BIOSYSTEMS ENGINEERING 115 (2013) 117–124

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Research Paper

Measurement and prediction of buffalo manure evaporation in the farmyard to improve farm management

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ARTICLE INFO

Article history:
Received 3 October 2012
Received in revised form
21 February 2013
Accepted 28 February 2013
Published online 19 April 2013

In order to evaluate the performance of two empirical models for buffalo (*Bubalus bubalis*) manure evaporation, predictions were compared with measured data. The two models were developed by adapting the potential evapotranspiration (ET_o) models of Tombesi–Lauciani and Hargreaves. The data used for assessing the manure evaporation in situ, were derived from the manure weights recorded using an experimental platform installed within the farmyard and equipped with load cells. The experiments were carried out in Serre (SA), in the South of Italy in the period from 23 June to 24 September 2011. The most efficient model, in terms of closeness between estimates and measures, was implemented from 2006 to 2010, allowing for annualised calculation of evaporation. On this basis, an optimal management strategy was established, which corresponds to maximising manure evaporation, minimising the use of the scraper from the 100th day of the year (DOY) to the 250th DOY. This leads to a potential reduction in weight of the manure by 650 kg m^{-2} [yard] $year^{-1}$, which corresponds to management cost reduction of about 30%.

1. Introduction

Buffalo husbandry contributes substantially to the economy of Campania region of Southern Italy. The sector is a major employer in the region and the export of milk products contribute significantly to foreign exchange earnings. It is estimated that there are about 260,000 buffalo heads reared in the region (ISTAT, 2010) and the industry contributes an annual turnover of 500 million € (Infascelli, Faugno, Pindozzi, Pelorosso, & Boccia, 2010). The main product, the buffalo's milk, is used for production of Mozzarella cheese, which is one of the major food products of the region. The intensive nature of buffalo husbandry on limited land leads to the production of high quantities of manure. This leads to problems of non-point pollution source (NPS) due to nitrogen in the production areas. The current manure management approach employed to prevent NPS pollution is by using it as fertiliser (Burton & Turner, 2003; Infascelli, Boccia, & Pelorosso, 2007; Infascelli, Pelorosso, & Boccia, 2009). However, limited availability of nearby arable land, poses an enormous management challenge in terms of costs, time needs, equipment and environmental aspects. The approach entails a complex manure management plan, involving storage in huge tanks during winter, followed by surface spreading or incorporation into the soil using specialised equipment. One of the problems related to the agronomic management of manure is nitrogen volatilisation, mainly as ammonia. When surface spreading method of manure application is employed, nitrogen volatilisation can be as high as 68% of the total ammoniacal nitrogen (TAN) (Huijsmans, Hol, & Hendriks, 2001; Huijsmans, Hol,

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http://dx.doi.org/10.1016/j.biosystemseng.2013.02.011

Nomenclature

a	Environmental constant
A_d	Daily manure production, kg day^{-1}
AW	Manure weight on the platform, kg day^{-1}
D	difference between simulated and measured value, mm day^{-1}
DF	Degrees of freedom
DOY	Day of the year
EF	Modelling efficiencies index, dimensionless
ET	Evapotranspiration, mm day^{-1}
ET_o	Potential evapotranspiration, mm day^{-1}
EV	Manure evaporation, mm day^{-1}
F	Corrective factor of Thornthwaite, units of 30 days of 12 h each
F-value	SS_{model}/DF_{model}
K	Constant, dimensionless
M	Measured value, mm day^{-1}
$\overline{M}$	Mean of measured data, mm day^{-1}
MS	Mean square
NPS	Non point pollution source
$p(t)$	Level of likelihood, dimensionless
R	Coefficient of correlation, dimensionless
R^2	Coefficient of determination, dimensionless
R_a	Extraterrestrial radiation, MJ m^{-2} day^{-1}
RF	Daily rainfall, mm day^{-1}
RH	Relative air humidity, %
S	Simulated value, mm day^{-1}
S.E.	Standard error
S	Simulated model
SS	Sum of squares
T	daily temperature, °C
TAN	Total ammoniacal nitrogen
Subscripts	
TL	Tombesi–Lauciani
H	Hargreaves
i	ith day of the year
$(i-1)$	$(i-1)^{th}$ day of the year
max	maximum value
min	minimum value
mean	mean value

& Vermeulen, 2003; Webb, Pain, Bittman, & Morgan, 2010). In the case of buffalo manure, the nitrogen content is about 2 kg m^{-3}, i.e., about 50% less than that reported in literature for dairy cattle, to which buffalo manure was equalized (Campanile et al., 2010; Pindozzi, Faugno, Okello, & Boccia, 2012). The low nitrogen concentration suggests that the costs of spreading could be greater than its agronomic benefits (Faugno et al., 2012; Pindozzi et al., 2012). Therefore, to evaluate the best buffalo manure management strategy, it is necessary to know the evolution of the manure volume while it is still in the farmyard. It could be convenient to reduce management cost by minimising the removal of the manure from the paddock, during the hottest period of the year, in order to exploit natural evaporation of manure in situ.

The objective of this paper is to compare two predictive models of water evaporation after calibration, with the results of continuous weight measurement of manure, over an experimental platform, installed to flush with the floor of the farmyard. The models are derived from potential evapotranspiration (ET_o) that is the evaporating power of the atmosphere at a specific location and time of the year and it does not consider the crop characteristics and soil factors (Allen, Pereira, Raes, & Smith, 1998). The aim is to assess the amount of evaporation during the year and to evaluate possible alternative strategies for the management of buffalo manure in the farmyard. The predictions from the models are compared on the basis of a set of statistical parameters and metrics (Confalonieri, Acutis, Bellocchi, & Donatelli, 2009; Confalonieri, Bregaglio, & Acutis, 2010; Fagnano, Acutis, & Postiglione, 2001).

2. Materials and methods

The research activities were carried out in a farm located in Serre, Campania region, in the South of Italy. The farm was selected to be representative of the typical buffalo farm in the Campania Region in terms of livestock numbers and management practices (Fig. 1).

Manure evaporation from the paddock was evaluated based on measurements of the weight of manure that accumulated over a platform equipped with load cells and installed to be flushed with the floor of the farmyard. The data used in this study are from the research activities described in detail by Pindozzi et al. (2012). The platform was 2 m long by 1 m wide, built of stainless steel and placed to flush with the floor, and supported by four load cells Fig. 2a). The assembly was installed in the farmyard under normal operating conditions Fig. 2b). The data were acquired every 15 min by a CR10X data logger (Campbell Scientific, Inc. Logan, UT USA.). A meteorological station was also installed within the farm, to collect data of the microclimate of the study area. It was equipped with a pyranometer, relative humidity (RH) and temperature sensors, a tipping bucket rain gauge and an anemometer, all connected to the data logger. For rainfall the total amount per day was considered, and mean daily values were considered for all the other meteorological parameters.

The main assumption for developing the predictive model is that manure evaporation from the paddock is related to the same parameters that control ET_o. It was assumed that the manure evaporation (EV) can be expressed by Eq. (1):

$$EV = K \cdot ET_o, \tag{1}$$

where, K is a constant. To predict manure evaporation two different model predictions were considered and their results were compared. The first prediction was developed on the basis of Tombesi–Lauciani model given by Eq. (2) (Leone, 2011). It was used because it expressly considers RH, and has been found to be suitable for estimating evapotranspiration (ET) in Southern Italy (Tombesi, Lauciani, & Scandella, 1972; Tombesi, Moretti, Francaviglia, & Favola, 1985).

$$ET_{TL} = aT^{0.91}10^{-0.8RH}F, \tag{2}$$

Fig. 1 – Location of experimental site, in Campania region, South of Italy.

where, ET_{TL} is the evapotranspiration in mm day^{-1}, a is an environmental constant that is normally equal to 1.13, T is the mean daily temperature in °C, RH is the mean daily RH in %, F is the corrective factor of Thornthwaite (1948) and represents the mean possible duration of sunlight at a latitude of 40° North, expressed in units of 30 days of 12 h each. Corrective values for different months of the year are reported in Table 1.

The second model used was developed on the basis of the Hargreaves equation (Hargreaves, Hargreaves, & Riley, 1985). This is one of the most commonly used relationships because the outputs can be easily calculated. The Hargreaves ET method is advantageous because it requires only temperature data to be measured. It was considered because it is a good base line for determining the water consumption at the farm scale in the study area (Fagnano et al., 2001). The Hargreaves equation is given by Eq. (3);

$$ET_H = 0.0022 \cdot R_a \cdot (T_{mean} + 17.8) \cdot \left(T_{max} - T_{min}\right)^{0.5}, \qquad (3)$$

where, ET_H is the evapotranspiration in mm day^{-1}; T_{mean}, T_{max} and T_{min} are the mean, maximum and the minimum daily temperature in °C, respectively; R_a is the extraterrestrial radiation in MJ m^{-2} day^{-1} and is calculated as indicated by Allen et al. (1998).

The predictive model to assess evaporation of manure was developed starting from the mass of manure on the platform, which is given by Eq. (4);

$$AW_i = AW_{i-1} + RF + A_d - EV, \qquad (4)$$

where, AW_i is the manure weight on the platform on the ith day of the year (DOY); AW_{i-1} is the manure weight on the platform on day $(i-1)$th DOY; RF is the daily rainfall amount; A_d is the daily manure production and EV is the manure evaporation.

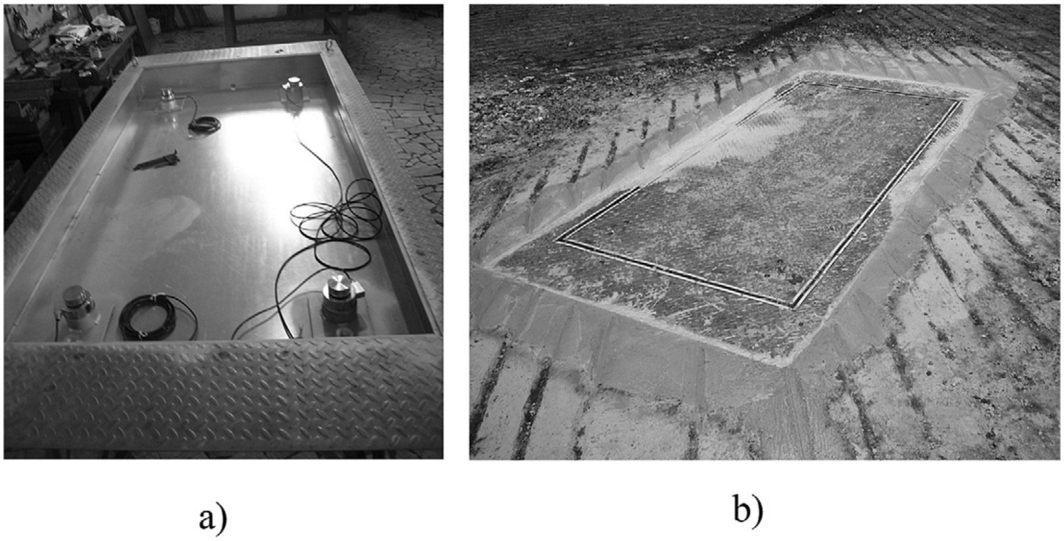

Fig. 2 – Instrument for measuring manure weight: a) arrangement of load cell, b) complete assembly of the platform.

The period of the observations was from the 24th of June to the 24th of September each year, that is; from the 178th DOY to the 268th DOY. Subsequently, when the Tombesi–Lauciani model is considered, the total mass of manure accumulation on the platform was given by Eq. (5);

$$AW_i = AW_{i-1} + RF + A_d - K_{TL} \cdot ET_{TL} \tag{5}$$

When the Hargreaves model was considered, the mass of manure on the platform was given by Eq. (6).

$$AW_i = AW_{i-1} + RF + A_d - K_H \cdot ET_H \tag{6}$$

The daily manure production, A_d was calculated from the assessment of the daily manure production per buffalo head, estimated at about 40 kg, half of which was assumed to be evenly distributed over the farmyard area and other half in cubicles and feeding area. To estimate the average daily manure generation per head, a farmyard surface area of about 5 m^2 per buffalo head was assumed, that means a manure production of 4 kg m^{-2} day^{-1}, was considered. The EV terms were expressed in kg m^{-2} day^{-1}, assuming manure density value of 1000 kg m^{-3}. The RF terms were the daily value registered by tipping bucket rain gauge. The values of K_{TL} and K_H were evaluated as the values that minimised the square difference between predicted and measured data.

Days with missing data, or in which the instruments registered abnormal values, were excluded from the data processing.

The performance of the two models was analysed and compared in terms of the agreement between measured data and predicted values (Confalonieri et al., 2009). Several parameters were used to assess the performance of the models. An *F*-test was used to evaluate the significance of the model, associated with a level of likelihood *p*(*t*) to evaluate the closeness between predicted and measured values. Other statistical parameters investigated were the efficiency of the model results to the mean of observations (EF), the correlation between estimates and measurements (*R*) and a measure to quantify the square difference between estimates and measurements (R^2).

The modelling efficiencies index (EF) was calculated using Eq. (7);

$$EF = 1 - \frac{\sum_{i=1}^{n} (D_i)^2}{\sum_{i=1}^{n} \left(M_i - \overline{M}\right)^2}, \tag{7}$$

where, *n* is the number of estimates; D_i is the difference between S_i and M_i, that are the ith simulated and the ith measured values, respectively;$\overline{M}$ is the mean of measured values. The maximum value of the index is 1 when there is a total agreement between the prediction and observed data. A value of 0 indicates that the predictive capacity of the model is equal to that of the mean value of the observed data, positive values indicate that the model is a better predictor than the average of observations. The minimum level is negative infinity ($-\infty$). The EF index is useful because it allows for the identification of inefficient models (Loague & Green, 1991). The *F*-statistic is the ratio between predictability and precision and is provided together with its significance level *p*(*t*); if $p(t) \le 0.05$, then the model is significant (Confalonieri et al., 2009, 2010). Calculations were made using the Analysis Toolpack of Microsoft Excel® software.

When the most accurate model was found it was implemented over a period of five years using an historical meteorological series from the nearest weather station located in

Table 1 – Corrective values of Thornthwaite (1948).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Corrective factor (lat. 40°N)	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81

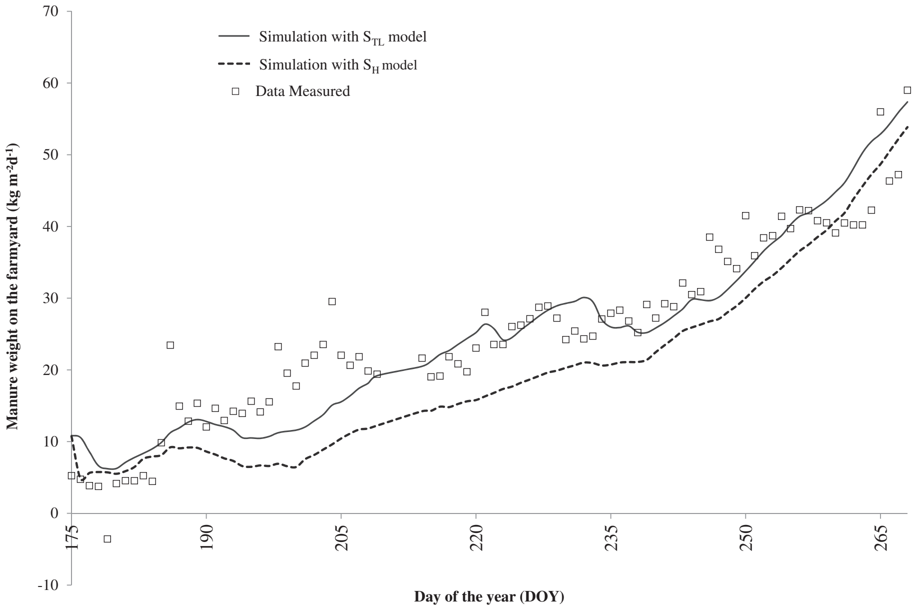

Fig. 3 – Comparison between simulated (S_{TL} and S_H models) and measured data using the experimental platform.

Battipaglia, in the province of Salerno. Daily rainfall data from the nearest weather station were added to the daily manure weight. The model was executed over a period of five years from 2006 to 2010. The mean annual rainfall was about 800 mm $\mathrm{year^{-1}}$. Consequently the total EV, over a period of one year, was calculated as the difference between the maximum (EV_{max}) and the minimum (EV_{min}) quantity of the potential. The potential EV_{max} corresponds to a situation when manure is left in the farmyard for as long as possible without being scraped off, while EV_{min} is the value registered when the manure is removed continuously.

3. Results and discussion

The resulting K_{TL} and K_H values were 0.416 and 0.291, respectively. The models indicated as S_{TL} and S_H and are presented by Eqs. (8) and (9);

$$S_{TL} : AW_i = AW_{i-1} - 0.416\, ET_{TL} + 4(\mathrm{kg\ m^{-2}\ day^{-1}}) \tag{8}$$

$$SH : AW_i = AW_{i-1} - 0.291\, ET_H + 4(\mathrm{kg\ m^{-2}\ day^{-1}}) \tag{9}$$

Figure 3 shows plots of the two predictive models given by Eqs. (8) and (9) compared to the filtered data. The peaks observed in the measured manure weight can be explained by accumulation of manure over the platform caused by movements of the manure by the animals. The parameters of the regression analysis related to the two models are reported in Tables 2 and 3.

The comparison of the statistical parameters reported in Tables 2 and 3 lead to the conclusions that the two models are quite similar: the R^2 values are very close to each other and the EF index is in both cases near to 1, this implies that both models are efficient. Nevertheless the S_{TL} model gave better agreement between predicted and measured values, as is demonstrated by the comparison of the parameters reported in Table 2 and by the regression line and regression equation coefficient in Fig. 4. This also confirms results from studies that have demonstrated that the Hargreaves ET underestimates the ET when compared to results of other ET models (El Nesr, Alazba, & Amin, 2011; Fagnano et al., 2001).

Figure 5 shows predicted values of manure weight that accumulated in the farmyard without being scraped off. Considering the average value over a period of 5 years, the trend of the manure weight was developed. This is what could occur in the case of manure left in the farmyard for as long as possible, exploiting the natural evaporation. Similarly a similar chart was plotted, in which the contribution of EV was neglected, this situation is representative of the case when manure is scraped off continuously. Figure 6 shows a comparison between two different management strategies. The series EV_{max} was developed from the cumulative manure weight in the storage tank without scrapping manure from the paddock, while EV_{min} occurs when scrapping is carried out. From this simulation it possible to deduce that there is a potential reduction in manure weight of about 650 kg m^2 year, that is, about the 30% of the yearly manure weight.

Table 2 – Statistics of regression for comparison of the evaporation simulation model S_{TL} and S_H, based on the Tombesi–Lauciani evapotranspiration model and the Hargreaves evapotranspiration model, respectively.

Parameters	S_{TL}	S_H
R	0.922	0.913
R^2	0.851	0.834
S.E.	4.827	5.296
EF	0.814	0.782
No. of observations	90	90

Table 3 – Anova table for comparison of the evaporation simulation model S_{TL} and S_H, based on the Tombesi–Lauciani evapotranspiration model and Hargreaves evapotranspiration model, respectively.

	DF		SS		MS		F-value		p(t)	
	S_{TL}	S_H	S_{TL}	S_H	S_{TL}	S_H	S_{TL}	S_H	S_{TL}	S_H
Regression	1	1	11,703.8	12,411.2	11,703.8	12,411.2	502.283	442.568	3.9E-38	4.3E-36
Residuals	88	88	2050.5	2467.83	23.30	28.0435				
Total	89	89	13,754.3	14,879						

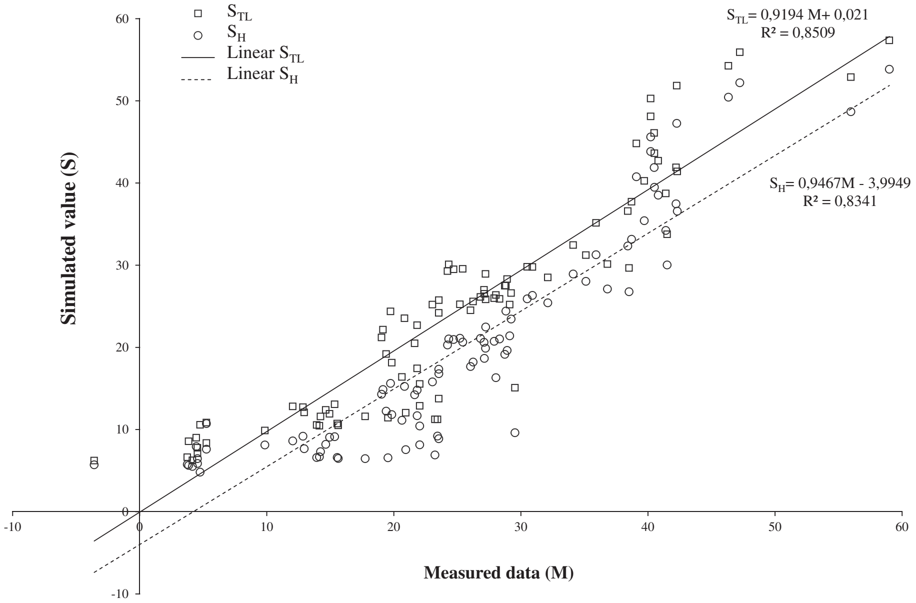

Fig. 4 – Simulated vs. measured data of manure weight given by S_{TL} and S_H models.

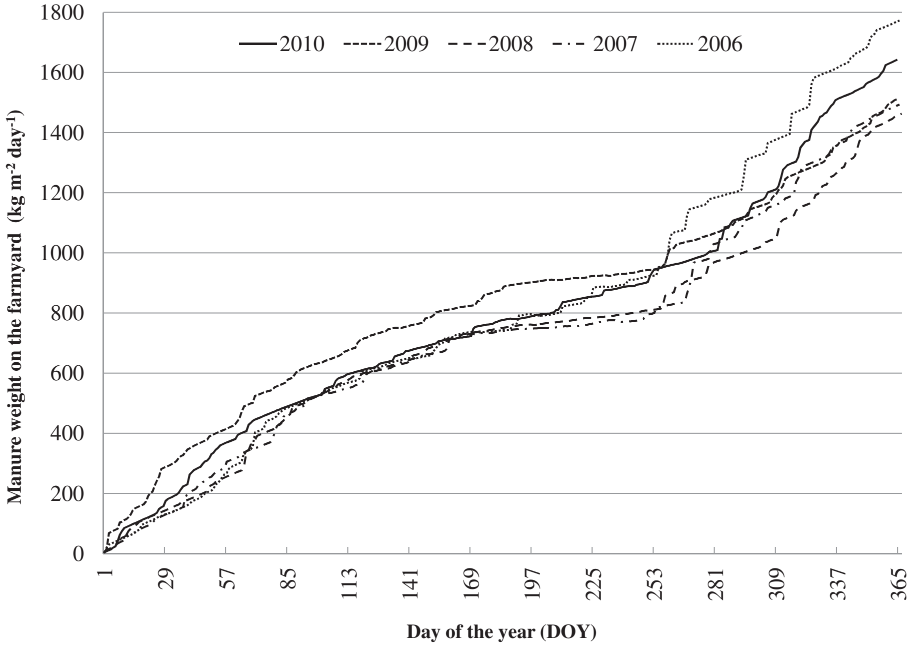

Fig. 5 – Manure weight prediction considering meteorological series of the nearest weather station over a period of five years.

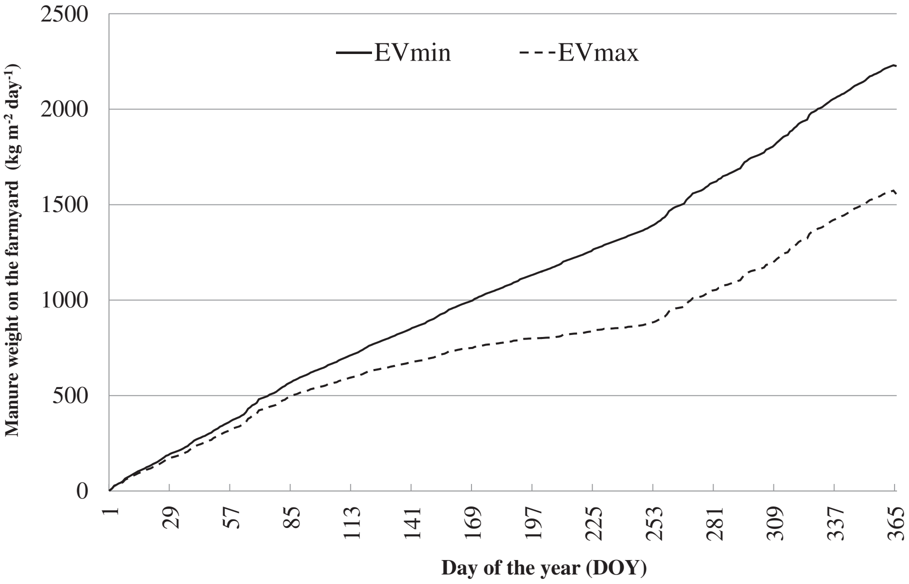

Fig. 6 – Predicted weight of manure in the storage tank under two different manure management regime.

The optimal management strategy corresponds to operating the scrapers in the period between the two inflection points of the graph, that is operating manure scrapers from 1st to 100th DOY, minimising the use of scrapers from 100th to 250th DOY and operating the scrapers again from 250th to 365th DOY. It should be noted that this management strategy, if strictly applied, is not suitable from the point of view of the animal health and the ammonia emissions. Ammonia is an irritant gas that may be implicated in the onset of certain diseases (asthma, chronic bronchitis) among farmers and animals and also in reducing animal performance (Portejoie, Martinez, & Landmann, 2002).

4. Conclusions

Based on the prediction model developed, it would be possible to reduce about 650 kg m^{-2} [farmyard], of manure mass through evaporation, which is about the 30% of the total amount. When compared to single heads of buffalo, the reduction is about 130 kg $head^{-1}$ $year^{-1}$. From these data it was deduced that the period used to improve the model and forecasts ranged from 100th to 250th DOY. The algorithm generated is easy to apply and conceptually robust. Therefore, management decisions with this algorithm are not likely to be contradicted by improvements in the determination of the coefficients.

Acknowledgements

The research activities were funded by Campania Region. Campania Region was not involved in study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication. Special appreciation to Dr. Franco Consalvo, who gave us the possibility to carry out the research activities in his buffalo farm.

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