



CASE STUDY: Development of a Seasonal Prediction Model for Manure Excretion by Dairy Cattle

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ABSTRACT

More accurate estimates of dairy cattle manure excretion are needed for manure management, nutrient plans, renewable bioenergy production, and environmental assessment. Consequently, it is important to quantify manure excretion by dairy herds. Current estimates use only a few animal groups and average herd characteristics to estimate fixed rates of manure excretion throughout the year. However, manure excretion varies seasonally and should be predicted based on dynamic herd group characteristics. In addition, improved prediction parameters should be incorporated. This study describes the creation of a stochastic dynamic herd model to predict seasonal manure excretion according to herd characteristics regarding milk production, pregnancy rates, and culling rates using improved prediction parameters. The Markov-chain model employed defines more than 1,400 cow states according to parity, month in milk, and pregnancy status, and includes season of the year according to pregnancy and culling rates. Although overall estimates of our model were not substantially different from commonly used approaches, strong seasonal variations of manure excretion found with our model are missed when using

other approaches. Our model also gives the opportunity to tailor dairy farm specific parameters such as milk productivity, pregnancy rates, and culling rates to more accurate predictions. Predictions of the seasonal variation in dairy manure excretion aids in addressing issues related to manure use and recycling needs, bioenergy production, and assessment of environmental impacts.

Key words: Markov-chain, dynamic stochastic simulation, herd dynamic prediction, environmental impact, dairy manure excretion

INTRODUCTION

More accurate estimates of dairy cattle manure excretion (feces plus urine) are needed for manure management, nutrient plans, renewable bioenergy production, and environmental assessment. Manure excretion is unavoidable and an intrinsic part of any dairy farm production system; yet, specific amounts of manure excreted vary substantially and are not well understood. Calculated amounts of manure excretion are usually estimated using standard parameters and average herd characteristics (Van Horn et al., 2001, 2003; ASABE, 2005; Sporcic et al., 2006). However, parameters are periodically revised and new models are being developed (Karmakar et al., 2007) to better under-

stand herd dynamics and manure excretion characteristics.

An understanding of the seasonality of manure excretion is also critical for determining opportunities for manure use (Cabrera et al., 2006). For example, higher amounts of manure nutrients can be recycled in crop fields during spring and summer when plants are most actively growing; the potential for renewable energy produced from manure would decrease toward late summer, when lesser quantities of manure are excreted.

Better prediction equations have become available. For example, Weiss (2004) presented equations of manure prediction based on DMI and milk production from 232 treatments in Ohio. Nennich et al. (2005) compiled data from around the United States and parameterized prediction models that resulted in better prediction characteristics of manure excretion using milk production and DMI rather than BW. Work by Weiss (2004) and Nennich et al. (2005) are major advancements to current standards (USDA, 1992; ASABE, 1999, 2005) and provide increased accuracy in manure prediction. Therefore, the improved prediction equations should be incorporated into models for predicting manure excretion.

The objective of this research was to develop and evaluate a stochastic dynamic model of herd performance

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to predict seasonal manure excretion by using local herd characteristics and improved predictor parameters. The goal was to create a baseline model for Southwest conditions for integration with other dairy farm components to assess whole dairy farm opportunities for manure use and recycling.

MATERIALS AND METHODS

This study integrates a newly created simulation model of herd dynamics for the Southwest with the current parameterizations of manure excretion (Nennich et al., 2005) to predict manure excretion at the farm level, based on cow production stage and seasonality.

Stochastic Simulation of Milking Cow Dynamics

A Markov-chain approach (St-Pierre and Thraen, 1999; de Vries, 2004; Cabrera et al., 2006) simulates the dynamics of the dairy herd by calculating the number of milking cows (MC) in each of more than 1,400 definable cow production stages, by month. From these variables manure excretion is calculated. Cow production state is characterized by 3 dimensions: lactation or parity (l ; 1 to 9), month in milk (i ; 1 to 20), and month of pregnancy (j ; non pregnant 0 to 9 mo pregnant). For example, $MC_{2,10,5}$ denotes a group of cows in second lactation with 10 mo in milk that are 5 mo pregnant. Table 1 contains a list of all variables defined for the model. Because the breeding program starts after cows are over 2 mo in milk (standard voluntary waiting period of 60 d after calving), the months of pregnancy must be lower than the months in milk by at least 2 units ($i \geq j + 2$). Combinations in which months in milk are not higher or equal to pregnancy months plus 2 are excluded from the model.

Chances for milking cows to become pregnant (PG) and to be culled (CU) at any specific time depends on local indices that are affected by par-

ity, month of the year (m ; 1 = January and 12 = December), and month in milk. Therefore, coefficients of milk production (MK) by milking cow group can be characterized by the stages defined with l , m , and i . For example, $CU_{2,6,8}$ denotes the culling rate for a group of second parity cows in the month of June with 8 mo in milk. Indices used for model development in regard to pregnancy, culling, and milk production rates are described in next section.

A series of integrated equations explain the dynamics of the milking cows and their production characteristics. First, the numbers of milking cows in any state and month are calculated by subtracting the culled animals using Equation 1. [Au: please verify that all equations are correct]

$$MC_{l,i+l,j} = (MC_{l,i,j}) \times [1 - (CU_{l,m,i}/100)] \quad [1]$$

for all l, j , and m

Then, the number of pregnant (Equation 2) and nonpregnant (Equation 3) cows are calculated using the pregnancy rates. In typical dairy reproduction programs, cows are targeted to conceive between 2 and 12 mo of milk. A cow diagnosed as pregnant when 12 mo in milk will calve during mo 20, whereas a cow that is not pregnant by mo 13 will be culled.

$$MC_{l,i+l,j+l} = (MC_{l,i,j}) \times (PG_{l,m,i}) \quad [2]$$

for all $l, i = 2 - 12$, and m

$$MC_{l,i+l,0} = (MC_{l,i,0}) \times [1 - (PG_{l,m,i}/100)] \quad [3]$$

for all l and m

Dry cows and heifers are not described, but are accounted similarly in the model. Dry cows gestate for 9 mo and then move to the next parity. Heifers become pregnant between 12 and 23 mo of age. The model assumes 50% of all newly born calves are female.

To start a simulation, the total number of adult cows in a herd is assigned to the cow state of first lactation, first month of milk, and non-pregnant ($CM_{1,1,0}$). Then, the simulation model distributes these cows and populates all possible cow states. Empirical trials of the model indicate that the model needs to run for 144 mo (12 yr) in order to populate all cow states. The model was consequently designed to run internally from mo 1 to 144, maintaining the overall population of the herd. Then, it continues running using the actual pregnancy and culling rates of the farm being modeled, displaying the results from the mo 145 to 156, which is the 13th year (January to December). The model was developed in Visual Basic embedded in Excel software. The final application is an Excel file containing macros.

New Mexico Indices

This study uses parameters found in the Dairy Herd Information Association (DHIA) records for New Mexico, compiled in 2006 by the processing centers of Raleigh, NC (<http://www.drms.org/>), Provo, UT (<http://www.dhiprovo.com/>), and Agri-Tech of Visalia, CA (<http://www.agritech.com/>). Specific details on data collected through DHIA can be found at the Dairy Records Management System (<http://www.drms.org/dhia.htm>). [Au: please verify web address; unable to access] These records include monthly data from 23 dairy farms across New Mexico, which represents 14% of the dairy population of the state, including detailed information of number of cows, milk production, pregnancy rates, and culling rates. The averages of the monthly summaries were used as the seasonal indices for 1) pregnancy rates, 2) culling rates, and 3) first, second, and third and higher lactation milk productivity.

These reports, however, do not have enough information to capture the interaction of these indices with respect to the cows' state in months in milk. Under the assumption that

Table 1. Variables of the New Mexico manure model in alphabetical order

| Variable (unit/month) ¹ | Definition |
|--------------------------------------|--|
| DY _m (number) | days in month <i>m</i> |
| F | Factor proportional to the difference between actual and calculated herd milk production |
| <i>i</i> (number) | months of milk production after calving (1–20, mature cows) or months of age (1–32, heifers) |
| <i>j</i> (number) | months of pregnancy (0–9, unbred or up to 9 mo pregnant) |
| <i>l</i> (number) | lactation or parity (0–9, heifer or up to 9 lactations) |
| LW (kg) | animal live weight |
| <i>m</i> (month) | month of the year (1'12, from January to December) |
| MC _{<i>l,i,j</i>} (head) | cows in lactation <i>l</i> , month in milk <i>i</i> , and month of pregnancy <i>j</i> |
| M _e (kg/day) | wet manure excreted by dairy cattle |
| M _e ^d (kg/day) | wet manure excreted by dry cows |
| M _e ^m (kg) | wet manure excreted by milking cows |
| M _e ^{farm} (kg) | wet manure excreted by milking and dry cows |
| MK _{<i>i,m,k</i>} (kg/day) | milk production for cows in <i>i</i> months in milk, during <i>m</i> month of the year, and in <i>k</i> lactation |
| MILK _m (kg) | herd milk production |
| RHA (kg/yr) | rolling herd average, 12-mo moving herd average of milk production |
| CU _{<i>i,m,k</i>} (%) | probability of culling cows with <i>i</i> months in milk, during month <i>m</i> of the year, and in <i>k</i> lactation |
| PG _{<i>i,m,k</i>} (%) | probability of pregnancy for cows with <i>i</i> months producing milk during month <i>m</i> of the year and <i>k</i> lactation |

¹Unless otherwise stated.

such correlation is universal, data from Cabrera et al. (2006) and de Vries (2004) were used to include proportional variations (percentage of increase or decrease) relative to months in milk for pregnancy rates, culling rates, and milk productivity.

Pregnancy Rates in New Mexico. Pregnancy rate is the percentage of successful conceptions during the 21-day estrus period of open cows. The overall average for New Mexico is 21.63% (minimum = 19.27%, maximum = 23.86%). Data indicate that the pregnancy rate is lower between January and May (lowest in February) and higher between June and December (highest in November; Figure 1A). These rates are assumed to remain constant across lactations (Cabrera et al., 2006).

A three dimensional matrix containing lactation, month of the year, and month in milk was used in Equations 2 and 3 (PG_{*l,m,i*}) to predict the number of unbred and pregnant cows and the calving activity at any time in the herd.

Culling Rates in New Mexico. Culling rate is the percentage of cows leaving the herd for any reason, in-

cluding death loss. The overall average culling rate for New Mexico dairies is 30.12% annually or 2.51% monthly. Figure 1B shows the yearly culling rate by month. The culling rate increases in late summer and early fall (highest is October) and decreases during winter and spring (lowest is May). These rates are assumed to be constant across lactations (Cabrera et al., 2006).

A three dimensional matrix containing lactation, month of the year, and month in milk was used in Equation 1 (CU_{*l,m,i*}) to predict the number of culled animals and update the number of survivals.

Milk Productivity in New Mexico. The overall rolling herd average (RHA) or average annual milk productivity per cow for the 23 herds in New Mexico for 2006 was 10,521 kg. Milk productivity increases with the number of lactations. Milk productivity is least during the first lactation (10,232 kg), greater in second lactation (11,142 kg), and even greater during the third and higher lactations (11,155 kg). Seasonal trends in milk productivity were observed with greater milk productivity in spring

and early summer (greatest in May) and lower productivity in late fall and early winter (lowest in November; Figure 1C).

A three dimensional matrix containing lactation, month of the year, and month in milk (MK_{*l,m,i*}) is used to predict the total herd milk production for any month according to lactation stage and month in milk.

Prediction of Milk Production in New Mexico

Milk (MILK) is predicted by aggregating the amount of milk produced by every state of milking cow in every month, multiplied by the number of cows in such state (Equation 4).

$$\text{MILK}_m = \sum_{l=1}^9 \sum_{i=1}^{18} \sum_{j=0}^7 (MC_{l,i,j}) (MK_{l,m,i}) \quad [4]$$

for *m* = any month

In order to tailor site specific predictions, milk productivity or RHA should be entered by the user instead of leaving the default to the average of 10,521 kg/cow per year. The RHA

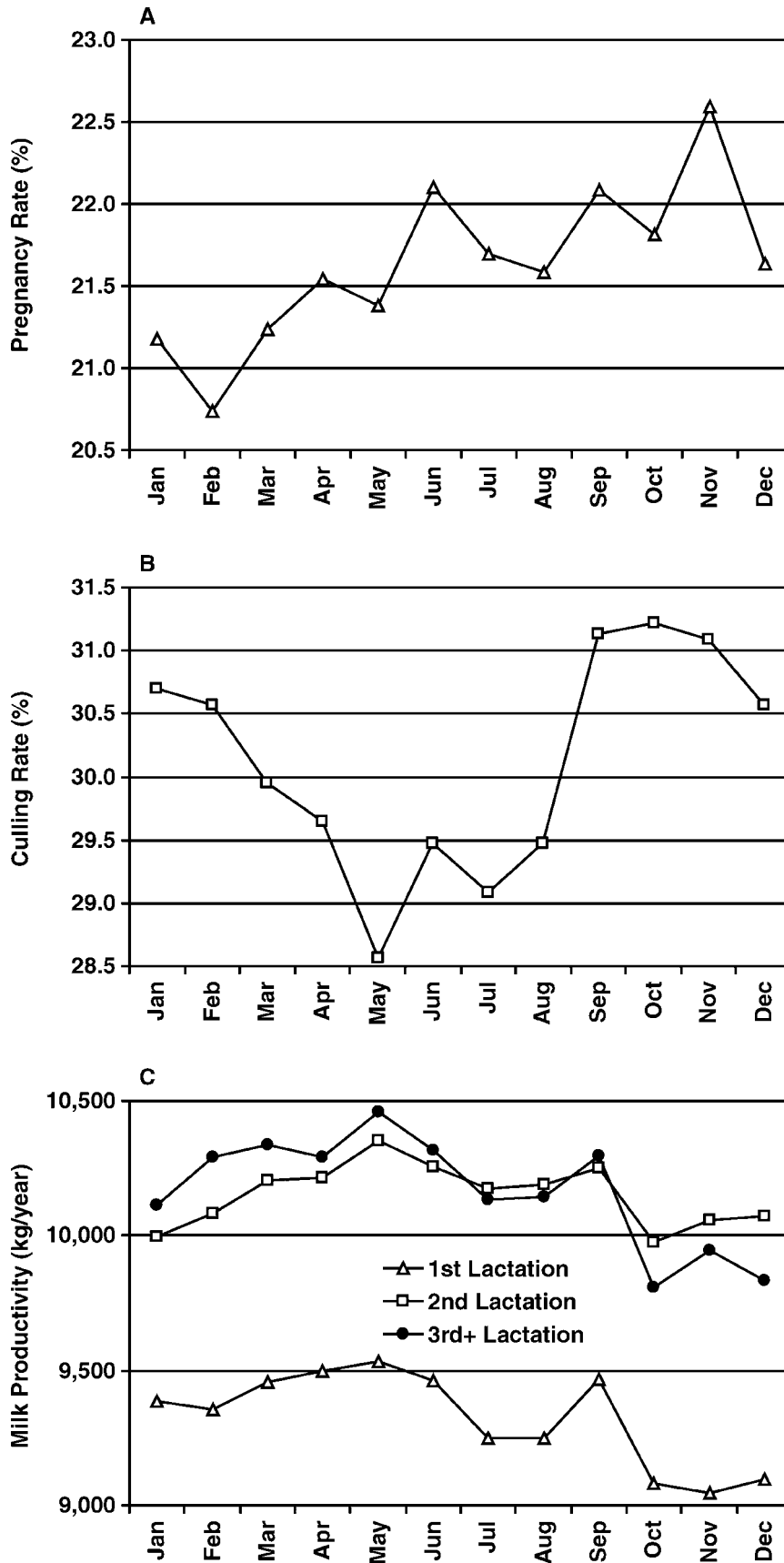


Figure 1. Pregnancy or conception rates (A), yearly culling rates (B), and milk productivity by lactation (C) in New Mexico by month.

is a key parameter in the prediction of manure excretion and is a well-known parameter in any dairy farm. The model includes an algorithm that adjusts the milk production curves of all cow states to match the user-defined RHA within a 5% range of the entered value, Equation 5.

If $MILK_m > 1.05 \times RHA$
then $MK_{l,m,i} \times F$, and

If $MILK_m < 1.05 \times RHA$
then $MK_{l,m,i}/F$

[5]

until $\sum_m^{11+m} MILK_m = RHA \pm 5\%(RHA)$

F is a factor proportional to the difference between $MILK_m$ and RHA.

Prediction of Manure Excretion in New Mexico

Nennich et al. (2005) studied large datasets around the United States and found that in ranked order, milk production and DMI are better predictors of manure excretion by lactating cows than is BW alone. These findings open a new set of opportunities for improving manure excretion predictions. Milk production is used as the main manure excretion predictor in the model because information on farm milk production is readily available for any dairy farm during any time period.

Results from Nennich et al. (2005) indicate that a milking cow daily excretes 0.616 kg of manure for every kilogram of milk produced, in addition to the constant manure excretion value of 46.25 kg, Equation 6.

$$M_e = (MK) \times 0.616 + 46.25 \text{ (kg)} \quad [6]$$

This equation, however, does not include a factor that may reflect the changes in manure excretion according to month in milk. Using the same dataset, a new equation including months in milk was developed [Equation 7; T. D. Nennich (2006, [Au: include institution, city and state of Nennich], personal commu-

nication). This equation shows an increase of 0.66 kg of manure excreted for every increase in month of milk and an increase of 0.726 kg of manure for every kilogram of milk produced, in addition to the constant manure excretion value of 38.80 kg.

$$M_e = (MK) \times (0.726) + (0.66) \times (i) + 38.80 \text{ (kg)} \quad [7]$$

Equation 8 was integrated with Equations 1 to 5 to predict manure excretion at the farm level by using milk production and cow state as main predictors. Equation 8 predicts manure excretion by an individual dairy farm during any month. A specific dairy farm is defined by the following parameters: number of adult cows, RHA, pregnancy rate, and culling rate.

$$m_e^m = \sum_{l=1}^9 \sum_{i=1}^{18} \sum_{j=0}^7 (MC_{l,i,j}) \left[(MK_{l,m,i})(0.33) + (0.66)(i) + 38.80 \right] (DY_m) \text{ (kg)} \quad [8]$$

for $m =$ any month

[Au: Please indicate placement of close bracket in equation]

where DY_m is the number of days in month m .

In addition, between 6 and 15% of adult cows are in a dry state (not producing milk) at any time and have a different rate of manure excretion than lactating cows. Therefore, the model used the ASABE (2005) standards that indicate that a dry cow produces 38.05 kg of manure in a day (Equation 9).

$$M_e^d = \sum_{l=1}^9 \sum_{i=12}^{20} \sum_{j=7}^9 (MC_{l,i,j}) (38.05) (DY_m) \text{ (kg)} \quad [9]$$

for $m =$ any month

The overall manure excreted in a dairy farm in a month is calculated by adding Equations 8 and 9 (Equation 10).

$$M_e^{\text{farm}} = M_e^m + M_d^d \text{ (kg) in any month} \quad [10]$$

Outcomes from the model are compared through Sensitivity Analyses (Johnson et al., 2007) regarding 1) pregnancy rates, 2) culling rates, and 3) milk productivity for New Mexico conditions and are summarized and aggregated by counties across the state. Seasonal outcomes from the model are also evaluated across years for a specific dairy farm in New Mexico.

RESULTS AND DISCUSSION

Manure Excretion for an Average Dairy in New Mexico

The model predicted the production of 45,812 [Au: write out TM] (TM) of wet manure per year for an average dairy farm in New Mexico that has 2,000 adult cows and the average DHIA indices for RHA or milk productivity (10,521 kg/cow per year), pregnancy rate (21.63%), and culling rate (30.12%). A total of 93% of this excretion was predicted to be from the milking cows, whereas the remaining 7% was from the dry cows.

These manure excretion predictions have strong seasonal variations throughout the year. Excretions are lower during September through De-

ember, medium during January through March and in August; and higher between April and July (Figure 2). The variation in manure excretion ranges from 3,510 to 3,928 TM/month (Figure 2). The trend toward more manure excretion between April and July occurs for several reasons. First, pregnancy rates are higher in the second half of the year (Figure 1A); consequently, there are more calves born and greater numbers of milking cows after the winter season. Second, culling rates are lower during the April through August period (Figure 1B); consequently, the number of cows is higher during these months. And third, milk productivity per cow increases between April and June (Figure 1C). During April through July there is greater milk production and consequently more manure excretion.

Van Horn et al. (2003) proposed an average of 63 kg of daily excretion for dairy cattle, which was based upon averaging high, medium, and low production cows with dry cows. The most recent standards indicate that lactating cows produce 68 kg and dry cows 38 kg of manure daily (ASABE, 2005), resulting in an average of approximately 66 kg of wet manure per cow per day. Using these approaches, overall dairy farm manure excretion is assumed to be constant throughout the year, and consequently is estimated by multiplying the daily aver-

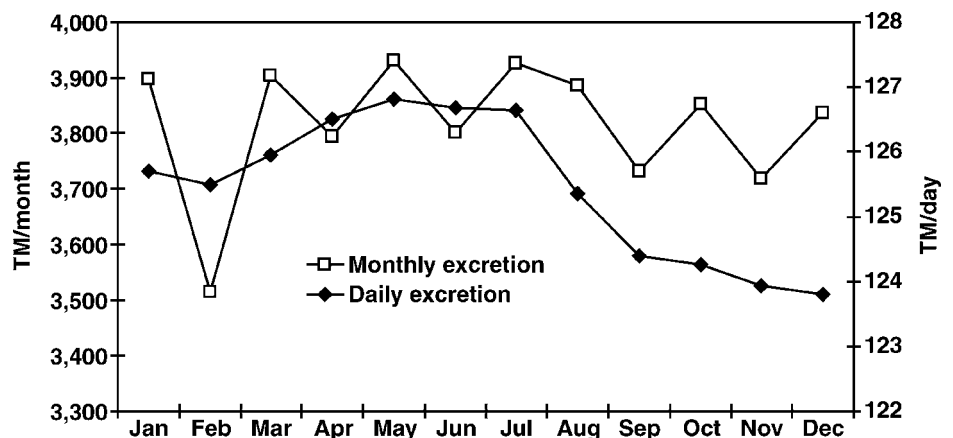


Figure 2. Manure excretion prediction in a 2,000-cow New Mexico dairy farm. TM = [Au: define TM].

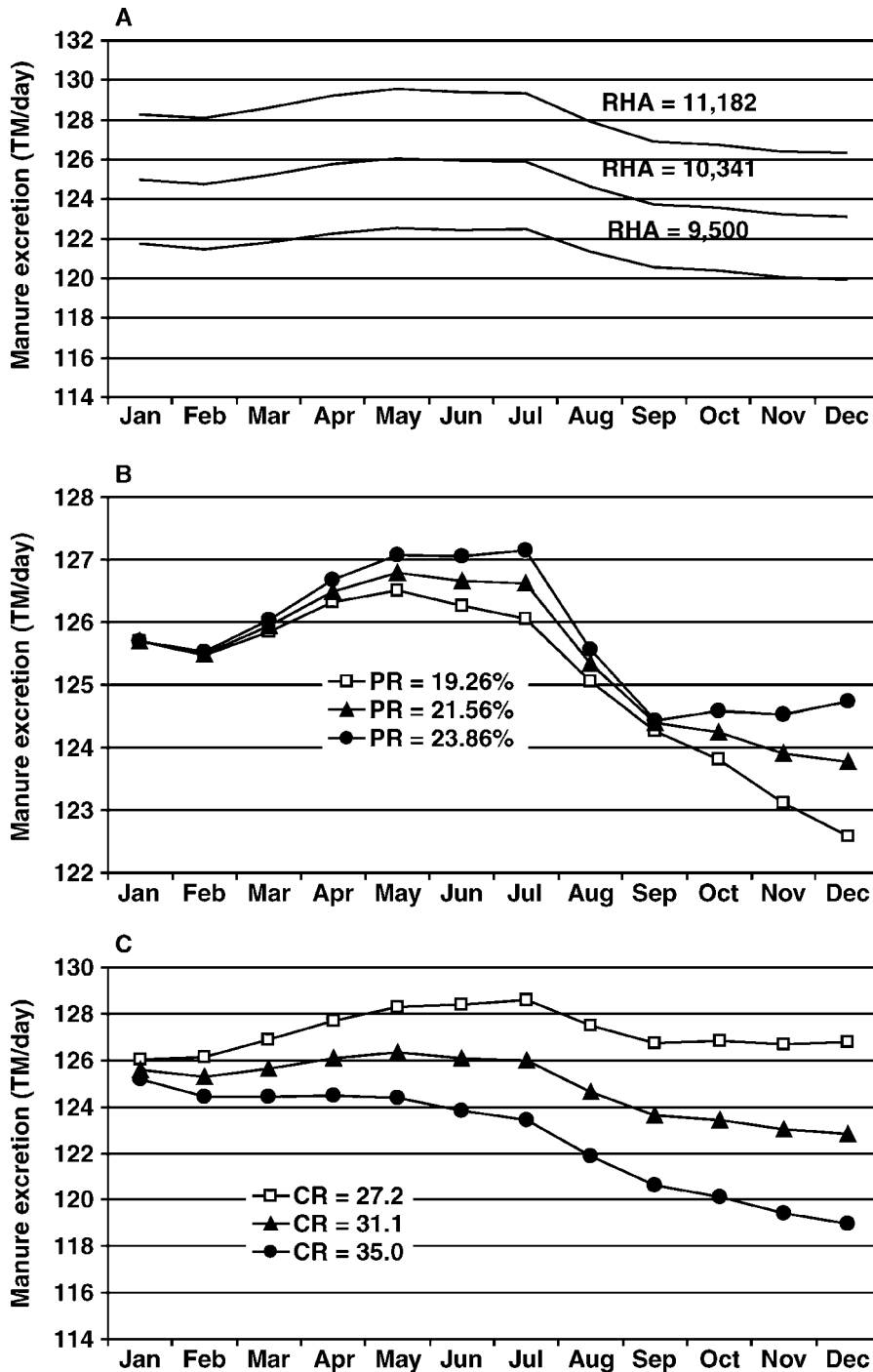


Figure 3. Manure excretion at different (A) milk productivity rates [rolling herd averages (RHA) in kilograms per cow per year], (B) pregnancy rates (PR = pregnancy rate), and (C) culling rates (CR = culling rate). TM = [Au: define TM. Also, is legend correct as edited?]

age excretion per cow by the number of cows in a herd.

Overall model predictions averaged 63 kg/cow per day, which are not substantially different from Van Horn et

al. (2003) or ASABE (2005) estimates — 4% lower than those proposed by the ASABE (2005) and virtually the same as those used by Van Horn et al. (2003). However, our

model differs from the earlier approaches by providing seasonal estimates by tailoring dairy farm specific parameters such as milk productivity, pregnancy rates, and culling rates.

Milk production exhibits seasonal fluctuations. The “spring flush” is well documented with milk production levels that can be as much as 20% greater than the yearly average (Cabrera and Hagevoort, 2007). Similarly, hot summers and cold winters can decrease milk production by similar amounts. This seasonality or environmental effect is not exclusive to milk production, but also impacts reproductive performance, health or disease outbreaks, feed and water consumption, and manure excretion (Jonker et al., 2002; Nennich et al., 2003).

Sensitivity of Manure Excretion to Milk Productivity (RHA)

Milk productivity (RHA) in the 2006 New Mexico dairy records varied between 9,500 and 11,181 kg/cow per year. Using average parameters for culling rates (30.12%) and pregnancy rates (21.63%), the variation in manure excretion was evaluated with respect to variations in the RHA. As expected, the excretion of manure varies in direct relation to the RHA. More specifically, for a 17.70% increase in RHA (9,500 to 11,182 kg/year), manure excretion increased 5.48% (44,317 to 46,746 TM/year; Figure 3A). Seasonal variation of manure excretion, within year, for differing rates of milk productivity and defined culling and pregnancy rates was also directly related to RHA.

Sensitivity of Manure Excretion to Pregnancy Rate

The observed pregnancy rate in the DHIA New Mexico records for 2006 varied from 19.23 to 23.86%. Using the average RHA of 10,521 kg/cow per year and the culling rate of 30.12%, the model predicted manure excretion for different pregnancy rates for a typical 2,000-cow dairy op-

Table 2. Predicted manure excretion ([Au: define TM]; TM) by dairy cattle in New Mexico

| | Chaves | Curry | Roosevelt | Doña Ana | Lea | Eddy | Others ² | New Mexico wet manure | New Mexico dry manure ³ |
|-------------------------------|-----------------------|-----------|-----------|-----------|---------|---------|---------------------|-----------------------|------------------------------------|
| No. of cows ¹ | 90,000 | 66,000 | 65,000 | 53,000 | 25,000 | 19,000 | 22,000 | 340,000 | 340,000 |
| | TM of manure excreted | | | | | | | | |
| January | 175,274 | 128,534 | 126,587 | 103,217 | 48,687 | 37,003 | 42,845 | 662,146 | 86,079 |
| February | 157,976 | 115,850 | 114,094 | 93,030 | 43,882 | 33,350 | 38,617 | 596,799 | 77,584 |
| March | 175,450 | 128,663 | 126,713 | 103,320 | 48,736 | 37,039 | 42,888 | 662,810 | 86,165 |
| April | 170,467 | 125,010 | 123,115 | 100,386 | 47,352 | 35,987 | 41,670 | 643,988 | 83,719 |
| May | 176,515 | 129,445 | 127,483 | 103,948 | 49,032 | 37,265 | 43,148 | 666,836 | 86,689 |
| June | 170,583 | 125,094 | 123,199 | 100,455 | 47,385 | 36,012 | 41,698 | 644,425 | 83,776 |
| July | 176,162 | 129,185 | 127,228 | 103,739 | 48,934 | 37,190 | 43,062 | 665,499 | 86,515 |
| August | 174,311 | 127,828 | 125,891 | 102,650 | 48,420 | 36,799 | 42,609 | 658,508 | 85,606 |
| September | 167,359 | 122,730 | 120,870 | 98,556 | 46,488 | 35,332 | 40,910 | 632,244 | 82,192 |
| October | 172,689 | 126,639 | 124,720 | 101,695 | 47,969 | 36,457 | 42,213 | 652,380 | 84,810 |
| November | 166,606 | 122,178 | 120,327 | 98,112 | 46,280 | 35,173 | 40,726 | 629,400 | 81,822 |
| December | 171,929 | 126,081 | 124,170 | 101,246 | 47,757 | 36,296 | 42,027 | 649,507 | 84,436 |
| Total (year) | 2,055,321 | 1,507,235 | 1,484,398 | 1,210,356 | 570,923 | 433,901 | 502,411 | 7,764,543 | 1,009,390 |
| Total (year) dry ³ | 267,191 | 195,940 | 192,972 | 157,346 | 74,220 | 56,408 | 65,313 | — | — |

¹2006 statistics, NASS (2007).

²Include Sierra, Valencia, Bernalillo, Torrance, and Luna counties.

³13% manure DM basis, ASABE (2005).

eration in New Mexico (Figure 3B). As expected, higher pregnancy rates lead to more lactating females and therefore greater predicted manure excretion. However, this impact is not monotonic because in months like February and September, the excretion would be very similar for different pregnancy rates, whereas it would have larger variation in months like July and December. These differences are because of the interaction of pregnancy rates with culling rates and milk productivity according to months in milk and season of the year. Changes in pregnancy rates cause herd population dynamic to change, which will affect culling and milk productivity changes and consequently the seasonal manure excretion. It happens, for example, that for the months of July and December, higher pregnancy rates influences lower culling rates and higher productivity, producing a large excretion difference. The opposite is true for the months February and September, when higher pregnancy rates have a compensatory impact of increasing

culling rates and decreasing productivity, yielding similar excretion rates.

Sensitivity of Manure Excretion to Culling Rate

The observed annual culling rate in the DHIA New Mexico records for 2006 varied from 27.2 to 35.0%. Using the New Mexico DHIA average RHA of 10,521 kg/cow per year and pregnancy rate of 21.63%, the model predicted higher amounts of manure excretion for lower culling rates (Figure 3C). As expected, lower culling rates result in more animals remaining in the herd. At a steady pregnancy rate, lower culling rates determine size expansion and consequently higher amounts of manure excreted. In Figure 3C the difference in manure excretion due to different culling rates increases over time because there will be an accumulated effect of culling animals, determining more or less animals carried over from one month to the next.

Manure Excretion by Counties and Geographic Regions in New Mexico

Assuming the DHIA average data for New Mexico of RHA of 10,521 kg/cow per year, pregnancy rate (21.63%), and the culling rate (30.67%), manure excretion by county in New Mexico was predicted using statistical data of geographic dairy cattle distribution in the state (NASS, 2007). Table 2 shows predicted manure excretion, by month, in New Mexico counties where dairy farms are located.

Dairy cows in the state of New Mexico produce 7.7 million TM of wet manure per year, which is equivalent to 1.0 million TM of dry manure. Thus, there is an opportunity and a need for the monthly use of 84,116 TM of dairy manure, with seasonal ranges from 77,584 TM (February) to 86,689 TM (May). Manure excretion is concentrated in the top milk producing counties of Chaves (20,537 to 22,947 TM/month), Curry (15,060 to 16,828 TM/month), Roose-

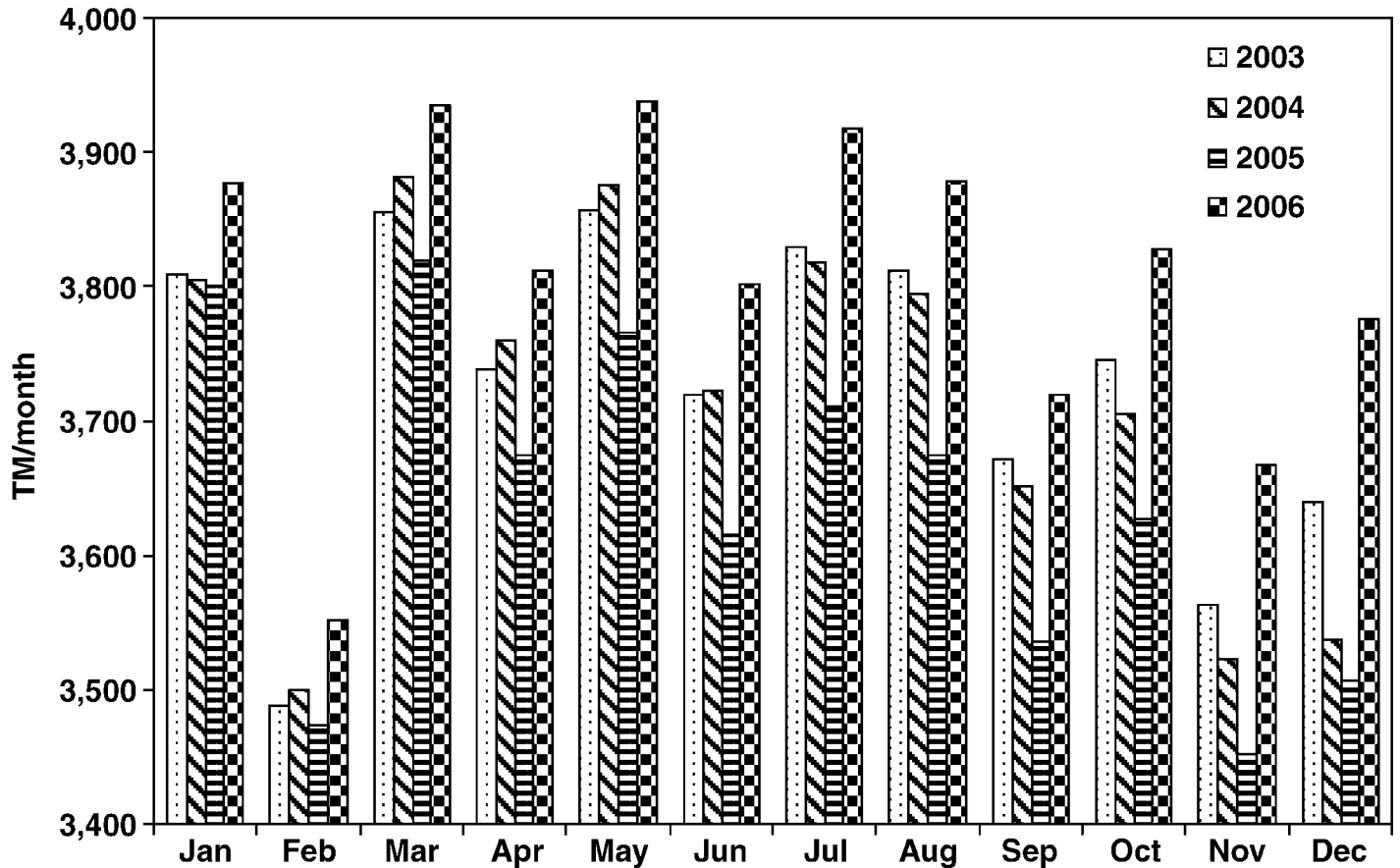


Figure 4. Seasonal manure excretion for a 2,000-cow dairy during 2003 through 2006. TM = [Au: define TM].

velt (14,832 to 16,572 TM/month), and Doa Ana (12,094 to 13,513 TM/month).

Evaluation of Seasonal Manure Excretion across Years

In order to test year to year seasonal variations in manure excretion, we selected a dairy farm and used its monthly data to run the model for 4 yr. Figure 4 displays the manure excretion estimates on a monthly basis. Managerial and environmental changes, including weather conditions, are reflected in pregnancy, culling, and productivity rates, which affect the seasonality of manure excretion. This evaluation confirmed the general seasonal pattern of higher excretion amounts during spring and summer and lower during fall and winter. However, there are specific monthly variations across years that are attributed to changes in environ-

mental and managerial conditions, yet those intra-year changes do not override the general seasonal patterns.

IMPLICATIONS

Predictions of the seasonal variation in dairy manure excretion is a substantial improvement over previous approaches and creates better opportunities for calculating manure recycling needs and aids in addressing issues related to bioenergy production, manure management, and assessment of environmental impacts. The predictions generated by the developed model are consistent with local and national predictions. Nonetheless, the model could likely be improved by collecting and including local experimental data to parameterize regional prediction equations of manure excretion. The stochastic

herd dynamic simulation model is considered a baseline model. Other modules can be developed and interfaced providing ample possibilities to study dairy farm systems along with increased input from producers. Until fully validated, caution is advised when using results of the model outside the parameters of the DHIA records for milk productivity, pregnancy rates, and culling rates that were used in the model development.

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