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A simplified approach to calculate slurry production of growing pigs at farm level

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ABSTRACT

A simplified approach to predict the amount of slurry produced by growing pigs at farm level is proposed. The inputs are initial (LWi) and final (LWf) live weights, production (t) and empty (empty) periods, feed consumption (FC), dry matter (DMD), N digestibilities and farm water consumption per pig (FWC). Estimates of the amount of water required (or arisen) per kg of feed for the various physiological functions were estimated by running a published mathematical model using data representing the ordinary conditions of rearing. Water excretion was estimated in two ways depending on: 1) free access (*ad lib*) to water; 2) restricted access (*forced*). In the first case, the proportion of water consumed ($wi_{ad\ lib}$) and those excreted with the urine ($wu_{ad\ lib}$) and the faeces (wfec) were quantified to be 2.9, 1.72 and 0.33 kg per kg of feed, respectively. From the urinary excretions of N and minerals, obtained as the difference between the digestible nutrient intakes and the retentions, the model predicted a urinary DM content of 2.1% (by weight). In the second case, for pigs receiving drinking water in forced ratio with the feed (wi_{forced}), the urinary production was calculated as $wu_{forced}=(wi_{forced}+wf+wo)-(wd+ws+wg+wfec+we)$, where wf=water content in feed (0.12 kg/kg), wo=water arising from nutrient oxidation (0.25 kg/kg), wd=water required for digestion (0.08 kg/kg), ws=water demand for protein and lipid synthesis (0.06 kg/kg), wg=water retained in body tissues (0.14 kg/kg) and we=water lost through evaporation (0.96 kg/kg). Estimates of fresh slurry production (faeces+urine) were regressed against the values resulting from empirical literature equations and referred to pigs fed water:feed ratios of 2.5:1, 2.9:1 and 4:1. The resulting regression (R^2=0.97), with a slope close to unity (1.05), indicated that the approach can be extended to predict the farm fresh slurry production with pigs having free access to water or kept on different water:feed ratios. In agreement with international literature, but not with the current Italian national standards, estimates of mature slurry productions ranged from 1.5 to 2.9 ton/pig/year with DM contents ranging from 8.3 to 3.7%. At farm level the use water meters is recommended as from FWC minus the estimated water consumption (FWC_{exp}) the farmer can evaluate the extra wastage and adjust the predicted mature slurry production.

Key words: Pig, Slurry, Water, Mathematical model.

RIASSUNTO

UN APPROCCIO SEMPLIFICATO PER VALUTARE, SU BASE AZIENDALE, LA PRODUZIONE DI LIQUAMI FRESCHI DI SUINI IN CRESCITA

Nel lavoro si propone un approccio semplificato per valutare su base aziendale la produzione di liquame suino fresco e il suo contenuto di SS. I principali input sono costituiti dai pesi vivi iniziali (LWi) e finali (LWf), dalle durate del ciclo di allevamento (t), dei periodi di vuoto (empty), dal consumo di mangime (FC), dai coefficienti di digeribilità di sostanza secca (DMD), azoto ed elementi macro minerali, e dal consumo aziendale di acqua per suino allevato (FWC). L'escrezione di SS con le feci è calcolata dal consumo di mangime e dalla digeribilità. Applicando un modello matematico di letteratura su dati rappresentativi delle condizioni ordinarie di allevamento sono stati stimati dei valori rappresentativi delle proporzioni di acqua (per kg di mangime) necessarie per le varie funzioni fisiologiche. L'escrezione di acqua è stata quindi stimata in due modi differenti in relazione a condizioni di libero accesso (ad lib) o meno (forced) all'acqua di bevanda. Nel primo caso le proporzioni di acqua consumata ($wi_{ad\ lib}$) e quelle escrete con le urine ($wu_{ad\ lib}$) e con le feci (wfec) sono state quantificate pari a 2,9, 1,72 e 0,33 kg/kg di mangime, rispettivamente. Dalle escrezioni urinarie di azoto e minerali, ottenute come differenza tra gli apporti digeribili e le ritenzioni, il modello impiegato ha stimato un contenuto urinario di sostanza secca pari al 2,1% del peso delle urine. Nel secondo caso, per suini che ricevono l'acqua in rapporti fissi con il mangime (wi_{forced}), la quantità di urine prodotte è ricavata dalla seguente relazione $wu_{forced}=(wi_{forced}+wf+wo)-(wd+ws+wg+wfec+we)$, dove wf è l'acqua contenuta nel mangime (0,12 kg/kg), wo è l'acqua che si origina dall'ossidazione metabolica dei nutrienti (0,25 kg/kg), wd è l'acqua assorbita per la digestione (0,08 kg/kg), ws è la quantità di acqua richiesta per i processi di sintesi (0,06 kg/kg), wg è la quantità di acqua ritenuta nei tessuti corporei (0,14 kg/kg) e we è la quantità di acqua persa per i processi di evaporazione (0,96 kg/kg).
Le produzioni stimate di liquami freschi (feci+urine) sono state confrontate per regressione con i valori risultati dall'applicazione di equazioni empiriche derivate dalla letteratura per rapporti acqua:mangime pari a 2,5:1, 2,9:1 e 4,0:1. La regressione (R^2=0,97), evidenziando un coefficiente angolare prossimo all'unità (1,05), ha indicato che l'approccio può essere applicato anche per rapporti "acqua:mangime" diversi da quelli indicati. In accordo con la letteratura internazionale, ma non con gli attuali standard nazionali, si è osservato che in condizioni ordinarie e per rapporti acqua:mangime compresi tra 2.5:1 a 4:1 ci si attende una produzione di liquame maturo variabile da 1,5 e 2,9 ton/suino/anno con contenuti di SS compresi tra 8.3 e 3.7%. A livello aziendale l'uso di contatori d'acqua è raccomandato e gli sprechi di acqua, valutati come differenza tra FWC e i valori stimati di consumo idrico (FWC_{exp}), possono essere utilizzati per correggere le stime di produzione di liquame maturo.

Parole chiave: *Suini, Liquame, Acqua, Modelli matematici.*

Introduction

Slurry production and N and P excretions are often estimated using table values according to the species and the category of animals reared. However, these coefficients are often outdated, not representing the modern animals and production practices and do not allow for site specific management practices to be incorporated. Published figures for the production of slurry by pigs vary widely, and as in the case of other livestock, live weight and productivity, diet and water intake and wastage, as well as housing and seasonal weather conditions are all factors which can influence the total quantity and the composition of the slurry (Powers, 2004).

A number of methods have been proposed for quantifying nutrient excretion (mainly N and P) by farm livestock. Direct measurements with livestock may provide the most accurate estimate of excreted nutrients, but require either total collection of faeces and urine or reliable markers for spot sampling. This is an expensive and time-consuming method and the values obtained can only be applied to similar types of livestock (breed, age, sex, growth rate, etc) and diets.

Estimates of nutrients excreted in slurry by direct measurements and analysis of the slurry may be achieved for a lower cost (in terms of the number of samples and analyses required). However, the amount of slurry produced is difficult to quantify, and taking representative slurry samples for analysis can be particularly difficult. This approach also suffers from the fact that the results obtained are applicable only to the particular factors and conditions prevailing during the period of observations and sampling.

A mass balance approach that considers animal diet and performance, proven to be an accurate means of predicting nutrients excretion, offers the advantage of tailoring a plan which reflects individual farm characteristics of what is actually produced. Nutritional based methods predict the amount of nutrients in fresh slurry more accurately than collection and analysis of slurry from animal pens because of the dynamic state of slurry after excretion whereby losses of nutrients and slurry volume occur (Powers, 2004). Mass balance approaches have been applied to predict N and P excretions on animal and farm level (Poulsen and Kristensen, 1998; Van Horn, 1998; ERM, 2001; ADAS, 2007; Schiavon *et al.*, 2008a, 2008b).

However, this approach is less reliable for predicting the volume or the weight of the slurry since the water balance cannot be represented by the simple relationship "intake minus retention". Some of the mathematical models addressed this issue (Aarnink *et al.*, 1992; Schiavon and Emmans, 2000; Dourmad *et al.*, 2003), however, they are not easily applicable because of the number and the nature of the required input. To predict fresh slurry production some empirical equations developed several years ago have been proposed (O'Callaghan *et al.,* 1971; quoted by Smith *et al.,* 2000), but the application of these equations to conditions different from those where the data were collected is questionable. Thus the aim of this work was the following:

1) to collate the available knowledge and develop a simplified model to predict the weight and the dry matter content of fresh slurry (ex animal) produced by growing pigs from simple inputs available at farm level.
2) to provide some literature figures to convert fresh (ex animal) into the "as removed" slurry amount.
3) to compare estimated slurry productions with scientific and institutional data reported in literature.

Material and methods

Inputs available at farm level and conceptual basis

Information usually available at farm level include the initial (LWi, kg) and the final (LWf, kg) live weight of the pigs, the length of production cycle (t, in days) and the empty periods (empty, in days). Feed consumption (FC) is also commonly recorded, particularly where commercial diets are used. However, in the case where dry feed is partially replaced by liquid ingredients or where home-made ingredients are used, the estimates of FC are generally less reliable. In any case, a tool to control FC is required by Public Institutions to control the data declared by the farms for slurry disposal. Feed conversion ratio (FCR) can be approximately predicted using the following relationships that we developed from a re-analysis of the data collected by Xiccato *et al.* (2005), regarding 39 farms, 141 production rounds for a total of 161,278 pigs fed restricted diets:

$$FCR=0.814+0.028*LWi+0.0101*(LWf-LWi)+0.00299*t \quad (R^2=0.80) \quad kg/kg \quad (1)$$

and so:

FC=FCR*(LWf-LWi) kg/(pig round) (2)

These equations refer to diets containing 88% DM and to total feed consumption (intake and spillage).

Farm water consumption can be easily measured through water meters, however from this aggregated information alone the major determinants of the slurry volume, i.e. the water drunk by the pigs, that excreted by the animals, that spilled from the water delivery system and that used for cleaning, cannot be distinguished. A quantification of these variables is required in order to provide to the operators indications about possible strategies for reducing the use and the wastage of water and the associated costs (i.e. reduction of the water:feed ratio, changes of diet composition to reduce the voluntary water intake, improving the water delivery systems to minimize the spillage, improving the operations associated to the use of water for cleaning, and so on).

Water balance under spontaneous and "forced" drinking conditions

The determinant factor which influences slurry production is the feed and water intake and, consequently, the faecal and the urinary excretions of water and dry matter. Water intake, as well as water excretion, has a very large variability due to a number of physiological and managerial aspects (Brooks and Carpenter, 1990; Schiavon *et al.*, 1997a, 1997b). There is little literature available on the effects of drinking water supply and diet composition on the amount and composition of faeces and urine from various categories of pigs. The complex nature and the interactions of the various factors affecting the water balance of the pig, only partially documented in literature, make it difficult to draw quantitative conclusions from single experiments (Mroz *et al.*, 1995), particularly when these are of short duration. There is increasing support for the view that further significant progress, unlikely to result from traditional empirical investigations alone, could be better achieved by integrating the current and the future knowledge in conceptual frameworks which may provide both predictive tools for and a sound understanding of whole animal performance.

A first basilar distinction must be made between systems in which the pigs are fed dry diet with free access to drinking water and those in which the diets are distributed through pipelines in liquid form, where a given "water to feed" ratio (wi_{forced}) is fixed by the farmer, usually ranging from 3:1 to 4:1. In these cases the amount of water supplied is likely to exceed the spontaneous consumption and the pig could be "forced" to excrete the excess of water by increasing the production of more diluted urine through the kidneys. The opposite can also occur; Faeti *et al.* (1998) reducing water:feed ratio from 3:1 to 2:1 did not observe any significant effect on growth performance, feed conversion ratio, and carcass quality of heavy pigs. This suggests that a restricted water regime can exploit the ability of the pig to concentrate the urine (Mroz *et al.*, 1995; O'Connell-Motherway *et al.*, 1998; Schiavon and Emmans, 2000) allowing for a marked reduction of slurry production.

When pigs have free access to water, water intake can be considered to be influenced by the variable amounts of water required to meet several physiological functions: digestion of nutrients, faecal excretion, growth, evaporation, osmotic regulation, and urinary excretion of end products of protein catabolism, salts, drugs, toxic compounds and antibiotics (Schiavon and Emmans, 2000). The components of the water balance considered are the following: water intake ($WI_{ad\ lib}$), water required for digestion (WD), water retained for the synthesis of proteins and fats (WS), water held in the faeces (Wfec), water retained in body tissues (WG), water lost for evaporation (WE), water required for urinary excretion ($WU_{ad\ lib}$), water content in feed (WF), water arising from oxidation of nutrients (WO). For spontaneous drinking conditions from a free surface of water, where no spillage of water was considered, Schiavon and Emmans (2000) proposed the following factorial relationship:

$$WI_{ad\ lib}=WD+WS+Wfec+WG+WE+WU_{ad\ lib}-(WF+WO) \text{ kg/(pig round)} \quad (3)$$

With this factorial approach it is assumed that the voluntary WI is the sum of the water required to sustain each physiological function, minus the amounts arising from the moisture content of the feed and from the metabolic oxidation of nutrients.

Under forced water provision the value of WI_{forced} is known and it can be assumed that the values of the other independent variables WF, WO, WD, WS, WG, WE and Wfec are the same as those quantified for the spontaneous drinking conditions. Thus, as proposed by Schiavon and Emmans (2000), the urinary excretion of water (WU_{forced}) can be quantified as:

$$WU_{forced}=WI_{forced}+WF+WO-(WD+WS+WG+WE+Wfec) \text{ kg/(pig round)} \quad (4)$$

Functions to predict spontaneous water intake and excretions

To predict water intake and the urinary and faecal excretions, under ordinary conditions of feeding and spontaneous drinking, the following relationships are proposed:

$$WI_{ad\ lib}=wi_{ad\ lib}*FC \text{ kg/(pig round)} \quad (5)$$
$$WU_{ad\ lib}=wu_{ad\ lib}*FC \text{ kg/(pig round)} \quad (6)$$
$$Wfec=wfec*FC \text{ kg/(pig round)} \quad (7)$$

where $wi_{ad\ lib}$, $wu_{ad\ lib}$ and wfec represent the proportions of water drunk and lost with urine and faeces per kg of FC, respectively.

The urinary excretion of DM (DMu; kg) was achieved, using the model of Schiavon and Emmans (2000), as the difference between the digestible intake of macro-minerals and N minus the corresponding body retentions. The excreted N was converted to urea equivalent and the excreted minerals were converted to salt equivalents, on the basis of their respective molecular weights. The DM content of urine was achieved as: $DMu/WU_{ad\ lib}=dm_u$ (kg/kg). Thus, the total weight of urine produced can be estimated as:

$$Urine_{ad\ lib}=WU_{ad\ lib}*(1.0+dm_u) \text{ kg/(pig round)} \quad (8)$$

Functions to predict "forced" water intake and excretion

Under forced water supply the ratio between the liquid feed or the water used and the feed consumed is known (wi_{forced}), and so after a simple correction for the DM content of the liquid feed ingredient used in addition to the feed, the amount of water consumed is:

$$WI_{forced}=(wi_{forced})*(1-x)*FC \text{ kg/(pig round)} \quad (9)$$

where x=DM content of the liquid ingredient (if water, x=0; if milk whey x can be assumed to be 0.055 kg/kg).

Assembling equations 4 and 9 the urinary excretion of water can be expressed as:

$$WU_{forced}=[wi_{forced}*(1-x)+(wf+wo)-(wd+ws+wg+wfec+we)]*FC \text{ kg/(pig round)} \quad (10)$$

where the various coefficients, expressed in kg per kg of feed consumed, (wf=moisture content of the feed; wo=water arising from nutrient oxidation; wd=water required for digestion; ws=water absorbed for the synthesis of macromolecules; wg=water retained in the body tissue; wfec=water required for faecal excretion; we=water lost for evaporation) need to be quantified.

For the urinary DM excretion it can be assumed that the amount excreted with urine in forced conditions is the same as that quantified for the spontaneous water drinking situation, and so:

$$Urine_{DM\ forced}=wu_{ad\ lib}*FC*dm_u \quad kg/(pig\ round) \quad (11)$$

Faecal dry matter excretion

From the amount of feed consumed and its dry matter content "(1-wf)" plus the digestibility (DMD) and, hence, indigestibility of the ration dry matter, the amount of faecal dry matter can be easily determined as:

$$Faeces_{DM}=FC*(1-wf)*(1-DMD) \quad kg/(pig\ round) \quad (12)$$

The digestibility of a whole diet can be estimated from the digestibility of each individual feed ingredient and the amount of each ingredient in the diet. For cereals and soybean diets the coefficient of digestibility usually ranges between 0.79 to 0.86 (LeGoff and Noblet, 2001). A mean value of 0.82 is here indicated to represent the ordinary condition.

Quantification of the equations' coefficients

The model proposed by Schiavon and Emmans (2000) was used for the quantification, under ordinary conditions of rearing, of the values of the variables and the constants of the above proposed equations. In this model the actual knowledge is summarized in functional and quantitative terms and it allows a full representation of the water balance of pigs growing in a known environment and on a known diet. The model was developed as an extension of the pig growth model described by Ferguson *et al.* (1994) and later updated by Wellock *et al.* (2003). The model of Schiavon and Emmans (2000) quantifies the daily water intake and excretion of growing pigs using functional relationships collated from literature and from experimental data and it is entirely based on that of Ferguson *et al.* (1994), for all those inputs and outputs regarding spontaneous or restricted feed intake, the consequent compositional growth and the nutrient excretion. The Ferguson *et al.* (1994) model predicts the chemical growth of the pig if the initial status, the pig potential for growth and the amount and the nutritional characteristics of the feed and the physical environment are adequately described. The compositional growth is then predicted, under unconstrained or constrained conditions, by combining day by day the effects of the pig potential for growth, the daily nutrients intake (energy, protein, amino acids and minerals) and the physical environment. Faecal and urinary excretion of nutrients are easily computed as the difference between intake and retention. A description and a test of this growth model has also been reported by ASPA (2003).

To run the model a quantitative description of the pig, the environment and the feed was required.

The pig was described using information obtained from Tagliapietra *et al.* (2005) on restricted fed heavy pigs where the independent variables of the Gompertz function describing the potential protein growth were quantified to be the following: protein mass at maturity (Pm)=33.4 kg; coefficient of relative growth (B)=0.0104 d^{-1}.

The environment was described considering a room temperature of 18°C for each day of the simulated period of growth (287 days), except for 30 days in which the ambient temperature was raised to 28°C. These temperatures were chosen on the basis of an analysis of historical series of data (40 years) collected in the Padana plain (North-eastern Italy) which indicates that on annual basis the average daily outdoor temperature was 14.0°C and that average daily temperatures close to 24°C are reached only during the months of July and August (Borin, 2004). It was considered that within the room the ambient temperature is commonly higher than that recorded outside. The temperature of 18°C was below the computed range of thermoneutrality. In a cold environment the basal level of the evaporative water losses can be considered relatively constant since the pigs maintain the heat balance mainly through the physical routes of convection, conduction and radiation (sensible heat losses), without the need to increase the evaporative losses (Blaxter, 1989; Aarnink *et al.*, 1992; Schiavon and Emmans, 2000; Huynh *et al.*, 2005). At higher temperatures pigs are forced to increase the evaporative losses to compensate for a lower heat loss by the sensible route (Blaxter, 1989; Huynh *et al.*, 2005). Higher evaporative heat losses require more water. In the model of Schiavon and Emmans (2000) it is assumed that pigs kept under ambient temperatures higher than the lowest critical temperature of the zone of thermal neutrality will increase water intake to meet the higher amount of water required for evaporation, without any change in the amounts of water required for the other physiological functions, including faecal and urinary losses. In the simulation the effect of hot temperatures (28°C) on water intake was considered for 30 days in order to take into account that at least for a part of their growth period pigs experience hot ambient conditions.

Feed was described using data collected from a large feed company and regarding the weekly amounts and the nutritional characteristics of the various diets distributed to pigs over 10 to 41 weeks of age (Table 1), which can be considered ordinary for the heavy pig industry in Italy (Tagliapietra *et al.*, 2004; Xiccato *et al.,* 2005).

The model was run with these inputs and, as a first check, the outputs of the model in terms of LW reached at the end of each week of age were compared with the corresponding values provided by the commercial feeding regime described in Table 1.

The tabled LW reached at the end of each feeding phase, expected under ordinary commercial conditions, were plotted against the simulated values. The result of the regression (Figure 1), indicated that there was a close agreement between the two sets of LW data. On the same run the model also provided estimates of the absolute amounts of water required for the various physiological functions over the whole growth period. As frequently done in literature (ARC 1981; NRC 1998), it was considered convenient to express these amounts in terms of kg of water per kg of feed consumed. The estimates are given in Table 2.

The predicted voluntary water intake increased from the first to the last feeding phase from 2.7 to about 3.0 kg of water per kg consumed feed (as sum of the water gained or spent for the various physiological functions). The results are in agreement with literature, where $WI\_FC_{ad\ lib}$ commonly ranged from 2.0 kg/kg to 3.5 kg/kg if the pigs are kept under optimal thermal conditions and fed a well balanced diet (ARC, 1981; Brooks and Carpenter, 1990; Mroz *et al.*, 1995; NRC 1998).

Among the corresponding contributions of water used for the various physiological functions listed in Table 2, the model estimated that, on average, drinking water represented 88% of total water input (2.68–3.02

Table 1. Feeding regime, diet chemical composition and expected growth performance of heavy pig. Data provided by a large feed producer[1].

		Feeding phase			
		1	2	3	4
Feeding program:					
Age	weeks	10 to 14	15 to 21	22 to 28	29 to 41
Initial LW	kg	25	41	75	111
Expected final LW	"	41	75	111	163
Average feed consumption	kg/d	1.23	1.90	2.37	2.78
Diet composition:					
Metabolizable energy	MJ/kg	13.2	12.9	12.6	12.6
Crude protein	%	17.6	16.2	15.5	14.0
Lysine	"	1.15	0.85	0.80	0.72
Methionine	"	0.33	0.25	0.24	0.22
Ca	"	1.00	1.05	0.90	0.85
P	"	0.70	0.68	0.60	0.55
Na (assumed)	"	0.13	0.13	0.13	0.13
Cl (assumed)	"	0.30	0.30	0.30	0.30
Mg (assumed)	"	0.13	0.13	0.13	0.13
K (assumed)	"	0.65	0.65	0.65	0.65

[1]In the original table data were expressed by week, from week 10 to 41. Here, for simplicity, data have been averaged for feeding phase.
LW: live weight.

kg/kg) and the remaining part was due to the feed (wf=0.12 kg/kg) and the metabolic water (wo=0.25 kg/kg). Water for digestion (wd=0.08 kg/kg) plus that for synthesis (ws=0.06 kg/kg) constituted less than 5% of the water drunk and a similar figure was found for water retained in tissue (wg=0.14 kg/kg). Considerable proportions, 29, 53 and 10%, of the total input of water were estimated to be used for evaporation (we=0.96 kg/kg), for urinary excretion (wu_{adlib}=1.72 kg/kg), and for faecal excretion (wfec=0.33 kg/kg), respectively. Note here that, for the assumptions done in the simulation, the value of "we" corresponds to the basal losses (85%) plus the extra water required for thermoregulation above the lowest critical point of the zone of thermal neutrality (15%).

The model of Schiavon and Emmans (2000) also provided indications about the DM content of fresh faeces and urine (dm_u), which averaged respectively 0.324 and 0.021 kg/kg. Part of the DM content of urine is represented by urea, which was estimated to be 0.0158 kg/kg, corresponding to 7.37 g N/l. Considering a urinary production of 800 kg/pig round (1.72*477), this value corresponds to a total urinary N excretion of 6.04 kg/pig round. This is in agreement with expectation for a pig growing from 25 to 163

Figure 1. Expected LW from data provided by a large feed producer for heavy pigs versus predicted LW (using the model of Ferguson et al. 1994) at the end of each feeding phase.

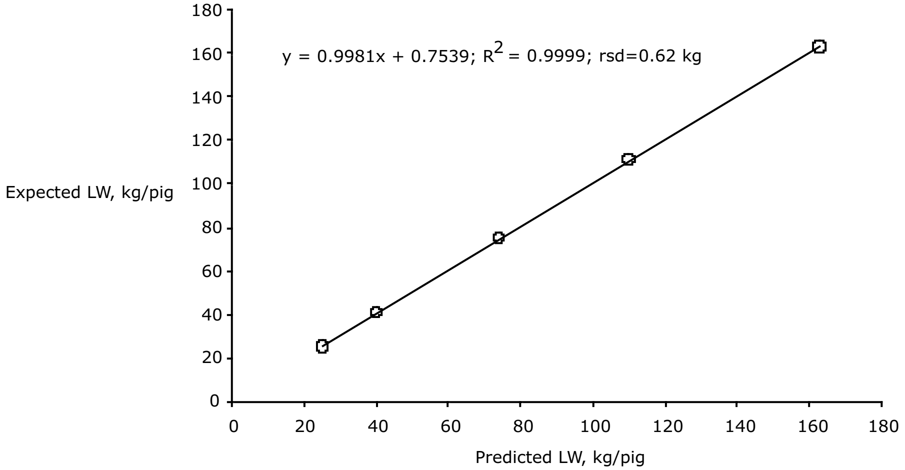


Table 2. Estimated values for the water balance components of pigs using the tabled feeding program and feed composition provided by the feed producer[1] as inputs to run the model of Schiavon and Emmans (2000).

		Feeding phase				
		1	2	3	4	Mean
Model estimates:						
Weeks of age		10 to 14	15 to 21	22 to 28	29 to 41	
Final live weight	kg	40	74	110	163	
Incomes of water:						
Drinking ($wi_{ad\ lib}$)	kg/kg feed	2.68	3.02	2.95	2.93	2.89
Feed (wf)	"	0.12	0.12	0.12	0.12	0.12
Nutrient oxidation (wo)	"	0.24	0.24	0.25	0.26	0.25
Outcomes of water:						
Digestion (wd)	"	0.07	0.08	0.08	0.07	0.08
Synthesis (ws)	"	0.05	0.06	0.06	0.05	0.06
Body retention (wg)	"	0.23	0.17	0.13	0.09	0.14
Faeces (wfec)	"	0.23	0.33	0.33	0.36	0.33
Evaporation (we)	"	0.87	1.02	0.98	0.91	0.96
Urine ($wu_{ad\ lib}$)	"	1.59	1.72	1.64	1.83	1.72

[1]More details are given in Table 1.

kg LW, retaining 0.024 kg of N per kg of live weight gain (Bittante *et al.*, 1990), consuming 477 kg of a feed with a CP density of 15%, and a CP digestibility of 82%. Poulsen and Kristensen (1998), for pigs receiving a constant water:feed ratio of 2.5:1 reported an average N content of urine of 7.9 g/kg.

Changes due to the dietary crude protein level

Increasing dietary crude protein level (CP) could induce a rise in the urinary volume, and in turn, in water consumption, due to the need to remove excess N from the body; excess minerals should have the same effect. It is noticeable that whereas some studies have shown an increase in drinking water associated with increasing dietary CP levels (Suzuki *et al.*, 1998), others observed a lack of effect (Jongbloed *et al.*, 1997). In the short duration experiment of Shaw *et al.* (2006) excess protein with respect to requirement tended to increase water consumption and significantly increased the water:feed ratio.

From a further application of the model of Schiavon and Emmans (2000) it resulted that water intake and the urinary losses increased, respectively, from 2.6 to 3.2 and from 1.5 to 3.2 kg/kg feed as a consequence of an increase of crude protein from 12.1 to 18.1% of feed (as weighted mean of the dietary CP content of all the diets used over the whole production period). Results are given in Table 3. It is expected that for an increase in the dietary CP from 12.1 to 18.1% the average daily water drunk increased from 5.89 to 6.99 kg/d, which corresponds to an average increase of 0.18 l/d per percentage unit of dietary CP. This figure is in agreement with those of the review of Mroz *et al.* (1995) who concluded that "in spite of confounding effects in most of the available studies, it can be stated that the quantity and quality of the dietary protein affect pig consumption and manure production. The lowering of CP concentration in a grower diet by 10 g/kg decreases water intake and urine volume by 0.10 to 0.30 l/d".

Thus, when the average dietary crude protein level is known the values of the coefficients of equations 5 and 6 ($wi_{ad\ lib}$, $wu_{ad\ lib}$) could be linearly related to the dietary CP content of the diet, and so $wi_{ad\ lib}=(a_i+a_s*CP)$ and $wu_{ad\ lib}=(wu_i+wu_s*CP)$. Interpolating the values given in Table 3 results that a_i=1.658 kg/kg; a_s=8.33 kg/kg; wu_i=0.495 kg/kg; wu_s=8.33 kg/kg;.

Table 3. Mean effects of the dietary crude protein level (12.1, 15.1 and 18.1% as fed) on water intake and urinary water losses of growing pigs fed restricted diet and receiving water ad libitum from 25 to 163 kg LW. Estimates achieved by the model of Schiavon and Emmans (2000).

		Mean dietary crude protein level		
		Low 12.1%	Conventional 15.1%	High 18.1%
Model estimates:				
Final live weight (LWf, 41 weeks of age)	kg/pig	162	163	164
Feed consumption (FC)	kg/pig round	477	477	477
Voluntary water:feed ratio ($wi_{ad\ lib}$)	kg/kg feed	2.68	2.89	3.18
Water lost with the urine ($wu_{ad\ lib}$)	"	1.52	1.72	2.02
Difference ($wi_{ad\ lib}$-$wu_{ad\ lib}$)	"	1.16	1.19	1.16
Average daily water drunk	kg/d	5.89	6.35	6.99

Changes of slurry occurring after excretion

Composition and amount of slurry are much more difficult to predict because slurry composition changes after excretion. Anaerobic digestion initiated in the large intestine of animals continues after excretion reducing the volume of excreta as the gases carbon dioxide, methane, ammonia and volatile fatty acids are emitted (Van Horn, 1998). After excretion, slurry volume and composition are also subjected to variations due to several factors related to the housing characteristics and the water delivery system, the farm cleaning practices, the aeration of housing rooms, the addition or not of bedding materials, the operations adopted for removing, storing and treating the slurry, as well as the weather conditions. The volume of slurry can also be influenced by evaporation of water, according to the climate, the housing and the storage systems used. Even though the determinant factor which influences slurry production is the feed and water intake and, consequently, the faecal and the urinary excretions of water and dry matter, all the above cited factors can influence the final volume and composition of the slurry, "as removed", and so large differences from farm to farm are expected, according to the site-specific conditions. Unfortunately, the development of tools to predict the changes of volume and composition of slurry after excretion is seriously constrained by a lack of information in the literature. Farmers and governmental organizations are interested both in 'as produced slurry' and in 'as removed slurry', in order to promote and plan the most efficient use of water and slurry on farms (Poulsen and Kristensen, 1998; ARDI, 2001; European Commission, 2003; Powers, 2004; ADAS, 2007; Manitoba, 2007). Some information will be given in the next section.

Dry matter and water losses occurring after excretion

Poulsen and Kristensen (1998) indicated DM losses occurring after excretion, due to the fermentation of organic matter and to volatilisation, on the order of 20% for fully and partially slatted floors and 30% for concrete solid floors. The reason for this difference was not clearly evidenced, but it is possible that on concrete floors slurry degradation could be influenced by a higher exposition on the floor surface for prolonged times. From a test of the MESPRO model proposed by Aarnink *et al.* (1992) it resulted that after 100 days of storage on average 17% of the excreted DM is converted into biogas, which consisted of about 6% carbon dioxide from urea conversion. In the model proposed by Aarnink *et al.* (1992), cited by Dourmad *et al.* (2003), the organic matter losses that occur inside the building (losses occurring outside the building and during spreading were not considered) have been related to the duration of the storage, to the DM content of the slurry and to its temperature. For an initial DM content of 5.6 and 8.9% the proportion of organic matter degraded was estimated to be on average 28 and 19% at 15°C and 35 and 23% at 20°C, respectively.

Additional amounts of water that dilute the slurry

Spillage of water is variable. In the IPPC document of the European Commission (2003) it is stated that "Traditional drinking nipples have a waste of 1.5 litre per day per finishing pig, but this figure may be reduced by using special drinking nipples, or even better by combining feed and water, i.e. by installing liquid feeding or wet feeders. Feeders with drinkers inside save about 20% of the total water consumption". In the model proposed by Schiavon and Emmans (2000), on which the present work is based, the spillage of water is not considered. Thus, an additional amount of water of about 0.5 m^3/pig/year could be indicated as reference value for pig farms with traditional nipple drinkers. It was also observed that erroneous spatial position and water low flow rate of nipple drinkers may substantially increase wastage (Li *et al.*, 2005). With respect to nipple drinkers, bowls minimize the wastage (Plagge and Leuteren, 1989).

Very little and inconsistent information is available about the amount of water used for cleaning. Procedures such as pre-soaking, use of soaps, and type of washing equipment all have significant impacts and can result in two to four fold differences in water usage for cleaning. In Appendix 3 of Poulsen and Kristensen (1998) it is reported that the amount of cleaning water is in the range of 20 to 40, 15 to 35 and 0 kg/pig "produced", respectively, for housing with fully slatted, partially slatted and solid floors. A first observation is that these data are not in agreement with expectations since the larger the slatted floor area, the lower should be the amount of water for cleaning use. A second observation is that whatever the value considered, the amount of cleaning water generally is negligible with respect to the volume of fresh slurry produced by the pig. By contrast, the European Commission (2003) report indicates that for pigs grown on solid, partly slatted and fully slatted floors, the amount of cleaning water is 15, 5 and 0 kg/pig/d, respectively. These figures are much more considerable since on an annual basis they correspond to about 5.2, 1.7 and 0.0 ton/pig/year for the three kinds of floor, respectively. The value of 0 indicated for fully slatted floors, both by Poulsen and Kristensen (1998) and European Commission (2003), is also questionable, since it is reasonable to consider some water usage, also in those systems where the liquid fraction of slurry is used as cleaning carrier. Surprisingly, in the same report (European Commission, 2003), and in the same table (Table 3), irrespective of the kind of floor, a much lower range (from 0.07 to 0.30 ton/pig/year) is proposed for pig finishing farms. These last figures are in agreement with those reported by Levasseur (1998) who, reviewing the results from various sources, indicated that for growing pigs fed prevalently wet diets the slurry production before and after washing averaged respectively 3.69 and 4.16 kg/d per pig. This corresponds to an average use of cleaning water of 0.47 kg/d per pig (0.15 ton/pig/year and 12% of the volume of slurry before washing). A survey conducted by ARDI (2001) reported an average value of 0.66 kg/pig/d, which corresponds to 0.22 ton/pig/year.

Additional dilutions of the manure can occur in uncovered manure storages due to rain fall. Slurry volume increases in those conditions where rainfall exceeds evaporation. This clearly depends on local climatic conditions. Taking as an example the Veneto Region, in the North-eastern part of Italy, the historical series of data presented by Barbi *et al.* (2007) indicate that the net precipitation (rainfall-evaporation) averaged +35 mm from the year 1959 to 1980, while from the year 1981 to 2004 the water balance averaged -48 mm, or -0.04 m^3 per m^2 of slurry tank. Similar data were given by Borin (2004).

Some literature coefficients about the DM losses occurring after excretion and the additional amounts of water due to spillage ($W_{spillage}$) and cleaning ($W_{cleaning}$) which can be used to convert the fresh into the "as removed" slurry production under ordinary conditions are given in Table 4.

Results and discussion

Test of the model

The simplified model was used to predict the faecal and the urinary excretions of water and dry matter by heavy (160 kg of LWf) and light (120 kg of LWf) pigs growing on 3 different conditions of water sup-

Table 4. Indicative values to convert the "fresh" into the "as removed" slurry production according to the housing system (presuming ordinary management practice).

Housing system		Solid floor	Partially slatted floor	Fully slatted floor	Source
DM losses (DM_{losses})	kg/kg	0.30	0.20	0.20	Pousen and Kristensen, 1998
Water diluting the slurry:					
-spillage from nipple drinkers ($W_{spillage}$)	kg/d	1.5	1.5	1.5	European Commission, 2003
-cleaning water ($W_{cleaning}$)	kg/pig/year	300	185	70	"
-rainfall in uncovered storages - evaporation ($W_{rain-evaporation}$)	kg/year	according to the local climatic conditions	according to the local climatic conditions	according to the local climatic conditions	

ply: free access to water (water:feed ratio of 2.9:1), "forced" water supply (water:feed ratio of 4.0:1) and restricted water supply (water:feed ratio of 2.5:1). To describe the system, the data of LWi, LWf and T given in Table 1, representing ordinary commercial conditions (Xiccato *et al.*, 2005), were used as inputs. In agreement with literature the predicted FCRs were close to 3.5 kg/kg for heavy pigs slaughtered around 160 kg LW (Tagliapietra *et al.,* 2004; Xiccato *et al.*, 2005) and to 2.9 for lighter pigs slaughtered around 110 to 120 kg LW (Poulsen and Kristensen, 1998; Van Horn, 1998; Dourmad *et al.*, 1999), respectively (Table 5).

The estimated amount of faeces excreted by heavy and light pigs were about 236 and 135 kg/pig round, respectively. The faecal DM content was around 32%. Faecal DM contents ranging from 26 to 33% have been measured by several Authors (Koenegay and Graber, 1968; Monetti *et al.*, 1996; O'Connell-Motherway *et al.*, 1998; Poulsen and Kristensen, 1998; Bailoni *et al.*, 1999; Partanen *et al.*, 2002; Sardi *et al.*, 2002; Fernandez, 2006). Literature also indicates that faecal DM content can be influenced by the proportion of different faecal constituents and their water-holding capacity (Schiavon and Emmans, 2000), in particular of some fibrous components, such as sugar beet pulps (Cooper and Tyler, 1959a, 1959b; Canh *et al.*, 1997). However, for the practical purpose of this model, it is more important to consider that the water:feed ratio does not exert considerable effects on the faecal moisture content (Kornegay and Graber, 1968; O'Connell-Motherway *et al.*, 1998).

Huge variations in the urinary excretion of water were predicted according to the water:feed ratio assumed. Under restricted drinking the model predicted a urinary production of about 646 kg/pig round, whereas for the *ad libitum* and the forced water supply the urinary production was estimated to be 848 and 1370 kg/pig round, respectively. For light pigs the expected urinary water excretions are proportionately lower. With

Table 5. Estimates of slurry production and its DM content of pigs growing in different conditions of water supply.

		Heavy pigs			Light pigs		
Water: feed ratio		2.5:1[1]	2.9:1[2]	4.0:1[3]	2.5:1[1]	2.9:1[2]	4.0:1[3]
Inputs:							
Initial live weight (LWi)	kg	25	25	25	25	25	25
Final live weight (LWf)	"	163	163	163	120	120	120
Production times (t)	d	210	210	210	130	130	130
Empty times	"	14	14	14	14	14	14
Rounds per year		1.63	1.63	1.63	2.53	2.53	2.53
DM digestibility	%	82	82	82	82	82	82
Estimated FCR[4]	kg/kg	3.5	3.5	3.5	2.9	2.9	2.9
Outputs:							
Water consumption	kg/pig round	1208	1396	1932	689	796	1102
Faecal DM excretion	"	77	77	77	44	44	44
Faecal water excretion	"	159	159	159	91	91	91
Urinary DM excretion	"	18	18	18	10	10	10
Urinary water excretion	"	628	830	1352	358	474	771
Fresh slurry production	"	881	1084	1606	503	618	916
Fresh manure DM content	%	11.9	9.5	6.2	11.9	9.5	6.2

[1]*water:feed ratio assumed for restricted access to drinking water.*
[2]*water:feed ratio assumed for spontaneous drinking.*
[3]*water:feed ratio assumed for forced supply of water by wet feeding.*
[4]*Feed conversion ratio estimated as 0.814+0.028*Lwi+0.0101*(LWf-LWi)+0.00299*t (eq. 1).*

respect to the unrestricted situation, the reduction of the water:feed ratio to 2.5:1 increased the urinary DM concentration from 2.1 to 2.8%, where as the forced water:feed ratio of 4:1 reduced the DM concentration of urine to 1.3%. The proportion of urine accounts for 73, 78 and 85% of the fresh slurry produced, respectively, for the three increasing water:feed ratios. In agreement with our data, Poulsen and Kristensen (1998) found, for 35 to 90 kg LW pigs fed a fixed ratio of water:feed of 2.5:1, that urine represented on average 72% of the fresh slurry produced.

The estimated amount of fresh manure produced by a heavy pig during the production period increased from 0.88 to 1.08 and 1.61 ton/pig round, while for a light pig the fresh manure production increased from 0.50 to 0.62 and 0.92 ton/pig round, respectively, for the three increasing water:feed ratios.

The outputs of the model were compared to those obtained by O'Callaghan *et al.* (1971), quoted by Smith *et al.* (2000). These Authors suggested that the daily production of fresh slurry (y) can be estimated based on total feed and water intake (x). They proposed the following empirical relationships between daily excretion (faeces+urine) and feed plus water intake for fattening pigs:

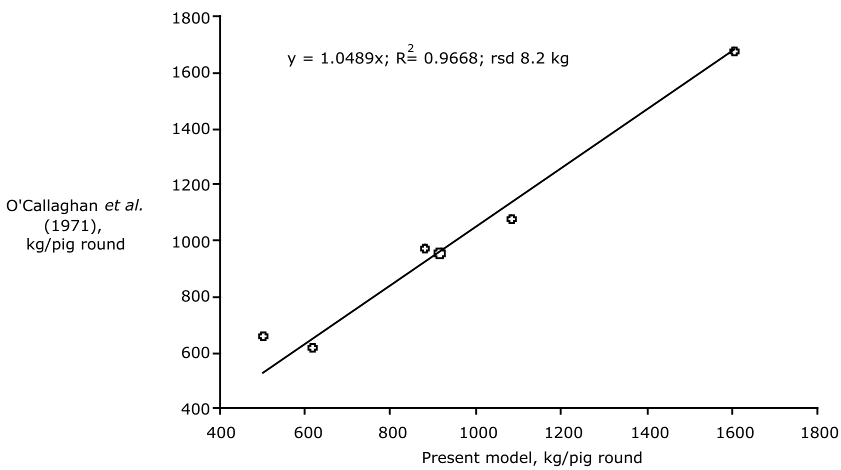
Ad lib water (water:feed=2.76:1)
y=0.562*x+0.092
r=0.817

Pipeline wet feeding (water:feed=2.50:1)
y=0.563*x+0.098
r=0.955

Pipeline wet feeding (water:feed=4.00:1)
y= 0.717*x–0.263
r=0.980

An application of these equations to the data of Table 2, regarding the initial and final LW, the length of production time and the intake of feed plus water, for heavy and light pigs, produced estimates of fresh slurry productions very close to those achieved with the present approach (Figure 2). This agreement indicates that this approach can be used to predict accurate estimates of the fresh slurry production by growing pigs kept under water:feed ratios different from the three fixed values used by O'Callaghan *et al.* (1991), also when the pigs' water consumption is unknown. It must be observed that little variations of the water: feed ratios are associated with strong variations in the amounts of water used and of slurry produced, and so the 3 fixed water: feed ratios considered by O'Callaghan cannot be applied for intermediate situations. The voluntary water:feed ratio observed by O'Callaghan (2.76 kg/kg) was close to that found in this paper (2.89 kg/kg). It must be noted, however, that this value has been achieved by using as input for the model of Schiavon and Emmans (2000) values of pig potential for growth (low), diet composition

Figure 2. Estimates of fresh *excreta* production (faeces+urine) for heavy and light pigs (kg/pig/round) kept under different water:feed ratios (2.76:1 ad lib, 2.5:1 and 4:1 simulated pipeline feed) using the empirical equation proposed by O'Callaghan et al. (1971) regressed against those achieved using the present model.



(cereal soybean based diet), feeding regime (restricted) and environmental temperatures ordinary for the pig production system of Italy. For other situations a recalibration of the equations could be required and this can be easily done by following the approach described. Nevertheless, the solid agreement of the values of fresh slurry production achieved in this paper with those achieved by O'Callaghan indicated that the quantification of the various components of the water balance was acceptable.

The estimated DM content of fresh slurry was on the order of 11.9, 9.5 and 6.2%, for the three increasing water:feed ratios 2.5:1, 2.9:1 and 4:1, respectively. The European Commission (2003) reported a decrease in DM content from 13.5 to 7.8% for water:feed ratios increasing from 1.9:1 to 2.6:1. The ASAE (2003) standards reported that fresh pig manure contains on average 11% DM. For piglets of 25-30 kg LW O'Connell-Motherway *et al.* (1998) measured DM contents of manure of 11.9 to 6.9 and 5.3% for water: feed ratios increasing from 2:1 to 3:1 and 4:1, respectively. For 80 to 90 kg LW pigs housed in metabolism cages and receiving different diets (15% CP) mixed with water in a fixed ratio (2.5 1/kg feed) Canh *et al.* (1997) reported a slurry DM content ranging from 8.3 to 10.2%. Some variations of DM content of manure at similar water:feed ratios with different diets can be expected mainly as result of different DM digestibility of feed ingredients, different water holding capacity of the undigested feed ingredients and different dietary electrolyte loads.

Expected annual slurry productions

The expected amount and DM content of slurry produced on an annual basis are given in Table 6. For heavy pigs receiving a dry meal with water freely available from nipple drinkers an average slurry production ranging from 2.06 to 2.53 ton/pig/year and a DM content ranging from 4.2 to 6.0 % depending on housing system was estimated. The expected farm water consumption under ordinary conditions [(FWC_{exp}=WI_{forced} (or $WI_{ad\ lib}$)+$W_{spillage}$+$W_{cleaning}$)] ranged from 2.89 to 3.09 ton/pig/year. Heavy pigs receiving wet meals with a water:feed ratio of 4:1 are expected to produce 2.66 to 2.87 ton/pig/year of slurry with a DM content of 3.7 to 4.6%. FWC_{exp} ranged from 3.21 to 3.45 ton/pig/year. A restriction of the water/feed ratio to 2.5:1 could induce a marked reduction both of the amount of slurry produced to about 1.48 to 1.69 ton/pig/year, and FWC_{exp} to about 2.04 to 2.27 ton/pig/year. The values estimated for light pigs are slightly lower with respect to the ones predicted for heavy pigs.

These results are in solid agreement with data provided by literature (Poulsen and Kristensen, 1998; Smith *et al.*, 2000; DEFRA, 2002; European Commission, 2003; MANITOBA, 2007). They reported amounts of "as removed" slurry ranging from about 1.1 to 2.63 ton/pig/year, where the higher amounts were reported for water:feed ratios of 4.0:1 (Table 7).

The standard Italian values reported by MIPAF (2006) for the "as removed" slurry production are much higher, ranging from 3.4 to 6.6 ton/pig/year depending on the housing and the cleaning system. Considering that, under ordinary conditions of heavy pig production assumed here, the amount of DM excreted per pig place, discounted for the DM losses after excretion, is around 107-122 kg/pig/year; this would mean that the average DM content of the slurry, according to the MIPAF standards for the slurry volumes, should range from 3.6 to 1.6%. The little information about the DM, or total solid content of pig slurry in Italy shows a great variation with values ranging from 1.5 to 8.0% (Negrini, 1995; Grignani and Zavattaro, 1999; Sangiorgi *et al.*, 2000;

Table 6. Estimates of "as removed" slurry production, its DM content and expected farm water consumption under different conditions of water supply and housing system.

		Heavy pigs			Light pigs		
Water: feed ratio		2.5:1[1]	2.9:1[2]	4.0:1[3]	2.5:1[1]	2.9:1[2]	4.0:1[3]
Fresh slurry production:	ton/pig/year	1.44	1.77	2.62	1.28	1.57	2.32
Fresh manure DM content	%	11.9	9.5	6.2	11.9	9.5	6.2
Kind of floor:							
Solid (nipple drink only for *ad lib* drinking)							
- slurry production per pig	ton/pig/year	1.69	2.53	2.87	1.55	2.32	2.58
- slurry DM content	%	6.3	4.2	3.7	6.2	4.1	3.7
- expected farm water consumption (FWCex)	ton/pig/year/	2.27	3.09	3.45	2.05	2.81	3.09
Partially slatted (nipple drink only for *ad lib* drinking)							
- slurry production	kg/pig/year	1.59	2.46	2.77	1.43	2.27	2.48
- slurry DM content	%	7.7	5.0	4.4	7.6	4.8	4.4
- expected farm water consumption (FWCex)	ton/pig/year	2.15	3.00	3.33	1.93	2.70	2.98
Fully slatted (nipple drink only for *ad lib* drinking)							
- slurry production	kg/pig/year	1.48	2.06	2.66	1.32	1.89	2.36
- slurry DM content	%	8.3	6.0	4.6	8.3	5.8	4.6
- expected farm water consumption (FWCex)	ton/pig/year	2.04	2.89	3.21	1.82	2.58	2.86

[1]*water:feed ratio assumed for restricted access to drinking water.*
[2]*water:feed ratio assumed for spontaneous drinking on dry feed plus 1.5 kg/d of spillage due to nipple drinkers.*
[3]*water:feed ratio assumed for forced supply of water by wet feeding.*

Garella, 2008; Martìnez-Suller *et al.*, 2008). The lower values of this range are probably due to wastage and the use of cleaning water. Since these latter amounts are not predictable, the measurements of the farm water consumption through water-meters must be considered as input. The farm water consumption, expressed on a pig basis (FWC, kg/pig/year), can provide useful information. For example, the difference FWC - FWC_{exp} can be used to evaluate the extra or the lower amount of water wasted with respect to

Table 7. Annual slurry production and DM content (as *excreta* and as removed) from different sources.

Source	Slurry production "as *excreta*" Amount ton/pig/year	Slurry production "as *excreta*" DM content %	Slurry production "as removed" Amount ton/pig/year	Slurry production "as removed" DM content %	Range of LW kg	Notes
Levasseur (1998)	1.03 to 1.56		1.24 to 1.63		25 to 110	
Poulsen and Kristensen (1998)[1]	1.07		1.45	8.3	30 to 100	Solid floor water:feed = 2.5:1
Poulsen and Kristensen (1998)[1]	1.07		1.51	7.0	30 to 100	Partially slatted floor water:feed = 2.5:1
Poulsen and Kristensen (1998)[1]	1.07		1.51	6.5	30 to 100	Fully slatted floor water:feed = 2.5:1
Smith et al. (2000)[2]	1.48	10			35 to 105	Dry meal fed
Smith et al. (2000)[2]	2.37	6			35 to 105	Wet fed (4:1)
DEFRA (2002)			1.5		35 to 105	Dry meal fed
DEFRA (2002)			2.4		35 to 105	Wet meal fed (4:1)
ASAE (2003)	1.65	11			61 kg mean	
European Commission (2003)	0.88 to 1.38	13.5 to 7.8				Water:feed ratios from 1.9:1 to 2.6:1
European Commission (2003)			1.1 to 2.63		30 to 120	No data for heavy pigs
MIPAF (2006)			6.6		31 to 160	Solid floor
MIPAF (2006)			4.0		31 to 160	Partially slatted floor
MIPAF (2006)			3.4		31 to 160	Fully slatted floor
ADAS (2007)	1.22				31 to 65	
ADAS (2007)	1.69				66 to 100	
DEFRA (2007)[2]	1.19				30 to 65	
DEFRA (2007)[2]	1.61				66 to 100	
Manitoba (2007)[2]	-		2.33	3.7	23 to 113	
Present work	1.44	11.9	1.48-1.69	6.3-8.3	25 to 160	Water:feed: 2.5:1
Present work	1.77	9.5	2.06-2.53	4.2-6.0	25 to 160	Water:feed:2.9:1
Present work	2.62	6.2	2.66-2.87	3.7-4.6	25 to 160	Water:feed:4.0:1

[1]*Data provided per pig produced and converted on annual basis considering 3.14 rounds/year.*
[2]*Data have been expressed on annual basis considering an occupancy of 0.90.*

Table 8. Summary of the equations proposed to predict fresh and mature slurry production at farm level.

Variables	Equations	Unit	Notes
1) Rounds =	365/(t + empty times)	$year^{-1}$	
Prediction of fresh and mature slurry production for spontaneous drinking:			
2) $WI_{ad\ lib}$ =	$wi_{ad\ lib}$ *FC*Rounds	kg/pig /year	$wi_{ad\ lib}$ = 2.89 or $wi_{ad\ lib}$ = 1.658+8.33*CP; kg/kg feed
3) $WU_{ad\ lib}$ =	$wu_{ad\ lib}$*FC*Rounds	"	$wu_{ad\ lib}$ = 1.72 or $wu_{ad\ lib}$ = 0.495+8.33*CP; kg/kg feed
4) $Urine_{ad\ lib}$=	$WU_{ad\ lib}$ *(1+ dm_u)*Rounds	"	dm_u = 0.021 kg/kg urine
5) UrineDM $_{ad\ lib}$ =	$Urine_{ad\ lib}$ - $WU_{ad\ lib}$	"	
6) Wfec=	wfec*FC*Rounds	"	wfec = 0.33, kg/kg feed
7) FaecesDM=	(1-wf)*(1-DMD)*FC*Rounds	"	
8) Faeces =	(Wfec+ FaecesDM)	"	
9) Fresh $slurry_{ad\ lib}$=	$Urine_{ad\ lib}$ + Faeces	"	
10) Fresh $slurryDM_{\_ad\ lib}$=	UrineDM $_{ad\ lib}$ + FaecesDM	"	
11) Mature $slurry_{ad\ lib}$=	Fresh $slurry_{ad\ lib}$ - (Fresh $slurryDM_{\_ad\ lib}$)(DMlosses)		
	+ $W_{spillage}$*t*rounds + $W_{cleaning}$	"	$W_{spillage}$ Reference values in Table 4
12) FWCexp =	$WI_{ad\ lib}$ + $W_{spillage}$*t*rounds + $W_{cleaning}$	"	$W_{cleaning}$ Reference values in Table 4
13) Wadj =	FWC - FWCexp	"	

Continued >>

Table 8. >> Continuation

14) AMSP =	Mature $slurry_{ad\ lib}$ + Wadj	
	(to be adjusted for the local net precipitation)	"
Prediction of fresh and mature slurry production under forced drinking conditions:		
15) WI_{forced}=	wi_{forced}*(1-x)*FC*Rounds	"
16) WU_{forced}=	[wi_{forced}*(1-x) –1.20]*FC*Rounds	"
17) $UrineDM_{\_forced}$=	$wu_{ad\ lib}$*0.021*FC*Rounds	"
18) $Urine_{forced}$ =	WU_{forced} + UrineDM $_{forced}$	"
19) FaecesDM=	(1-wf)*(1-DMD)*FC*Rounds	"
20) Faeces=	(Wfec+ FaecesDM)	"
21) Fresh $slurry_{forced}$ =	$Urine_{forced}$ + Faeces	"
22) Fresh slurryDM =	$UrineDM_{\_forced}$ + FaecesDM	"
23) Mature $slurry_{forced}$ =	Fresh $slurry_{forced}$ - (Fresh slurryDM_ $_{forced}$)(DM_{losses})	
	+ $W_{spillage}$*t*rounds + $W_{cleaning}$	"
24) FWCexp =	WI_{forced} + $W_{spillage}$*t*rounds + $W_{cleaning}$	"
25) Wadj =	FWC - FWC_{exp}	"
26) AMSP	Mature $slurry_{forced}$ + Wadj	
	(to be adjusted for the local net precipitation)	"

The list of the abbreviations is given in the Appendix.

Appendix

List of the abbreviations

Water balance components:

FWC = farm water consumption measured through water meters, kg/pig/year

FWC_{exp} = farm water consumption expected with spontaneous or forced drinking, kg/pig/year

$W_{spillage}$ = Water lost for spillage under ordinary conditions, kg/pig/day

$W_{cleaning}$ = water used for cleaning under ordinary conditions, kg/pig/year

Wadj = Adjustment factor for farm water usage with spontaneous or forced drinking, kg/pig/year

WD = water lost for digestion, kg/pig round

wd = water lost for digestion per unit of feed consumed, kg/kg feed

WE = water lost for evaporation, kg/pig round

we = water lost for evaporation per unit of feed consumed, kg/kg feed

WF = water gained from feed, kg/pig round

wf = water content in feed, kg/kg feed

Wfec = water excreted with faeces, kg/pig round

wfec = water excreted with faeces per unit of feed consumed, kg/kg feed

WG = water retained in body tissues, kg/pig round

wg = water retained in body tissues per unit of feed consumed, kg/kg/feed

$WI_{ad\ lib}$ = spontaneous water intake, kg/pig/year

$wi_{ad\ lib}$ = spontaneous water intake per unit of feed consumed, kg/kg

WI_{forced} = forced water intake, kg/pig/year

wi_{forced} = forced water intake per unit of feed consumed, kg/kg

WO = water arising from nutrient oxidation, kg/pig round

wo = water arising from nutrient oxidation per unit of feed consumed, kg/kg feed

WS = water for synthesis of body protein and lipid, kg/pig round

ws = water for synthesis of body protein and lipid per unit of feed consumed, kg/kg/feed

$WU_{ad\ lib}$ = water excreted with urine with spontaneous drinking, kg/pig/year

$wu_{ad\ lib}$ = water excreted with urine per kg of feed consumed with spontaneous drinking, kg/kg feed

WU_{forced} = water excreted with urine with forced drinking, kg/pig/year

wu_{forced} = water excreted with urine per kg of feed consumed with forced drinking, kg/kg feed

Diet and production variables:

CP = average crude protein content of the feed, kg/kg

DMD = Dry matter digestibility of diet, kg/kg

empty = duration of empty period days

FC = feed consumption, kg/pig round

FCR = feed consumed per unit of live weight gain, kg/kg

LWi = initial live weight, kg/pig

LWf = final live weight, kg/pig

t = duration of production period days

$wi_{ad\ lib}$ = water:feed ratio with spontaneous drinking, kg/kg

wi_{forced} = water:feed ratio with forced drinking, kg/kg

x = dry matter content of the liquid feed introduced in the wet diets, kg/kg

Faeces and urine:

dmu = DM content of urine with spontaneous drinking, kg/kg urine

Faeces = faecal excretion, kg/pig/year

$Faeces_{DM}$ = faecal excretion of dry matter, kg/pig/year

$Urine_{ad\ lib}$ = urine produced with spontaneous drinking, kg/pig/year

$Urine_{DM\ ad\ lib}$ = dry matter excreted with the urine with spontaneous drinking, kg/pig/year

$Urine_{forced}$ = urine produced with forced drinking, kg/pig/year

$Urine_{DM\ forced}$ = dry matter excreted with the urine with forced drinking, kg/pig/year

Slurry:

$Fresh\ slurry_{ad\ lib}$ = fresh slurry produced with spontaneous drinking, kg/pig/year

$Fresh\ slurry_{DM\ ad\ lib}$ = fresh slurry dry matter produced with spontaneous drinking, kg/pig/year

$Fresh\ slurry_{forced}$ = fresh slurry produced with forced drinking, kg/pig/year

$Fresh\ slurry_{DM\ forced}$ = fresh slurry dry matter produced with forced drinking, kg/pig/year

$Mature\ slurry_{ad\ lib}$: 'as removed' slurry production with spontaneous drinking, kg/pig/year

$Mature\ slurry_{forced}$: 'as removed' slurry production with forced drinking, kg/pig/year

AMSP = Adjusted mature slurry production with spontaneous or forced drinking, kg/pig/year

values given in Table 5 and 6. The value resulting from this difference can be added to the estimated mature slurry production in order adjust the estimate of slurry production for the specific farm considered.

The resulting equations of the simplified model are summarized in Table 8 and the abbreviations list is given in the Appendix.

Conclusions

This paper proposes a simplified approach to predict the amount of fresh and mature slurry produced by growing pigs based on simple inputs easily available at farm level. Some indicative values to convert the fresh into the 'as removed' slurry are also provided as guidelines. This approach can provide the operators with information useful to identify causes of water wastage, to minimize water consumption, volume of slurry to be handled and associated costs. From the sensibility analyses conducted in this paper it resulted that the major determinants of the 'as removed' slurry production are the feed and water consumption, the initial and the final LW, the duration of the growing period and the amounts of water wasted. The dietary CP has less importance, so the model can be simplified to the desired level of accuracy. However, slurry disposal depends on its N content. Thus, using the criteria of the mass balance approach, based on the same variables used here, the measurement of N content of feed will allow the quantification of the amount of N excreted which is diluted in the slurry. The result of this work could also be used by the public administration for updating of the current national standard values of slurry production (MIPAF, 2006) which are likely overestimated with respect to the values of the international literature, to the findings of this study and to what is frequently observed in practice.

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