Nitrogen BMP Efficiencies - Introduction

In an effort to advance understanding of practice efficiencies, a literature review was completed of recently published research from Iowa and surrounding states to update the nutrient reduction efficiencies, reduce uncertainty, and add new practices, if applicable to the Iowa Nutrient Reduction Strategy (INRS). This review is consistent with the need identified in the Iowa Nutrient Reduction Strategy Non-point Source Science Assessment that called for development of new practices and verification of practice performance. The original effort was completed in 2012 and updated performance and new practices represent progress made by work supported by the Iowa Nutrient Research Center (INRC) and other organizations. Published, peer-reviewed studies were identified through structured keyword searches and a forward citation search of INRS literature cited for nitrogen practices in the most recent version of the INRS. Literature listed in the Iowa Nutrient Research Center library was also reviewed. A total of 23 new studies were added. The Iowa Nutrient Reduction Strategy Science Team reviewed the approach and results consistent with the original Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen Transport in the Mississippi River Basin. All literature needed to meet the following criteria to be used in the calculation of efficiencies, consistent with those used for the original NRS-Science Assessment:

1. Relevant to the nitrogen BMPs listed in the INRS (or an updated, Science Team approved BMP)
2. Included experimental data from field studies that quantified nitrogen (as nitrate) loss; and
3. Was conducted in Iowa or surrounding states.

All identified literature that met the criteria above found is cited in this document, along with the sources used in the previous tabulation of efficiencies in the INRS and included in the summary tables of the BMP efficiencies (Tables 1, 2, and 3). Table 4 details updated yield changes for each BMP. Nitrogen rate impacts can be estimated using Figure 1.

This report follows the order of practices listed in Table 2 of the INRS - Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen Transport in the Mississippi River Basin. Practices of timing (spring pre-plant/sidedress vs. fall applied and soil test based sidedress applications compared to pre-plant), source (swine manure applications), nitrogen application rate, nitrification inhibitor, living mulches, perennial (Conservation Reserve Program (CRP)), and grazed pastures had no updated literature that met the requirements. Of note is that a 3-yr crop rotation, which is a corn-soybean-small grain system, was added based on literature. In many but not all cases, the variability in estimated practice performance was reduced by adding additional data. Another important aspect is that the yield effects on corn from rye cover crops was reduced to zero with the additional data.

The areal performance of edge-of-field practices on nitrate reduction are reported in Table 3. A significant amount of research on these practices since 2017 has demonstrated that while the percent reduction of a practice can be reported (i.e., pound N), the treated acres by the practice – and the load reduction per acre treated (i.e., pound N per acre treated) – best characterize the nitrate reduction efficiency of these practices. The treated acres for these practices is the area that contributes water to the specific practice, not just the area of the practice itself. As with the implementation of any BMP, the nitrogen percent removal of an individual practice will be a function of the design and acres treated by the practice, which could result in disproportionate percent removal but similar pounds of N removed per acre treated. As a result, the INRS Science Team believes reporting nitrate removal per acre treated is a more reflective performance metric.

In this report, the headings for each practice include the flow-weighted nitrate concentration (FWNC) reduction averages for each practice as compared to the control, which is almost all cases a traditional corn-soybean system. Standard deviations are in parentheses following the average efficiencies. The bolded numbers indicate the updated efficiencies averages and standard deviations. "—" indicates no data. Edge-of-field practices are now reported in pounds of nitrate removed per acre treated in addition to a % reduction.

Table 1. Updated nitrogen in-field BMP efficiencies for flow-weighted nitrate concentration (FWNC) reduction. Bolded practices are BMP efficiencies that were updated by this literature review. n=site years, SD=standard deviation, --- indicates no data and no update to previous values, Practice in italics (3-yr rotation) is a practice added based on this review. **Nitrogen rate impacts will depend on current nitrogen application rate and then updated rate consistent with INRS.

Practice		**Updated Reduction in % FWNC**		**Previous Reduction in % FWNC**		**Studies used**
		Mean (SD)	**Site years n**	**Mean (SD)**	**Site years n**	
Timing	**Fall to spring pre-plant application**	6 (16)	21*	6 (25)	29	5
	Spring pre-plant/sidedress (40-60) vs. fall applied	5 (13)	6*	5 (28)	11	2
	Sidedress - Compared to pre-plant application	1 (14)	7*	7 (37)	10	3
	Sidedress - Soil test based compared to pre-plant	4 (15)	19*	4 (20)	35	4
Source of Nitrogen	Liquid swine manure compared to spring applied fertilizer	---	---	4 (11)	10	1
	Poultry manure compared to spring applied fertilizer	5 (40)	38	-3 (20)	6	3
Nitrogen Application Rate**	Reduce to Maximum Return to Nitrogen value 149 kg N/ha (133 lb N/ac) for CS and 213 kg N/ha (190 lb N/ac) for CC	---	---	10	---	---
Nitrification Inhibitor	Fall - Compared to Fall-Applied without Inhibitor (EPA approved inhibitors)	5 (20)	31	9 (19)	22	3
Cover Crops	**Rye - Rotational average**	28 (26)	37*	31 (29)	28	14
	Rye - Cont. Corn	27 (25)	10	---	---	4
	Rye - C/S Corn year	27 (30)	27	---	---	6
	Rye - C/S Soybean year	30 (27)	27	---	---	7
	Oat	25 (6)	4	28 (2)	2	2
Living Mulches		---	---	41 (16)	7	4
Perennial	**Energy Crop**	87 (21)	16	72 (23)	8	4
	CRP	---	---	85 (9)	8	3
Extended rotation	***3 yr.***	15 (34)	8	---	---	2
	4+ yr.	27 (25)	8	42 (12)	8	4
Grazed Pastures	No pertinent information from Iowa – Assume similar to CRP	---	---	85	---	---
Buffers		87 (27)	26	91 (20)	14	5

Drainage Water Management**	Controlled drainage	40 (28)	27	33 (32)	15	9
Shallow Drainage **		32 (18)	16	32 (15)	12	3

*n and SD were calculated differently than previous publication to have the site years reflect a rotational average.

** These are load reductions rather than concentration reductions

Table 2. Nitrate reduction efficiencies for edge-of-field practices. SD = standard deviation, n = number of site years.

Practice	**Updated Reduction in % FWNC**		**Previous Reduction in % FWNC**		**Studies used in Updated Estimates**
	Mean (SD)	**Site years n**	**Mean (SD)**	**Site years n**	
Bioreactors	24 (17)	35	43 (21)	14	2
Saturated Buffers	45 (24)	29	50 (13)	2	2
Multi-purpose Oxbow	63 (18)	5	42 (6)	1	2
Wetlands	30 (17)	59	52		1

Table 3. Nitrate load reduction per treated acre for edge-of-field practices. SD = standard deviation.

Practice	**Average N load removed per treated area in lbs N/ac (SD)**
Bioreactors	5 (4)
Saturated Buffers	10 (6)
Multi-purpose Oxbow	6 (5)
Wetlands	12 (6)

Table 4. Corn yield changes for BMPs with demonstrated nitrogen loss reduction. SD = standard deviation, n = number of site years. Practice in italics (3-yr rotation) is a practice added based on this review.

Practice	**Updated % Yield Change**		Previous % Yield Change	
	Mean (SD)	**Site years n**	Mean (SD)	Site years n
Timing-Fall to spring pre-plant application	4 (16)	28	4 (16)	26
Timing- Spring pre-plant/sidedress (40-60) vs. fall applied	-	-	10 (7)	7
Sidedress - Compared to pre-plant application	4 (9)	7	0 (3)	5

Sidedress - Soil test based compared to pre-plant	-	-	13 (22)	21
Source - Swine	-	-	0 (13)	31
Source - Poultry	-4 (22)	100	- 2 (14)	66
Nitrification Inhibitor	-	-	6 (22)	26
Cover Crops - Rye	0 (10)	45	-6 (7)	24
Cover Crops - Oat	-4 (1)	5	-5 (1)	3
Living Mulches	-	-	-9 (32)	37
Extended Rotation – 3 yr.	4 (15)	6	-	-
Extended Rotation – 4+ yr.	7 (6)	11	7 (7)	17
Drainage water management (controlled drainage)	-5 (4)	9		
Shallow drainage	-3 (4)	9		

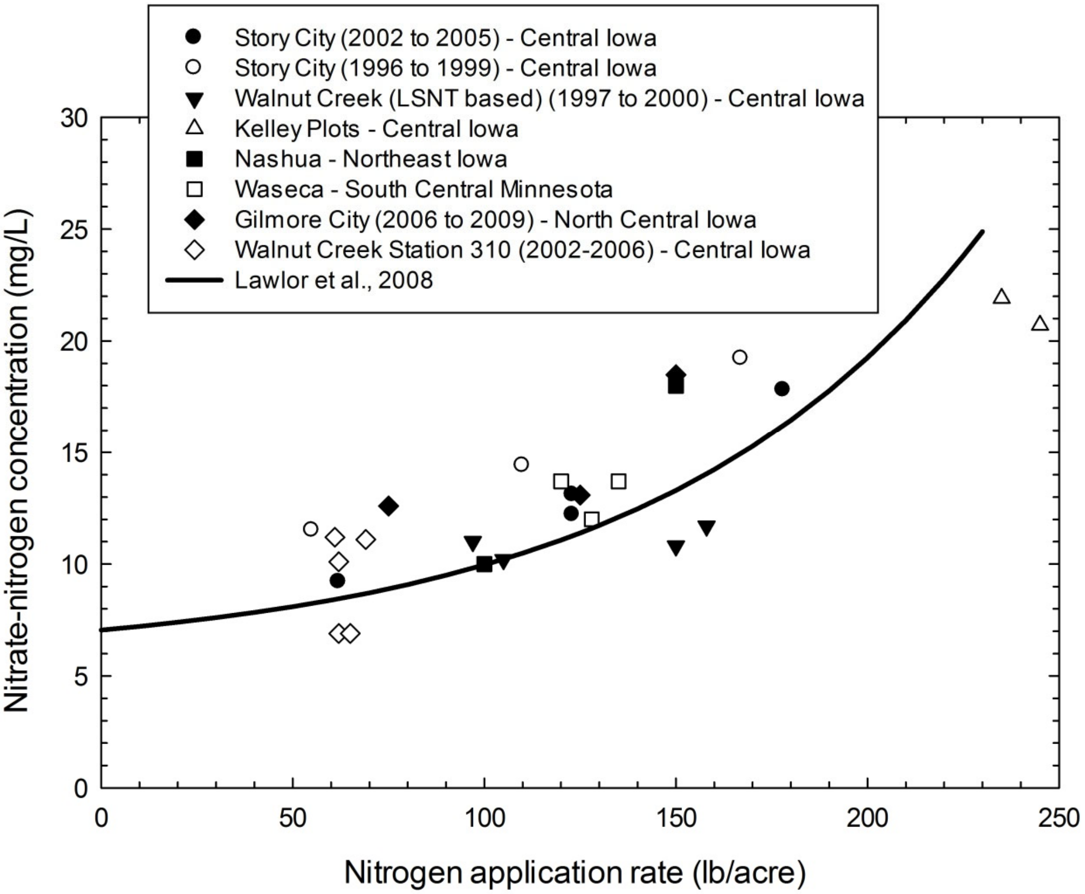

Figure 1. Nitrogen application rate effect from various studies on tile drainage nitrate-N concentration for a corn-soybean rotation compared to the tile-flow response curve developed by Lawlor et al. (2008).

CR: 6 (16) | 6 (25) **Timing - Fall to spring preplant**

CR: 5 (13) | 5 (28) **Timing - Spring pre-plant/sidedress (40-60) vs. fall applied**

A total of 11 papers were reviewed for the BMP of timing. One of these papers met the aforementioned criteria and was used in the calculations for the table.

New Literature

Jaynes, D. B. 2015. Corn yield and nitrate loss in subsurface drainage affected by timing of anhydrous ammonia application. Soil Science Society of America Journal. 79: 1131-1141.

Jaynes (2015) investigated various nitrogen application timings of anhydrous ammonia: in the fall after harvest (F) at 196 kg N/ha, in the spring before planting (PP), or as an early sidedress (SD) at rates of 168 kg N/ha, and an accidental fourth treatment of N application over applied by threefold on two plots (FH). The study was completed in a C/SB rotation from 2010-2013. Over the two corn years, yields for the FH and SD treatments were at least 1.5 Mg/ha greater than for the F and PP treatments. Flow-weighted annual N concentrations in the tile drainage were significantly different and followed the pattern FH > F > SD > PP.

Previous Literature

Lawler Helmers unpublished

Clover, M. W. 2003. Impact of nitrogen management on corn grain yield and nitrogen loss on a tile drained field. Master of Science, University of Illinois, Urbana-Champaign, IL.

Randall, G. W., and J. E. Sawyer. 2008. Chapter 6 - Nitrogen application timing, forms, and additives, p. 73-85 Final report: gulf hypoxia and local water quality concerns workshop. ed. American Society of Agricultural and Biological Engineers, Saint Joseph.

Randall, G. W., and J. A. Vetsch. 2005a. Corn Production on a subsurface-drained mollisol as affected by fall versus spring application of nitrogen and nitrapyrin. Agronomy Journal. 97: 472-478.

Randall, G. W., and J. A. Vetsch. 2005b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. Journal of Environmental Quality. 34: 590-597.

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003a. Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and nitrapyrin. Agronomy Journal 95:1213-1219

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. Journal of Environmental Quality. 32: 1764-1772.

CR: 1 (14) | 7 (37) **Sidedress – Compared to pre-plant application**

CR: 4 (15) | 4 (20) **Sidedress – Soil test based compared to pre-plant**

Two additional paper was looked at for the BMP of sidedress. One of these papers met the aforementioned criteria and was used in the calculations for the table.

New Literature

Jaynes, D. B. 2015. Corn yield and nitrate loss in subsurface drainage affected by timing of anhydrous ammonia application. Soil Science Society of America Journal. 79: 1131-1141.

> Jaynes (2015) investigated various nitrogen application timings of anhydrous ammonia: in the fall after harvest (F) at 196 kg N/ha, in the spring before planting (PP), or as an early sidedress (SD) at rates of 168 kg N/ha, and an accidental fourth treatment of N application over applied by threefold on two plots (FH). The study was completed in a C/SB rotation from 2010-2013. Over the two corn years, yields for the FH and SD treatments were at least 1.5 Mg/ha greater than for the F and PP treatments. Flow-weighted annual N concentrations in the tile drainage were significantly different and followed the pattern FH > F > SD > PP.

Previous Literature

Baker, J., and S. Melvin. 1999. ADW Annual Report. Iowa State University, Ames, IA.

Bakhsh, A., R. S. Kanwar, T. B. Bailey, C. A. Cambardella, D. L. Karlen, and T.S. Colvin. 2002. Cropping system effects on NO3-N loss with subsurface drainage water. Transactions of the ASAE 45:1789-1797.

Clover, M. W. 2003. Impact of nitrogen management on corn grain yield and nitrogen loss on a tile drained field. Master of Science, University of Illinois, Urbana-Champaign, IL.

Jaynes, D. 2009. Crop Yield and Nitrate Losses from Sidedressing N at Canopy Closure - Poster. Agricultural Science Association.

Jaynes, D. B., and T. S. Colvin. 2006. Corn yield and nitrate loss in subsurface drainage from midseason nitrogen fertilizer application. Agronomy Journal. 98: 1479-1487.

Jaynes, D. B., D. L. Dinnes, D. W. Meek, D. L. Karlen, C. A. Cambardella, and T. S. Colvin. 2004. Using the late spring nitrate test to reduce nitrate loss within a watershed. Journal of Environmental Quality. 33: 669-677.

Kanwar, R. S., D. L. Karlen, and R. M. Cruse. 1995. Swine manure and N-management systems: Impact on groundwater quality. p. 91-94 Proc. Clean Water - Clean Environment - 21st Century: Team Agriculture - Working to protect water resources, Kansas City, MO1995. ASAE.

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003a. Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and nitrapyrin. Agronomy Journal 95:1213-1219

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. Journal of Environmental Quality. 32: 1764-1772.

CR: -- | 4 (11) **Source - Swine**

A total of 12 papers were reviewed for the BMP of nitrogen source of manure. No additional studies for swine manure applications met the criteria. Two of these papers for poultry manure applications were used in the calculations for the table.

Previous Literature

Lawlor, P. A., M. J. Helmers, J. L. Baker, S. W. Melvin, and D. W. Lemke. 2011. Comparison of liquid swine manure and ammonia nitrogen application timing on subsurface drainage water quality in Iowa. Transaction of the ASABE. 54(3): 973-981.

Rakshit, S. 2002. Liquid swine manure as a nitrogen source for corn and soybean production. Soil Science, Iowa State University, Ames, Iowa.

CR: 5 (40) | -3 (20) **Source - Poultry**

New Literature

Nguyen, H. Q., R. S Kanwar, N. L. Hoover, P. Dixon, J. Hobbs, C. Pederson, and M. L. Soupir. 2013. Long-term effects of poultry manure application on nitrate leaching in tile drain water. Transactions of the ASABE. 56(1): 91-101.

Nguyen et al. (2013) conducted a study from 1998 to 2009, monitoring water quality of corn and soybean rotation plots under different nutrient applications of poultry manure and urea ammonium nitrate. Results showed that poultry manure, applied at of a rate of 168 kg N per hectare, lowered flow-weighted nitrate concentrations compared to UAN and poultry manure applied at a 336 kg N per hectare. Additionally, results indicated that the beginning stages of crop growth nitrate loss to tile drainage is the time period where nitrate loss to drainage water is most likely to happen.

Wu, C. 2016. Long term effect of poultry manure application on water quality, yield under a corn-corn system in Iowa. Graduate Theses and Dissertations. Paper 15179.

Wu (2016) assessed the effects of poultry manure application to continuous corn cropping systems on N and P losses and crop yields from 2010-2014. Treatments were single manure, double manure, and a urea ammonia nitrogen control. Soil and water samples were collected to evaluated N and P losses. Subsurface water samples were taken from drainage tiles weekly and following precipitation during the research period (2010-2014). Single application resulted in higher yields, and lower nitrate-N loads and concentration than double application and urea ammonia.

Previous Literature

Chinkuyu, A. J., R.S. Kanwar, J. C. Lorimor, H. Xin, and T. B. Bailey. 2002. Effects of laying hen manure application rate on water quality. Transactions of the ASAE. 45: 299-308.

Ruiz Diaz, D., J. Sawyer, and A. P. Mallarino. 2011. On-farm evaluation of poultry manure as a nitrogen source for corn. Soil Science Society of America Journal. 75: 729-737.

Ruiz Diaz, D. A., J. A. Hawkins, J. E. Sawyer, and J. P. Lundvall. 2008. Evaluation of in-season nitrogen management strategies for corn production. Agronomy Journal. 100: 1711-1719..

CR: -- | 10 (--) **Nitrogen Application Rate**

A total of 22 papers were reviewed for the BMP of application rate. None of these papers met the criteria.

Previous Literature

Bakhsh, A., R. S. Kanwar, and D. L. Karlen. 2005. Effects of liquid swine manure applications on NO3-N leaching losses to subsurface drainage water from loamy soils in Iowa. Agriculture, Ecosystems and Environment 109: 118-128.

Jaynes, D., T. Colvin, D. Karlen, C. Cambardella, and D. Meek. 2001. Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate. (in English) Journal of Environmental Quality. 30: 1305-1314.

Kanwar, R. S., D. L. Karlen, and R. M. Cruse. 1995. Swine manure and N-management systems: Impact on groundwater quality. p. 91-94 Proc. Clean Water - Clean Environment - 21st Century: Team Agriculture - Working to protect water resources, Kansas City, MO1995. ASAE.

Lawlor, P. A., M. J. Helmers, J. L. Baker, S. W. Melvin, and D. W. Lemke. 2008. Nitrogen application rate effect on nitrate-N concentration and loss in subsurface drainage for a corn-soybean rotation. Transactions of the ASABE. 51: 83-94.

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. Journal of Environmental Quality. 32: 1764-1772.

CR: -- | 4.6 (20) **Nitrification Inhibitor**

A total of two papers and one report were reviewed for the BMP of nitrification inhibitor. A new study for Centuro (Pronitridine) was included.

Helmers, M.J. and Sawyer, J. 2021. Progress Report for Gilmore City Drainage Water Quality Research Facility.

This study documented the use of Centuro as a nitrification inhibitor at the Gilmore City Drainage Water Quality Research Facility. This was studied from 2016-2020. This work evaluated fall applied anhydrous ammonia with and without Centuro. Nitrate-N concentrations and loads were monitored. Centuro is an EPA approved nitrification inhibitor as is Nitrapyrin.

Previous Literature

Clover, M. W. 2003. Impact of nitrogen management on corn grain yield and nitrogen loss on a tile drained field. Master of Science, University of Illinois, Urbana-Champaign, IL.

Ellsworth, J., K. Balkcom, and A. M. Blackmer. 1999. Fertilization to rescue corn crops following losses of fall nitrogen. p. 301-304 Proc. Integrated Crop Management, Ames, IA1999. Iowa State University.

Nelson, D. W., and D. M. Huber. 1980. Performance of nitrification inhibitors in the Midwest (east), p. 75-88, In S. Matthias, et al., (eds.) Nitrification Inhibitors - Potentials and Limitations - ASA Special Publication Number 38. American Society of Agronomy Soil Science Society of America, Madison, Wisconsin.

Owens, L.B. 1987. Nitrate leaching losses from monolith lysimeters as influenced by nitrapyrin. Journal of Environmental Quality. 16: 34-38.

Randall, G. 2008. Managing nitrogen for optimum profit and minimum environmental loss Integrated Crop Management. ed. Iowa State University, Ames.

Randall, G. W., and J. A. Vetsch. 2005a. Corn Production on a subsurface-drained mollisol as affected by fall versus spring application of nitrogen and nitrapyrin. Agronomy Journal. 97: 472-478.

Randall, G. W., and J. A. Vetsch. 2005b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. Journal of Environmental Quality. 34: 590-597.

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003a. Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and nitrapyrin. Agronomy Journal 95:1213-1219

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003b. Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by time of nitrogen application and use of nitrapyrin. Journal of Environmental Quality. 32: 1764-1772.

CR: 28 (26) | 31 (29) **Cover Crops - Rye**

CR: 25 (6) | 28 (2) **Cover Crops - Oats**

A total of 28 papers were reviewed for the BMP of cover crops. Seven of these papers met the aforementioned criteria and were used in the calculations for the table. One study included an oat cover crop.

New Literature

Daigh, A. L. M., X. Zhou, M. J. Helmers, C. H. Pederson, R. Horton, M. Jarchow, and M. Liebman. 2015. Subsurface drainage nitrate and total reactive phosphorus losses in bioenergy-based prairies and corn systems. Journal of Environmental Quality. 44: 1638-1646.

Daigh et al. (2015) investigated subsurface drainage nitrate, total reactive P, and yields of bioenergy cropping systems and soil water storage dynamics due to land management practices of select annual- and perennial- based biofuel cropping systems from 2010-2013. Cropping systems evaluated were continuous corn (harvested for grain & 50% corn stover) with and without a winter cereal rye cover crop, mixed prairie (harvested annually for ABG biomass) with and without N fertilizer, and a C/SB rotation harvested only for grain. The C/SB rotations without residue removal and continuous corn with residue removal produced similar mean annual flow-weighted nitrate concentrations, ranging from 6 to 18.5 mg N/L during the study. In contrast, continuous corn with residue removal and with a cover crop had significantly lower nitrate concentrations of 5.6 mg N/L when mean annual flow-weighted values were avg. across the study. Prairie systems with or without N fertilization produced significantly lower concentrations below <1 mg NO3/L than all row crop systems throughout the study.

Krueger, E. S., T. E. Ochsner, J. M. Baker, P. M. Porter, and D. C. Reicosky. 2012. Rye-corn silage double-cropping reduces corn yield but improves environmental impacts. Agronomy, Soils and Environmental Quality 104: 888-896.

Krueger et al. (2012) compared environmental impacts and forage production of monocrop corn silage and rye-corn silage double crop systems with multiple corn planting dates and high-rate manure application near Morris, MN from 2007-2009. Corn for silage was seeded into a silt loam as a monocrop in early and mid-May and as a double-crop after rye in mid-May and early June, and manure was fall applied. Soil nitrate-N to 90 cm accumulated at an average rate of 71 kg N/ha/y with monocropping, but accumulation was not observed with double-cropping. Average soil solution nitrate-N concentration was high with monocropping (52 mg/L) and double-cropping (37 mg/L).

Martinez-Feria, R. A., R. Dietzel, M. Liebman, M. J. Helmers, and S. V. Archontoulis. 2016. Rye cover crop effects on maize: A systems-level approach. Field Crops Research. 196: 145-159.

This study evaluated data from continuous corn treatments (with and without a cover crop) in Iowa, USA from 2009-2014. Measurements included: soil water and temperature, drainage water and nitrate losses, soil nitrate, rye shoot and root biomass, along with C:N, and maize yields. Results show that rye cover crop reduced drainage by 12% and nitrate losses by 20% (or 31% per unit of N applied), and maize yields by 6%. Includes study years from Daigh et al. Data was not duplicated.

O'Brien P. L., B. D. Emmett, R. W. Malone, M. R. Nunes, J. L. Kovar, T. C. Kaspar, T. B. Moorman, D. B. Jaynes, and T. B. Parkin. 2022. Nitrate losses and nitrous oxide emissions under contrasting tillage and cover crop management. Journal of Environmental Quality. doi: 10.1002/jeq2.20361. Epub ahead of print. PMID: 35443288.

O’Brien et al. (2022) evaluate nitrous oxide emissions and nitrate losses in drainage water for a fields trial under different tillage and cover crop systems. Treatments included in this study were no-till with zero nitrogen fertilizer, no-till with a rye cover crop, no-till with no cover crop, fall tillage (chisel plow) with an oat cover crop, and fall tillage (chisel plow) with no cover crop. The no-till, rye cover crop treatment reduced nitrate concentration by 67% compared to the no-till treatment. Over the two years of the study, yield was not significantly different between cover crop treatments

Parkin, T. B., T. C. Kaspar, D. B. Jaynes, and T. B. Moore. 2016. Rye cover crop effects on direct and indirect nitrous oxide emissions. Soil Biology and Biochemistry. 80: 1551-1559.

Parkin et al. (2016) measured direct soil emissions of nitrous oxide and nitrate-N leaching over a 10-year period in a C/SB rotation with and without a winter rye cover crop to estimate nitrous oxide emissions using multiple measures. Nitrate-N exported in the tile drains was summed for each plot during the study (2004–2013) and cumulative treatment means calculated. The presence of a rye cover crop significantly (P = 0.029) reduced nitrate–N leaching losses (no rye = 359.2 kg NO3–N/ha; rye = 166.6 kg NO3–N/ha).

Preza-Fontes, G., C. M. Pittelkow, K. D. Greer., R. Bhattarai, and L. E. Christianson. 2021. Split-nitrogen application with cover cropping reduces subsurface nitrate losses while maintaining corn yields. Journal of Environmental Quality. 50: 1408-1418.

Preza-Fontes et al. (2021) investigated nitrate losses in drainage water for continuous corn. Treatments applied in the study include different timings of nitrogen fertilizer and the presence of a cereal rye cover crop. The treatment of 40% preplant and 60% sidedressed nitrogen fertilizer that was accompanied with a cereal rye cover crop, reduced flow-weighted nitrate concentration by 35% and nitrate load by 37%. When looking at yield, the treatment including a cereal rye did not significantly change grain yield compared to the treatment of the same nitrogen fertilizer application with no cover crop.

Waring, E. R., A. Lagzdins, C. Pederson, and M. J. Helmers. 2019. Influence of no-till and a winter rye cover crop on nitrate losses from tile-drained row-crop agriculture in Iowa. Journal of Environmental Quality. 49: 292-303.

Waring et al. (2019) evaluated seasonal and annual nitrate concentration and loads for eight different treatments in north-central Iowa. The treatments were chisel plow (CT), chisel plow with winter cereal rye (CTr), no-till (NT), and no-till with winter cereal rye (NTr) for both corn and soybean crops. Both the treatments of no-till and conventional till with winter cereal rye showed nitrate reductions compared to conventional till. For corn, the five-year average of nitrate concentration for the treatments were 16.7 mg/L (CT), 11.8 mg/L (CTr), 11.4 mg/L (NTr), and 11.1 mg/L (NT).

Previous Literature

Kaspar, T. C., D. B. Jaynes, T. B. Parkin, and T. B. Moorman. 2007. Rye cover crop and gamagrass strip effects on NO3 concentration and load in tile drainage. Journal of Environmental Quality. 36: 1503-1511.

Kaspar, T. C., D. B. Jaynes, T. B. Parkin, T. B. Moorman, and J. W. Singer. 2012. Effectiveness of oat and rye cover crops in reducing nitrate losses in drainage water. Agricultural Water Management. 110: 25- 33.

Pederson, C., R. Kanwar, M. Helmers, and A. Mallarino. 2010. Impact of liquid swine manure application and cover crops on groundwater water quality. Iowa State University, Ames, IA.

PFI. 2011. Cover crop effect on cash crop yield: year 2. Practical Farmers of Iowa, Ames, IA.

Qi, Z., M. J. Helmers, R. D. Christianson, and C. H. Pederson. 2011. Nitrate-nitrogen losses through subsurface drainage under various agricultural land covers. Journal of Environmental Quality. 40(5): 1578-1585.

Sawyer, J., J. Pantoja, and D. Barker. 2011. Nitrogen Fertilization of Corn Grown with Cover Crop. Iowa State University, Ames, IA.

Strock, J. S., P. M. Porter, and M. P. Russelle. 2004. Cover cropping to reduce nitrate loss through subsurface drainage in the northern U.S. corn belt. Journal of Environmental Quality 33:1010-1016.

Notes

Cover crops reduction fraction was calculated by comparing rotational averages with and without cover crops. Reduction fractions were also calculated for cover crops following each crop (corn and soybeans) for the different rotations of corn/soybean and continuous corn.

CR: -- | 41 (16) **Living Mulches**

No additional papers for living mulches were found in our review.

Previous Literature

Qi, Z., M. J. Helmers, R. D. Christianson, and C. H. Pederson. 2011. Nitrate-nitrogen losses through subsurface drainage under various agricultural land covers. Journal of Environmental Quality. 40(5): 1578-1585.

Sawyer, J. E., P. Pedersen, D. W. Barker, D. A. R. Diaz, and K. Albrecht. 2010. Intercropping corn and kura clover: response to nitrogen fertilization. Agronomy Journal. 102: 568-574.

Zemenchik, R. A., K. A. Albrecht, C. M. Boerboom, and J. G. Lauer. 2000. Corn production with kura clover as a living mulch. Agronomy Journal. 92: 698-705.

CR: 87 (21) | 72 (23) **Energy Crop**

A total of 16 papers were reviewed for the BMP of energy crops. Two of these papers met the criteria required and were used in the calculations for the table.

New Literature

Daigh, A. L. M., X. Zhou, M. J. Helmers, C. H. Pederson, R. Horton, M. Jarchow, and M. Liebman. 2015. Subsurface drainage nitrate and total reactive phosphorus losses in bioenergy-based prairies and corn systems. Journal of Environmental Quality. 44: 1638-1646.

Daigh et al. (2015) investigated subsurface drainage nitrate, total reactive P, and yields of bioenergy cropping systems and soil water storage dynamics due to land management practices of select annual- and perennial- based biofuel cropping systems from 2010-2013. Cropping systems evaluated were continuous corn (harvested for grain & 50% corn stover) with and without a winter cereal rye cover crop, mixed prairie (harvested annually for ABG biomass) with and without N fertilizer, and a C/SB rotation harvested only for grain. The C/SB rotations without residue removal and continuous corn with residue removal produced similar mean annual flow-weighted nitrate concentrations, ranging from 6 to 18.5 mg N/L during the study. In contrast, continuous corn with residue removal and with a cover crop had significantly lower nitrate concentrations of 5.6 mg N/L when mean annual flow-weighted values were avg. across the study. Prairie systems with or without N fertilization produced significantly lower concentrations below <1 mg NO3/L than all row crop systems throughout the study.

McIsaac, G. F., M. B. David, and C. A. Mitchell. 2010. Miscanthus and switchgrass production in Central Illinois: Impacts on hydrology and inorganic nitrogen leaching. Journal Environmental Quality. 39: 1790-1799.

McIsaac et al. (2010) completed a 4-year field study that examined the soil moisture and inorganic N leaching in a corn-soybean rotation and two different perennial grass systems of *Miscanthu*s and switchgrass. The study was completed in east-central Illinois from 2005 to 2008. The corn-soybean rotation leached 40.4 kg N per ha per year on average. This compares to the *Miscanthus* fields of 3.0 kg N per ha per year and the switchgrass field that lost on average 1.4 kg N per ha per year.

Previous Literature

Helmers, M. J. 2011a. BE nitrate and flow data Unpublished data.

Helmers, M. J. 2011b. COBS nitrate and flow data Unpublished data.

CR: -- | 85 (9) **CRP**

No additional papers for living mulches were found in our review.

Previous Literature

Qi, Z., M. J. Helmers, R. D. Christianson, and C. H. Pederson. 2011. Nitrate-nitrogen losses through subsurface drainage under various agricultural land covers. Journal of Environmental Quality. 40(5): 1578-1585.

Randall, G. W., D. R. Huggins, M. P. Russelle, D.J. Fuchs, W.W. Nelson, and J. L. Anderson. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. Journal of Environmental Quality. 26: 1240-1247.

Tomer, M., K. Schilling, C. Cambardella, P. Jacobson, and P. Drobney. 2010. Groundwater nutrient concentrations during prairie reconstruction on an Iowa landscape. Agriculture Ecosystems & Environment 139:206-213.

CR: 15 (34) | -- **Extended Rotations – 3-year**

CR: 27 (25) | 42 (12) **Extended Rotations – 4+ year**

A total of 12 papers were reviewed for the BMP of extended rotations. One of these papers met the criteria required and was used in the calculations for the table.

New Literature

Tomer, M. D., and M. Liebman. 2014. Nutrients in soil water under three rotational cropping systems, Iowa, USA. Agriculture, Ecosystem, and Environments. 186: 105-114.

> This study tracked nitrate and P in soil water under three cropping systems suited for the U.S. Midwest, including two-year (C/SB; 2YS), three-year (C/SB/small grain/red clover; 3YS), and four-year (C/SB/–small grain/alfalfa–alfalfa; 4YS) systems at the ISU Marsden Farm. Nutrient applications were based on soil-test results, and solely comprised inorganic fertilizers to 2YS corn. In the 3YS and 4YS systems, nutrients were provided by legume residues, and a managed balance of composted manure, and inorganic fertilizers. Soil water was collected from 2004 through 2011 using suction samplers. The 4YS system had smaller concentrations of NO3-N during the established alfalfa and subsequent corn crop than other crop-years in the experiment. Mean concentrations of NO3-N were 1.1 mg NO3-N/L under alfalfa and 6.5 mg NO3-N/L under the following 4YS corn crop, compared to average concentrations between 8.7 and 18.1 mg NO3-N/L among all other crop-years.

Previous Literature

Kanwar, R. S., R. M. Cruse, M. Ghaffarzadeh, A. Bakhsh, D. L. Karlen, and T. B. Bailey. 2005. Corn-soybean and alternative cropping systems effects on NO3-N leaching losses in subsurface drainage water. Applied Engineering in Agriculture. 21: 181-188.

Tomer, M. 2011. Extended Rotation Nitrate-N Reduction, In D. Jaynes, (ed.), Verbal communication between Mark Tomer and Dan Jaynes ed.

Notes

Previous papers had two years of alfalfa in a 4- or 5-year rotation. The added paper includes a 3-year rotation and only has one year of alfalfa in both its extended rotations. Data was then broken out into two groups, 3-year rotation and a 4+ year rotation. The 3-year rotation includes data on strip cropping from Kanwar et al. (2005).

CR: -- | 85 (--) **Grazed Pastures**

One paper was reviewed for the BMP of grazed pastures. It did not meet the criteria.

Previous Literature

Sources from OH, not used in tabular report. Assumed to be similar to CRP

CR: 87 (27) | 91 (20) **Buffers**

A total of four papers were reviewed for the BMP of buffers. One of these papers met the aforementioned criteria.

New Literature

Groh, T. A., T. M. Isenhart, and R. C. Schultz. 2020. Long-term nitrate removal in three riparian buffers: 21 years of data from the Bear Creek watershed in Central Iowa, USA. The Science of the Total Environment. 740: 140114.

Groh et al. (2020) report nitrate data from three buffer sites located in Central Iowa over 21 years. Two out of the three sites in the Bear Creek Watershed were established on previously row-cropped land while the last site was established on pasture. Buffers were established in 1990 and 1994. For the multi-species buffers planted in previously row-cropped land, nitrate removal showed an increase after 6-10 years of establishment. The cool season grass buffer did not see this increase in nitrate reduction over time.

Previous Literature

Mayer, P.M., S.K. Reynolds, M.D. McCutchen, and T.J. Canfield. 2007. Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality 36:1172-1180.

Osborne, L.L., and D.A. Kovacic. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology 29:243-258.

Schoonover, J.E., and K.W.J. Willard. 2003. Ground water nitrate reduction in giant cane and forested riparian buffer zones. Journal of the American Water Resources Association 39:347-354.

Spear, B.A. 2003. Fate and transport of nitrate in groundwater through three multi-species riparian buffers along Bear Creek in central Iowa. MS Thesis. Iowa State University, Ames, IA.

Yamada, T., S.D. Logsdon, M.D. Tomer, and M.R. Burkart. 2007. Groundwater nitrate following installation of a vegetated riparian buffer. Science of the Total Environment 385:297-309.

Bioreactors **LR - kg/ha: 5 (4)**

A total of 13 papers were reviewed for the BMP of bioreactors. Two of these papers met the criteria required and were used in the calculations for the table.

New Literature

Christianson, L. E., M. J. Helmers, A. Bhandari, and T. B. Moorman. 2013. Internal hydraulics of an agricultural drainage denitrification bioreactor. Ecological Engineering. 52: 298-307.

Christianson et al. (2013) evaluated the internal flow dynamics and several environmental parameters of a denitrification bioreactor treating agricultural drainage in Northeastern Iowa, USA with two tracer tests and a network of bioreactor wells. The bioreactor had a trapezoidal cross section and received drainage from approximately 14.2 ha at the Northeast Research Farm near Nashua, Iowa. Samples were taken five times from May 17 to Aug 24, 2011, and included flow conditions and internal parameters (temp., DO, oxidation-reduction potential). These parameters varied widely over the sampling time, which resulted in little to complete nitrate removal (7-100% mass reduction; 0.38-1.06 g N removed per cubic meter/bioreactor/day).

Christianson data on Illinois sites (2017-2020) sent via email

David, M. B., L. E. Gentry, R. A. Cooke, and S. M. Herbstritt. 2015. Temperature and substrate control woodchip bioreactor performance in reducing tile nitrate loads in East-Central Illinois. Journal of Environmental Quality. 45(3): 822-829.

David et al. (2015) evaluated the nitrate removal performance of a woodchip bioreactor during the first 3 year of operation and examined the major factors that regulated nitrate removal. The bioreactor had average monthly nitrate removal rates of 23 to 44 g N/cubic meter/d in year 1, which decreased to 1.2 to 11 g N/cubic meter/d in Years 2 and 3, likely because of highly degradable C in the woodchips. Based on a process-based bioreactor performance model, Bioreactor 1 would have needed to be 9 times as large as the current system to remove 50% of the nitrate load from this 20-ha field.

Previous Literature

Christianson, L. 2011. Design and performance of denitrification bioreactors for agricultural drainage. PhD, Iowa State University, Ames, Iowa.

Saturated Buffers **LR - kg/ha: 10 (6)**

A total of six papers were reviewed for the BMP of saturated buffers. Two of these papers met the criteria required and were used in the calculations for the table.

New Literature

Jaynes. D. B. and T. M. Isenhart. 2018. Performance of saturated riparian buffers in Iowa, USA. Journal of Environmental Quality 48:289-296.

Researchers Jaynes and Isenhart (2018) examined six saturated buffers across Iowa with a total of 17 site-years. Water flow, nitrate loads diverted and removed by the buffer, and tile nitrate concentrations were recorded for all the sites. The average nitrate load removal ranged from 13 to 179 kg N. The removal effectiveness ranged from 8 to 84%. The paper also provides a breakdown of cost per kg N removed ($2.94) and a mean annual cost ($213.83) for this practice.

Chandrasoma, J., R. Christianson, R. A. Cooke, P. C. Davidson, D. Lee, and L. Christianson. 2022. Saturated buffer design flow and performance in Illinois. Journal of Environmental Quality, 1–10.

Chandrasoma et al. (2022) observed drainage and nitrate loss in three saturated buffers in Illinois during 2018-2021. Sites were established as saturated buffers in 2013, 2016, and 2018. Two buffers consisted of smooth bromegrass while one was a multi-species buffer. All sites received drainage from crop fields consisting of a corn and soybean rotation. Drainage areas for the sites were 6.9, 9.9, and 11.9 hectares. Over all three sites, a 48% reduction in nitrate loss was observed. Load reductions for the sites ranged from 3.5 kg NO3–N per hectare per year to 25.25 5 kg NO3–N per hectare per year.

Previous Literature

Jaynes, D.B. and T.M. Isenhart. 2014. Reconnecting tile drainage to riparian buffer hydrology for enhanced nitrate removal. Journal of Environmental Quality 43: 631-638.

Drainage Water Management **LR - kg/ha: 15 (11)**

Shallow Drainage **LR - kg/ha: 12 (10)**

A total of 12 papers were reviewed for the BMP of drainage water management. Three of these papers met the criteria required and were used in the calculations for the table.

New Literature

Schott, L., A. Lagzdins, A.L.M. Daigh, K. Craft, C. Pederson, G. Brenneman, and M.J. Helmers. 2017. Effects of drainage water management on yield, drainage, water table, and volumetric water content in Southeast Iowa. *Journal of Soil and Water Conservation* 72(3): 251-259.

Schott et al. (2017) reported on controlled drainage and shallow drainage results for five years from southeast Iowa. This study was a continuation of Helmers et al. 2012) work.

Helmers, M.J., R. Christianson, G. Brenneman, D. Lockett, and C. Pederson. 2012. Water table, drainage, and yield response to drainage water management in southeast Iowa. *Journal of Soil and Water Conservation* 67(6): 495-501.

Helmers et al. (2012) reported on controlled drainage and shallow drainage from near Crawfordsville, IA. The results showed a decrease in drain flow and nitrate load from the drainage system but little impact on concentrations of nitrate-N.

Helmers M. J., L. Abendroth, B. Reinhart, G. Chighladze, L. Pease, L. Bowling, M. Youssef, E. Ghane, L. Ahiablame, L. Brown, N. Fausey, J. Frankenberger, D. Jaynes, K. King, E. Kladivko, K. Nelson, and J. Strock. 2022. Impact of controlled drainage on subsurface drain flow and nitrate load: A synthesis of studies across the U.S. Midwest and Southeast. Agricultural Water Management. 259: 107265.

Helmers et al. (2022) synthesis data from thirteen drainage water management sites across Iowa, South Dakota, Minnesota, Missouri, Indiana, Ohio, and North Carolina. Research sites had paired treatments of free drainage and controlled drainage under similar agronomic management. Data from these sites range from 2009 to 2017. Data comes from Transforming Drainage Database (https://datateam.agron.iastate.edu/td/dl/#tab_wdata)

Jaynes, D. 2012. Changes in yield and nitrate losses from using drainage water management in central Iowa, United States. Journal of Soil and Water Conservation. 67(6): 485-494.

Jaynes (2012) investigates the application of DWM to a 54-ac production C/SB field in Iowa from 2006-2009. Three of nine plots in the field were retrofitted with control structures to control drainage level. Water flow from the tile in each plot, nitrate concentration in the drainage, and crop yield were measured. Results show that there was a significant 21% decrease in tile flow, no significant decrease in nitrate concentration, and a significant 29% reduction in nitrate load leaching from the DWM treatment compared to conventional drainage. There were no yield benefits to corn; soybean yields increased by 8%, but it was unclear if this was the result of DWM or weather. Data in this paper is included in Helmers et al. (2022).

Nash, P., K. Nelson, and P. Motavalli. 2015. Reducing nitrogen loss with managed drainage and polymer-coated urea. Journal of Environmental Quality. 44: 256-264.

Nash et al. (2015) conducted a 4-yr study to determine whether use of managed subsurface drainage (MD) in combination with a controlled-release N fertilizer could reduce the amount of nitrate-N loss through tile drainage compared to free subsurface tile drainage (FD) with a noncoated urea application. Use of MD reduced annual nitrate-N loss in the tile drainage water by 78 to 85% in two of the four years. High nitrate-N loss reduction with MD compared with FD was largely due to dry growing season conditions in combination with wet conditions over the non-cropping period. Data in this paper is included in Helmers et al. (2022).

Previous Literature

ADMC. 2011. Drainage water management for midwestern row crop agriculture. Agricultural Drainage Management Coalition, Owatonna, MN.

Cooke, R., J. Nehmelman, and P. Kalita. 2002. Effect of Tile Depth on Nitrate Transport from Tile Drainage Systems. Proc. ASAE International Meeting, Chicago, IL 2002. ASAE.

Helmers, M., R. D. Christianson, G. Brenneman, D. Lockett, and C. Pederson. 2010. Water table response to drainage water management in southeast Iowa. Proc. XVII World Congress of the International Commission of Agricultural Engineering (CIGR), Quebec City, Canada2010. Canadian Society for Bioengineering.

Restored Oxbow LR - kg/ha 2 (--)

A total of five papers were reviewed for the BMP of restored oxbow. one of these papers met the criteria required and was used in the calculations for the table.

New Literature

Pierce, S., and K.E. Schilling. 2023. Nutrient retention in tile-fed and non-tile reconstructed oxbows in north central Iowa. JAWRA Journal of the American Water Resources Association. https://doi.org/10.1111/1752-1688.13124

This study reports on two tile fed oxbows in north central Iowa for 2020 and 2021.

Schilling, K.E., K. Kult, A., Seemon, K. Wilke, and C. S. Jones. 2018. Nitrate-N load reduction measured in a central Iowa restored oxbow. Ecological Engineering 124:19-22.

Schilling et al. (2018) constructed a tile-fed restored oxbow in the White Fox Creek floodplain of north-central Iowa. From March to November, nitrate concentrations ranged to <0.2 to 3.5 mg/l. Schilling et al. (2018) estimate the retention efficiency was 35.4% with the ability to retain 0.21 g N per m^2 per day. The authors acknowledge that the potential for restored oxbows for reducing nitrates are greater in scenarios that receive higher nitrate loads. While the retention efficiency goes down with higher nitrate inputs, a tile fed oxbow can reduce larger amounts of nitrates because of the sheer mass of nitrates input into the system compared to a flood fed oxbow.

Previous Literature

N/A

Wetlands **LR - kg/ha: 12 (6)**

A total of 12 papers were reviewed for the BMP of wetlands.

New Literature

Crumpton, W. G., G. A. Stenback, S. W. Fisher, J. Z. Stenback, and D. I. Green. 2020. Water quality performance of wetlands receiving nonpoint-source nitrogen loads: Nitrate and total nitrogen removal efficiency and controlling factors. Journal of Environmental. 49: 735– 744.

Previous Literature

Helmers, M., W. Crumpton, P. Lawlor, C. Pederson, G. Stenback, R. Christianson, and D. Green. 2008a. Water and Nutrient Research: In-field and Offsite Strategies. Iowa State University, Ames, IA.