MINI-LYSIMETERS EVAPOTRANSPIRATION MEASUREMENTS ON SUBURBAN ENVIRONMENT MISURE DI EVAPORAZIONE MEDIANTE MINI-LISIMETRI IN AMBIENTE SUBURBANO

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MINI-LYSIMETERS EVAPOTRANSPIRATION MEASUREMENTS ON SUBURBAN ENVIRONMENT

MISURE DI EVAPORAZIONE MEDIANTE MINI-LISIMETRI IN AMBIENTE SUBURBANO

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Abstract
Mini-Lysimeters (ML) installed in a farm of Milano University provide a direct measurement of evapotranspiration from reference crop. An indirect estimation of evapotranspiration has been carried out by means of micrometeorological algorithm of Penman –Monteith. Data produced by the ML has been compared with Penman-Monteith equation. Advantages and limits of the ML approach were evidenced.

Keywords: Mini-Lysimeter , evapotranspiration, micrometeorology.

Riassunto
I Mini-Lisimetri (ML) installati presso un'azienda agricola dell'Università degli Studi di Milano forniscono la misura diretta dell'evapotraspirazione da coltura di riferimento. Una stima indiretta di evapotraspirazione è stata condotta con l'utilizzo dell'equazione di Penman-Monteith. I dati prodotti dai ML sono stati messi a confronto con l'equazione di Penman-Monteith. Vantaggi e svantaggi dei ML sono infine stati messi in evidenza.

Parole chiave: *Mini-Lisimetri , evapotraspirazione, micrometeorologia*

Introduction
Evapotranspiration (ET) is the combination of the plants transpiration and soil surface evaporation; its values are directly measured by means of lysimeters.
Reference evapotranspiration (ET0) is the evapotraspirational consumption of an ideal crop (*Festuca pratensis L.* with infinite extension, shadowing completely the soil and with a canopy height of 0.12 m, albedo 0.23 and surface resistance 70 s/m) supposed in optimal conditions (optimal water and nutrient supply, absence of stresses due to pests and diseases). ET0 is currently estimated by means of (i) empirical models as Penman-Monteith or Heargreaves-Samani ones (Allen *et al*, 1998) or (ii) instrumental proxies like evaporation from atmometers or pan evaporimeters.
The maximum evapotranspiration (ETM) of a real crop canopy supposed in the same optimal conditions of the reference crop can be obtained multiplying ET0 values by a suitable crop coefficient (kc) that is function of the crop and the development stage.
Lysimeter measurements are adopted for hydrological balances of crops (Jones, 2004; da Silva *et al*, 2005; Liu *et al*, 2007, Ceccon *et al*, 2008), or to determine kc values (Tyagi et al, 2003). A lysimeter is a terrain block (a monolith of soil or a "disturbed" soil sample) inserted in a container, on which several measurements are carried out as, for example, weighting, chemical analysis on drainage water. There are two basic types of lysimeter: (i) Weighing Lysimeters (WL) for agricultural purposes and (ii) Non Weighing Lysimeters (NWL) for chemical analysis on drainage water. To obtain a reliable hourly evapotranspiration measurements, the ideal instrument is a high precision weighing lysimeter with an accuracy better that 0.1 mm of water (Aboukhaled at al., 1986).
The dimension of lysimeters used for estimation of water consumption of herbage and trees is usually about 3 – 10 m^3, in order to avoid rim effect; moreover, Mini-Lysimeters (ML), characterized by reduced soil volume (less than 1 m^3), have been recently adopted due to reduced installation and managements costs and good accuracy of measurement (Oke, 2004). Therefore, due to the limited weight of the soil block, ML can adopt the affordable and easily available load cell technology that can not be easily applied to classic lysimeters (Ervin and Koski, 2001; Diaz-Espejo and Verhoef, 2003).
Water need of plants in lysimetric experiments is supplied by natural rain, irrigation or by an artificially maintained water table ("constant water table" lysimeters). Gravitational drainage systems are cheaper, easy to install and require practically no maintenance.

Materials and methods
This work was carried out in a farm of Milano University: the Azienda Baciocca located at Cornaredo. This site consists of four weighing filled-in mini-lysimeter installed at the vertexes of a 20 x 20 m square area (400 m^2) covered with *Festuca arundinacea L.* (figure 9).
The area of each mini-lysimeter is 0.25 m2. The use of four lysimeters allows to obtain replications in order to study the spatial variability of microscale phenomena and measurements errors. The area is irrigated with five pop-up irrigators in order to maintain the whole area in optimal water conditions. The ML (Fig. 6 and 7) are inserted in the soil isolated by a concrete sump: the plastic container filled with mixed terrain (turf, sand and expanded clay). Signal converter is installed at the bottom of the pit. The weighting system is based on a load cell technology, giving a linear output in the range of 4-20 mA directly correlated with weight.

Tab. 1 - Evaluation of statistical performance of ETO measurements by Mini-Lysimeter and estimated by Penman-Monteith equation – (March 2008)

Tab. 1 - *Valutazione delle performance statistiche di ETO misurato con Mini-Lisimetri e stimati con l'equazione di Penman-Monteith – (Marzo 2008)*

Parameter	MAE	RRMSE	EF	CRM	CD	R2	Average ML	Average PM
Min	0.00	0.00	-inf.	-inf.	0.00	-inf.		
Max	+inf.	+inf.	1.00	+inf.	+inf.	+inf.		
Best	0.00	0.00	1.00	0.00	1.00	1.00		
Calc. Value	0.65	31.66	0.51	0.17	0.43	0.77	2.45	2.04

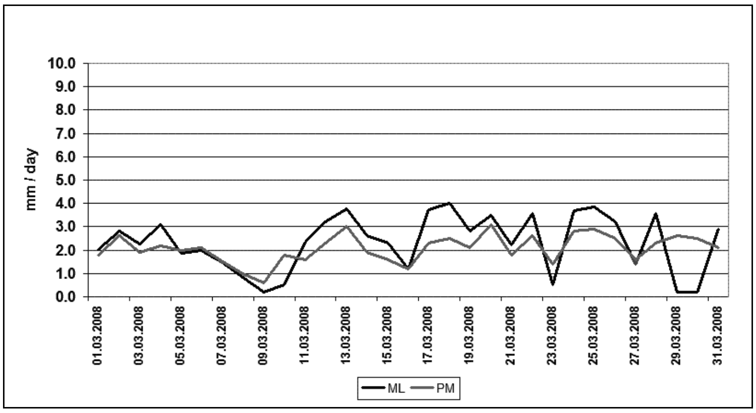

Fig. 1 - Comparison ET0 measured by mini-lysimeter (ML) and estimated by Penman-Monteith equation (PM) – (March 2008)

Fig. 1 - *Confronto ET0 misurato con i mini-lisimetri (ML) e stimati con l'equazione di Penman-Monteith (PM) – (Marzo 2008)*

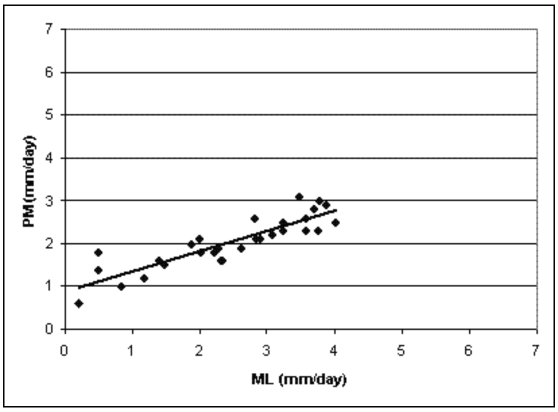

Fig. 2 - Scatterplot of ML and PM values during March 2008

Fig. 2 - *Scatterplot dei valori di ML e PM durante il mese di Marzo 2008.*

Tab. 2 - Evaluation of statistical performance of ETO measurements by Mini-Lysimeter and estimated by Penman-Monteith equation – (August 2007)

Tab. 2 - *Valutazione delle performance statistiche di ETO misurato con Mini-Lisimetri e stimati con l'equazione di Penman-Monteith – (Agosto 2007)*

Parameter	MAE	RRMSE	EF	CRM	CD	R2	Average ML	Average PM
Min	0.00	0.00	-inf.	-inf.	0.00	-inf.		
Max	+inf.	+inf.	1.00	+inf.	+inf.	+inf.		
Best	0.00	0.00	1.00	0.00	1.00	1.00		
Calc. Value	0.95	29.50	0.58	0.17	0.54	0.78	3.60	2.98

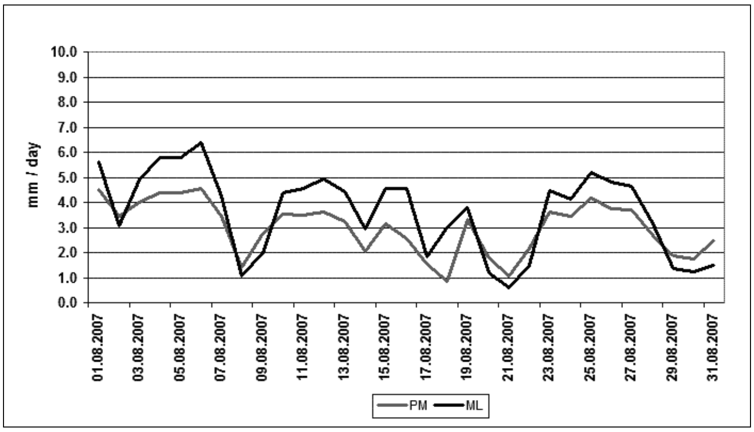

Fig. 3 - Comparison ET0 measured by mini-lysimeter and estimated by Penman-Monteith equation – (August 2007)

Fig. 3 - *Confronto ET0 misurato con i mini-lisimetri e stimati con l'equazione di Penman-Monteith – (Agosto 2007)*

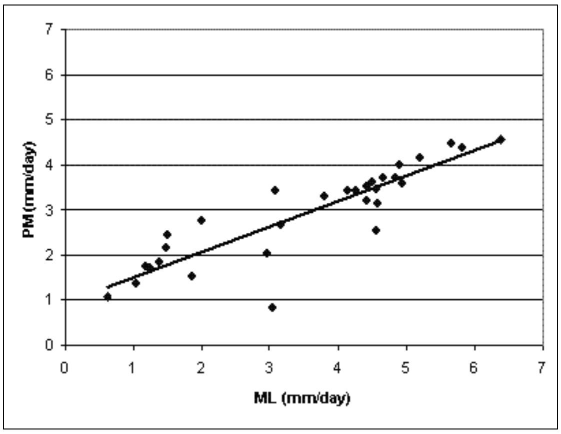

Fig. 4 - Scatterplot of ML and PM values during August 2007

Fig. 4 - *Scatterplot dei valori di ML e PM durante il mese di Agosto 2007*

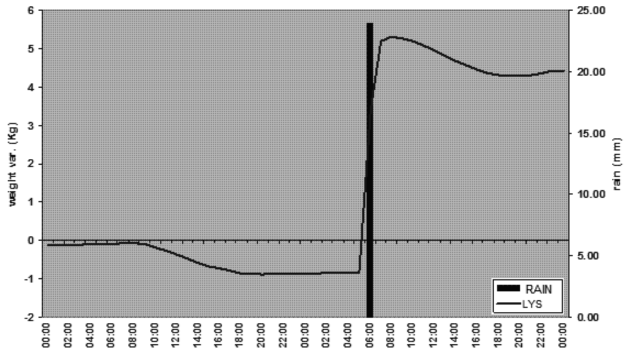

Fig. 5 - mini-lusimeter weight variation durino a rain event and rainfall measured by raingauge
Fig. 5 - *variazione di peso del mini-lisimetro durante un evento piovoso e misura con pluviometro.*

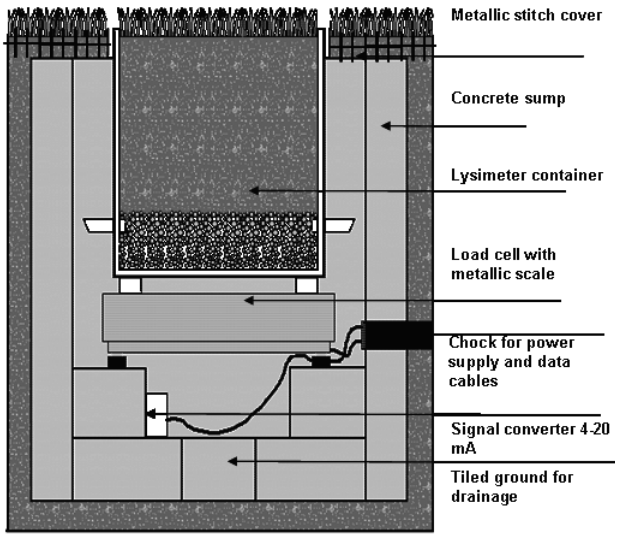

Fig. 6 - Description of mini-lysimeter apparatus.
Fig. 6 - *Descrizione dell'apparato mini-lisimetrico.*

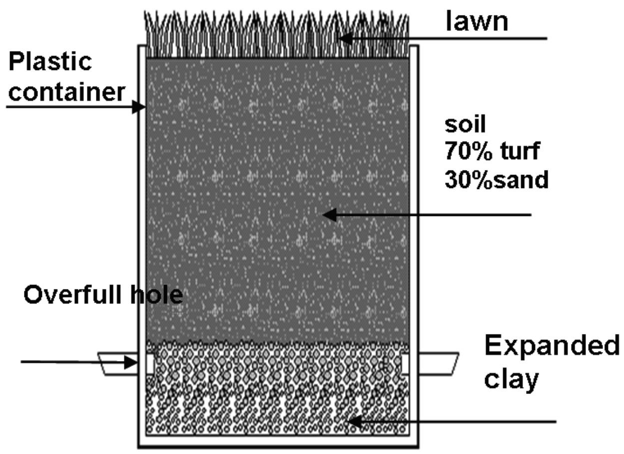

Fig. 7 - Description of mini-lysimeter plastic container
Fig. 7 - *Descrizione del contenitore mini-lisimetrico in plastica.*

The minimum weight is settled at 40 kg (corresponding to an output of 4 mA) and the maximum at 120 kg (20 mA), assuring a sensibility of measurements of 0.01 kg. Data from load cell are stored every minute by a data-logger.
The experimental site (Fig. 9) was equipped with an atmometer and a automatic weather station provided with 2 thermo-hygrometers at 2 different heights (1 and 1.80 meters) , a silicon cell pyranometer, an anemometer (speed and direction) and a rain gauge.

Results

Since the area of the mini-lysimeter is 0.25 m^2 , a change of 1 kg in weight is equivalent to 4 kg for 1 m^2 (4 mm of water). An example of validation of the measurement accuracy is represented by the rainfall event on 26/08/2006, when 24.6 mm of water felt during less than one hour. The load cell show a weight increase of 6.2 kg, equivalent to 24.4 mm, a value very close to the measured one by rain gauge (Fig. 5).
Experimental data for March 2008 and August 2007 will be presented and discussed. For these periods, the comparison between (i) daily aggregates of ML evapotranspiration measurements and (ii) daily evapotranspiration computed by Penman-Monteith equation using meteorological station data figures are shown in Fig. 1,2,3,4 and Tab. 1,2.
Average values show that the two methods are closer during March than August; furthermore scatterplots (Fig. 2, 4) show a slight underestimation of ET by PM equation. However all the statistical indexes, as root mean square error (RRMSE), mean absolute error (MAE) and correlation R^2 gave similar results in August and March. The good results of statistical indexes underline the similar responses of lysimeters and Penman-Monteith to different daily meteorological factors. On March data analysis, the rainy days of 29th and 30th were neglected because, as discussed below, rain represents a limit in lysimetric measurements.

Discussion

The most important differences between ML and PM equation, especially during hot summer days (Fig. 3) , are probably the result of the small dimension of lysimeters. In fact, as stated by Samie and de Villèle (1970), a lysimeter of 0.27 m^2 overestimates the evapotranspiration of about 27% compared to a 5m^2 one; for the same authors the ideal lysimeter has an area of 4 m^2 with a depth of 30-40 cm.
There are also micrometeorological explanations of the differences of behaviour among months: the rim of the container creates a discontinuity between the terrain of ML and the surroundings, giving origin to differences in ground temperature and water soil content. As a consequence ET measurements can be sometimes non representative of the surroundings.
Another important effect is an "oasis effect" (Allen *et al* 1991), caused by different soil coverages in the surrounding. In particular, during warm period the irrigated lawn get warmer slowly in comparison with surrounding areas not irrigated or covered with concrete. This causes

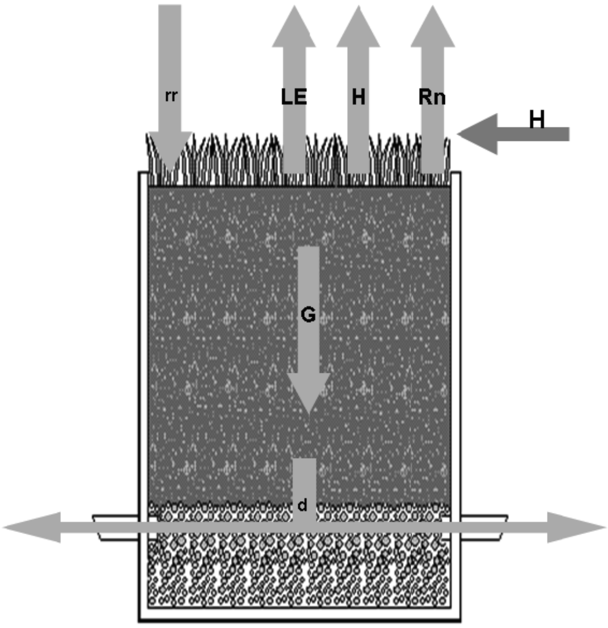

Fig. 8 - Description of vertical and horizontal flux in a mini-lysimeter. rr: rainfall, LE: Latent heat flux, H: Sensible heat flux, Rn: Net radiation, G: heat flux into the soil, d: drainage

Fig. 8 *- Descrizione dei flussi verticali e orizzontali in un mini-lisimetro. rr: pioggia, LE: flusso di calore latente, H: flusso di calore sensibile, Rn: radiazione netta, G: flusso di calore nel terreno, d: drenaggio*

a difference inf surface temperature and water content, getting start to advection of sensible heat fluxes from outside to the lysimeter or vice-versa. This thermal effect influences evapotranspiration and herewith the ML measurement can not be comparable with the estimations given by PM, that can only partially take into account these horizontal micrometeorological mechanisms (Fig. 8).

Another limit in ML measurements is represented by rain that can affect the computation of weight losses. Especially after heavy rainfall events, it is quite difficult to distinguish the decreasing of weight caused by percolation or by evapotranspirational water losses. For this reason it was decided to avoid computation of ET during rainy days. In order to avoid this problem, the irrigation was performed during nighttimes, when the ET0 is almost null.

Conclusions

ML is an instrument easily usable in different environments, cheaper than traditional lysimeters, and for this reason it could be affordable for most agrometeorological experiments and operational activities. For a correct measurement, it is important to maintain the measurement area meadow in in good conditions in order to limit micrometeorological effects.

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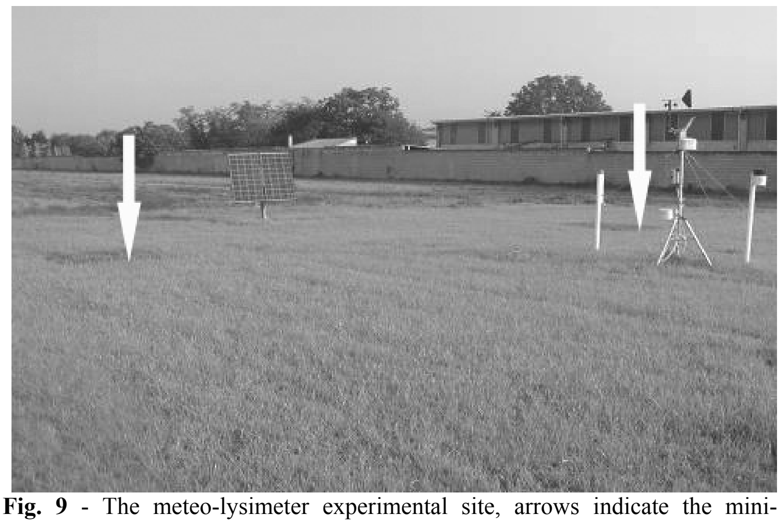

Fig. 9 - The meteo-lysimeter experimental site, arrows indicate the mini-lysimeters

Fig. 9 *- Sito sperimentale mini-lisimetrico, le frecce indicano i mini-lisimetri*