EFFECTIVE SETBACKS FOR CONTROLLING NUTRIENT RUNOFF LOSSES FROM LAND-APPLIED POULTRY LITTER

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SUMMARY

Field trials were conducted to determine the effective setback widths for controlling nutrient runoff losses from poultry litter-fertilized cropland under different management practices. Nitrogen and phosphorus losses in runoff water at varied setback widths of Delaware corn plots (45 m × 15 m) that received poultry litter at 9.6 Mg ha^{-1} on the up-gradient 15 m were quantified. The results reveal that 15-m setbacks achieved nutrient reduction equivalent to 30-m setbacks attained when soil incorporation or cover crop planting was practiced. When both practices were employed, 5-m setbacks achieved the equivalent nutrient reduction.

INTRODUCTION

The Delaware poultry industry generates approximately 290,000 Mg of litter waste annually, of which the majority is applied to nearby agricultural land as organic fertilizers (Montgomery, 2004). Nutrient losses via surface runoff from poultry litter following land application have resulted in significant water quality issues. According to the State of Delaware 2002 Watershed Assessment Report, 94% of the rivers/streams and 68% of the ponds/lakes in the state are impaired by nonpoint-source phosphorus (P) and nitrogen (N) mainly from historic over-application of organic fertilizers to croplands (DNREC, 2005).

Overland flow is the major pathway for nutrient export from manure-fertilized agricultural systems (Sharpley et al., 1999). Buffer strips or setbacks have been demonstrated effective in reducing nutrient runoff losses through physical interception (suspended particles) and biochemical fixation (soluble N and P) (Muscutt et al., 1993; Sharpley et al., 1994). The ability of a buffer zone in trapping nutrients is related to its width. It is evident that wider setbacks or buffer strips will achieve greater water-purification effects (Wilson, 1967). As a consequence, less land will be available for manure disposal if setbacks are excessively wide. To protect water resources while ensuring manure disposal and cropping land areas, the minimal width of application setbacks that provide necessary pollutant-trapping effects has to be determined.

The federal Clean Water Act requires a minimum 30-m (100-foot) setback between the manure application area and down-gradient surface waters; alternative conservation practices or field specific conditions have to provide pollutant reductions equivalent to or better than the reductions that would be achieved by the 100-foot setback (EPA, 2003). However, the proposed Delaware Concentrated Animal Feeding Operation (CAFO) regulations state that a 15-m setback is required if the manure is incorporated into soil within 2 d of application or a winter cover crop is planted. The setback can be reduced to 5 m if both soil incorporation and cover crop planting are employed. It is unclear whether these proposed alternative practices will provide nutrient-trapping effects equivalent to or better than that would be achieved by 30-m setbacks. This study was to determine under soil incorporation and/or cover crop planting conditions the minimal

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width of setbacks that generate nutrient-trapping results equivalent to that would be achieved by 30-m setbacks.

MATERIALS AND METHODS

Field trial

Eight plots each 15 m × 45 m were prepared on typical Delaware agricultural land with 2 ~ 3% slope gradients (Fig. 1), with the long side lying along the slope gradient. The soil was Sassafras sandy loam (fine-loamy, siliceous, semiactive, mesic Typic Hapludults). Selected physical and chemistry properties of the soil are given in Table 1. Four treatments were randomly assigned in duplicates to the plots: (1) Surface Application. Poultry litter was simply surface broadcast to the up-gradient 15 m; (2) Soil Incorporation. Poultry litter was incorporated into soil by disc plowing immediately following broadcasting; (3) Cover Crop. Cover crops were planted in the late fall and killed by herbicide prior to spring fertilization; and (4) Cover Crop + Soil Incorporation. Cover crops were planted on the plots through the winter time and killed by herbicide prior to spring fertilization. Poultry litter was soil incorporated following broadcasting.

Soybean was grown in the previous season. In late October, 2006, rye (*Secale cereale*) was planted on four randomly selected plots as winter cover crops. On April 10, 2007, the herbicide "Roundup" was applied to kill the rye. On May 2, 2007, poultry litter obtained from a local broiler farm was broadcast at 9.6 Mg ha^{-1} over the up-gradient 15 m of the plots. Nutrient contents of the poultry litter are listed in Table 2. The down-gradient 30 m was used as setback, receiving no poultry litter. For the treatments requiring soil incorporation, the applied litter was incorporated into the top 15 cm soil by tillage using a disc plow immediately after litter application; the setback area was also mechanically turned. Corn seeds were then drill-planted at 17 cm interval in 70 cm-spacing rows perpendicular to the field slope into all the plots, including the 30 m setback areas.

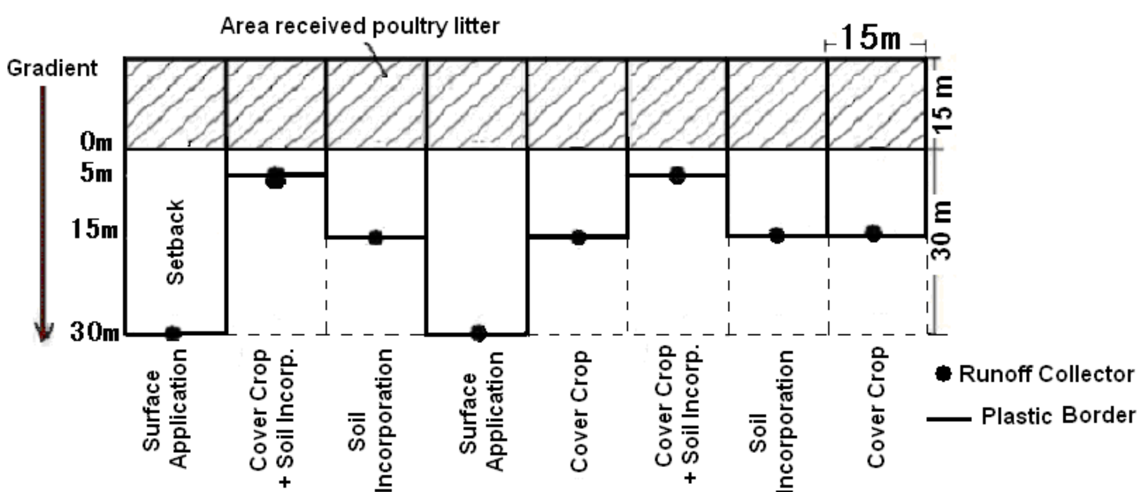

Fig.1. Layout of experimental plots showing treatments, poultry litter-fertilized area, runoff collector position, and plot isolation border.

Plastic tanks (0.47 m^3 or 124 gallon) were buried under the ground of the setbacks to collect runoff water. For the treatments Surface Application, Soil Incorporation, Cover Crop, and Cover Crop + Soil Incorporation, the collection tanks were installed at 30 m, 15 m, 15 m and 5 m down-gradient from the litter fertilized areas, respectively, as indicated by black dots in Fig 1. All plots were hydrologically isolated by 10 cm polyethylene plates buried in soils to a depth of 5 cm. Runoff water was directed to the collection tanks through open holes in the tank covers.

Runoff sample collection and analysis

Runoff water samples were collected monthly or after severe rainfall events. Water was withdrawn out of the collection tanks using a hand pump and the volume was measured. A subsample of approximately 1,000 mL was obtained from each runoff collector and stored at 4ºC prior to chemical analysis.

To measure total phosphorus (TP) and total nitrogen (TN) concentrations of runoff water, 20 mL of the bulk solution were drawn from each sample immediately after up-and-down mixing and digested with sulfuric acid and potassium persulfate in a 50-mL glass tube at 121°C for 60 min ((Jeffries et al., 1979). The digest was passed through a 0.22 μm filter and measured for TP and TN using the phosphomolybdate blue methods (Murphy and Riley, 1962) and a Shimadzu TOC/TN analyzer (Shimadzu, Tokoyo, Japan), respectively.

Another aliquot (~ 50 mL) of the bulk solution was centrifuged and passed through a 0.45 μm glass fiber filter to remove any particulates. The filtrate was analyzed for total dissolved P (TDP) after acid digestion, total dissolved N (TDN) using a TOC/TN analyzer, and dissolved inorganic P (DIP, PO_4^{3-}-P), and dissolved inorganic N (DIN, NH_4^+-N + NO_3^--N) using ion chromatography techniques (Metrohm IC 790, Metrohm Ltd., Herisau, Switzerland).

Data analysis

The runoff rate of test plots was calculated following the equation below:

$$R = V \times 10^{-3} \times 43.55 \qquad [1]$$

where R is the runoff rate (m^3 ha^{-1}), V is the volume (L) of water received in the runoff collectors, 10^{-3} is the coefficient to convert L into m^3, and 43.55 is the coefficient to extrapolate the test plot area from 225 m^2 to 1 hectare.

Nutrient runoff losses from individual plots during the whole growing season were estimated by summing up the nutrient runoff losses in each sampling interval:

$$Loss_d = \Sigma\, Loss_{d,i} = \Sigma\, (C_{d,i}R_{d,i}) \qquad [2]$$

where $Loss_d$ is the cumulative runoff losses of P and N (g ha^{-1}), $Loss_{d,i}$ is the nutrient loss rate at the d^{th} collector in the i^{th} rain event (g ha^{-1}), d is the serial number of the runoff collector, i is the i^{th} sampling event, $C_{d,i}$ is the nutrient concentration in the runoff water collected at the d^{th} collector during the i^{th} sampling interval (mg L^{-1}), $R_{d,i}$ is the runoff rate at the d^{th} collector in the i^{th} rain event (m^3 ha^{-1}).

Student's t-test was performed to evaluate differences in cumulative runoff losses of TP, TDP, TN, TDN, DIP and DIN between differently treated plots. Nutrient runoff losses from the surface application plots with a 30-m setback were treated as the reference level and compared with other treatments. Level of significance was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Nutrient contents of poultry litter

The applied poultry litter contained 40.4 g kg^{-1} of TN and 15.1 g kg^{-1} of TP, of which 57.2% and 17.2%, respectively, were water soluble. Of the water soluble nutrients, inorganic P (73%)

was the dominant P form while organic N (59.5%) and NH_4-N (40.3%) were the major N forms. Nitrate-N (NO_3-N) only accounted for 0.2% of the water soluble N.

Fertilization rates for corn production in the area are recommended at 150 kg N ha^{-1} and 30 kg P ha^{-1} (Layon, 1999; Chratochvil; 2009). Through the poultry litter 387.8 kg N ha^{-1} and 145.0 kg P ha^{-1} were applied (Table 2). Nevertheless, merely 29.0% of the N and 25.2% of the P in the poultry litter were plant-available during the first growing season (Guo et al., 2009). Therefore, the applied poultry litter provided 112.5 kg N ha^{-1} and 36.5 kg P ha^{-1} utilizable by the corn crops, basically meeting the nutrient requirements.

Runoff rates

Surface runoff occurs when rainfall intensity exceeds soil infiltration rate. Soils in the test plots exhibited an average infiltration rate of 263.03 mm hr^{-1} (160 – 480 mm hr^{-1}). As such, surface runoff occurred predominantly in the summer and early fall when thunderstorms brought high density rains. The initial runoff samples were collected on May 31, 2007, right after a heavy rain event. Collection of runoff water continued until December 28, 2007. As given in Table 3, runoff rates of the test plots during sampling intervals ranged from 0.43 to 1.43 m^3 ha^{-1}, varying with dates and influenced unclearly by the management practices.

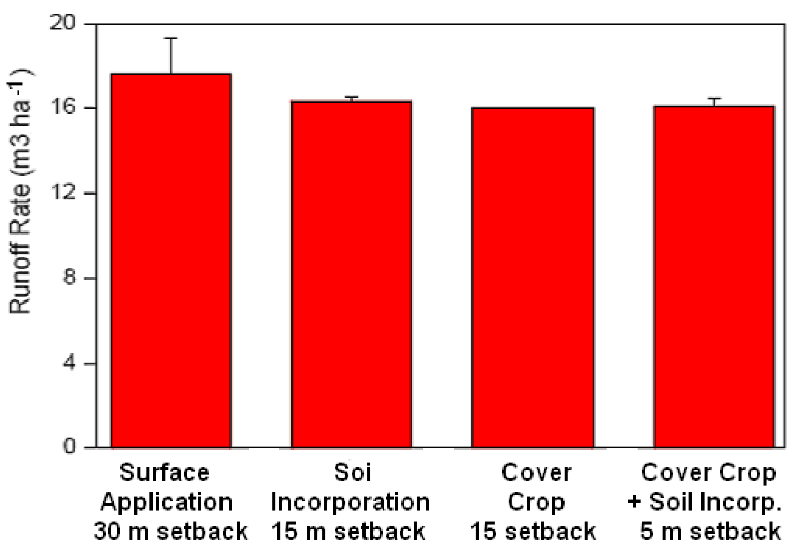

Fig. 2. Cumulative runoff rates (m^3 ha^{-1}) of differently managed plots

The bulk runoff rates of the plots through the whole growing season are presented in Fig. 2. From May to December, the cumulative runoff occurring at the experimental site was averagely 16.45 m^3 ha^{-1}. No significant differences were detected among the differently managed plots.

Concentrations of nutrients in runoff water

Concentrations of TP in runoff water from the poultry litter-fertilized plots ranged from 0.09 to 7.56 mg L^{-1}, with an average of 1.48 mg L^{-1} (Fig. 3-TP). For the first batch samples collected on May 31, Surface Application showed the highest concentration (0.77 mg L^{-1}) while the Soil Incorporation had the lowest (0.16 mg L^{-1}) (Fig. 3-TP). Peak TP concentrations occurred in runoff collected on August 27: Soil Incorporation was the highest (7.56 mg L^{-1}) and Surface Application was 4.62 mg L^{-1} (Fig. 3-TP). The peak concentration concurred with the highest rainfall amount and intensity during that period. Noticeable soil water erosion occurred and carried soil particles, organic debris, and poultry litter to the runoff collection tanks, forming a layer of soil on the tank bottom. The eroded soil contained high content of P (Table 1) and elevated the TP levels in runoff water.

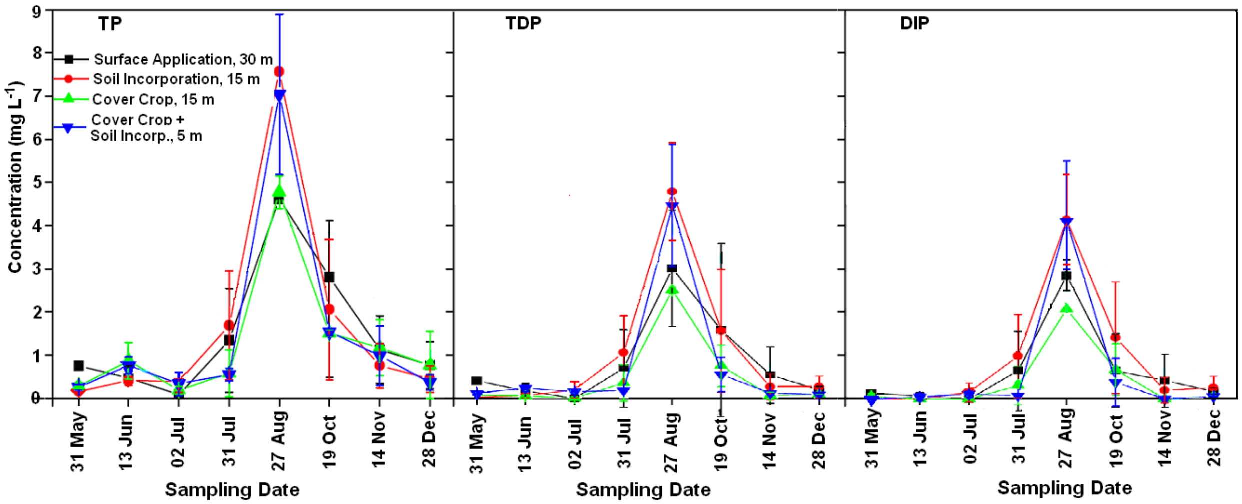

Fig. 3. Concentrations of total phosphorus (TP), total dissolved phosphorus (TDP), and dissolved inorganic phosphorus in runoff water from differently managed plots.

The major fraction of TP in runoff was dissolved P. The concentration of runoff TDP fluctuated between 0.00 and 4.9 mg L^{-1}, with an average of 1.0 mg L^{-1} (Fig. 3-TDP). The predominance of TDP in runoff TP was also discovered by Pionke et al. (1999), who used historical data of watershed storm flows to determine seasonal differences in nutrient transport. Although surface application of animal manure may cause accumulation of P at the soil surface and result in increased P runoff, especially for dissolved P (Sharpley and Smith, 1994), soil incorporation by mechanical plowing may give rise to accelerated soil water erosion, causing deteriorated nutrient runoff losses. In runoff samples collected on August 27, the lowest (2.59 mg L^{-1}) and the highest (4.94 mg L^{-1}) TDP concentrations were observed for the Cover Crop and Soil Incorporation treatments, respectively (Fig. 3-TDP). At the end of the experiments, TDP in runoff water from the manure-fertilized plots decreased to less than 0.3 mg L^{-1}.

The TDP consisted of DIP and DOP (dissolved organic P). In the first three batches of runoff water DOP was the major form of TDP, but in later runoff, DIP became predominant. The concentration of DIP in runoff ranged from 0.0 to 4.3 mg L^{-1}, averaging at 0.84 mg L^{-1} (Fig. 3-DIP). Runoff from the treatments Soil Incorporation, Surface Application, Cover Crop, and Cover Crop + Soil Incorporation had average DIP of 0.92, 0.64, 0.41, and 0.62 mg L^{-1}, respectively. In a cultivated watershed with poultry litter application at 9 Mg ha^{-1}, Harmel et al. (2004) reported annual mean and maximum DIP concentrations of 0.52 and 2.15 mg L^{-1} respectively.

Total nitrogen (TN) in the runoff water demonstrated a much higher concentration than TP. The TN concentration ranged from 1.1 and 232.4 mg L^{-1} and averaged at 24.7 mg L^{-1} (Fig. 4-TN). It increased initially with time and reached the peak on August 27. In the first batches of samples, the Surface Application treatment demonstrated the highest TN (4.51 mg L^{-1}) while the Cover Crop + Soil Incorporation exhibited the lowest (1.12 mg L^{-1}). Overall, the average concentration of TN in runoff from the differently treated plots followed the order: Cover Crop (40.5 mg L^{-1}) > Soil Incorporation (24.1 mg L^{-1}) > Surface Application (20.1 mg L^{-1}) > Cover Crop + Soil incorporation (14.2 mg L^{-1}).

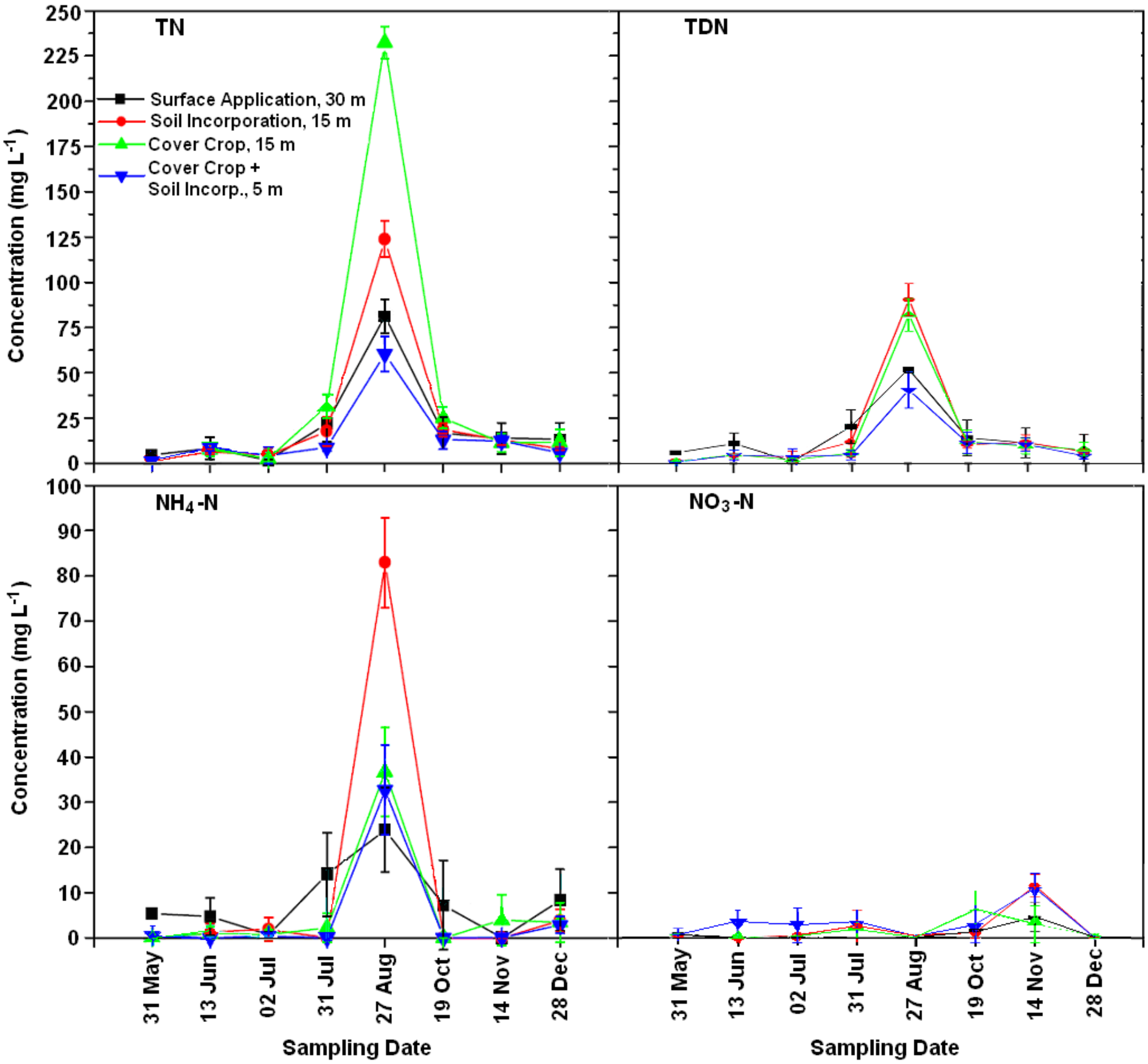

Fig. 4. Concentrations of total nitrogen (TN), total dissolved nitrogen (TDN), dissolved ammonium-N (NH_4-N), and dissolved nitrate-N (NO_3-N) in runoff water from differently managed plots.

The TN was in both dissolved and particulate forms. Concentrations of TDN in the runoff ranged from 0.6 to 90.3 mg L^{-1}, with an average of 14.6 mg L^{-1} (Fig. 4-TDN). Similar to TN, TDN also peaked out its concentration on August 27. Of the TDN, NH_4-N was the dominant form (Fig. 4-NH_4-N). Concentrations of NH_4-N fluctuated between 0.0 and 82.9 mgL^{-1} (average 7.5 mg L^{-1}). The initial runoff from the Surface Application plots had an NH_4-N at 5.4 mg L^{-1}, 92.4% of the TDN; while the other treatments during the same period had NH_4-N less than 0.5

mg L^{-1} (Fig. 4-NH_4-N), demonstrating the effect of management practices. Concentrations of NO_3-N in runoff water were rather low, in the range of 0.0 to 3.8 mg L^{-1} (average 0.5 mg L^{-1}; Fig. 4-NO_3-N). Nitrate was a product from microbial nitrification of ammonium (Pierson et al., 2001). Evidently, only a small portion of NH_4^+ in runoff was oxidized to NO_3^-.

Nutrient mass runoff losses

Losses of P and N nutrients in runoff water from the differently managed plots during the experimental period were computed using Eq. 2 and 3. As illustrated in Fig. 5, losses of TP from the treatments Surface Application, Soil Incorporation, Cover Crop, and Cover Crop + Soil Incorporation were estimated at 22.6, 23.5, 18.3, and 17.9 g ha^{-1}, respectively. Of the lost TP, TDP accounted for 12.3, 12.8, 7.2, and 6.6 g ha^{-1}, respectively; and DIP, 9.2, 9.6, 4.8, and 4.2 g ha^{-1}, respectively. In terms of TP, TDP, and DIP runoff losses, no significant differences (t test p-value >0.05) were observed between these different treatments, suggesting reduced setback widths in combination with soil incorporation and/or cover crop planting did provide nutrient reductions equivalent to that achieved by a 30 m setback in litter surface application.

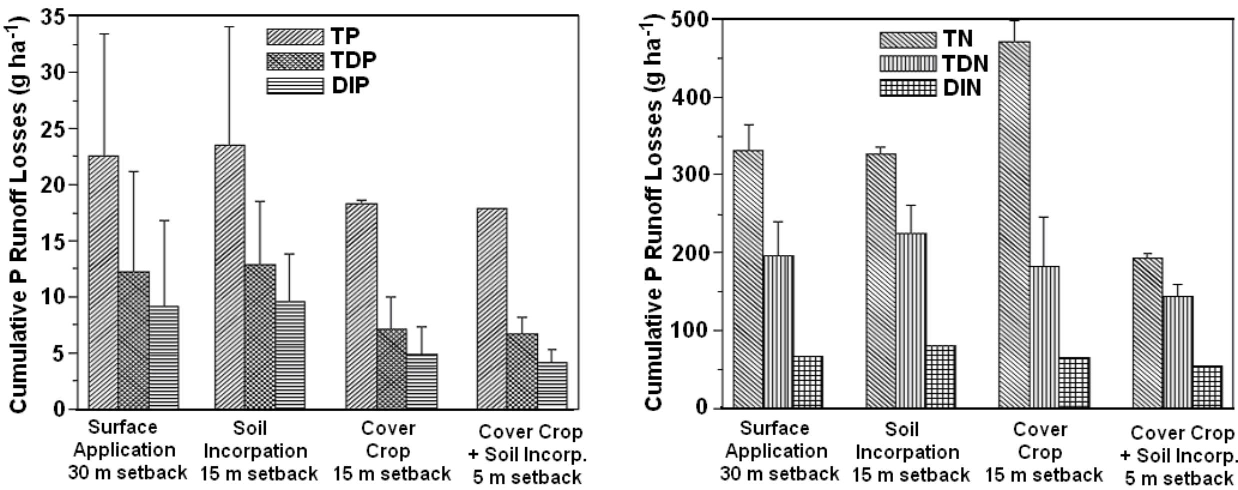

Fig. 5. Cumulative runoff losses of phosphorus (Left) and nitrogen (Right) from differently managed plots

Cumulative losses of TN via runoff from Surface Application, Soil Incorporation, Cover Crop, and Soil Incorporation + Cover Crop were 331.7, 327.0, 471.6, and 192.6 g ha^{-1}, respectively. In addition to particulate N, dissolved N (TDN) was another form of N lost in runoff water: the TDN losses for the treatments were 196.7, 225.4, 181.8, and 143.7 g ha^{-1}, respectively. Of the lost TDN, DIN was dominant. Losses of DIN were 166.1, 200.9, 161.0, and 134.6 g ha^{-1}, respectively, for these differently managed plots (Fig. 5).

Runoff losses of TN from the Soil Incorporation plots (327.0 g h^{-1}) were close to those from the Surface Application (331.7 g ha^{-1}), although the former had setbacks (15 m) shorter than the later (30 m), indicating the effectiveness of soil incorporation on reducing N runoff losses from land-applied animal manure. The Cover Crop treatment demonstrated significantly higher runoff losses in TN (t test P-value < 0.025) than Surface Application, while slightly lower in TDN and DIN (Fig. 5). By reducing rainfall erosivity and increasing water infiltration, cover crop residues decreased the transport capacity of runoff water and encouraged sediment deposition (Ross et al., 2002). When both soil incorporation and cover crop planting are employed, the effect on nutrient runoff reduction can be augmented. Cumulative losses of TDN in the Cover Crop + Soil Incorporation treatment were significantly lower than that in the Surface Application (P-value < 0.05, Fig. 5).

Effective setback width for controlling nutrient runoff losses

To determine the effective setback width under specific management practices for reducing nutrient runoff losses, cumulative runoff losses of different forms of N and P nutrients from the treatments Soil Incorporation, Cover Crop, and Cover Crop + Soil Incorporation were compared with those from Surface Application with a 30-m setback. Statistical analyses indicate that no significant differences existed except for TN (Table 4), in which from Cover Crop + Soil Incorporation with a 5-m setback were significantly lower (t test p-value < 0.0025) while from Cover Crop with a 15-m setback were significantly higher (t test p-value <0.025).

Indeed, if appropriately employed, soil incorporation and winter cover crop could effectively reduce nutrient runoff losses and thus, decreases the width of effective setbacks required for poultry litter application. In combination, cover crop and soil incorporation provided better nutrient reductions than the management practices alone and could further reduce the effective setback width.

CONCLUSIONS

Installation of setbacks between animal manure-fertilized areas and adjacent, down-gradient open water bodies is an effective approach for controlling non-point source water pollution by nutrients. This one-year field study conducted in Central Delaware demonstrates that when poultry litter was surface broadcast at 9.6 Mg ha^{-1} to a non-till corn field with sandy loam soil, a 30 m setback controlled the nutrient runoff losses at 22.5 g P ha^{-1} and 325 g N ha^{-1}. Soil incorporation and/or cover crop had mixed effects on nutrient concentrations in runoff water but helped reduce overall nutrient runoff losses. When winter cover crop was planted or the poultry litter was incorporated into soil immediately following application, a 15-m setback provided equivalent nutrient reductions. As both cover crop planting and soil incorporation were simultaneously implemented, a 5-m setback achieved comparable nutrient reductions. The results suggest that to effectively control nutrient runoff losses from land-applied poultry litter, the 30 m setback required by the federal Clean Water Act may be reduced to 15 m if cover crop or soil incorporation is practiced; the setback may be further reduced to 5 m if bother cover crop and soil incorporation are practiced.

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Table 1. Selected physical and chemical properties of soil at the experimental site.

Parameter	Value
Particle size composition	sand 500 g kg^{-1}, silt 480 g kg^{-1}, clay 20 g kg^{-1}
pH*	5.9 ± 0.02
EC* (dS m^{-1})	0.33 ±0.00
Organic carbon content (g kg^{-1})	13.5 ±0.27
CEC ($mmol_c$ kg^{-1})	146 ±0. 3
Total N (mg kg^{-1})	108.7 ±1.48
Mehlich-III P (mg kg^{-1})	85.4 ±0.11
Water soluble nutrients	
PO_4-P (mg kg^{-1})	8.4 ±3.2
NO_3 -N (mg kg^{-1})	0.2 ±0.04
NH_4-N (mg kg^{-1})	5.8 ±0.80

* Measured in 1:1 soil/water paste.

Table 2. Nutrient contents of poultry litter applied to field plots.

Parameter	Value
pH	6.0
Moisture content	35.12 %
Electronic conductivity	13.8 dS m^{-1}
Total N	40.4 g kg^{-1}
Total P	15.1 g kg^{-1}
Organic C	377g kg^{-1}
Water soluble nutrients	
Dissolved organic C	94.3 g kg^{-1}
Dissolved N	23.1 g kg^{-1}
Dissolved P	2.6 g kg^{-1}
Dissolved inorganic P	1.9 g kg^{-1}
NH_4^+-N	9.3 g kg^{-1}
NO_3^--N	0.053 g kg^{-1}

Table 3. Average runoff rates ($m^3\ ha^{-1}$, mean ± stdev) of differently managed plots*.

Runoff rate $m^3\ ha^{-1}$	Surface Application 30 m setback	Soil Incorporation 15 m setback	Cover Crop 15 m setback	Cover Crop + Soil Incorp. 5 m setback
31 May	0.65 ± 0.04	0.52 ± 0.13	0.52 ± 0.02	0.43 ± 0.03
13 Jun.	0.50 ± 0.05	0.59 ± 0.16	0.70 ± 0.25	0.74 ± 0.04
02 Jul.	1.10 ± 0.08	1.12 ±.06	1.18 ± 0.16	1.16 ± 0.33
31 Jul.	0.70 ± 0.10	0.45 ± 0.14	0.71 ± 0.13	0.60 ± 0.08
27 Aug.	0.53 ± 0.06	0.51 ± 0.07	0.52 ± 0.03	0.44 ± 0.09
19 Oct.	1.36 ± 0.09	1.43± 0.05	1.32 ± 0.13	1.32 ± 0.04
14 Nov.	1.08 ± 0.14	0.93 ± 0.06	0.82 ± 0.02	1.04 ± 0.06
28 Dec.	1.13 ± 0.12	0.98 ± 0.09	0.67 ± 0.08	0.74 ± 0.06

Table 4. Significance of treatment differences in nutrient reductions as indicated by P-values in Student's t tests.

Surf. application vs.	P-value					
	TP	TDP	DIP	TN	TDN	DIN
Soil Incorporation	>0.40	>0.40	>0.40	>0.40	<0.10	<0.10
Cover Crop	>0.40	>0.25	>0.25	<0.025	>0.25	>0.40
Cover Crop + Soil Incorporation	>0.25	>0.25	>0.25	<0.0025	<0.05	>0.10