Barn Age Impact on Nutrient Leaching for Turkey Barns Built on Clay Loam Soils

J. Zhu, A. Luo, Y. Zhou, P. M. Ndegwa, D. Schmidt

Abstract. *This project investigated the age effect of turkey barns built on clay loam soils on the soil properties. Three turkey barns with ages of 10, 20, and 45 years were studied, and soil samples were collected both inside and outside the barns in 30.54 cm intervals to a depth of 152.7 cm. The information obtained indicated that turkey barn litter had little influence on the clay loam soil moisture content, regardless of the barn age. For barns less than 10 years old, only the topsoil layer (30.54 cm) had increased nitrate and ammonium nitrogen concentrations. Therefore, replacing the topsoil layer every 10 years may be an option to reduce potential groundwater pollution by nitrogen leaching. For barns over 20 years old, repairing the barn floor to hinder nitrogen leaching becomes virtually impossible. A linear relationship was observed for soil nitrate concentration with ammonium concentration with a correlation coefficient of 0.9515, indicating that the high nitrate concentration found in the soil was likely caused by the nitrification process. Data also showed that phosphorus leaching into clay loam soils was a relatively slow process, and replacing the topsoil layer of the barn floor every 20 years may be considered as an option to prevent this. Although barn age had a profound impact on soil pH, the correlation of the reduced soil pH with nutrient distribution in soil profiles was not observed.*

Keywords. *Turkey barns, Age effect, Clay loam soils, Nutrient seepage, Groundwater pollution.*

As the poultry industry grows rapidly, so does the concern about the environmental impact of poultry production on the natural resources. There is some concern about potential pollution of groundwater by leaching of nutrients from deep–bedded litter systems. An early study indicated that high nitrogen concentrations in soil beneath confinement buildings were related to chicken raising operations (Robertson, 1977). Later studies continued to report that high nitrogen concentrations found in groundwater in Delaware were linked to poultry production (Ritter and Chirnside, 1984; Denver, 1991). Two studies conducted by Ritter (1991) and Ritter et al. (1994) provided further evidence that there appeared to be a correlation between high nitrate concentrations in drinking water wells and proximity to broiler houses. Andres (1991) estimated that potential nitrate fluxes from sub–basins in the Indian River watershed were greater from poultry farms than from non–poultry areas. Lomax et al. (1995) sampled 30 broiler houses in Delaware and found that the average soil nitrogen content beneath the barn floors was significantly higher than the background (250 mg/kg vs. 8 mg/kg). Haberstroh (1997) revealed high concentrations of nitrogen in the soil under turkey buildings in North Dakota. These studies have prompted the need for further study of the potential pollution issues caused by the nutrient seepage from deep–bedded litter systems.

In order to prevent groundwater pollution caused by nutrient seepage, variables (such as soil type, soil moisture content, barn age, water table depth, etc.) that may affect the seepage process need to be closely examined. In the aforementioned studies, the researchers selected sites based heavily on geographical locations and water tables, without paying much attention to the role that each variable could play in this process. This makes it difficult to differentiate one variable from the other in terms of its impact on nutrient seepage. As a result, in evaluating the seepage problem of a particular site, these studies failed to provide knowledge of each individual variable such as soil type, water table, barn age, or combinations thereof. Therefore, in order to obtain information on the impacts of independent variables, research should be planned in such a way that only one variable is studied at a time, with other variables being held constant as much as possible.

The objective of this study was to investigate the barn age effect on nutrient seepage. Three turkey barns of different ages were specially selected in the same area in southern Minnesota to reduce the variations among the selected sites in soil characteristics and water table that may interfere with the objective of the study. In doing so, the barn age effect on nutrient seepage from the barn floor could be isolated by examining the nutrient profiles in soils beneath the three

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Table 1. Soil type classification along the sampling depth for the three farms.

Sampling Depth (cm)	10–year barn				20–year barn				45–year barn			
	Sand (%)	Silt (%)	Clay (%)	Soil Type	Sand (%)	Silt (%)	Clay (%)	Soil Type	Sand (%)	Silt (%)	Clay (%)	Soil Type
30.54	32.1	36.7	31.2	Clay loam	38.0	36.8	25.2	Loam	37.5	39.6	22.9	Loam
61.08	39.3	34.1	26.6	Loam	41.3	26.3	32.4	Clay loam	36.6	35.4	28.0	Clay loam
91.62	41.7	23.9	34.4	Clay loam	35.3	25.5	39.2	Clay loam	35.2	31.0	33.8	Clay loam
122.16	39.1	28.2	32.7	Clay loam	43.0	28.5	28.5	Clay loam	40.2	32.2	27.6	Clay loam
152.7	37.4	26.7	35.9	Clay loam	31.7	30.3	38.0	Clay loam	24.9	44.1	31.0	Clay loam

barns. Potential techniques to reduce groundwater pollution by nutrient seepage from turkey buildings are also discussed.

Materials and Methods

Site Selection and Soil Sampling Techniques

Three turkey barns with ages of 10, 20, and 45 years were selected and sampled in this project. Each barn was built on a similar soil type in order to study the age effect on nutrient seepage into the soil. All three farms selected in this study were located on clay loam soils and in the same area of southern Minnesota. Soil information for each farm is presented in table 1. A truck–mounted, hydraulic–powered soil sampling probe was used to collect all the soil core samples. Each core sample could be 152.7 cm long, consisting of a maximum of five soil samples of 30.54 cm each. This sampling scheme provided information that reflected the downward nutrient profile in the soil. All samples were collected along the building centerline (fig. 1) since water pipes as well as other utility lines were located on both sides inside the buildings. The four "+" signs outside the sampling site indicate the locations for control (background) samples. The control sampling points were, if possible, always 4.58 m away from the building edge and in the middle of the building length. Soil sampling was usually conducted when the barn was empty, during a short break after the mature birds were removed for marketing and before the barn was restocked with young birds. Information provided by the farm managers indicated that all three barn floors were constructed of native soil from the farm sites, with surface compaction being the only treatment used in the barn floor construction. The three barns have a similar bird density on the floor, and the litter is cleaned using bulldozers and front–end loaders.

Sample Analysis

All soil samples were air–dried and ground. Air–dried samples were used for the analysis of ammonium–nitrogen, nitrate–nitrogen, Olsen–phosphate, and pH according to the standard methods provided by the Soil Science Society of America and American Society of Agronomy (SSSA and ASA, 1996). Moisture content of each sample was measured immediately after sampling using the oven–drying method. Each ground soil sample was well mixed in a plastic bucket and was placed in an airtight bag labeled with farm, house, location, depth, and sampling date. In addition to the above analysis, one core sample collected from the center of each site was also analyzed 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 USDA (1982).

Means and standard deviations for samples from each depth were calculated based on the number of samples at this particular depth. The same method was also applied to the background samples. Statistical paired–*t* tests were employed to compare sample means at the same depth between different locations at a significance level of $\alpha = 0.05$ using Microsoft Excel's *t* test package.

Results and Discussion

Soil Textural Analysis

The soil textural components are presented in table 1. Although the clay content ranged from 22% to 39% across the sites, which could affect the soil permeability, the soil composition from the three sites was similar, with clay loam being the dominant soil classification. Therefore, in the following discussion, data comparisons between different sites were made with the assumption that all three barns were built on clay loam soils.

Moisture Content of Soil Samples

The means and standard deviations of the moisture content in the soil samples collected from the three turkey barns at various depths are presented in table 2. The moisture content for all the samples ranged from 15% to 22% on a wet basis. Statistical analysis indicated that there were limited differences in moisture content between samples from different barns and at different depths. The data suggest that the age of turkey barns built on clay loam soils probably will

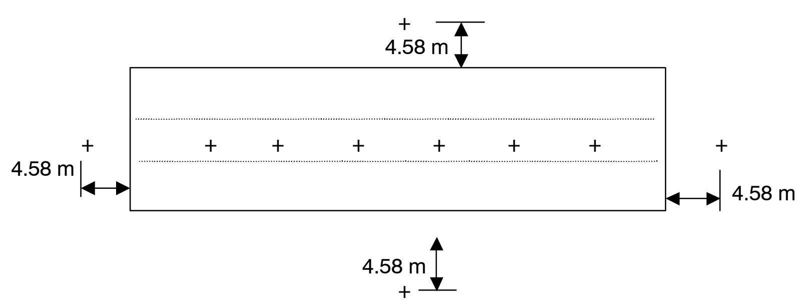

Figure 1. Soil sampling locations (designated by "+") inside and outside a site.

Table 2. Moisture content of soil samples collected from the three barns and the control.[a]

Sampling Depth (cm)	10–year barn (%)	20–year barn (%)	45–year barn (%)	Control (%)
30.54	0.15 ±0.019 a,x	0.18 ±0.013 a,c,x	0.20 ±0.006 b,x	0.20 ±0.011 b,c,x
61.08	0.17 ±0.015 a,x,y	0.20 ±0.029 a,b,x	0.21 ±0.012 b,x	0.21 ±0.010 b,x
91.62	0.20 ±0.017 a,y	0.21 ±0.030 a,x	0.20 ±0.017 a,x	0.21 ±0.003 a,x
122.16	0.20 ±0.024 a,y	0.21 ±0.016 a,x	0.20 ±0.013 a,x	0.22 ±0.009 a,x
152.7	0.21 ±0.027 a,y	0.20 ±0.022 a,x	0.21 ±0.024 a,x	0.21 ±0.014 a,x

[a] Different letters (a, b, c) indicate significant difference in data between columns, while different letters (x and y) indicate significant difference in data between rows.

not affect the moisture content of the soils underneath the barn floors.

Nitrate and Ammonium Nitrogen Concentrations

Figure 2 illustrates the nitrate–nitrogen (NO_3–N) concentrations in the soil samples collected beneath the barn floors. A significant increase in NO_3–N in the top 30.54 cm of soil was observed for all the barns sampled as compared to the control. For the 20–year and 45–year barns, the NO_3–N concentration was significantly higher than the control at depths up to 122.16 cm below the floor surface. There was no statistically significant difference among all the samples at a depth of 152.7 cm. This suggests that if the groundwater level is below 152.7 cm, then pollution of groundwater by nitrate leaching from turkey barns built on clay loam soils appears unlikely, even if the barns were in continuous operation for 45 years. It was also observed that, although there was no statistically significant difference in NO_3–N concentration between the 20–year and 45–year barns due to large variation, the average values of the 20–year barn were higher than those of the 45–year barn. This observation cannot be explained based on the information in this study.

For the 10–year barn, it is apparent that the topsoil layer contains significantly higher NO_3–N concentration than the samples for the rest of layers. As a matter of fact, the NO_3–N concentrations for samples from layers 2 to 5 were about the same as for the control samples except for the sample from layer 2, which was a little higher than its counterpart. This observation may suggest that if the groundwater level is high and groundwater pollution by NO_3–N becomes a concern, then seepage of NO_3–N from turkey barn floors built on clay loam soils may, in theory, be minimized by replacing the topsoil layer every 10 years. Practically, however, there might be technical difficulties in replacing the topsoil and re–compacting the surface inside the building, since the impact of such operation on the building structure is unknown. Further research to explore this possibility may thus be worthwhile. In addition, according to the data from this study, if a barn is older than 20 years, then the age impact on NO_3–N leaching into soil profile disappears, and the barn floor has probably reached a stage beyond possible remediation for controlling potential groundwater pollution by NO_3–N leachate.

A similar situation was observed for soil ammonium–nitrogen (NH_4–N) concentrations (fig. 3); however, the barn age effect on the downward migration of NH_4–N appears to be greater. The topsoil samples from all three barn floors demonstrated significantly higher NH_4–N concentrations than the control. In the next sampling depth from the top, only two barns (20–year and 45–year) showed significantly increased NH_4–N concentrations. At the sampling depth of 91.62 cm, only the 45–year barn generated soil samples that contained higher NH_4–N concentration than the control samples. When the sampling depth went beyond 91.62 cm, the NH_4–N concentration for all the soil samples was no longer statistically different from each other, although the average NH_4–N concentrations for the 45–year barn stayed consistently higher than the rest of soil samples. According to the data presented in figure 3, the same option for preventing NO_3–N pollution (i.e., replacing the topsoil layer every 10 years) may be considered to reduce potential groundwater pollution by NH_4–N seepage.

The above observations clearly indicate that barn age seems to influence soil nitrogen concentrations beneath the barn floor, which is consistent with the findings reported by Lomax et al. (1995) in broiler houses. Another study by Ritter

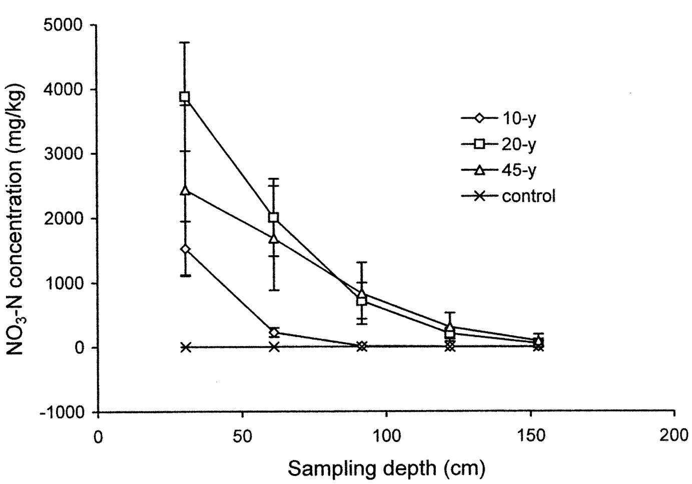

Figure 2. Nitrate–nitrogen distribution in soil profile along the sampling depth for all sites (error bars indicate standard deviations).

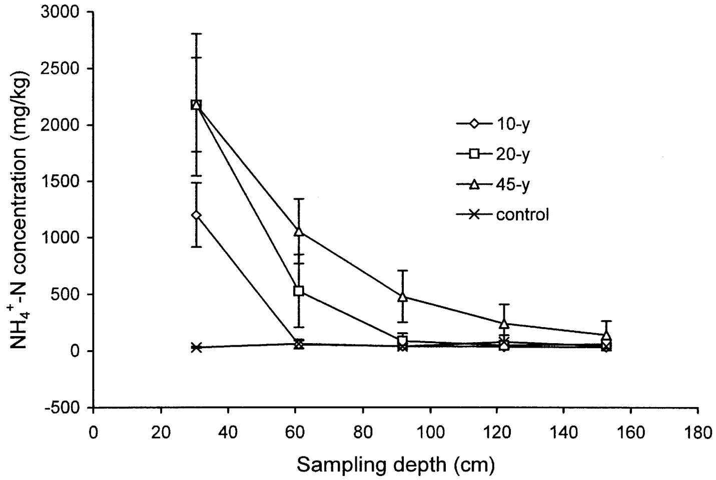

Figure 3. Ammonium–nitrogen distribution in soil profile along the sampling depth for all sites (error bars indicate standard deviations).

et al. (1994) reported that barn age impacted soil nitrogen concentrations for broiler houses built on sandy loam soils. The three broiler houses in their study were 13, 29, and 30 years old.

One interesting scenario observed from figures 2 and 3 was that both NH_4–N and NO_3–N concentrations in the topsoil (30.54 cm) increased significantly from year 10 to 20 but remained statistically unchanged thereafter up to year 45. Although data are limited, this may imply that the saturation concentrations of clay loam soil for NH_4–N and NO_3–N are possibly around 2200 and 4000 mg/kg, respectively, and it takes about 20 years of continuous operation to reach saturation. When saturation is reached, the soil's holding capacity for these two forms of nitrogen can be considered maximized, so downward leaching of nutrients can be expected to accelerate. This information may be helpful in developing techniques to avoid groundwater pollution by the accelerated downward movement of nutrients.

Regardless of the variations in data, it is interesting to note that the curves shown in figures 2 and 3 look relatively similar. This may indicate that a relationship between NH_4–N and NO_3–N exists, because the latter is usually considered to be produced from the former through the biological process of nitrification. Figure 4, in which the NO_3–N data are plotted against the NH_4–N data, provides strong evidence for this hypothesis. A linear correlation between these two variables is clearly seen in figure 4 with a correlation coefficient of 0.9515 (R^2 = 0.9053). The ammonium–nitrogen detected in the soils from this study may explain about 91% of the nitrate–nitrogen present in the same soils. In other words, about 91% of the NO_3–N in the soils could be generated by the nitrification of NH_4–N. Evidence supporting this hypothesis can also be found in the study by Ritter et al. (1994), in which the broiler houses that had the highest nitrate concentrations always had the highest ammonia concentrations. Since animal manure is the primary source of ammonium–nitrogen, technologies for reducing the output of nitrogen in animal manures (such as dietary manipulation) will certainly be of significance in helping reduce nitrate–nitrogen formation in the soil, thus reducing the potential of polluting groundwater by leaching.

Soil pH

The influence of turkey litter on soil pH is profound, as indicated in figure 5. Even for the 10–year barn, the soil pH was significantly reduced up to 91.62 cm in depth as compared to the control samples. For the other two barns (20–year and 45–year), the soil pH was statistically lower than the control throughout the entire sampling depth, and there were no statistically significant differences observed between the two barns. The reduction in soil pH may be caused by a number of factors, one of which could be the

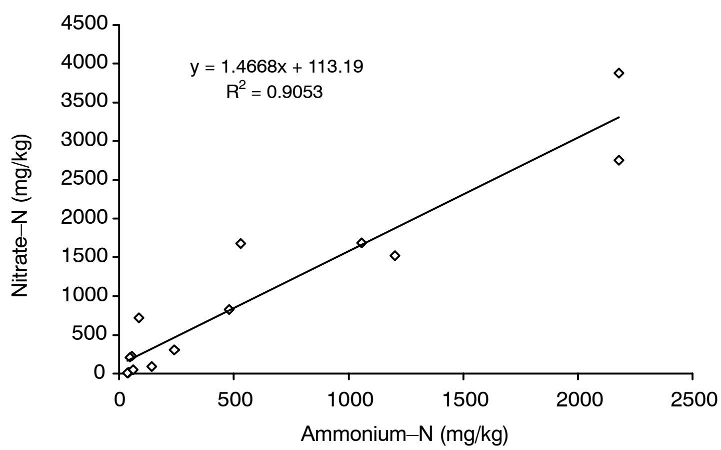

Figure 4. Correlation between nitrate–nitrogen and ammonium–nitrogen in soil samples.

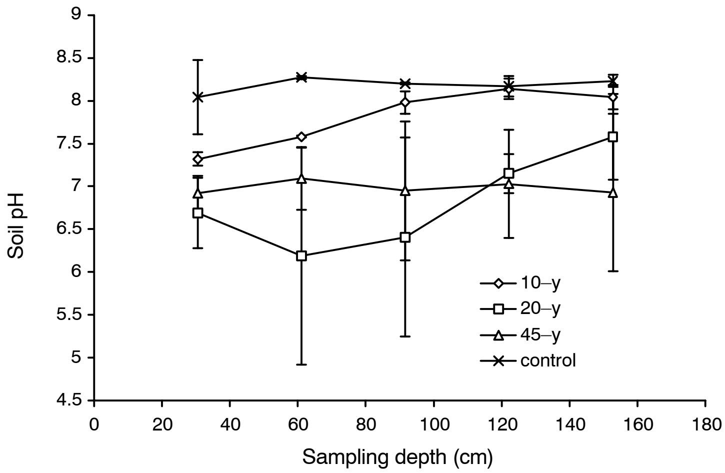

Figure 5. Soil pH variation along the sampling depth for all sites (error bars indicate standard deviations).

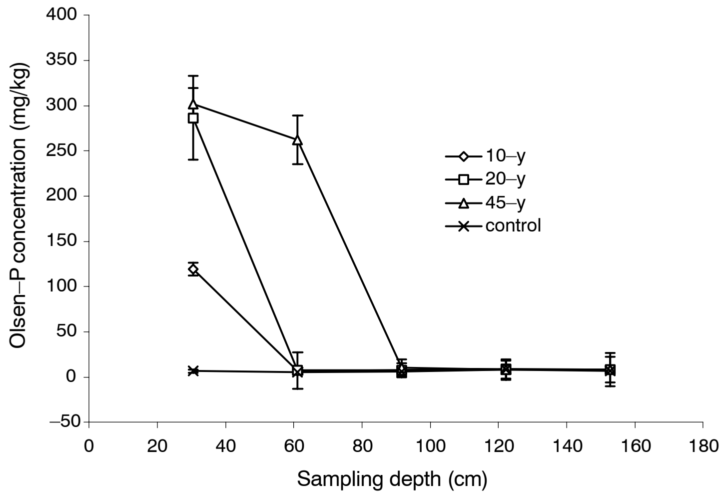

Figure 6. Olsen–P distribution in soil profile along the sampling depth for all sites (error bars indicate standard deviations).

nitrification of ammonium–nitrogen to nitrate–nitrogen, a process that produces H^+ ions, leading to a lowered pH. Adriano et al. (1974) found in their study on cattle waste that leaching of nitrates into the soil was signaled by the reduced soil pH due to significant nitrification. It may be assumed that the high concentration of NO_3–N found in the topsoil from this study is due to substantial nitrification that must have taken place during the years of operation, especially for the two older barns. However, the data do not fully support the concept of using soil pH as an indicator of nitrate leaching. For example, although the 45–year barn has a lower soil pH than the control, the NO_3–N concentrations are not correlated with the pH levels observed at various depths. As a matter of fact, the NO_3–N concentrations at the bottom two intervals in the sampling depth are not significantly different from the control samples (fig. 2), which is inconsistent with the case for pH (fig. 5). Therefore, using soil pH data to estimate the leaching of nitrates may lead to erroneous conclusions. Another cause of reduced pH in the soil could be the litter treatment for ammonia emission control, in which the litter pH is reduced to between 6.5 and 7.0. Consulting with the farm owners, however, excluded this possibility, since no such control agencies have ever been applied to the litter.

Olsen–Phosphate Concentrations

Figure 6 clearly indicates the barn age effect on phosphorus in the soil. Both the 10–year and 20–year barns have significantly higher phosphorus concentrations in the topsoil (30.54 cm) than the control, but the 20–year barn has more than twice the amount of phosphorus of the 10–year barn, indicating a substantial increase in phosphorus concentration in the topsoil between year 10 and 20. However, it appears that the rate of phosphorus accumulation in the topsoil decreased tremendously after 20 years, which can be seen by comparing the data from the 20–year and 45–year barns (fig. 6). The observation may also indicate that the saturation concentration of phosphorus in the soil can be reached after 20 years of operation. Instead of continuing to accumulate in the topsoil, the ortho–phosphorus started to move downward. This is reflected in the soil phosphorus profile for the 45–year barn, in which the phosphorus concentration in the second soil layer was significantly higher than those for the other two barns and the control. However, the phosphorus concentration dropped drastically as depth increased (fig. 6). As a result, no statistically significant difference was found between the samples from the barns and the control for the rest of the sampling depths. According to such information, it may be concluded that leaching of phosphorus into the soil is a relatively slow process, since the soil 91.62 cm below the ground surface appears to be unaffected by the downward movement of phosphorus even when the turkey barn has been in continuous operation for 45 years. In addition, since there is no difference in soil phosphorus concentration in the second sampling layer between the 10–year and 20–year barns, then replacing the topsoil layer (30.54 cm) every 20 years, if technically feasible, may be considered an option for preventing potential phosphorus pollution to groundwater.

CONCLUSIONS

- According to the data from this study, it may be concluded that turkey litter has little influence on the clay loam soil moisture content, even if the turkey barn is in continuous use for up to 45 years.
- For a barn age of 10 years, the increase in both nitrate–nitrogen and ammonium–nitrogen concentrations was only observed in the topsoil layer (30.54 cm). As barns age (over 20 years old), the nitrogen leachate goes deeper into the soil, which will make remediation more difficult. It may be unnecessary to worry about groundwater pollution by nitrogen leaching if the turkey barns built on clay loam soils are less than 45 years old and the groundwater level is below 152.7 cm. The data also appear to suggest that the saturation concentrations of clay loam soils for ammonium–nitrogen and nitrate–nitrogen are 2200 and 4000 mg/kg, respectively.
- This study found a linear relationship between ammonium–nitrogen and nitrate–nitrogen in the clay loam soil on which the turkey barns were built, with a correlation coefficient of 0.9515.
- It appears that turkey litter has a significant influence on the clay loam soil pH, which was reduced in the top three sampling depths for the 10–year barn (by 0.22 to 0.72) and in all depths for the 20–year (by 0.65 to 2.08) and 45–year barns (by 1.12 to 1.3). However, there is insufficient evidence to link soil pH with the extent of nitrate leaching based on the data in this study because the nitrate profile along the soil sampling depth was not in response to the pH distribution. Therefore, using pH alone to predict nitrate leaching may be misleading, at least in this case. More research is thus warranted.
- Similar to the nitrogen scenario, the increase in phosphorus concentration in the topsoil layer (30.54 cm) stopped at a barn age of 20 years. After that, the phosphorus in the topsoil tends to move downward in the soil profile. Since there is no difference in phosphorus concentration between the 10–year and 20–year barns in the soil intervals below 30.54 cm, the ortho–phosphorus seepage into the groundwater can theoretically be mitigated by replacing the topsoil layer (30.54 cm) every 20 years. However, the technical feasibility of such a practice needs further study.

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