A new model for dung decomposition and phosphorus transformations and loss in runoff

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Abstract. Non point-source pollution of fresh waters by agricultural phosphorus (P) can accelerate eutrophication of surface waters and limit their use for drinking, recreation, and industry. An important pathway of agricultural P transport is surface runoff, to which unincorporated dung from grazing cattle can be a significant contributor. Computer models commonly used to identify agricultural areas with a high potential for P export do not adequately simulate dung application to the soil surface, dung disappearance, and dung P loss to runoff. We developed a new model to simulate these processes for grazing cattle dung. The model simulates dung organic matter decomposition and assimilation into soil by bioturbation as a function of air temperature and dung moisture. We validated that the model can accurately predict rates of dung disappearance, using data from 12 published studies. The model also simulates four pools of inorganic and organic P, P mineralisation to water-extractable P, leaching of dung water-extractable P into soil by rain, and loss of dissolved inorganic P in runoff. We validated the ability of the model to reliably simulate these P processes, using data from six published dung P transformation studies and six runoff studies. Overall, the model represents a novel approach for assessing the environmental impact of grazing dairy and beef cattle. Research should investigate the impact of dung deposition rate as a function of time and animal diet and type, where deposition occurs relative to runoff movement, weather conditions, and the ability of dung pad crusting to reduce P release to runoff.

Additional keywords: dung, phosphorus, runoff, model.

Introduction

Non-point source pollution of fresh waters by agricultural phosphorus (P) can accelerate eutrophication of surface waters and limit their use for drinking, recreation, and industry (Carpenter et al. 1998). A major pathway of P transport from agricultural soils is surface runoff. Phosphorus solubilised from unincorporated animal manures can substantially contribute to P loads transported in surface runoff (Kleinman and Sharpley 2003; DeLaune et al. 2004a, 2004b). Recent research has focused on better understanding and minimising P transport in runoff from both machine-applied manures (Moore et al. 2000; Harmel et al. 2004; Vadas et al. 2007b) and dung from grazing animals (Mapumo et al. 2002; O’reagain et al. 2005; Haan et al. 2006; Kurz et al. 2006; Capece et al. 2007; Dougherty et al. 2008). These latter studies highlight the potentially significant impact of animal-deposited dung on P loss in runoff.

The challenge for the agricultural community, from scientists to producers, is to identify areas with a high potential for P export, accurately quantify that P export, and assess the ability of alternative management practices to minimise P export. Water-quality simulation models are seen as a relatively rapid and cost-effective way to help achieve these goals (Sharpley et al. 2002; Garcia et al. 2008). However, commonly used field-and watershed-scale models often do not adequately simulate manure application to the soil surface, manure transformations, and direct P loss from surface manure to runoff. Vadas et al. (2007a) developed the SURPHOS model to simulate such P processes for machine-applied manures; however, we are not aware of any process-based model for grazing animals that simulates dung deposition to pastures, dung decomposition and P transformations, or dung P loss in runoff. Thus, the objective of this research was to develop and validate a model to simulate these dung-related processes.

Model description, calibration, and validation

Our dung model consists of three parts that simulate: (i) dung disappearance, (ii) dung P transformations, and (iii) loss of dissolved dung P in surface runoff. The model operates on a daily time-step and requires input for daily precipitation (mm), daily runoff (mm), daily average temperature (°C), dung dry matter deposited in each pad (kg), dung moisture content (%), and area of each pad (cm²). A pad is defined as the dung
deposited on the soil surface in an approximately circular geometry during a single faecal voiding.

When each dung pad is deposited, the model simulates dung disappearance as a function of two processes: decomposition of organic matter (OM), and physical assimilation in soil by macro-invertebrates (bioturbation) (Haynes and Williams 1993). The decomposition and assimilation of dung pads have been investigated in numerous studies (Holter 1979; Holter and Hendriksen 1988; Madsen et al. 1990; Aarons et al. 2004; Lee and Wall 2006). These studies show that dung pads may be completely integrated into soil within 100 days of deposition, although the rate of disappearance can vary widely depending on climate and dung moisture content (Floate 1970a, 1970b; Dickinson et al. 1981; Rowarth et al. 1985; Dickinson and Craig 1990; Wilkerson et al. 1997), and on the presence of specific soil fauna. For example, Hirata et al. (2009) observed very slow rates of cattle dung decomposition in grazed forest and proposed that the lack of dung beetles prevented faster decomposition, such as might occur in grazed grasslands. As the time required for complete dung disappearance increases, the opportunity for that dung to contribute P to runoff also increases. Therefore, it is important to be able to simulate the variability observed in the rate of dung disappearance. We designed our model to allow dung disappearance to be a function of both air temperature and dung moisture, which is consistent with field observations where drier dung disappears more slowly than wetter dung, and faster during warmer seasons.

Our dung model uses equations from the SURPHOS manure model (Vadas et al. 2007a) to simulate dung P transformations with time after deposition and dissolved P loss in runoff from fields where dung has been deposited by grazing cattle. The following sections detail the equations used to simulate dung disappearance and P processes. We developed the equations for dung disappearance using a calibration process, but we did not calibrate the P equations. However, we validated the output from all equations against data from the literature.

### Dung disappearance and moisture content

We used an empirical calibration process to develop the dung disappearance and moisture content equations. The intent was to develop equations where dung disappearance is a function of commonly available model variables, i.e. air temperature and rainfall. We used data from Dickinson et al. (1981) and Dickinson and Craig (1990) for dung disappearance and from Sinton et al. (2007) for dung moisture to develop and calibrate model equations. The calibration process involved first developing dung disappearance equations which would result in a regression equation relating predicted and measured dung mass values through time that had a slope not significantly different from unity and a y-intercept not different from zero. We then applied these equations to simulate changes in dung moisture, using only a visual comparison of measured and predicted values to assess the success of the equations. We used visual inspection because our intention was accurate prediction of dung mass through time, rather than dung moisture. If equations poorly predicted dung moisture, we altered them until dung moisture was reasonably predicted. We then assessed if these revised equations accurately simulated dung mass. If not, we revised them again and re-applied them to simulate dung moisture. We continued this iterative process until we had a set of equations that would reasonably simulate changes in dung moisture content with time and accurately simulate rates of dung disappearance. These equations are detailed below.

The model simulates a daily rate of dung OM decomposition (kg/day) and a subsequent decrease in mass as:

\[
\text{OM decomposition} = 0.003 \times \text{TFA}^{0.5}
\]  

where TFA is a temperature factor defined in Eqn 2. In laboratory experiments, Floate (1970a, 1970b) found that decomposition of manure OM increased with increasing temperature but not with manure moisture, and measured a daily rate of decomposition of ~0.003 kg/day, which is the same rate of decomposition measured by Dao and Schwartz (2010) during a 353-day incubation of dairy manure. The TFA varies between 0 and 1.0 and is taken from Stroo et al. (1989) as:

\[
\text{TFA} = \frac{[(2)(32^2)(T^2) - T^4]/32^4}
\]  

where T is average daily air temperature (°C). The number 32 relates to the temperature (°C) where OM decomposition is at an optimum. Equation 1 shows that dung OM will decompose faster as temperatures increase but is not a function of dung moisture.

The daily dung assimilation rate (kg/ha.day) due to bioturbation is calculated as:

\[
\text{Dung assimilation} = 30.0 \times e^{[3.5 + (\text{dung moisture})]} \times \text{TFA}^{0.1}
\]  

The assimilation rate is then calculated by the area (ha) covered by a dung pad, to calculate assimilation in kg. Coefficients in Eqn 3 were developed during the calibration process. The model allows dung moisture content to range between 0 and 0.9. At optimum temperatures, the rate of dung assimilation (kg/ha.day) will range between 30 and 830. The lower limit is taken from Esse et al. (2001) and Gallagher and Wollenhaupt (1997), who provide estimates of the rate of manure or plant residue assimilation into soils, and the upper limit allows for total dung disappearance in ~60 days, which is among the fastest rates observed in field studies. Equation 3 shows that assimilation is a non-linear function of both temperature and dung moisture. If dung moisture goes to 0, assimilation will still proceed unless air temperature is <0°C. Together, Eqns 1 and 3 allow dung disappearance to be a function of both air temperature and dung moisture, which is consistent with field observations where drier dung disappears more slowly than wetter dung.

The model simulates daily decreases in the area (cm²) covered by each dung pad as the product of the initial pad area at deposition and a rate factor of 0.002. This equation is designed to match field observations of Sinton et al. (2007), in which the area covered by dung pads after 150 days of field weathering was about two-thirds of the area covered at deposition. These results are fairly consistent with those of Barth (1993), who measured a daily rate of cattle dung area decrease of 0.0045, and Herd et al. (1993), who measured a daily rate of horse dung area decrease of 0.0025.
The model simulates daily changes in dung moisture (expressed as a decimal between 0 and 0.9). If daily precipitation occurs, but is <4 mm, the model holds dung moisture at the same value as the previous day. If precipitation is >4 mm, dung moisture is increased as:

\[
\text{Moisture increase} = -0.3(\text{current moisture}) + 0.27 \quad (4)
\]

Equation 4 is designed so the potential increase in moisture is greater for drier dung than wetter dung but is not a function of the amount of precipitation (given that rain is >4 mm). The maximum possible increase in moisture is 0.27. If no precipitation occurs, dung moisture decreases as:

\[
\text{Moisture decrease} = [-0.05(\text{current mass}/\text{applied mass}) + 0.075] \times \text{TFA} \quad (5)
\]

Equation 5 is designed so the rate of drying increases as air temperature increases and as the dung mass, expressed relative to original mass at the time of deposition, decreases. The logic is that freshly deposited dung has a lesser surface area to volume ratio and will be able to maintain its moisture content more than decomposed dung, whose surface area to volume ratio has increased. At ideal temperatures, the daily rate of drying is 0.025 for freshly deposited dung and 0.075 for fully decomposed dung.

Figure 1 shows model calibration data for dung moisture content for data from Sinton et al. (2007), who monitored moisture content in 2.1-kg, 30-cm-diameter, artificial dung pads through four seasons in New Zealand. The model reasonably simulated changes in moisture contents across the annual variability in rainfall and temperature, with a model efficiency of 0.63 (Nash and Sutcliffe 1970). Measured and simulated values differed most after 50 days, when little dung mass was left on the soil surface and accurate simulation of dung moisture may not be as critical to model performance. Figure 2 shows model calibration data for dung dry mass for data from Dickinson et al. (1981) and Dickinson and Craig (1990), who monitored changes in mass of 15- or 20-cm-diameter, artificial dung pads over ~90 days during spring and fall in the UK. Pads were subjected to several treatments, including uncovered and exposed to natural precipitation, uncovered and exposed to precipitation and periodic irrigation, covered for the duration of the experiment, or both covered and uncovered for different periods. These treatments created a variety of dung moisture regimes that would affect rates of disappearance. The model was able to accurately simulate dung disappearance through time, with a model efficiency of 0.94. The slope and intercept of the regression line relating measured and predicted values were not significantly \((P>0.05)\) different from unity and zero, respectively. The standard error values for the intercept and
slope were 0.0067 and 0.0378, respectively. Equations 3 and 5 show that the rate of dung disappearance is a function of dung moisture, and dung drying rate is, in turn, a function of the degree of dung disappearance. Calibration data in Figs 1 and 2 show that our model was able to effectively balance these two interrelated processes so that the overall rate of dung disappearance was accurately simulated.

Following the development and calibration process, we validated the ability of the model to simulate the rate of dung disappearance with an independent dataset from 12 published studies (Table 1). We did not use data from Dickinson et al. (1981), Dickinson and Craig (1990), or Sinton et al. (2007) during validation. In all validation studies, artificial dung pads were applied to field plots and monitored for the rate of disappearance. Dung pads were created by pouring previously collected dung into a cylinder of known area, ranging from ~200 to 700 cm² in the studies, which was placed on the soil surface. Initial dung pad wet weights ranged from 0.7 to 1.9 kg, and initial moisture content from 0.78 to 0.90. These weights and moistures are consistent with those measured from actual grazing cattle (James et al. 2007). Studies were conducted in nine countries over a variety of seasonal and climatic conditions. Figure 3 shows the relationship between measured and simulated dung dry weights for the 12 studies. The slope and the intercept of the regression line relating measured and predicted values were significantly ($P<0.05$) different from unity and zero, respectively. The standard error values for the intercept and slope were 0.0027 and 0.0280, respectively. However, a model efficiency of 0.85 demonstrates that the model was able to reliably simulate dung disappearance through time.

We conducted a sensitivity analysis of five model input parameters that affect prediction of the rate of dung disappearance, i.e. temperature, precipitation, and initial dung mass, moisture content, and area. Baseline values for mass, moisture, and area were 1.95 kg, 0.85, and 346 cm², respectively. Baseline daily temperatures ranged from 7.5 to 26.3°C, and baseline daily precipitation from 0 to 58.4 mm. We varied these five inputs by ±25, ±10, ±10, and ±25% and determined the % change in the number of days predicted for dung to completely disappear, whose baseline value was 190 days. Results in Fig. 4 show that the model was least sensitive to initial dung moisture content, followed by temperature and precipitation. The model was much less sensitive to increases, than to decreases, in precipitation, primarily because the increase in dung moisture, which in turn affects the rate of disappearance, does not change if precipitation is >4 mm. Increases and decreases in temperature had a similar effect on model output in the ranges we tested. Decreases in temperature actually increased the rate of dung disappearance because they allowed dung to maintain its moisture content, which in turn caused faster disappearance. However, as temperatures approach 0°C, dung disappearance slows again. Model results were most sensitive to changes in initial dung mass and area, with potential model output variability ranging from 20 to 40%. This could have practical implications when simulating dung mass as a function of animal characteristics (e.g. dairy calves or lactating cows), or dung pad area as a function of pasture development and its effect on animal intake and dung pad consistency (i.e. wetter dung pads may spread out to cover a greater area at deposition). Model sensitivity to changes in dung mass and area were fairly proportional, with

![Graph showing the relationship between dung dry mass (kg) and Predicted dung dry mass (kg). The line of best fit is described by the equation $y = 0.96x + 0.01$ with $r^2 = 0.94$.](image)

**Fig. 2.** Relationship between dung dry mass data as measured by Dickinson et al. (1981) and Dickinson and Craig (1990) and simulated during model development.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Location</th>
<th>Season</th>
<th>Initial dung wet weight (kg)</th>
<th>Initial dung moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aarons et al. (2004)</td>
<td>Australia</td>
<td>Autumn</td>
<td>1.3</td>
<td>0.89</td>
</tr>
<tr>
<td>Aarons et al. (2009)</td>
<td>Australia</td>
<td>Autumn</td>
<td>1.9</td>
<td>0.87</td>
</tr>
<tr>
<td>Dimander et al. (2003)</td>
<td>Sweden</td>
<td>Summer, autumn</td>
<td>1.0</td>
<td>0.86</td>
</tr>
<tr>
<td>Gittings et al. (1994)</td>
<td>Ireland</td>
<td>Spring, summer, autumn</td>
<td>1.3</td>
<td>0.82–0.90</td>
</tr>
<tr>
<td>Herrick and Lal (1996)</td>
<td>Costa Rica</td>
<td>Spring, summer</td>
<td>1.5</td>
<td>0.78–0.82</td>
</tr>
<tr>
<td>Kaneda et al. (2006)</td>
<td>Japan</td>
<td>Autumn</td>
<td>0.7</td>
<td>0.89</td>
</tr>
<tr>
<td>Lee and Wall (2006)</td>
<td>UK</td>
<td>Spring, summer, autumn</td>
<td>1.5</td>
<td>0.88</td>
</tr>
<tr>
<td>Lovell and Jarvis (1996)</td>
<td>UK</td>
<td>Summer</td>
<td>1.5</td>
<td>0.83</td>
</tr>
<tr>
<td>Lumaret and Kadir (1995)</td>
<td>France</td>
<td>Spring, summer</td>
<td>1.0</td>
<td>0.78</td>
</tr>
<tr>
<td>Omaliko (1981)</td>
<td>Nigeria</td>
<td>Summer</td>
<td>1.1</td>
<td>0.83</td>
</tr>
<tr>
<td>Svendsen et al. (2003)</td>
<td>Denmark</td>
<td>Spring, summer, autumn</td>
<td>1.0</td>
<td>0.87</td>
</tr>
<tr>
<td>Yamada et al. (2007)</td>
<td>Japan</td>
<td>Spring, summer</td>
<td>1.0</td>
<td>0.86–0.88</td>
</tr>
</tbody>
</table>
% change in output approximately equal to % change in input. However, the effect on model prediction of P dynamics, as described later in conjunction with sensitivity analysis results in Fig. 7, is much less. Regardless, it will be important when using the model to have accurate input data for dung mass and area, especially with respect to the spatial and temporal variability that can exist for grazing herds (Tate et al. 2000, 2003).

**Dung phosphorus transformations**

The model simulates four pools of dung P (kg): water-extractable inorganic P (WEP$_1$) and organic P (WEP$_0$), and non water-extractable inorganic P (non-WEP$_1$) and organic P (non-WEP$_0$) (Fig. 5). Dung WEP$_1$ and WEP$_0$ pools represent P that can be leached from manure by rain. Manure WEP can be measured by shaking fresh dung with de-ionised water at a dry-weight-equivalent, water-to-dung solids ratio of 250 : 1 for 1 h, filtering extracts through 0.45-μm filters, and measuring P in filtrates colourimetrically (Murphy and Riley 1962). Manure WEP$_0$ is estimated by digesting the same filtrates, analysing digests for P colourimetrically, and calculating the difference in P between digested and undigested samples. Dung non-WEP is estimated by measuring total P in dung, typically by acid digestion, and taking the difference between dung total P and total WEP. The model assumes 75% of dung total non-WEP is non-WEP$_0$ and 25% is non-WEP$_1$.

After deposition, the model simulates dung P mineralisation by transferring P from the non-WEP pools to the WEP pools. Non-WEP$_0$ is transferred (kg) daily as:

$$\text{Non-WEP}_0 \text{ transfer} = \text{non-WEP}_0 \times 0.01 \times \min(\text{TFA or dung moisture})$$  \hspace{1cm} (6)

where ‘min’ is the minimum of TFA or dung moisture; 75% of mineralised non-WEP$_0$ is added to the WEP$_1$ pool and 25% is added to the WEP$_0$ pool. Transfer of non-WEP$_1$ is calculated as for non-WEP$_0$ except with a rate constant of 0.0025. All mineralised non-WEP$_1$ is added to the WEP$_1$ pool. The model also simulates mineralisation of WEP$_0$ with the same equation, but with a rate constant of 0.1, and adds all mineralised WEP$_0$ to the WEP$_1$ pool. The overall effect of the P transformation equations is to eventually convert dung P into WEP$_1$.

The model simulates two processes whereby dung P is incorporated into soil over time. The first is through dung assimilation into soil by bioturbation, which was described earlier. The model assimilates all four dung P pools (kg), with an example calculation for WEP$_1$ as:

$$\text{WEP}_1 \text{ assimilation} = (\text{WEP}_1)/(\text{current dung mass}) \quad (\text{dung assimilation})$$  \hspace{1cm} (7)

The second process is when precipitation leaches WEP from dung into soil. When rain falls, WEP$_1$ and WEP$_0$ are leached from manure based on the ratio of rain to manure dry matter (W, cm$^3$/g). An example calculation for WEP$_1$ is:

$$\text{WEP}_1 \text{ leached (kg)} = [1.2W/(W + 73.1)] \times (\text{manure WEP}_1)$$  \hspace{1cm} (8)

**Fig. 3.** Relationship between dung dry mass data as measured in 12 published studies and simulated during model validation.

**Fig. 4.** Results of a model sensitivity analysis showing the effect of changes in model variables on the rate of dung disappearance (model output).

**Fig. 5.** Schematic diagram of the phosphorus processes simulated in the dung model.
Leaching of WEP\(_3\) is calculated with Eqn 8 but is multiplied by a factor of 1.6. The W is calculated as:

\[
W = (\text{precipitation})/ (\text{dung dry mass})(\text{dung area})(100000)
\] (9)

where precipitation is in cm, dung mass is in kg, dung area is in ha, and 100 000 ensures cm\(^2\)/g units. If surface runoff occurs, some leached manure P is transferred to runoff, with the concentration of dissolved P in runoff (mg/L) calculated as:

\[
\text{Runoff dissolved } P = (\text{WEP leached})/ (\text{precipitation})/ (\text{field area})(\text{PDFATOR})
\] (10)

where units are mm for precipitation and ha for area. Equation 10 calculates a concentration of WEP leached from dung and then multiplies it by a PDFATOR, which is a P distribution factor that varies between 0 and 1.0, to calculate the runoff P concentration. The PDFATOR is calculated as:

\[
\text{PDFATOR} = (\text{runoff}/ \text{precipitation})^{0.225}
\] (11)

Field area is used in Eqn 10 (instead of dung area as in Eqn 9) so that runoff generated from areas not covered by dung will dilute P concentrations in runoff from areas covered by dung. A mass of P in runoff (kg) is calculated by multiplying runoff P concentrations by runoff volumes. Manure P that infiltrates into soil is calculated as the difference between P leached from manure and P transported in runoff.

We validated Eqns 6–9 to assess how accurately they simulate changes in dung P concentrations through time after deposition. We used data from six studies (Dickinson et al. 1981; Dickinson and Craig 1990; Aarons et al. 2004, 2009; Yamada et al. 2007; Bourke et al. 2008). All studies applied artificial dung pads to field plots and monitored changes in dung total P during the process of dung disappearance. Because none of the studies measured dung WEP, we assumed that WEP\(_1\) was 50% of dung total P, and WEP\(_O\) was 5% of dung total P (Kleinman et al. 2005). We simulated the experimental conditions with our model and compared measured total P with the sum of the four simulated dung P pools. Figure 6 shows that the model was able to accurately simulate changes in dung total P through time with a model efficiency of 0.83. The slope and intercept of the regression line relating measured and predicted values were not significantly (\(P>0.05\)) different from unity or zero. The standard error values for the intercept and slope were 0.0300 and 0.0443, respectively.

We conducted a sensitivity analysis of six model input parameters that affect prediction of changes in dung P content, including temperature, precipitation, initial dung mass, moisture content, area, and %WEP. Baseline values for mass, moisture, area, and %WEP were 1.95 kg, 0.85, 346 cm\(^2\), and 50%, respectively. Baseline daily temperatures ranged from 7.5 to 26.3\(^\circ\)C, and baseline daily precipitation ranged from 0 to 58.4 mm. We varied these six inputs by +25, +10, −10, and −25% and determined the % change in the total amount of P leached out of dung by rain, where the baseline value was 962 mg. Results in Fig. 7 show that the model was least sensitive to variability in initial dung moisture and area, followed by precipitation, temperature, and initial mass, all of which had a similar effect on model output. Results show that model output was not greatly changed by variability in these five parameters, with output changing by 5–10% at most. Model results were much more sensitive to the initial %WEP in dung, where variability could change model output by 15–20%.

![Fig. 6. Relationship between dung total phosphorus data as measured in six published studies and simulated during model validation.](image)

![Fig. 7. Results of a model sensitivity analysis showing the effect of changes in model variables on the total amount of phosphorus leached out of dung by rain (model output).](image)
Loss of dung-dissolved inorganic phosphorus in surface runoff

To validate the predictions of dissolved P in runoff over time after deposition of dung by grazing cattle, we used data from six studies (Sauer et al. 1999; Edwards et al. 2000a, 2000b; Butler et al. 2006, 2008; Soupir et al. 2006). In these studies, artificial dung pads were applied to small field plots ranging in size from 1.0 to 14.6 m² or to soil boxes 0.18 m². Dung pad application protocols ranged from applying dung just once, to repeated applications over several weeks, to simulate different grazing patterns. The amount of dung applied to plots ranged widely and was based on target annual P application rates of 24.6 kg/ha (Soupir et al. 2006), or continuous annual stocking rates of 4 cows/ha (Butler et al. 2006, 2008), 3.7 animal units (AU, 450 kg bodyweight)/ha (Edwards et al. 2000b), or rotational stocking rates of 6.7 or 14.8 AU/ha with 7 days of grazing and 21 days of rest (Edwards et al. 2000a, 2000b). Rain was applied to plots or boxes with a rainfall simulator to generate surface runoff at times after dung application that ranged from as little as 1 day to as much as 21 days after initial dung application. Protocols also varied from conducting just one rainfall simulation to conducting a series of simulations over several months. Overall, the studies represented a wide range of situations to validate our model’s ability to predict dissolved P loss in runoff from cattle dung.

We simulated the experimental conditions of the seven studies with our dung model and predicted the concentrations of dissolved inorganic P in runoff from dung. We also estimated the contribution of soil to dissolved P in runoff (mg/L) by using reported soil test P concentrations (mg/kg) and an extraction coefficient of 0.0025 (Vadas et al. 2005, 2007a). We then compared measured and simulated dissolved inorganic P concentrations in runoff.

Figure 8 shows that the model was able to reliably simulate runoff P. The slope and the intercept of the regression line relating measured and predicted values were not significantly (P > 0.05) different from unity or zero, respectively, and model efficiency was 0.61. The standard error values for the intercept and slope were 0.0795 and 0.0905, respectively. In the six studies, soil test P ranged from 10 to 200 mg/kg, with resulting runoff dissolved P contributions from 0.03 to 0.50 mg/L. Given that the majority of measured dissolved P concentrations were <1.0 mg/L, soil likely contributed a significant portion of the measured dissolved P in runoff. This makes it difficult to clearly distinguish whether soil P or dung P had a more significant impact on runoff P. However, our model predicted the correct magnitude of grazing dung’s contribution to P loss in surface runoff, especially when compared with studies that document much greater dissolved P concentrations in runoff when manure is applied by machine at rates to meet crop fertility (especially nitrogen) requirements (Kleinman and Sharples 2003; Daverede et al. 2004; Vadas et al. 2007b). However, it is clear that we validated our model with data from fairly well-controlled dung and runoff experiments. Validation is needed with data from larger scale studies where animals are allowed to freely graze and thus create greater temporal and spatial variability in dung deposition.

Conclusions

We developed a new model to simulate grazing cattle dung disappearance and P transformations and loss in runoff. The model simulates dung organic matter decomposition and assimilation into soil by bioturbation as a function of air temperature and dung moisture. We validated that the model can accurately predict rates of dung disappearance, using data from 12 published studies. The model also simulates four pools of inorganic and organic P, P mineralisation to inorganic WEP, leaching of dung WEP into soil by rain, and loss of dissolved inorganic P in runoff. We validated the ability of the model to reliably simulate these P processes using data from six published dung P transformation studies and six runoff studies. We are not aware of other existing, process-based models that simulate the same processes as our dung P model. Thus, our model represents a novel approach for assessing the environmental impact of grazing dairy and beef cattle. Further research should investigate the impact of dung deposition rate as a function of time and animal diet and type, where deposition occurs relative to runoff movement, weather conditions, and the ability of dung pad crusting to reduce P release to runoff.

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Manuscript received 14 September 2010, accepted 19 November 2010

http://www.publish.csiro.au/journals/sr