THE MANITOBA LAND CALCULATOR: A TOOL TO ESTIMATE LAND REQUIREMENTS FOR MANURE APPLICATION IN MANITOBA, CANADA

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HIGHLIGHTS

- The Manitoba Land Calculator is a tool to estimate land requirements for new and expanding livestock operations.
- This new tool reflects Manitoba production practices and recent advances in animal and crop performance.
- Considerably more land is needed for management of manure phosphorus than when only nitrogen is considered.
- Sufficient land for application of manure supports the environmental sustainability of livestock production.

ABSTRACT. *The planning of new livestock and poultry facilities or expansion of existing facilities should ensure sufficient land for manure application. Decision support tools used to establish land requirements for manure nutrients should take into consideration advances in animal genetics, performance, feeding strategies, and available feeds. This article presents a new tool for estimating land requirements for new and expanding pig, beef, dairy, and poultry operations in the province of Manitoba, Canada. The Manitoba Land Calculator (MLC) estimates land requirements for manure nitrogen (N) and phosphorus (P). It uses a mass balance approach to estimate nutrient excretion by livestock and poultry based on typical Manitoba feeding practices, weight gain, and production cycles. Crop nutrient utilization and removals can be calculated for 20 common crops grown in Manitoba using reliable long-term yields and farm-specific crop areas. Two case studies (pig and poultry) were selected from the Livestock Technical Review Public Registry on the Government of Manitoba website to illustrate the inputs and outputs associated with the MLC. The results indicated that land requirements increased by 4.6-fold and 5.7-fold for the poultry and pig operations, respectively, compared to the previous provincial methodology due to the inclusion of P in the model. Securing additional land during the planning stages will support the implementation of nutrient stewardship principles that ensure the long-term environmental sustainability of livestock operations.*

Keywords. *Animal production, Land requirements, Livestock and poultry, Manure, Mass balance, Nutrient excretion.*

Agricultural systems are facing significant pressure to increase productivity to meet the food demand of a growing population (Delgado et al., 2019). Satisfying the food demand resulting from population growth will require an increase in both crop and animal production (Alexandratos and Bruinsma, 2012; Delgado et al., 2019; Mottet et al., 2017). While livestock products are critical to meet future food demand, animal production systems have been under increasing scrutiny due to their potential negative impacts on the environment. Pollution from manure is the primary environmental concern

(Subbotin et al., 2017). While manure is an excellent source of nutrients for crop production (Long et al., 2018; Thayer et al., 2012; Yang et al., 2016), excess N and P build up in soils when manure is applied above crop nutrient requirements, increasing the risk of loss to surface and groundwater (Lory et al., 2008; van Dijk et al., 2016; Velthof et al., 2014). However, this dynamic depends on manure nutrient availability (Lory et al., 2008), which can vary spatially and temporally (Andersen and Pepple, 2017).

To improve the environmental sustainability of livestock and poultry production and to mitigate potential negative environmental impacts, beneficial nutrient management practices are needed. The 4R nutrient stewardship framework (right source, right rate, right timing, and right placement) is intended to maximize crop uptake and minimize losses of nutrients (Cordeiro et al., 2016). Among the 4Rs, the application rate is one of the most important factors affecting nutrient losses from manured land (Ontkane et al., 2006). In some instances, the application rate has been deemed more

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influential than timing, method of application, and mineralization rates (Dinnes et al., 2002; Power and Schepers, 1989).

Sufficient land is critical for sustainable manure application rates over the long-term. One method of accurately estimating land requirements for livestock and poultry operations is to balance nutrient excretion by the livestock and poultry with nutrient utilization and/or removal by the crops grown on the land receiving the manure. Several tools exist to estimate nutrient excretion from livestock and poultry. For example, the Integrated Farm System Model (IFSM) uses process-based simulations to estimate nutrient excretion in beef and dairy operations (Rotz et al., 2012). ASABE Standard D384.2 (ASABE, 2005) provides an equation-based approach using empirical data that integrates animal feeding practices and performance into final estimates for total solids and N and P excretion for seven livestock and poultry species (Koelsch, 2006). Mass balance methodologies have also been developed for estimating manure nutrient excretion (Angel et al., 2003; Applegate et al., 2003).

Nutrient management tools are critical for environmental sustainability in livestock and poultry-intensive areas, such as some areas in the Province of Manitoba in Canada (Loro et al., 2013). Manitoba accounts for 4%, 11%, 24%, and 6% of the total Canadian production of dairy, beef, pigs, and chickens (broiler and layers), respectively (Canada, 2020), but this production is expected to increase due to provincial strategies aimed at sustainably increasing livestock and poultry production in Manitoba by 35% (Manitoba, 2019). To facilitate sustainable livestock and poultry expansion, the Government of Manitoba has developed the Manitoba Land Calculator (MLC), a user-friendly tool that estimates the amount of land needed for long-term management of the manure N and P generated by livestock and poultry operations. The objectives of this article are to describe the MLC and present two case studies comparing land requirements estimated by the MLC and by the previous methodology used by the province.

MATERIALS AND METHODS

MANITOBA LAND CALCULATOR (MLC)

The MLC is a tool developed and currently used by Manitoba Agriculture and Resource Development to estimate the provincial land requirements for new and expanding livestock and poultry operations that are seeking municipal approval to build livestock and poultry facilities. The MLC is Microsoft Excel-based and is comprised of two major sections: (1) livestock and poultry nutrient excretion, and (2) crop nutrient uptake and removal. Nutrient excretion can be estimated for pig (P), beef (B), dairy (D), and poultry (Po) operations (table 1). All livestock and poultry categories can be combined into a single farm, and the total nutrient excretion of the farm can be estimated. The MLC uses a mass balance approach in which the nutrients excreted in manure are the difference between the nutrients ingested in feed and the combined amount of nutrients retained as weight gain and exported in production (i.e., milk for dairy cows and eggs for laying hens). Crop nutrient uptake and removal can be estimated for 20 crops based on cropped area, realistic long-term yields, and crop nutrient concentrations (table 2). Finally, the land base required for any

Table 1. Livestock and poultry categories and respective operations and feeding groups in the Manitoba Land Calculator (MLC).

Category	Operation Type ^[a]	Feeding Group
Pig (P)	NA	Gestating sow
	NA	Nursing sow
	NA	Nursing litter
	NA	Live cull sow
	NA	Bred gilt
	NA	Gilts (purchased)
	NA	Boars
	NA	Weanlings/nursery
Beef (B)	NA	Growers/finishers
	Cow calf	Mature cows (>2 years old)
	Cow calf	Bred heifer (14 months to 2 years)
	Cow calf	Replacement heifers (7 to 14 months)
	Cow calf	Nursing calves (0 to 7 months)
	Cow calf	Bulls
	Feeder	Feedlot cattle, long keep
	Feeder	Feedlot cattle, short keep
Dairy (D)	Feeder	Backgrounders, pasture
	Feeder	Backgrounders, confined
	NA	Lactating mature cows
	NA	Lactating first calf heifer
	NA	Dry cows
	NA	Calves, 0 to 3 months
	NA	Calves, 4 to 13 months
	NA	Replacement, >13 months
Poultry (Po)	Chicken	Light broilers
	Chicken	Broilers
	Chicken	Broiler breeder pullets
	Chicken	Broiler breeder hens
	Eggs	White layer pullets
	Eggs	White layer hens
	Eggs	White breeder pullets
	Eggs	White breeder hens
	Eggs	Brown layer pullets
	Eggs	Brown layer hens
	Eggs	Brown breeder pullets
	Eggs	Brown breeder hens
	Turkey	Broiler turkey (0 to 9 weeks)
	Turkey	Hen turkey (0 to 11 weeks)
	Turkey	Heavy hens (0 to 14 weeks)
	Turkey	Toms (0 to 14 weeks)
	Turkey	Breeding hen growers (0 to 30 weeks)
	Turkey	Breeding hens (31 end of lay)
	Turkey	Breeding tom grower (0 to 17 weeks)
	Turkey	Breeding tom grower (17 to 30 weeks)
	Turkey	Breeding tom (31 end of lay)

^[a] NA = not applicable for the operation type.

new and expanding livestock and poultry operation is calculated using the total nutrient excretion for the farm and the average nutrient uptake and removal for the crop rotation.

A combination of user-defined animal and crop inputs (table 3), optional default values, constants (table 4), and a series of equations (table 5) comprises the workflow of the MLC (fig. 1). The user must input the total number of animals in each animal category and the type of manure storage system to estimate N losses from the housing system and storage. Default values are provided for animal weights but can be modified by the user for some categories of beef and poultry, as these livestock and poultry systems have a wide range of production practices. Similarly, the number of days on feed per cycle and the number of cycles per year also have default values that can be adjusted for beef and poultry (table 3). The required user-defined crop inputs include the land area for each crop grown and the respective realistic long-term average yield for each crop (table 2).

Table 2. Nitrogen and phosphorus concentrations in western Canada crops (adapted from Manitoba, 2009).

Crop	P ₂ O ₅ Removal ^[a] (kg Mg ⁻¹)	N Uptake ^[b] (kg Mg ⁻¹)
Alfalfa	6.9	29
Barley grain	8.8	29
Barley silage	5.9	17.2
Canola	20.8	63.8
Corn grain	7.9	27.3
Corn silage	6.4	15.6
Dry edible beans	13.9	-
Fababeans	17.9	84
Flax	11.6	51.4
Grass hay	5.0	17.1
Lentils	10.3	50.8
Oats	8.1	33.4
Pasture (grazed)	5.0	17.1
Peas	11.5	51
Potatoes	0.9	5.7
Rye	8.0	29.8
Soybeans	14.0	86.7
Sunflower	11.0	-
Spring wheat	9.8	35.2
Winter wheat	8.5	22.5

^[a] P removal in the harvested portion of the crop is used because repeated applications of manure above crop removal rates result in long-term buildup of soil test P and increased risk to surface water.

^[b] N uptake by the crop, which is larger than N removal, is used to more accurately estimate the land needed for N-based manure application rates, which are the standard in Manitoba.

Table 3. Inputs required by the MLC for estimating nutrient excretion for the pig (P), beef (B), dairy (D) and poultry (Po) categories.

Input	Description	Categories ^[a]
1	Manure storage and treatment ^[b]	P, B, D, Po
2	Number of animals (places)	P, B, D, Po
3	Weight in (kg) ^[c]	P, B, D, Po
4	Weight out (kg) ^[c]	P, B, D, Po
5	Days on feed per cycle ^{[c],[d]}	B, Po
6	Number of cycles per year ^{[c],[d]}	B, Po

^[a] Each input applies to all categories listed.

^[b] The storage type, defined by the user, generates N volatilization values as follows: 10% of the total N in the manure for in-barn losses and covered liquid storage; 20% for uncovered liquid storage in steel or concrete tanks, solid manure sheds, and manure pack with no field storage; 30% for uncovered liquid storage in earthen structures or mole hills (a system used in dairy production in Canada in which manure is pushed or pumped into an engineered storage and stacks as the liquid fraction pools around the solids); and 40% for compost, field storage, mechanically dried manure, and manure deposited on pasture.

^[c] For these inputs, defaults are provided but can be modified by the user for beef and poultry operations.

^[d] For pig and dairy operations, these variables are constants (table 4).

The MLC sequentially calculates the livestock and poultry average weight, weight gain per cycle (table 5, eqs. 1 and 2) and feed consumption per day for beef and dairy (as a percentage of body weight, table 5, eq. 3). For pigs, feed consumption rates are constants (table 4, constants 2 and 3). The MLC converts feed consumption to protein consumed per animal per day (table 5, eq. 4) and per cycle (table 5, eq. 5) based on the typical protein content of Manitoba feeds and then into feed N consumed per animal per cycle (table 5, eq. 6). Feed P consumed per animal per day (table 5, eq. 7) and per cycle (table 5, eq. 8) is also estimated using the typical P content of Manitoba feeds. The MLC estimates milk consumption (table 5, eq. 9) by young stock (i.e., nursing pig litters and beef calves, table 1) to account for the nutrients lost by the sow/dam via milk production (table 5, eqs. 10 to 16).

The total amounts of N and P retained in animal weight gain (table 5, eqs. 17 and 18), as well as the N and P exported in dairy milk (table 5, eqs. 19 and 20) and eggs (table 5, eqs. 21 and 22), are estimated per cycle using literature values for N and P in whole animals, milk, and eggs (table 4, constants 10, 13, 14, 15, 17, and 18). Total retention for the cycle is then summed for all livestock and poultry (table 5, eqs. 23 and 24). The MLC estimates the amounts of nutrients excreted as the difference between the total amounts of N and P consumed and the total amounts retained (table 5, eqs. 25 and 30) per cycle (table 5, eqs. 26 and 31) and per year (table 5, eq. 27). Phosphorus excreted is converted to P₂O₅ excreted per cycle, per year, and per flock or herd per year (table 5, eqs. 32 to 34) to be consistent with crop removals, which are expressed in P₂O₅. The total N excreted is adjusted for volatilization losses in the animal housing and during storage (table 5, eq. 29). The P and volatilization-adjusted N excreted are then balanced with crop P removal and crop N uptake to generate the land requirements. The MLC does not make recommendations for application rate based on timing, form, and method of application. For that, farmers in Manitoba prepare manure management plans (Manitoba, 2021a) that consider specific aspects of manure handling, nitrogen volatilization due to land application, residual soil nutrient values, and specific crop nutrient requirements.

FARM PRACTICES GUIDELINES (FPG)

The Farm Practices Guidelines (FPG) for livestock and poultry producers in Manitoba (Manitoba, 1994, 1995a, 1995b, 1998a, 2000) described manure management systems and practices for pig, beef, dairy, and poultry operations that reduced the risk of pollution and minimized odor experienced by neighbors. They contained the former methodology used by the Province of Manitoba for estimating the land requirements for new and expanding livestock and poultry operations. This methodology was used in the 1990s and early 2000s when the main public concern was excess application of manure N that could result in nitrate contamination of groundwater.

In contrast to the MLC, the FPG estimated land requirements based on N only. The FPG used a simple five-step calculation that required animal numbers and days on feed as inputs (fig. 2) and knowledge of the manure and cropping systems. The number of animals was converted to animal units (AU) derived from ASABE Standard D384.1. (ASABE, 2003) using daily N excretion values for dairy, beef, pigs, layers, broilers, and turkeys (0.45, 0.34, 0.52, 0.84, 1.1, and 0.62 kg per 1000 kg live animal weight per day, respectively) adjusted to achieve 73 kg N excreted year⁻¹. The pig AU were further adjusted to account for Manitoba feeding practices using the broad assumption that 70% of the N consumed was excreted (Manitoba, 1998a). The land requirements for new and expanding livestock and poultry operations were estimated in the FPG by adjusting the AU using a series of multiplication factors to account for N losses related to various storage and management practices (table 6) and crop N utilization for annual and perennial crops on light, medium, and heavy textured soils when manure was applied in the spring or fall (table 7).

Table 4. Constants used by the MLC to estimate nutrient excretion for pig (P), beef (B), dairy (D), and poultry (Po) operations.

Constant	Description	Units	Categories	Range ^[a]	Source ^[b]
1	Average daily milk production per cow ^[c]	kg d ⁻¹	D	28 to 31	CanWest DHI (2018)
2	Feed consumed per animal per day	kg d ⁻¹	P ^[d]	2.3 to 6.5	NRC (2012); PIC (2013)
3	Feed consumed per animal per cycle	kg cycle ⁻¹	P ^[e]	34 to 308	NRC (2012)
4	Feed consumed per animal per day	% of body weight	Po	2.61 to 157.5	Amy Johnston, ARD, pers. comm. (20 Oct. 2019)
			B	2.1 to 2.7	Kim Ominski, University of Manitoba, pers. comm. (23 Jan. 2015); Yurchak and Okine (2004)
			D	2.0 to 3.7	NRC (2001)
5	Days until weaned	days	P	21	Robyn Harte, ARD, pers. comm. (20 Nov. 2019)
			B	210	Kim Ominski, University of Manitoba, pers. comm. (23 Jan. 2015)
6	Crude protein ^[f]	%	P	14 to 20	Robyn Harte, ARD, pers. comm. (20 Nov. 2019)
			B	10 to 12	Kopp et al. (2004)
			D	10.7 to 22.5	Plaizier et al. (2004)
			Po	11 to 23	Amy Johnston, ARD, pers. comm. (20 Oct. 2019)
7	Milk consumed per piglet per day	g	P	900	Adapted from Noblet and Etienne (1989)
8	Milk consumed per beef calf per day	kg	B	5.8	Kopp et al. (2004)
9	Protein content of milk for young stock	%	P	5.3	Csapó et al. (1996)
			B	3.8	Kopp et al. (2004)
10	N content per kg gain	g kg gain ⁻¹	P	26	Bikker and Blok (2017)
			B	26	Tamminga (2006)
			D	27	Andrew et al. (1994)
			Po	26 to 35	Liu et al. (2017); dos Santos et al. (2017); de Avila et al. (2003); Robinson and Robinson (1991)
11	P content of feed	%	P	0.46 to 0.64	Manitoba (2013); Robyn Harte, pers. comm. (20 Nov. 2019)
			B	0.19 to 0.33	Kopp et al. (2004)
			D	0.22 to 0.48	NRC (2001); Plaizier et al. (2004)
			Po	0.51 to 0.78	Amy Johnston, ARD, pers. comm. (20 Oct. 2019)
12	P content of milk for young stock	%	P	0.15	Bikker and Blok (2017)
			B	0.12	Hidirolou and Proulx (1982)
13	P content per kg gain	g kg gain ⁻¹	P	5.3 to 5.8	Bikker and Blok (2017)
			B	7.1	Tamminga (2006); Gibson et al. (2002)
			D	8.3	Marcondes et al. (2010)
			Po	4 to 6.6	Lambert et al. (2014); Shastak et al. (2012); Applegate et al. (2008)
14	Protein content of milk for market	%	D	3.3	CanWest DHI (2018)
15	P content of milk for market	%	D	0.09	Goselink et al. (2015); Plaizier et al. (2004)
16	Number of eggs per bird per cycle	n	Po	118 to 330	Amy Johnston, ARD, pers. comm. (20 Oct. 2019)
17	N content of egg	g egg ⁻¹	Po	1.16 to 1.7	Manitoba (2021b); Halley (2016); Ghane et al. (2015)
18	P content of egg	g egg ⁻¹	Po	0.09 to 0.21	Lambert et al. (2014); Neijat et al. (2011); Adeyeye (2009); Godwin et al. (2005)
19	Conversion factor for protein to N		P, B, D, Po	6.25	-
20	Conversion factor for P to P ₂ O ₅		P, B, D, Po	2.29	-
21	Number of piglets per litter	n	P	13.2	Manitoba (2019)
22	Number of cycles per year ^[g]	n	P	1.0 to 26.1	-
			B	1.0	-
			D	1.0 to 4.2	-
			Po	1.0 to 7.0	-
23	Days on feed per cycle ^[g]	days	P	14 to 365	-
			D	86 to 348	-

^[a] Constant ranges include values for all feeding groups within each livestock and poultry category (table 1), except where noted.

^[b] “pers. comm.” indicates personal communication.

^[c] Milk destined for market only.

^[d] Includes all pig feeding groups except nursery and grower/finisher pigs.

^[e] Includes nursery and grower/finisher pigs.

^[f] Percentage of feed consumed for pigs and poultry, and percentage of dry matter intake for dairy and beef.

^[g] For beef and poultry, these variables have default values that can be adjusted by the user.

Table 5. Equations used by the MLC to estimate nutrient excretion for pig (P), beef (B), dairy (D), and poultry (Po) operations.

Equation	Variable	Units	Categories	Mathematical Description ^[a]
Livestock and poultry weights				
1	Average animal weight	kg	P, B, D, Po	(Input 3 + Input 4) / 2
2	Weight gain per cycle	kg place ⁻¹ cycle ⁻¹	P, B, D, Po	Input 4 – Input 3
Feed consumption				
3	Feed consumed per animal per day ^[b]	kg d ⁻¹	P ^[c]	Constant 3 / Constant 23
			B, D	Eq. 1 × Constant 4
			Po	Constant 3 / Input 5
4	Feed protein consumed per place per day	kg d ⁻¹	P ^[c] , B, D, Po	Eq. 3 × Constant 6
5	Feed protein consumed per place per cycle	kg cycle ⁻¹	P ^[d]	Constant 2 × Constant 6
			B, Po	Eq. 4 × Input 5
			P, D	Eq. 4 × Constant 23
6	Feed N consumed per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 5 / Constant 19
7	Feed P consumed per place per day	kg d ⁻¹	P ^[d]	Constant 2 × Constant 11
			P ^[c] , B, D, Po	Eq. 3 × Constant 11
			P, D	Eq. 7 × Constant 23
8	Feed P consumed per place per cycle	kg cycle ⁻¹	B, Po	Eq. 7 × Input 5
Milk consumption				
9	Milk consumed per litter per day	g	P	Constant 7 × Constant 21
10	Milk protein consumed per litter/calf per day	g litter ⁻¹ d ⁻¹	P	Eq. 9 × Constant 9
		kg calf ⁻¹ d ⁻¹	B	Constant 8 × Constant 9
11	Milk protein consumed per litter/calf per cycle	kg litter ⁻¹ cycle ⁻¹	P	(Eq. 10 × Constant 5) / 1000
		kg calf ⁻¹ cycle ⁻¹	B	Eq. 10 × Constant 5
12	Milk N consumed per litter/calf per cycle	kg (litter or calf) ⁻¹ cycle ⁻¹	P, B	Eq. 11 / Constant 19
13	Milk P consumed per litter/calf per day	g litter ⁻¹ d ⁻¹	P	Eq. 9 × Constant 12
		kg calf ⁻¹ d ⁻¹	B	Constant 8 × Constant 12
14	Milk P consumed per litter/calf per cycle	kg litter ⁻¹ cycle ⁻¹	P	(Eq. 13 × Constant 5) / 1000
		kg calf ⁻¹ cycle ⁻¹	B	Eq. 13 × Constant 5
Total consumption				
15	N consumed per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 6 + Eq. 12
16	P consumed per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 8 + Eq. 14
Retention in weight gain				
17	N retained in weight gain per cycle ^[c]	kg cycle ⁻¹	P, B, D, Po	Constant 10 × Eq. 2
18	P retained in weight gain per cycle ^[c]	kg cycle ⁻¹	P, B, D, Po	Constant 13 × Eq. 2
Retention in milk and eggs				
19	N exported in milk per cycle	kg cycle ⁻¹	D	Constant 1 × Constant 14 / 100 / Constant 19 × Constant 23
20	P exported in milk per cycle	kg cycle ⁻¹	D	Constant 1 × Constant 15 / 100 / Constant 23
21	N retained in eggs	kg cycle ⁻¹	Po	(Constant 16 × Constant 17) / 1000
22	P retained in eggs	kg cycle ⁻¹	Po	(Constant 16 × Constant 18) / 1000
Total retention (function of weight gain, milk, and eggs)				
23	N retained per cycle	kg cycle ⁻¹	P, B	Eq. 17 + Eq. 12
			D	Eq. 17 + Eq. 19
			Po	Eq. 17 + Eq. 21
24	P retained per place per cycle	kg cycle ⁻¹	P, B	Eq. 18 + Eq. 14
			D	Eq. 18 + Eq. 20
			Po	Eq. 18 + Eq. 22
Excretion				
25	Manitoba total N excreted	%	P, B, D, Po	1 – (Eq. 23 / Eq. 15)
26	N excreted per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 25 × Eq. 15
27	N excreted per place per year	kg year ⁻¹	B, Po	Eq. 26 × Input 6
			P, D	Eq. 26 × Constant 22
28	N excreted per herd or flock per year	kg year ⁻¹	P, B, D, Po	Eq. 27 × Input 2
29	N excreted per herd or flock adjusted for N loss	kg N year ⁻¹	P, B, D, Po	Eq. 28 × Input 1
30	Manitoba total P excreted	%	P, B, D, Po	1 – (Eq. 24 / Eq. 16)
31	P excreted per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 16 × Eq. 30
32	P ₂ O ₅ excreted per place per cycle	kg cycle ⁻¹	P, B, D, Po	Eq. 31 × Constant 20
33	P ₂ O ₅ excreted per place per year	kg year ⁻¹	B, Po	Eq. 32 × Constant 22
			P, D	Eq. 32 × Input 6
34	P ₂ O ₅ excreted per herd or flock per year	kg year ⁻¹	P, B, D, Po	Eq. 33 × Input 2

^[a] Inputs are from table 3, and constants are from table 4.

^[b] This variable is constant 2 (table 4) for all pigs except nursery and grower/finisher.

^[c] Equation for nursery and grower/finisher pigs only.

^[d] Equation for all pigs except nursery and grower finisher.

^[e] Includes retention for all livestock and poultry including pig litters consuming exclusively milk and beef calves consuming milk and grass.

(a) Beef

* Weight in and weight out default values provided for beef can be changed by user.

**Including N and P in milk consumed by calves.

*** Default values of days on feed and number of cycles provided for beef can be changed by user.

(b) Dairy

* Weight in and weight out values are constants for dairy and cannot be easily changed by user.

** Days on feed are constant for dairy.

(c) Pig

* Weight in, weight out, and days on feed are constants for pigs and cannot be easily changed by user.

** Including N and P in milk consumed by nursing litter.

*** Including N and P in milk produced by nursing sow.

(d) Poultry

* Weight in and weight out are constants for poultry.

** For layers/breeding operations.

Figure 1. Flowcharts indicating major inputs, constants, and calculations used to estimate nutrient excretion for (a) beef, (b) dairy, (c) pig, and (d) poultry operations. Not all constants are shown in the flowcharts because they are used for transformations or intermediate calculations.

Figure 2. Land area (ha) required for a livestock and poultry operation according to the Farm Practices Guidelines (FPG).

CASE STUDIES COMPARING MLC AND FPG

Two case studies were used to compare the MLC and the FPG nutrient excretion estimates and the provincial land requirements. A pig operation and a poultry operation were selected from the Livestock Technical Review Public Registry (Manitoba, 2020c).

Pig Operation

The first case study was a nursery pig operation (24,000 weanlings, equivalent to 792 AU) comprised of four barns located in southwestern Manitoba. Liquid manure was stored in an outdoor earthen manure storage structure and applied in the fall using partial injection (i.e., Aerway manure application system with tines or coulters that disturb the soil and dribble the manure in a single pass). The cropland area available to the farm consisted of 577 ha distributed among canola (297 ha), soybeans (116 ha), and spring wheat (163 ha) production, with respective long-term average yields from the Manitoba Agricultural Services Corporation (MASC) database (Manitoba, 2020b) of 2.3, 2.6, and 3.5 Mg ha⁻¹ (yields adjusted to 15% moisture content). The soils in the area are loamy (medium to heavy texture; Manitoba, 2016). For consistency, an FPG soil and crop N utilization factor of 0.35 was used because the associated crop N utilization (165 kg ha⁻¹) corresponded most closely to the crop N utilization generated by the MLC. The earthen manure storage and partial injection resulted in a storage and application coefficient of 0.59 (table 6).

Poultry Operation

The second case study was a poultry operation located in southeastern Manitoba with a total capacity of 135,000 white laying hens. The operation was equivalent to 1120.5 AU. Solid manure was stored in an enclosed solid manure building and was applied primarily in the fall on annual crops via broadcast application and incorporation within 48 h. The cropland associated with the farm consisted of 678 ha distributed among alfalfa (65 ha), canola (153 ha), corn grain (153 ha), soybeans (153 ha), and spring wheat (153 ha). The long-term average yields (9.0 Mg alfalfa ha⁻¹, 2.89 Mg canola ha⁻¹, 8.3 Mg corn grain ha⁻¹, 2.56 Mg soybeans ha⁻¹, and 4.07 Mg spring wheat ha⁻¹) were established using the MASC database (yields adjusted to 15% moisture content; Manitoba, 2020a). The soils in the area are classified as clay

Table 6. Coefficients used to adjust for N lost from manure storage and application method.^[a]

Manure Storage Method	Application Method			
	Injection	Broadcast and Incorporate within 48 h	Broadcast	Sprinkler
Liquid manure systems				
Enclosed	0.83	0.81	0.64	0.60
Open (except earthen)	0.78	0.76	0.60	0.56
Earthen	0.59	0.57	0.45	0.42
Solid manure systems				
Daily scrape		0.71	0.60	
Manure pack		0.67	0.56	
Open lot		0.48	0.40	

^[a] Source: Manitoba (1994, 1995a, 1995b, 2000).

Table 7. Coefficients used to adjust for soil and nitrogen utilization based on annual applications.^[a]

Based on annual applications			
Type of Crop	Nitrogen Utilization ^[b] kg ha ⁻¹	Soil and Crop Nitrogen Utilization Factor ^[c]	
		Spring	Fall
Forages, established stands			
Alfalfa	250	0.29	0.23
Grasses	165	0.43	0.35
Grass-alfalfa mixtures	195	0.37	0.30
Annual crops			
Medium to heavy soils	90	0.81	0.65
Light soils	65	1.08	0.86

^[a] Source: Manitoba (1994, 1995a, 1995b, 2000).

^[b] Nitrogen taken up by the crop per hectare per year.

^[c] Nitrogen utilization factor associated with N utilization rates and used in the FPG calculations.

(fine textured; Manitoba, 2016). For consistency, an FPG soil and crop N utilization co-efficient of 0.30 (table 7) was used because the associated crop N utilization (195 kg ha⁻¹) corresponded most closely with the crop N utilization generated by the MLC. A storage and application coefficient of 0.71 (table 6) was used to reflect practices that most closely resemble those used by the poultry operation.

RESULTS

PIG OPERATION

According to the MLC, 86,507 and 38,795 kg of manure N and P₂O₅, respectively, were produced in the pig facility per year before losses. These amounts corresponded to approximately 48% and 47% of the total N and P fed, respectively. Nitrogen losses from the barns and earthen manure storage structure were estimated at 25,952 kg N. The average crop N uptake and phosphorus (P₂O₅) removal were 155 and 41 kg ha⁻¹, respectively. At the time of approval, the land estimates for this operation were 390 and 937 ha for manure N and P, respectively. In contrast to the MLC, the AU calculation within the previous FPG methodology estimated 57,816 kg N excreted, of which 23,704 kg were assumed to be lost from storage and application. This resulted in a land requirement of 164 ha using the previous FPG methodology.

POULTRY OPERATION

According to the MLC, 81,011 and 53,606 kg of manure N and P₂O₅, respectively, were produced in the poultry facility per year. These amounts corresponded to

approximately 59% and 84% of the total N and P fed, respectively. The N loss from the barn and solid manure storage building represented 16,202 kg N. The average crop N uptake and P_2O_5 removal were 193 and 49 kg ha⁻¹, respectively. At the time of approval, the land estimates using the MLC were 335 ha for manure N and 1,091 ha to achieve P balance. In contrast to the MLC, the AU calculation within the previous FPG methodology estimated 81,796 kg of N excreted, of which 23,721 kg N were assumed to be lost during storage and application. This resulted in a land requirement of 239 ha for manure N using the previous FPG methodology.

DISCUSSION

For the pig operation case study, the MLC indicated that about 50% of the nutrients fed to the weanlings was excreted in manure, which is consistent with the range of 30% to 60% retention for N reported in the literature (NRC, 2012). Dourmad et al. (1999) showed an average excretion of 44% for both N and P. A review by Millet et al. (2018) reported N efficiencies of 46% and a predicted improvement to 57% for pigs in the finishing stage. Another study in France, The Netherlands, and Denmark reported P excretion of 52% for weanlings (Poulsen et al., 1999) as a consequence of improved nutrient utilization, resulting in lower excretion when compared to other classes of pigs (e.g., sows with 79% P excretion). Almeida and Stein (2010) reported P excretion rates of 45% of total P consumed by pigs. It should be noted that P excretion in manure may be impacted by strategies such as feeding low-bioavailability mineral P supplements combined with phytase, or feeding high water-soluble P supplements (Liu et al., 2020). The feeding formulations in the MLC are defined by constants that reflect current industry practices and cannot be changed by the user. This approach was taken to minimize the input requirements and make the tool user-friendly. New feeding strategies may be factored into the MLC if they become widely adopted by industry.

For the poultry operation, the MLC estimated N and P excretions of 59% and 84%, respectively. These findings are within the ranges reported in a summary of more than 80 peer-reviewed articles over 18 years, demonstrating that N excretion ranged from 25% to 70%, while P excretion ranged from 56% to 86.4% (Applegate et al., 2003). A study evaluating N excretion in layer hens fed a range of dietary crude protein (17% to 13%) demonstrated that N excretion decreased from 54% to 49% as the crude protein content of the diet decreased (Latshaw and Zhao, 2011). A recent local study with laying hens in Manitoba determined that total P excretion as a percentage of total P intake ranged from 85% to 89% (Jing et al., 2018). The authors concluded that total P excretion decreased proportionally with reduced total P intake as a result of decreasing dietary available P. Current feeding practices tend to overestimate the P requirements of livestock and poultry, leading to excess excretion of P in the manure (Jing et al., 2018). The Canadian Food Inspection Agency (Canada, 2021) has proposed modernization of current livestock and poultry feeding regulations, which will

allow lower inclusion of dietary P in animal feeds, creating the potential for reduction of P excretion in poultry manure.

In addition to using a mass balance approach, one of the most significant differences between the FPG methodology and the MLC is the inclusion of P in the land requirement estimates. Manure application in Manitoba is primarily based on crop N requirements (Cordeiro et al., 2016), which often results in a buildup of soil test P, increasing the risk of P loss to surface water and accelerated eutrophication (Withers et al., 2019). As a result, Manitoba adopted regulations that allow manure to be applied based on N until soils reach a concentration of 60 mg kg⁻¹ of Olsen soil test P (Manitoba, 1998a). At this point, application rates must account for P removal by crops. Phosphorus application rates are typically much lower than N application rates, resulting in a much larger land area required for P-based manure application (Menzi et al., 2010).

The crop nutrient utilization and removal components were also expanded in the MLC because the FPG contained a narrow range of crop types and N utilization only (table 7). The MLC contains crop data for 20 of the most common crops grown in Manitoba. Crop nutrient utilization and removals are calculated based on operation-specific rotations, realistic long-term yields, and land available to the operation. The volatilization losses used in the MLC have not been updated significantly, using generic estimates of in-barn and storage losses adapted from the FPG.

As a result of the improvements discussed above, the MLC typically generates larger land requirements for manure application than the FPG, as illustrated by the pig and poultry case studies presented here. For the pig operation case study, the MLC increased the N land requirement by 2.4-fold compared to the FPG methodology. This increase was primarily due to the larger estimate of excreted N by the MLC (86,507 kg year⁻¹) compared to the FPG (57,816 kg year⁻¹). The FPG N excretion estimate was similar to that of the 1993 ASABE Standard (61,495 kg year⁻¹). This is to be expected because the FPG AU calculation incorporated early ASABE estimates. The value reported in the current 2005 ASABE Standard (0.41 kg N excreted per finished weanling) generates 9,840 kg N excreted by 24,000 weanlings finished in 36 days (per cycle). If the operation runs nine cycles in a year, then 88,560 kg N year⁻¹ would be excreted, indicating that the ASABE N excretion estimates increased between 1993 and 2005 and are much closer to the MLC.

Notably, the 2005 ASABE Standard provides excretion as a total for each production phase to avoid misuse of daily average values (ASABE, 2005). However, production-phase excretion totals are dependent on the parameters used for calculation and should only be used if the operation meets those criteria. For example, the typical values for nursery pigs in the 2005 ASABE Standard assume that the piglets are fed for 36 days and have an average weight of 12.5 kg, whereas the MLC assumes that nursery pigs are fed for 52 days and have an average weight of 17 kg. The MLC assumptions were based on 2016 production practices in Manitoba. Current trends are toward longer cycles, typically eight or nine weeks (Tricia Schmalenberg, Maple Leaf Agri-Farms, personal communication, 2 Feb. 2021; Matthew

Reimer, HyLife, personal communication, 2 Feb. 2021), although the exact cycle length can be influenced by the finisher space available. Continuous changes in production practices reinforce the need to update models regularly or develop flexible tools that can be adjusted by the user, as appropriate.

Despite the larger N excretion estimated by the MLC, N losses by volatilization from the barn and storage (25,952 kg year⁻¹) were similar to those estimated by the FPG (23,704 kg year⁻¹), presumably because the MLC adapted volatilization estimates from the FPG. In addition, the crop N utilization factors chosen for the FPG simulation were as close as possible to the more accurate N utilization values generated by the MLC to account for known changes in crops and increases in yields over the last 20 years.

In contrast to the pig case study, the estimates of N excretion from the poultry operation were similar for the MLC (81,011 kg year⁻¹) and the FPG (81,796 kg year⁻¹). The 2005 ASABE Standard reports N excretion for layers as 0.0016 kg N excreted per animal per day, resulting in yearly N excretion of 77,112 kg year⁻¹ for 135,000 layers if the barn is filled to capacity for 357 days of the year (as in the MLC), a value that is similar for both the MLC and FPG estimates. Differences in N losses due to volatilization between the MLC and the FPG resulted in a land base requirement for N that was 1.4-fold larger with the MLC than with the FPG.

When P was considered in the land calculations, the land requirements increased substantially, regardless of operation type. The land needed to balance the pig manure P with crop P removal increased the land estimate for the nursery by 5.7-fold when compared to the FPG land requirement for N. This increase is in agreement with previous findings reported in the literature for Manitoba (Salvano et al., 2004). There are no P losses in the MLC; therefore, the P land requirement is based solely on P excretion. The 2005 ASABE Standard estimates that 0.068 kg P are excreted per finished weanling, resulting in 3,737 kg P₂O₅ for 24,000 weanlings finished in 36 days. If the operation runs nine cycles in a year, then 33,635 kg P₂O₅ year⁻¹ are excreted, indicating that the ASABE P excretion estimate was approximately 15% lower than the MLC estimate (38,795 kg) for P₂O₅ excretion.

For the poultry operation, the P land requirement increased by 4.6-fold compared to the N-based FPG estimate. The 2005 ASABE Standard reports P excretion for layers at 0.00048 kg P per animal per day, resulting in yearly P₂O₅ excretion of 52,975 kg year⁻¹ for 135,000 layers if the barn is filled to capacity for 357 days of the year, which is very similar to the MLC estimate of 53,606 kg for P₂O₅ excretion. Increases in land requirements for balancing P application and removal should be acknowledged when planning livestock and poultry expansion because more land may be needed over time to avoid excessive buildup of soil P.

The MLC does not include the impact of manure treatment on land requirements because manure treatment systems are not common in Manitoba. In most areas of Manitoba, manure nutrients can be land-applied sustainably using beneficial management practices, including sustainable application rates. Moreover, assessments of different manure treatment

technologies, such as manure composting and separation, indicated that the efficacy of these treatments was low due to the cold climate conditions prevailing in Manitoba, variability in manure composition, and economic constraints (Ackerman and Cicek, 2013; Agnew et al., 2010; Kotyk and Grieger, 2014). However, as livestock and poultry production intensify in specific regions of the province, the land available for manure application becomes more limited. In these regions, manure must be transported greater distances, and manure treatment may become more attractive.

CONCLUSIONS

The Manitoba Land Calculator (MLC) is an adaptable and user-friendly tool developed in the Province of Manitoba, Canada, to estimate land requirements for new and expanding livestock and poultry operations. The MLC estimates land requirements for N and P based on Manitoba-specific livestock and poultry production practices and animal performance. It uses a mass balance approach to estimate livestock and poultry nutrient excretion and incorporates operation-specific estimates of crop nutrient utilization and removals. Two case studies comparing the MLC to the previous FPG methodology used in Manitoba showed land requirements based on N to be 1.4 to 1.5 times greater when using the MLC. However, to achieve P balance, as much as 4 to 6 times more land may be needed than was required using the N-based FPG methodology of the 1990s and early 2000s. Awareness of the land requirements for P balance during the planning stages is necessary to ensure that livestock and poultry operations have access to sufficient land within economical transport distances from the operation. Sufficient land enables producers to apply manure at rates following 4R nutrient stewardship principles, which reduces the risk of losing surplus nutrients to surface and groundwater.

ACCESSING THE MLC

The Manitoba Land Calculator (MLC) is available for download at the Manitoba Agriculture and Resource Development website (Manitoba, 2020a). The downloadable version of the MLC supports applications for new and expanding livestock and poultry operations. The MLC requires limited data entry from the user; however, most of the calculations and variables are hidden from the user and cannot be changed. A copy of the MLC in open format may be requested from Manitoba Agriculture and Resource Development for research purposes.

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