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The Age Effect of Dairy Feedlots on Manure Nutrient Seepage in Loam Soils

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This project investigated the age effect of dairy feedlots, built on loam soils, on the nutrient seepage process. Soil samples from four dairy feedlots, 20, 40, 60, and 100 yr old, were taken both inside and outside the sites in about 30 cm depth intervals to 153 cm. It was found that for feedlots less than 20 yr old, only the topsoil layer (30 cm) had increased nitrate nitrogen concentration. For feedlots older than 20 yr, the seepage of nitrate nitrogen went deeper into the soil. The potential for pollution of groundwater by both ammonium and nitrate nitrogen may be reduced by moving animals to a new feedlot site every 40 yr if the water table is 61 cm below the ground surface. In addition, since the seepage rates for these two chemical species accelerate in the sampling depths from 92 to 153 cm as the feedlot age approaches 60 yr, continuing to use feedlots older than 60 yr is not recommended even if the water table is 153 cm below the ground surface. A linear relationship was observed between nitrate and ammonium concentrations in soil (coefficient of determination $R^2 = 0{\cdot}94$). The leaching of phosphorus into loam soils was found to be a relatively slow process because only the topsoil layer (30 cm) had the raised phosphorus concentration after 60-yr operation, and therefore, is considered unlikely to contribute to groundwater pollution for feedlots less than 60 yr old.

1. Introduction

Much concern has been voiced over manure nutrient contamination of groundwater supply from dairy feedlots (Arnold & Meister, 1999; Maule & Fonstad, 2002). Large dairy herds result in organic waste being concentrated in a relatively small land area. One early study found high nitrate nitrogen (NO_3-N) concentrations from soil cores collected from some Colorado corrals and heavily fertilised, irrigated cropland; however, almost no NO_3-N was found beneath other corrals (Stewart *et al.*, 1967). The low NO_3-N values were considered to be due to denitrification beneath these corrals. In another study, Schuman and McCalla(1975) reported on nitrate contamination of groundwater supply from deep percolation of feedlot wastewater in Nebraska. In a recent study conducted by Arnold and Meister (1999), elevated levels of nitrate, ammonia, chloride, total Kjeldahl nitrogen, and total dissolved solids were found from groundwater samples collected from seven dairy feedlots during a period of 6 yr in New Mexico. The reported mean concentrations for all nutrient contaminants tended to increase as the size of dairy herds increased, with NO_3-N being the only groundwater contaminant measured that showed a consistently increasing trend from 1992 to 1997. Dantzman *et al.* (1983) studied the age effect of feedlots on leaching, examining the chemical elements in soil under feedlots after 10- and 15-yr operation on a fine sandy soil. The objective of the current study is to examine the effect of long-term use of feedlots (20–100 yr) on leaching in a loam soil.

In order to prevent groundwater pollution caused by nutrient seepage, variables (such as soil type, feedlot age, water table depth, *etc.*) that may affect the seepage process need to be closely examined. The aforementioned studies were site specific to provide profiles of chemical components in the soil, with little information in terms of the role of each individual variable in the nutrient leaching process. Since the objective of this study is to investigate the effect of feedlot age on nutrient seepage, four dairy feedlots of different ages were selected from the same area in southern Minnesota to achieve sites with closely consistent soil characteristics and water table. The effect of feedlot age could then be isolated by examining the nutrient profiles in the soils. Based on the results from this study, potential techniques to reduce the associated groundwater pollution are also discussed.

2. Materials and methods

2.1. *Site selection and soil sampling techniques*

Four dairy feedlots of ages 20, 40, 60, and 100 yr were selected and sampled in this project. To study the age effect, all four sites were located on loam soils and in the same area of southern Minnesota (the distance between sites ranged from 2 to 5 km) to minimise the potential effect of variations in soil textural components and rainfall amount on nutrient seepage. However, animal density between the sites remained variable and therefore, three factors were employed to correct the soil nutrient data from the 20-, 60-, and 100-yr sites, respectively, based on the data from the 40-yr site, which had the highest density of animals (Table 1). By using the highest density of animals in calculating the correction factors, the corrected nutrient concentrations tended to represent a worst-case scenario for the data set. The adjusted nutrient concentrations were used for discussions in the following sections.

Each site-specific correction factor was used for all nutrient species in the soil on that particular site and only applied to the differences in nutrient concentration between the samples from the field and their counterpart from the background (*i.e.* background samples were not corrected). As such, the formula used to calculate the adjusted nutrient concentrations for nitrate, phosphorus, and ammonium nitrogen was given in Eqn (1):

Table 1
General information on the dairy feedlots sampled

Feedlot	*Age, yr*	*Animal density, cows m^{-2}*	*Correction factor**
1	20	0·078	3·795
2	40	0·296	1·0
3	60	0·043	6·884
4	100	0·016	18·5

*For nutrient seepage data (correction factor = 0·296/animal density).

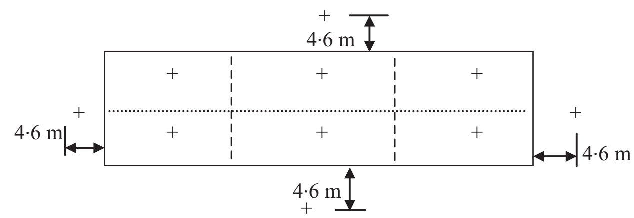

Fig. 1. Soil sampling locations designated by a symbol '+' inside and outside a site

$$C_{adj} = (C_{raw} - C_{bk})k + C_{bk} \quad (1)$$

where: C_{adj} is the adjusted nutrient concentration; C_{raw} is the measured field nutrient concentration; C_{bk} is the measured background nutrient concentration; and k is the correction factor.

This method enables the nutrient distribution in the soil to be revealed and compared with respect to the age of the sites under study. The increase in nutrient concentration in the soil is assumed to be linearly related to the animal density and the effect of animal density to be independent of feedlot age.

A truck mounted, hydraulic powered soil sampling probe was used to collect all the soil core samples. Each core sample was 153 cm long, consisting of five individual samples (about 30 cm each). This sampling scheme provided information reflecting the downward nutrient profile in the soil. The sampling layout is presented in *Fig. 1* and six samples were taken from each feedlot—one from the centre of each section of the grid. Neither water troughs nor feeding sections were contained in the sampling areas. Additional three control (background) samples were taken from four possible locations outside the perimeter, around 460 cm away from the site edge and centred to the site length.

2.2. *Sample analysis*

All soil samples were air-dried and ground. Air-dried samples were analysed for ammonium nitrogen, nitrate nitrogen, and Olsen-phosphate using standard methods (SSSA & ASA, 1996). Each ground soil sample was well mixed in a plastic bucket and was placed in an airtight bag labelled with farm name, sampling location, depth, and sampling date. One randomly selected core sample from each site was also analysed for soil textural components using the method presented by Gee and Bauder (1986). The soil type classification was determined based on the procedures recommended by the United States Department of Agriculture (USDA, 1982).

Means and standard deviations for measurements from each depth were calculated based on the number of samples at this particular depth at a site. The same method was also applied to the background samples. Statistical t tests were employed to compare sample means at the same depth between different sites, and also between different depths at a site, at a significance level α of 0·05 using Microsoft Excel t-test package.

3. Results and discussion

3.1. *Soil textural analysis*

The soil textural components are presented in Table 2. Although the clay content ranges from 16·4 to 37·5% across the sites, which could affect soil permeability, the soil textural composition from the four sites is similar with loam being the dominant soil classification. Therefore, in the following discussion, data comparisons between different sites are made with the assumption that all four feedlots are built on loam soils.

Table 2
Soil texture classification for various sampling depths at the four dairy feedlots identified by site age

Sampling depth, cm	*Sand, %*	*Silt, %*	*Clay, %*	*Class**
20-yr feedlot				
30	46·4	32·1	21·5	L
61	41·8	35·6	22·5	L
92	38·9	41·3	19·8	L
123	36·5	40·1	23·4	L
153	25·6	36·9	37·5	CL
40-yr feedlot				
30	42·7	36·6	20·7	L
61	40·7	40·1	19·3	L
92	45·2	28·0	26·9	L
123	46·6	30·8	22·6	L
153	45·7	31·3	23·0	L
60-yr feedlot				
30	44·7	37·6	17·7	L
61	51·5	27·7	20·8	L
92	58·9	24·7	16·4	SL
123	48·8	34·3	16·9	L
153	44·7	34·7	20·5	L
100-yr feedlot				
30	50·9	32·1	17·0	L
61	46·9	32·3	20·7	L
92	47·5	33·1	19·4	L
123	46·9	31·9	21·2	L
153	50·6	32·1	17·3	L

*L, loam; CL, clay loam; SL, sandy loam.

3.2. *Nitrate and ammonium nitrogen concentrations*

Table 3 presents the nitrate nitrogen (NO_3-N) concentrations in the soil samples collected from all the feedlots. For the 20-yr site, there is no statistical difference between the data from the feedlot and the control, at all sampling depths, possibly due to large variations in data. However, the average NO_3-N levels in the samples from the feedlot are slightly higher than those from the control. For the 40-yr site, besides the raised average NO_3-N concentrations in all samples, the topsoil layer contains significantly greater concentrations of NO_3-N than the control. The accumulation of NO_3-N in the topsoil is most likely caused by the ageing of the site. There are five soil layers in the 60-yr site which have higher NO_3-N concentrations than those in the control, compared to four such layers in the 100-yr site. If the data are compared layer by layer between different sites, the age effect on NO_3-N accumulation in each soil layer as well as its downward movement can be clearly seen. In the first layer, the NO_3-N concentrations increase significantly from the 20-yr site to the 60-yr site. In the second layer, the difference in NO_3-N concentration exists among the 40-, 60-, and 100-yr sites, with no difference between the 20- and 40-yr sites. When the depth increases to 92 cm, the statistical difference in NO_3-N concentration between the 40-yr site and the 20- or 60-yr sites disappears. The concentrations of NO_3-N in these layers are significantly lower than that of the 100-yr site.

If examined from the groundwater pollution perspective, the results shown in Table 3 present a timetable of operation by which pollution of groundwater by NO_3-N may occur at different depths. For instance, it appears that dairy feedlots in continuous operation for 20 yr does not have any polluting impact on groundwater because there is no statistical difference between the data from the feedlot and the control. Similarly, it appears less likely from the statistical standpoint for the feedlots in continuous operation for 40 yr to cause NO_3-N pollution to water tables 61 cm below the ground surface. But if compared with the control, such statements may need further investigation because the average levels of NO_3-N in the soil to 122 cm are actually higher than those for the control. For the 60-yr site, statistically higher values of NO_3-N concentration than those for the control are observed for all the depths, indicating that the situation could worsen when the sites become older than 60 yr. This possibility apparently occurs at the 100-yr site where the NO_3-N concentrations at the 61 and 122 cm depths exceed those for the 60-yr site. These findings lead to an observation that for dairy feedlots that are in continuous operation for 60 yr or more, the likelihood of

Table 3
Nitrate nitrogen distribution in the soil profile for all sites*

Sampling depth, cm	*NO_3-N, mg kg^{-1}*				
	Site ages				*Control*
	20- yr	*40- yr*	*60- yr*	*100- yr*	
30	$31{\cdot}8 \pm 20{\cdot}5^{a,x}$	$108{\cdot}1 \pm 17{\cdot}9^{a,y}$	$153{\cdot}2 \pm 20{\cdot}5^{a,z}$	$195{\cdot}7 \pm 29{\cdot}6^{a,z}$	$13{\cdot}8 \pm 7{\cdot}7^{a,x}$
61	$17{\cdot}5 \pm 11{\cdot}7^{a,x}$	$40{\cdot}2 \pm 30{\cdot}6^{b,x}$	$133{\cdot}6 \pm 25{\cdot}7^{a,y}$	$255{\cdot}5 \pm 44{\cdot}8^{a,b,z}$	$9{\cdot}7 \pm 4{\cdot}3^{a,x}$
92	$16{\cdot}4 \pm 15{\cdot}6^{a,x}$	$42{\cdot}6 \pm 29{\cdot}8^{b,x,y}$	$88{\cdot}7 \pm 18{\cdot}8^{a,b,y}$	$307{\cdot}2 \pm 50{\cdot}7^{b,z}$	$8{\cdot}2 \pm 3{\cdot}6^{a,x}$
122	$13{\cdot}8 \pm 14.2^{a,x}$	$31{\cdot}9 \pm 25{\cdot}7^{b,x,y}$	$65{\cdot}3 \pm 19{\cdot}7^{b,c,y}$	$271{\cdot}2 \pm 47{\cdot}1^{b,z}$	$9{\cdot}5 \pm 5{\cdot}8^{a,x}$
153	$14{\cdot}9 \pm 11{\cdot}9^{a,x,y}$	$23{\cdot}5 \pm 19{\cdot}7^{b,x,y}$	$53{\cdot}1 \pm 13{\cdot}6^{c,x}$	$72{\cdot}1 \pm 70{\cdot}6^{c,x,y}$	$10{\cdot}5 \pm 6{\cdot}0^{a,y}$

*Letters a, b, and c indicate statistical differences in data between rows, while letters x, y, and z indicate statistical differences in data between columns. Statistical *t* tests were used to compare the data at a significance level α of 0·05. The number of samples is 6 for feedlot sites and 9 for the control.

polluting groundwater by leaching of NO_3-N may be substantially increased even if water tables are located at depths lower than 153 cm from the ground surface.

The effect of site age on the potential for NO_3-N pollution of groundwater as observed in this study may aid in the development of strategies to alleviate such pollution. For instance, for the 20-yr site, it might be acceptable that the topsoil layer contains a higher NO_3-N concentration than deeper layers where the NO_3-N concentrations are similar in magnitude. If the groundwater level is high and the groundwater pollution by NO_3-N becomes a concern, the seepage of NO_3-N from dairy feedlots built on loam soils can theoretically be minimised by replacing the topsoil layer every 20 yr. Practically, however, there might be technical difficulties in physically carrying out such a treatment. An alternative to the replacement of surface soil layer in order to mitigate the pollution problem is to move the animals to a new site every 20 yr and return the existing site to farmland for nitrogen consuming crops. The proposed alternative herein comes with an assumption that each new site is a fresh site which is however in most cases not guaranteed. For an old site (*e.g.* 100 yr) which may have significantly accumulated nitrogen in the soil as a result of repeatedly uses in the past, simply using a fixed, 20-yr interval for rotation will not always be accurate in terms of protecting groundwater from pollution. Therefore, the actual rotation frequency has to be determined by the nitrogen data in the soil on a case by case basis, which depends on the nitrogen consumption rate of crops grown as well as the amount of additional nitrogen fertilizer applied to the land over the years. The site rotation frequency can be reduced to every 40 yr if the groundwater table is 61 cm below the surface. If the feedlots are 60 yr or older, the NO_3-N will leach deeper than the five sampling layers in this study. Consequently, the chance for groundwater pollution will be increased substantially even if the water table is 153 cm below the ground surface. Since penetration to the 153 cm depth appears to have occurred in less than 60 yr (Table 3), the actual soil depth affected by the NO_3-N leachate is unknown for sites older than 60 yr. Therefore, to safely guard groundwater resources against pollution by NO_3-N leaching, the feedlot sites should be rotated every 40 yr.

A similar situation is observed for soil ammonium nitrogen (NH_4-N) concentrations (Table 4); however, the age effect on the NH_4-N downward migration appears to be greater. Topsoil samples from all the sites demonstrate significantly higher NH_4-N concentrations than the control. In the second sampling depth, only two sites (60 and 100 yr) show significantly increased NH_4-N concentrations. Also, a horizontally bell-shaped distribution in NH_4-N concentration (higher in middle layers than in top and bottom layers in the soil) is observed for the two oldest sites, which probably reveals a NH_4-N seepage pattern over the course of operation. In other words, when the site ages, a significant amount of ammonium nitrogen tends to move down instead of continuing to accumulate in the topsoil. Since the increased NH_4-N concentration is only detected in the topsoil layer for both the 20- and 40-yr sites compared to the control (Table 4), the technique for preventing NO_3-N pollution may also be considered here to reduce potential groundwater pollution caused by seepage of NH_4-N, *i.e.* either replacing the topsoil layer or moving animals to a new site every 40 yr.

The data in Tables 3 and 4 can be used to calculate the seepage rates in different sampling layers during ageing of the feedlots. In the topsoil layer, the NO_3-N seepage rate is highest from year 20 to year 40 and slows down thereafter (*Fig. 2*). While in the second sampling depth (61 cm), the largest increase in the NO_3-N seepage rate occurs between year 40 and 60. In a similar manner, the NO_3-N seepage rates for the sampling depths of 92 cm and 122 cm increase most abruptly between year 60 and 100. These observations delineate the pattern of seepage of NO_3-N over the course of operation of dairy feedlots

Table 4
Ammonium nitrogen distribution in the soil profile for all sites *

Sampling depth, cm	*NH_4-N, mg kg^{-1}*				
	Site ages				*Control*
	20- yr	*40- yr*	*60- yr*	*100- yr*	
30	$125 \pm 48{\cdot}7^{a,x}$	$152 \pm 92{\cdot}5^{a,x}$	$739 \pm 54{\cdot}2^{a,y}$	$1036 \pm 185{\cdot}1^{a,z}$	$40 \pm 12{\cdot}3^{a,s}$
61	$119 \pm 46{\cdot}9^{a,x}$	$73 \pm 106{\cdot}8^{a,x}$	$913 \pm 127{\cdot}7^{a,y}$	$1674 \pm 176{\cdot}4^{b,z}$	$46 \pm 30{\cdot}1^{a,x}$
92	$93 \pm 99{\cdot}1^{a,x}$	$70 \pm 54{\cdot}7^{a,x}$	$499 \pm 65{\cdot}7^{b,y}$	$2469 \pm 159{\cdot}6^{c,z}$	$36 \pm 18{\cdot}5^{a,x}$
122	$70 \pm 92{\cdot}7^{a,x}$	$41 \pm 23{\cdot}8^{a,x}$	$366 \pm 62{\cdot}8^{c,y}$	$1962 \pm 135{\cdot}4^{b,z}$	$32 \pm 8{\cdot}8^{a,x}$
153	$73 \pm 57{\cdot}8^{a,x,y}$	$44 \pm 34{\cdot}5^{a,x}$	$185 \pm 65{\cdot}5^{d,y}$	$1363 \pm 168{\cdot}8^{a,z}$	$30 \pm 7{\cdot}8^{a,x}$

*Letters a, b, c, and d indicate statistical differences in data between rows, while letters x, y, z, and s indicate statistical differences in data between columns. Statistical *t* tests were used to compare the data at a significance level α of 0·05. The number of samples is 6 for feedlot sites and 9 for the control.

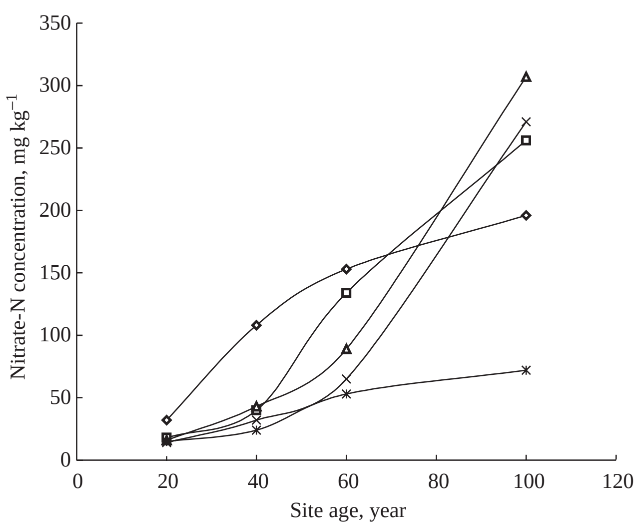

*Fig. 2. Nitrate-N seepage at different sampling depths in relation to site ages: ◇, sampling depth of 31 cm; □, sampling depth of 61 cm; △, sampling depth of 92 cm; ×, sampling depth of 122 cm; *, sampling depth of 153 cm*

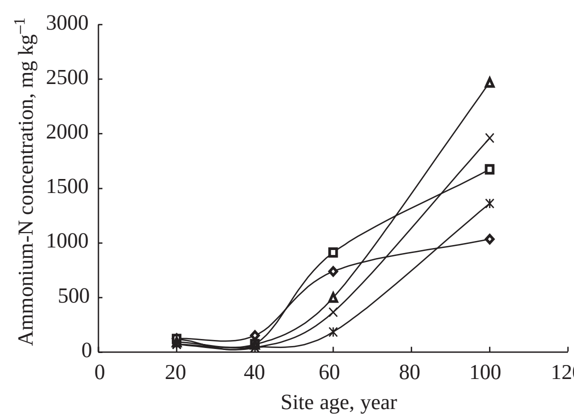

*Fig. 3. Ammonium-N seepage at different sampling depths in relation to site ages: ◇, sampling depth of 31 cm; □, sampling depth of 61 cm; △, sampling depth of 92 cm; ×, sampling depth of 122 cm; *, sampling depth of 153 cm*

built on loam soils. If the water table is located within 122 cm from the ground surface, to avoid an accelerated deterioration of groundwater quality due to NO_3-N pollution, the maximum length of operation for feedlots built on loam soils appears to be 60 yr. A similar scenario can also be observed for ammonium nitrogen as shown in Fig. 3.

The data patterns in Figs. 2 and 3 suggest a relationship between NH_4-N and NO_3-N through the biological 'nitrification' process. A strong linear correlation between these two variables can be seen in Fig. 4 with a correlation coefficient of 0·97 (coefficient of determination $R^2 = 0{\cdot}94$), which means about 94% of the variation in NO_3-N in the soils could be attributed to nitrification of a relatively constant proportion of NH_4-N.

3.3. *Olsen-phosphate concentrations*

Figure 5 indicates the age effect on the phosphorus distribution in the soil. With the exception of the 20-yr site, phosphorus concentrations are significantly higher in the topsoil (30 cm) when compared to the control sites and a significant increase is apparent, relative to the age of the respective site. However, there is a rapid decline in these values as the sampling depth increases to 61 cm, so that there is no statistical difference between the data from the 40- and 60-yr sites. As the site age approaches 100 yr, downward movement of phosphorus is apparent and the levels are significantly higher than the controls at all depths. Since there is no difference in phosphorus concentration at all sampling depths between the 20-yr site and the control, it may be inferred that dairy feedlots built on loam soils may not pose a threat to water resources if the site is in continuous use for 20 yr or less. Due to the fact that the phosphorus levels are

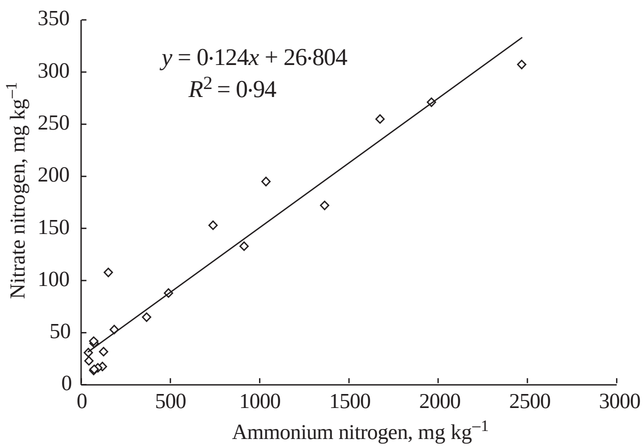

Fig. 4. Correlation between nitrate nitrogen and ammonium nitrogen in soil samples: —, linear regression line; R^2, coefficient of determination

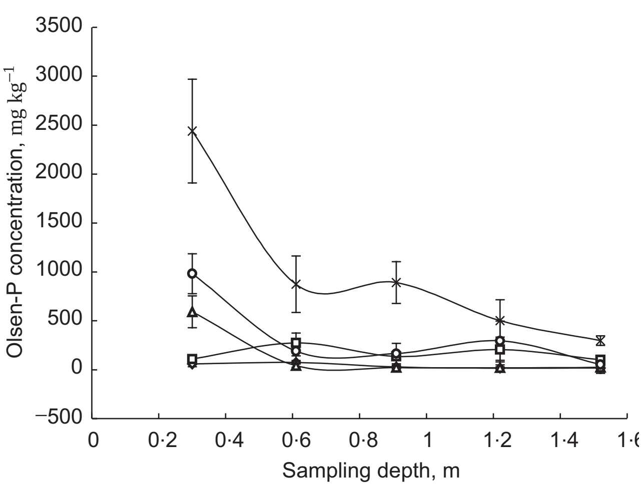

Fig. 5. Olsen-phosphate distribution in soil profile for all sites (error bars indicate the standard deviations): ◇, control; □, 20-yr site; △, 40-yr site; ○, 60-yr site; ×, 100-yr site

only significantly higher in the topsoil layers of the 40- and 60-yr sites, a possible solution would be to either replace the topsoil layer or rotate feedlot sites every 60 yr to avoid the potential leaching of phosphorus into groundwater. Similarly, technical feasibility and environmental sustainability of implementing the proposed techniques need further investigation. The use of dairy feedlots older than 60 yr should be discouraged due to the substantially increased chance for phosphorus to move deeper in the soil, resulting in possible pollution to the groundwater. However, it should be recognised that the leaching of phosphorus in loam soil is still a relatively slow process since it will take 60 yr of continuous operation before the soil 61 cm below the ground surface potentially becomes affected by the phosphorus downward movement.

4. Conclusions

For feedlots of 20 yr old, the increase in nitrate nitrogen concentration is only observed in the topsoil layer (30 cm). As feedlots age (over 20 yr old), the nitrate nitrogen leachate goes deeper into the soil, as shown by the other three sites in which significantly higher NO_3-N concentrations than the controls are observed in the top one, two, and four sampling depths for the 40-, 60-, and 100-yr sites, respectively. The risk of groundwater pollution from NO_3-N leaching is limited if the feedlots built on loam soils are less than 40 yr old and the groundwater level is below 61 cm. However, for feedlots in continuous operation for over 60 yr, the potential pollution threat to groundwater is increased tremendously even if the water table is located 153 cm from the ground surface.

For both NH_4-N and NO_3-N, the pollution threat to groundwater can be reduced by moving animals to a new feedlot site every 40 yr and returning the existing site to farmland for nitrogen-consuming crops, if the water table is 61 cm below the ground surface. In addition, since the seepage rates for both NH_4-N and NO_3-N in the sampling depths from 92 to 153 cm accelerate as the age of feedlots approaches 60 yr, the continued use of feedlots that are older than 60 yr should be discouraged even if the water table is 153 cm below the ground surface.

A strong linear relationship ($R = 0{\cdot}97$) exists between ammonium and nitrate nitrogen in the loam soil on which dairy feedlots are sampled in this study.

Raised phosphorus concentration levels occur only in the topsoil layer (30 cm). These levels increase with the feedlot age for feedlots up to 60 yr old. If the water table is 61 cm below the ground surface, the risk of groundwater pollution by leaching of phosphorus would not appear to be significant for feedlots less than 60 yr old. Similarly, since there is no difference in phosphorus concentration between the three youngest sites in the soil intervals below 30 cm, the ortho-phosphate seepage into groundwater can theoretically be mitigated by replacing the topsoil layer (30 cm) or changing the feedlot site every 60 yr.

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