration [1]. This balance, called NEP (Net Ecosystem Production) has become a critical characteristic of terrestrial ecosystem in order to study their reaction to the increase in atmospheric CO₂ concentration. Another fundamental property of an ecosystem is NPP (Net Primary Production), which refers to the net production of organic carbon by plants and it is usually measured over a period of one year, or more [2]. The term includes not only the growth of primary producers, but also the C transfer to root symbionts

(mycorrhizal fungi for example), the production of roots exudates and plant VOCs (Volatile Organic Compounds). Net primary productivity is equivalent to GPP (Gross Primary Productivity) minus autotrophic respiration (R_a):

$$NPP = GPP - R_a \quad (1)$$

Net ecosystem productivity, or NEE (Net Ecosystem Exchange) with an opposite sign, is defined as the difference between the amount of C fixed by photosynthesis (GPP) and the total ecosystem respiration:

$$NEP = -NEE = GPP - R \quad (2)$$

Net ecosystem productivity has been also defined by some authors as the net rate of C accumulation in ecosystems [3]. The two definitions are equal in a simple ecosystem model in which the rate of C accumulation results from the balance between photosynthesis and respiration. NEE is defined by atmospheric scientists as a C input to the atmosphere,

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or as the CO₂ flux from the ecosystem to the atmosphere. Values are negative when the system sequesters C (photosynthesis) and positives when the system releases C (respiration).

The present study does not consider the entire biome over large temporal and spatial scale but some representative areas sampled several times over one year to account the seasonal variability and in different position to account for spatial heterogeneity. Authors assumed that in the turfgrass ecosystem non-biological oxidation, import and export of C are negligible if compared to the magnitude of other fluxes. The main environmental factors affecting rate of photosynthesis in turfgrass are light intensity, temperature and CO₂ concentration. Temperature influences both photosynthesis and respiration. At low temperature, photosynthesis is limited because of chemical reactions, catalyzed by enzymes, goes slowly [4]. A few studies tested how the expected increase in soil temperature could affect NEE on turfgrass. Zhou [5] simulated global warming effect on urban lawns (*Zoysia japonica*) from winter to springtime. The increase of soil temperature (5 °C) influenced the turfgrass, transforming the system from source to a sink of C. During the transition period from winter to spring, photosynthesis feedback was more sensitive than respiration to the increase of temperature. NEE estimated in this period pinpointed the switch from winter C source to spring C sink. The increase of temperature (3.5 °C) on plots of *Festuca arundinacea* in California [6], showed an increase in rates of ecosystem respiration, particularly in winter when heterotrophic respiration was dominant, and a significant decrease in NEE.

1.2 Methodologies for Gas Exchange Estimates

Correct measurements of CO₂ fluxes between vegetation and the atmosphere are a prerequisite to calculate the C balance [7]. The methodological approaches adopted for the calculation of the ecosystem C balance are two: the whole-system

balance (micrometeorological methods) and small-chamber enclosures (SC) [8].

The micrometeorological approaches include all those methods that measure only the net CO₂ exchange between the ecosystem and the atmosphere, without quantifying the single specific fluxes and pools within the system. These methods have the advantage of not creating major disturbances on the environment surrounding the plant-soil system. At the same time they are not suited for plot experiments because of their large spatial-scale.

The SC (or canopy-chamber methods) provides measurement of the most important C fluxes within the system individually. These approaches are suitable for NEE estimates at experimental plot scales or for comparing different land use on small areas close each other.

These methods require static (closed) or dynamic (open) enclosures in which the trace gas concentration is monitored over the time with an IRGA (Infrared Gas Analyzer). Moreover, variation (increase or decrease) of CO₂ concentration over the time due to plant-soil activities are used to calculate CO₂ fluxes. Photosynthesis, vegetation respiration by leaves and non-leaf tissue, roots and soil respiration are considered.

1.3 Gas Exchange Measurement on Turfgrass: Small-Chambers Enclosure Approach

Several studies utilized SC approach to determine CO₂ exchange fluxes between atmosphere and bare soil or low-stature canopies, such as tundra, grassland, forest understory vegetation, various crops and turfgrass (Table 1).

However, only few studies provide seasonal values of NEE on turfgrass [9, 10], while none of them provide an annual estimate of NEE. Authors do not know European studies of NEE using canopy-chambers methods on turfgrasses.

The estimate of the CO₂ fluxes with the SC approach reports the rate of CO₂ accumulation or

Table 1 Turfgrass gas exchange measurements as reported in the literature.

Site	Tipology	Instrumrntation	NEE $\mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$	Pnet	Pg	Season	Publication
Irvine (California), United States	Festuca arundinacea	LI-COR + chamber	-6.38 ± 1.41 -7.18 ± 0.47			Sum. Win.	Pataki, 2006
Quebec City (Canada)	Different urban lawns	Gas chromatogr. + chamber	-1.29 ÷ +14.32			Spr. Sum. Aut.	Allaire, et al., 2008
Beijing (China)	Urban lawn (Zoysia japonica)	IRGA + automatic chambers	+0.13			Win.	Zhou, et al., 2012
Victoria (Australia)	Different urban lawns (Microlaena spp., Festuca spp., Lolium spp.)	IRGA +automatic chambers	+4.60 ÷ +18.70			Sum. Aut.	Livesley, et al., 2010
Manhattan (Kansas), United States	Festuca arundinacea, Lolium perenne	IRGA + chambers	-12.3			Spr.	Lewis, 2010 (ch.3)
Wooster (Ohio), United States	Festuca arundinacea and Lolium perenne colonized by fungal endophyte	LI-COR + chamber	+3.15 ÷ +15.14			Sum.	Singh, 2007
Manhattan (Kansas), United States	Festuca arundinacea Lolium perenne	LI-COR + chamber, Bremer and Ham methpd	+9.62 +10.16 +9.41	14.33 14.05 11.54	17.37 17.33 14.07	Spr. Sum. Aut.	Bremer and Ham, 2005
Manhattan (Kansas), United States	Cynodon dactylon Zoysia japonica Festuca arundinacea Poa pratensis	LI-COR + chamber, Bremer and Ham method		25.2 (*) 18.4 (*) 20.7(**) 6.4 (*)	43 (*) 33 (*) 27 (**) 20 (**)	Sum. Aut.	Lewis, 2010 (ch.5)
Chile	Festuca arundinacea (cv. Cochise and Bingo) Cynodon dactylon	IRGA + chamber	-15 -75			Su. Spr. Aut.	Acuna, et al., 2012

All the values are expressed in $\mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$. P_{net} and P_g are related to fluxes toward the atmosphere while NEE (Net Ecosystem Exchange) concerns fluxes towards soil. Data with * represent the maximum flux value of the season. (*) and (**) are collected respectively on DOY 217 and 262.

release over the sample period. However the measurement method inherently alters the normal ambient conditions, changing the CO_2 concentration.

1.4 Aim and Scope

The objectives of this study are to (1) calculate the NEE of turfgrass and its seasonal variation over one year; (2) study the relationships between CO_2 fluxes and environmental variables such as air temperature and PAR and (3) compare the NEE of areas characterized by different degrees of maintenance.

2. Material and Methods

2.1 Study Site

The study was conducted at the Verona Golf Club,

located in Sommacampagna (45°24' N, 10°51' E), in the province of Verona (Italy). The golf course includes 18 holes and, together with facilities, occupies 54 hectares. The course is situated in a hilly area (140 meters of altitude) and is influenced by the climate of the Lake Garda, which is 15 kilometers away.

The turfgrass of the experimental field of our case study (18th hole) was established approximately 40 years ago. Right from the start, the course was conducted with an agronomic and eco-compatible system of management with a low impact on the environment. All the playing surfaces were irrigated daily from March to November, with the exception of days with precipitation higher than 10 mm. The only

area that was not irrigated was rough.

2.2 Experiment Description, Instrumentation and Flux Calculation

The study was conducted from August 2012 to September 2013 at the Verona Golf Club. The area used for the surveys was the 18th hole of the golf course, extended for 18.270 m², positioned close to the club house.

The hole included different playing areas, characterized by different species composition and management intensity (Table 2). In descending order from the high

maintained playing areas, authors define green, tees, collar, fairway, semi-rough and rough.

The degree of management of each playing area was determined collecting data regarding cultural operations during the surveys period. The green of the case-study hole, for example, was mowed almost every day during the growing season, while fair ways was mowed three times per week. Mowing activities were interrupted only from December to February. The cultural operation affecting maintenance is mowing, fertilization and agrochemical application.

Table 2 Grass compositions and subdivision of playing areas in 3 maintenance categories: HI (High Intensity), MI (Medium Intensity) and LI (Low Intensity). Measuring points grouped per area and surfaces.

Hole area	Grass species	%	Surface area (ha)	Percentage of hole area (%)	Nr of sampling points	Relative management intensity
Green	Poa annua	50	0.0541	3.00	1	High
	Agrostis stolonifera	50				
	Lolium perenne	30				
	Agrostis stolonifera	30				
Tee	Poa annua	20	0.0512	2.80	2	High
	Cynodon dactylon	15				
	Other weeds	5				
	Agrostis stolonifera	60				
Collar	Poa annua	35	0.012	0.70	1	High
	Cynodon dactylon	5				
	Poa annua	30				
	Agrostis stolonifera	25				
	Lolium perenne	20				
Fairway	Cynodon dactylon	10	0.6675	36.50	9	Medium
	Trifolium repens	5				
	Paspalum distichum	5				
	Other weeds	5				
	Lolium perenne	35				
	Cynodon dactylon	25				
Semirough	Poa annua	25	0.28	15.30	3	Medium
	Festuca arundinacea	5				
	Poa pratensis	5				
	Other weeds	5				
	Cynodon dactylon	20				
	Lolium perenne	20				
Mount and rough	Poa annua	20	0.762	41.80	4	Low
	Festuca arundinacea	10				
	Poa pratensis	10				
	Trifolium repens	5				
TOTAL	Other weeds	15	1.8268	100	20	

Within the course, 20 NEE measurement points were marked with iron plates positioned in different playing areas. These areas were grouped in 3 categories according to their degree of maintenance: HI (High Intensity), including tees, green and collar, MI (Medium Intensity), including fairway and semi-rough and LI (Low Intensity), including rough. HI, MI and LI had respectively 4, 12 and 4 measurement points (Table 2). The number of measuring points repeated for playing areas was proportional to the width of their area within the hole.

Whole-canopy gas exchange measurements were performed with a portable IRGA (EGM-4, PP Systems, UK) equipped with a canopy chamber (CPY-2, PP Systems, UK) characterized by the following measures: 14.5 cm height $\times$ 14.6 cm diameter, 167 cm² of exposed area, 2,425 cm³ of volume.

The chamber, designed for closed system measurement of canopy CO₂ fluxes, is transparent and fitted with an air mixing fan and sensors for measurement of PAR and air temperature. A tapered stainless steel edge (10 mm) is attached along the base of the chamber to push into the soil and improve the seal between the chamber and the soil surface.

Covering vegetation with a closed chamber modifies the microclimate conditions in the chamber headspace. In little time, natural process controlling fluxes are disturbed by the changed conditions, and the CO₂ concentration gradients between soil, vegetation and air are altered. Moreover, leaks from the unsealed between the stainless steel ring and the soil surface may affect the fluxes measurement.

For the study the authors considered the CO₂ flux values collected at the end of the each measurement that lasted between 32 and 40 seconds. The surveys were carried out every 2 weeks, for a total of 23 measurement days over one year. Each survey consisted in 5 measures taken at 5.30, 9.30, 14.00, 18.00 and 22.00, for each of the 20 measurement points. Every single measurement lasted 40 seconds in the first 6 surveys, then 32 seconds for the rest of the

study. In order to account for the effect of the chamber on the headspace parameters, temperatures inside the chamber were recorded at the beginning and at the end of each measurement. The variation of pressure within the chamber was not considered influential for the CO₂ flux measurement. The chamber was positioned every time in the same positions, following a random order between one point and the other. The instrument (IRGA and chamber), has an inbuilt data logger, and provided the value of CO₂ flux expressed as $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ CO₂. The basic formula adopted for computing CO₂ flux (J_c) is:

$$J_c = \rho_m \frac{V}{A} \frac{\Delta\text{CO}_2}{\Delta t} \quad (3)$$

where J_c is the CO₂ flux ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), ρ_m is the molar density of air ($\mu\text{mol}\cdot\text{air}\cdot\text{m}^{-3}\cdot\text{air}$) calculated from the ideal gas law, V is the chamber volume (m³ air), A is the chamber area (m²) and $\Delta\text{CO}_2/\Delta t$ is the rate changes over time of CO₂ concentrations within the chamber ($\mu\text{mol CO}_2 \mu\text{mol}^{-1}\cdot\text{air}\cdot\text{s}^{-1}$) [11].

Together with the CO₂ concentration (ppm), and flux, the air temperature (°C) and the PAR ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) inside the chamber were recorded by chamber-integrated sensors.

Daily CO₂ flux values for each measurement point were obtained from the integration of the 5 measurements with the trapezoidal rule, by approximating the region under the graph of the function fitting the data as trapezoid and calculating its area. The 5 measurement times were chosen in order to be representative of the different light and temperature conditions during a day. The estimated daily NEE was then considered representative of the period between one measurement day and the following (approximately 15 days, except in the beginning of October and at the end of December). The same approach was then used to calculate the annual NEE.

2.3 Statistical Analysis

Normality of the NEE annual data was tested with

the Shapiro-Wilk test. One-way analysis of the variance (ANOVA) with Statgraphics Centurion XV (StatPoint Inc., USA) was carried to test the effect of the management intensity on the seasonal and annual cumulated values of NEE. A multiple comparison procedure was then used to analyze statistically significant differences among means using the Tukey's honest significance test ($p < 0.05$). Homogeneity of variance was checked using Levene's test before analysis. The significance of the relationships between ecosystem respiration and temperature during the night and between photosynthesis and PAR during the day, have been tested by linear regression analysis with Table Curve 2D, v4.07 (Systat Software Inc., USA).

3. Results

3.1 Meteorological and Phenological Seasonality in the Studied Turfgrass

Fig. 1 reports mean monthly values of air temperature and cumulated precipitation during the studied period: cumulative precipitation was 2,356 mm, abundant during autumn and springtime, exceeding 100 mm per month in September, October and November 2012 and March, April and May 2013, with an extraordinary peak on May 2013 (243 mm).

Precipitation reached minimum values during summer 2013, with June, July and August having 50, 12 and 40 mm of rain, respectively (Fig. 1). July and August 2013 fall in the aridity period, according to Walter postulate [12].

Considering the trend of meteorological data during this study, turfgrass growing season in Golf Club Verona lasted in autumn and in spring. Turf remained green during summer, tolerating drought thanks to the irrigation, and was dormant in winter.

3.2 Net Ecosystem Exchange Measurement

Fig. 2 shows the daily average NEE trends and PAR values for each maintenance category, as measured in the 5 sampling times in 4 representative days of the different seasons, while Table 3 shows the seasonal variability on single daytime and nighttime measurements.

In springtime and autumn diurnal values of NEE were similar both in the maxima and in the minima, the latter representing the highest diurnal uptake rates observed in the whole period (-2.46 and $-2.13 \mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$ respectively). Night time respiration was however higher in spring time and summer than in autumn (4.78 compared to $2.75 \mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$). The maximum and minimum diurnal values during

Fig. 1 Monthly mean air temperature and cumulative rainfall during the experimental period.

Red bars indicate monthly precipitations, blue line indicate monthly temperature variations.

Fig. 2 Daily trend of photosynthetically active radiation (PAR) and average net ecosystem exchange (NEE) for each maintenance category on four representative days in autumn (25th October), winter (8th February), spring (27th May) and summer (30th July).

Maintenance categories are HI, MI and LI, $n = 4$ for LI and HI, 12 for MI. PAR values are measured from the meteorological station.

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Table 3 Diurnal and nocturnal extremes values of net ecosystem exchange (NEE) divided for turf phenological season. NEE values are expressed in $\mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$. Maintenance categories are HI, MI and LI.

Turf season	Date	NEE ($\mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$)		Category
Winter	16/11/12 (survey: 10.00)	-2.05	daily min	LI (mount)
15-Nov.-15-Mar. (4 months)	16/11/12 (survey: 10.00)	-0.01	daily max	LI (rough)
	1/3/12 (survey: 22.00)	0.72	nocturnal max	MI (semi-rough)
Spring	11/4/12 (survey: 14.00)	-2.46	daily min	MI (fairway)
15-Mar.-15-Jul. (4 months)	5/7/12 (survey: 09.30)	3.72	daily max	HI (tee)
	4/7/12 (survey: 22.00)	4.78	nocturnal max	MI (fairway)
Summer	13/8/12 (survey: 14.00)	-1.49	daily min	LI (mount)
15-Jul.-15-Aug. (1 months)	30/7/12 (survey: 18.00)	1.97	daily max	MI (semi-rough)
	30/7/12 (survey: 22.00)	4.36	nocturnal max	LI (mount)
Autumn	20/9/12 (survey: 14.00)	-2.13	daily min	LI (mount)
15-Aug.-15-Nov. (3 months)	4/10/12 (survey: 18.00)	2.85	daily max	LI (mount)
	4/10/12 (survey: 22.00)	2.75	nocturnal max	MI (semi-rough)

Fig. 3 Relation between PAR ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) and CO_2 flux ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$) on four representative days in autumn (25th October), winter (8th February), spring (27th May) and summer (30th July).

summer were closer to zero (-1.49 and $1.97 \mu\text{mol CO}_2 \text{ m}^{-2} \cdot \text{s}^{-1}$ respectively) compared to spring time and autumn. During the winter, the diurnal values of NEE were always negative while nocturnal respiration obviously showed the lowest values (Table 3).

During the day, the relationship between CO_2 flux ($\mu\text{mol m}^{-2} \cdot \text{s}^{-1}$) and PAR ($\mu\text{mol m}^{-2} \cdot \text{s}^{-1}$) was well described by linear functions (Fig. 3). Fig. 10 shows

the relationship between NEE and PAR in 4 days representative of different season. The C uptake of the system (negative NEE) increases in absolute value with increasing PAR, though the slope of the regression lines varies in the different season (Fig. 3). The 27th of July, notwithstanding the high PAR values, NEE was often positive, indicating that C losses prevailed over uptakes.

NEE sampled with PAR equal to zero (nocturnal and early morning measurements) represents the ecosystem respiration ($R_{eco} = R_a + R_h$) whose relation with air temperature inside the chamber is well described by an exponential function. Fig. 4 reports the relationship between air temperature inside the chamber and CO_2 flux during the whole year for each management category (Figs. 4a, 4b and 4c).

Fig. 5 shows the annual trend of NEE for each category of maintenance intensity. NEE ranged

between -9.41 and $+70.53 \text{ mgC}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. In the period between 16th November 2012 and 27th March 2013 the mean daily NEE was $-2.05 \text{ mgC}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$, with values ranging from -9.41 to $7.06 \text{ mgC}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ for all the categories. In April 2013, values of NEE quickly increased, reaching a peak of CO_2 emission comprised between 30 and $50 \text{ mgC}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$. In May, NEE was again close to zero then gradually increased during the summer peaking in July at values comprised between 40 and $70 \text{ mgC}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$.

Fig. 4 Relationship between ecosystem C flux and air temperature inside the chamber with $PAR = 0$ (nocturnal measurements). All the measurement values are divided for maintenance categories: low intensity (LI, blue), medium intensity (MI, yellow) and high intensity (HI, red).

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Fig. 5 Annual trend of daily net ecosystem exchange (NEE) of turfgrass under different management intensities. Bars are SE of the mean, $n = 4$ for LI and HI, 12 for MI.

Table 4 Average daily net ecosystem exchange (NEE) for turfgrass anaged at different maintenance degree in the four turf phenological seasons.

Average daily NEE ($\text{mg C} \cdot \text{m}^{-2}$)			
Turf season	LI	MI	HI
Winter (8 surveys)	0.86 ± 1.60	-4.21 ± 0.97	-2.78 ± 1.57
Spring (8 surveys)	25.15 ± 5.11	26.91 ± 3.65	14.99 ± 4.43
Summer (3 surveys)	59.73 ± 7.77	57.10 ± 4.30	40.68 ± 5.51
Autumn (4 surveys)	31.10 ± 2.35	18.15 ± 2.05	11.44 ± 2.84

Maintenance categories are HI, MI and LI. Values are mean $\pm$ SE of the mean, $n = 8$ for winter and spring, 3 for summer and 4 for autumn. The source of replication is the number of points measured in each management area.

The sequestrated C during the daytime resulted slightly greater than the emitted C during the night in late autumn and winter, whereas from spring to early autumn, the C via autotrophic and heterotrophic respiration exceeded that sequestered by photosynthesis, hence NEE trend during this period assumed positive values.

All the maintenance categories areas showed similar NEE trends (Fig. 5), however the mean daily CO_2 fluxes were different according to the intensity of maintenance and the season (Table 4).

Mean daily values of NEE in HI were lower than those in MI and LI in spring, summer and autumn, whereas in winter the lower mean daily value was in MI and, together with the HI value of the same season, was the only seasonal negative rate. The higher CO_2 fluxes values were reached in summer for all categories (Table 4). The results of the ANOVA show how the cumulative NEE is affected differently by

management intensity along the year (Table 5), with MI and HI having significant lower NEE values than LI ($p < 0.05$) in autumn and winter, while in summer HI was significantly lower than MI but not than LI. No significant differences between management intensities were found in springtime.

This different seasonality of the NEE resulted as well in its annual integration (Fig. 6). The annual NEE showed a decrease (therefore an increase in the annual C budget) with the increase of the intensity of management, with HI significant lower ($p < 0.05$) than LI, while MI was not significantly different from both LI and HI (Fig. 7).

4. Discussion

4.1 Criticism of the Measuring System

Annual estimates of NEE with small chambers approach can be influenced mainly from two types of errors: (1) connected to the measuring system and (2)

Table 5 Average cumulative net ecosystem exchange (NEE) for each turf phenological season, at different maintenance degree, obtained from the integration of daily NEE by the trapezoidal rule.

Maintenance categories are HI, MI and LI. Values are mean $\pm$ SE of the mean, $n = 8$ for winter and spring, 3 for summer and 4 for autumn. Different letters indicate statistically significant differences, $p < 0.05$. All statistical analysis was carried out using ANOVA. The source of replication is the number of points measured in each management area.

Average cumulative seasonal NEE ($\text{mgC}\cdot\text{m}^{-2}$)				
	Autumn	Winter	Spring	Summer
LI	2.24 ± 0.21 b	0.36 ± 0.11 b	2.35 ± 0.33 a	2.50 ± 0.15 ab
MI	1.43 ± 0.11 a	-0.40 ± 0.08 a	2.35 ± 0.26 a	2.40 ± 0.18 b
HI	1.04 ± 0.16 a	-0.27 ± 0.11 a	1.26 ± 0.20 a	1.56 ± 0.17 a

Fig. 6 Annual cumulative net ecosystem exchange (NEE) of turfgrass under different management intensities.

Values are means, $n = 4$ for LI; 12 for MI; 4 for HI. Bars are SE of the mean. Different letters indicate statistically significant differences, $p < 0.05$.

Fig. 7 Annual trend of daily net ecosystem exchange (NEE) of turfgrass in relation to temperature and PAR.

Bars on NEE trend are SE of the mean, $n = 20$.

related to the measurement frequency, timing and duration overtime.

As discussed by several authors to enclose the vegetation in a chamber may cause a perturbation of micro environmental variables such as pressure, incoming radiation, temperature and CO_2

concentration in the chamber headspace. This together with possible leaks in the closed system may alter the natural CO_2 flux of the system.

Despite some studies indicating pressure variation as an important factor affecting soil respiration [13] and NEE estimates with transparent chambers in

turfgrass [14], other studies proved that short closure times for transparent chambers caused only negligible error in CO₂ flux calculation [15]. In the present study this variable was not measured nor controlled and the disturbance caused by possible changes in pressure were considered negligible.

Concerning greenhouse effect, literature reported chamber temperature increases between the start and the end of the measurement of 3 °C [16, 17], 1-2 °C [15], 0.7 °C [18]. As tested by previous studies, the authors reduced the measurement period as much as possible in order to minimize the greenhouse effect. In the measurements the difference of temperature between inside and outside the chamber, calculated on the period with higher average environmental temperatures was, on average, $+0.47 \pm 0.76$ °C (SE, $n = 700$), which is comparable to that reported by previous studies.

An inhibition on photosynthesis likely occurs when the CO₂ concentration inside the chamber quickly decreases as a consequence of the fixation by the plants. The change of CO₂ concentration from standard conditions altered the concentration gradients beneath the chamber, making CO₂ concentration a limiting factor that altered photosynthesis and, therefore, C uptake. In other words, the measurement method itself alters the measures. This combined effect of temperature and CO₂ concentration likely increased during the warm season, enhancing the underestimation when the photosynthetic activity is higher.

4.2 Net Ecosystem Exchange of the Turfgrass

High precipitation recorded in the studied period, together with the irrigation provided in all the hole surfaces, excepted for rough, likely created optimal soil moisture content for turfgrass during the whole year. As a consequence, the turf has followed the typical growing pattern for cool-season grasses, which consists of two distinct growing periods, one during autumn (15 of August to 15 of November) and another

during the springtime (15 of March to 15 July) when daily optimal temperatures were reached (Fig. 5).

Figs. 1 and 4 highlight the seasonality of the NEE in the turfgrass. The trends seem to follow more the temperature trend (Fig. 7) than the physiological activity of the turf; however interaction between the two likely occurs. During the winter, the NEE values close to zero (Table 4), but always negative, indicate a prevalence of the photosynthesis over the respiration.

Daily values of NEE measured in spring and autumn are similar (Table 3). In both cases maximum C accumulation was sampled at 14.00 in correspondence to maximum PAR conditions. Despite NEE is usually negative on the surveys carried out in the morning and early afternoon, average daily NEE in spring and autumn resulted positive (Table 4).

Water availability may have affected the magnitude of the soil respiration, as suggested by some studies [19, 20] influencing the net CO₂ flux of the turf. The influence of moisture content on soil CO₂ is complex because it affects several components of the plant-soil system (roots, microbes, gas transport through the soil, etc.).

In the turfgrass the availability of subtle-broken organic matter (turfgrass clippings) and water (precipitation and irrigation), combined to the warm temperatures, could have influenced the CO₂ fluxes, enhancing diurnal and nocturnal soil respiration during the whole growing season. The peak in NEE observed in the two surveys carried out in April (Fig. 5) is concomitant with the start of the physiological activity of the turf and with a sudden increase of 10 °C in the air temperature after the winter period. Although the diurnal CO₂ uptake was among the higher registered in the period, the respiration during the night was twice as high (Table 3) thus leading to a net daily source of C.

Fig. 6 shows also a low average PAR value registered on the 26th of April, when the NEE peaked, which could have reduced the photosynthetic activity.

5. Conclusion

The present study partially fills the gap of annual NEE estimates of turfgrasses. Several studies adopted the SC method to estimate turfgrass NEE only for short-period surveys. Through the SC approach we show for the first time the seasonal trends of NEE as affected by intensity of management. The positive NEE values, although small in absolute value, may have been influenced by the alteration of environmental factors at canopy level inside the chamber. Authors suppose that the increase of temperature and the variation of CO₂ concentration inhibited photosynthesis and increased soil respiration. The agreement of our findings with the available estimates of NEE measured with the same approach seems to confirm the limits of the methodology and suggests that different approaches used for estimating C sequestration may be the main variable for turfgrass assessment as C sink or source.

The intensity of turf management seems to have an influence on its C balance. Carbon dioxide emissions from high intensity surfaces were lower compared to low intensity ones, however this could be the result of methodological errors and need further research to understand which maintenance variables are determinant on turfgrass C sequestration. Although an exact quantification of the error affecting our estimates is not possible, the study shows a turfgrass system close to equilibrium for C fluxes in the considered period.

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