Winter Manure Literature Review – Document Summaries

Peer Reviewed Studies

Summary (100 words)	Bullets	Source
The SurPhos computer model was used and incorporated data from previous studies to better understand the impacts of imminent runoff incidents and manure application during the winter on dissolved P losses. P runoff increased 2.5 to 3.6 times after manure application in winter compared to other seasons. Fields prone to decreased runoff levels resulted in reduced P loss. The SurPhos model proved to work in a variety of P modeling circumstances if the inputs were highly accurate. The researchers concluded that field conditions and long-term weather conditions are better indicators of resulting P runoff than short-term weather conditions.	• Used SurPhos computer model • Assess impact of application in winter and when runoff is imminent on dissolved P loss • "Winter manure application increase P loss by 2.5-3.6 times" • Increased loss happened between late Nov. through early March • Max loss in late Jan. and early Feb. • "Delaying manure application when runoff is imminent reduces loss anytime" • Moving application to fields with less runoff reduces P loss 3.4-7.5 times • Greatest runoff P concentration when snowmelt occurs soon after manure application • "Applying manure in good seasons and fields of low runoff will help more than basing off short-term weather" • More runoff in winter because of high manure P available	Vadas, P. A., Good, L. W., Jokela, W. E., Karthikeyan, K. G., Arriaga, F. J., & Stock, M. (2017). Quantifying the Impact of Seasonal and Short-term Manure Application Decisions on P Loss in Surface Runoff. Journal of Environmental Quality, 46(6), 1395-1402.

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Prepared for the North Central Region Water Network Manure and Soil Health Working Group
August 31, 2017

Summary (100 words)	Bullets	Source
Nutrient levels were measured on 6 watersheds over a 3 year time span. Two watersheds were control, 2 were swine manure and 2 were turkey litter. Turkey litter was applied at a rate of 6.84 dry matter Mg/L, swine manure was applied at a rate of 1.06 to 0.64 dry matter Mg/ L. Total cumulative runoff was measured and it was the most in 2011 which could be due to higher precipitation rates that year. Nutrients were measured as ratios of pre/post application concentrations from 0.57 to 8.02, 0.36 to 11.71, and 1.35 to 127.84 for nitrate, phosphate, and ammonia, respectively.	• "The highest NH_4^+ concentrations were found in 2009 in runoff from the Turkey 2 watersheds, 4 days post-application" • "In this extreme case, the NH_4^+ concentration peaked at 54 mg/L, falling to less than 20 mg/L in the next event" • "The highest nitrate concentrations were measured in runoff from Swine 2 in 2009 and 2010; which measured 32 and 24 mg L^{-1} for those respective years, exceeding the EPA regulation of 10mg/L for safe drinking water" • "Runoff from watersheds receiving swine waste were ≤11 mg L^{-1} in 2009 and 2010, and ≤5 mg L^{-1} in 2011"	Shappell, N. W., Billey, L. O., & Shipitalo, M. J. (2016). Estrogenic activity and nutrient losses in surface runoff after winter manure application to small watersheds. Science of The Total Environment, 543, Part A, 570–580.

In the Pipestone Creek Watershed of Southeastern Saskatchewan, the nutrient losses from fertilized cropland and perennial pastures were measured during the Spring 2010 snowmelt. Compared to the particulate form, nutrients were primarily lost in the dissolved form. Larger amounts of particulate P were found in pasture runoff compared to cropland runoff, while higher concentrations of dissolved reactive P were found in cropland runoff. Higher amounts of total N, ammonium, and particulate total N were in pasture runoff in comparison to cropland runoff. Total C and dissolved organic C were present in greater quantities in cropland runoff compared to pasture runoff.	• "Nutrient loss was primarily in dissolved form instead of particulates"
	• "More N was lost from pastures as dissolved ammonium than cropland"
	  » More dissolved organic N lost from croplands
	  » Particulate total N higher in runoff from pasture than cropland
	  » Total N higher in runoff from pasture than cropland
	• Particulate total N higher in runoff from pasture than cropland
	• Total N higher in runoff from pasture than cropland
	• "More concentrations of dissolved reactive P in runoff from cropland"
	• "Higher particulate P in runoff from pastures"
	• Total C runoff higher in cropland
	  » Dissolved organic C concentration: higher in runoff from cropland
	  » Particulate organic C and particulate total C higher in pasture
	• Runoff from cropland had more dissolved K, Na, and S
		Cade-Menun, B. J., Bell, G., Baker-Ismail, S., Fouli, Y., Hodder, K., McMartin, D. W., & Wu, K. (2013). Nutrient loss from Saskatchewan cropland and pasture in spring snowmelt runoff. Canadian Journal of Soil Science, 93(4), 445-458.

Summary (100 words)	Bullets	Source
Dairy manure was applied to soil surfaces at temperatures of 15.7°C, 4.8°C, and -1.1°C to analyze how soil temperature affect N losses in runoff and leachate as well as how manure application time impacts overwinter N losses. As soil temperature decreased, losses of NH4-N, organic N, and total N increased during artificial precipitation events. On average, when the soil temperature decreased from 15.7°C to 4.8°C, the runoff volume increased 12%. When manure was applied in early fall, there was great overwinter losses of NO_3-N. When manure was applied during winter, there were greater overwinter losses of NH_4-N.	• "As soil temperature decreased, losses of NH4-N, organic N, and total N exponentially increased" » Increased amount of runoff volume during precipitation » "Decrease in soil temp from 15.7°C to 4.8°C resulted in 12% increase in runoff volume" • Application date and soil temperature impacted the majority forms of N losses » Early fall application: overwinter NO_3-N losses were the greatest » Winter application: overwinter NH_4-N losses were the greatest • After 1st rainfall, NH_4-N runoff decreased significantly during 2nd rainfall • Overwinter NO_3-N loss inversely related to overwinter NH_4-N losses • N retention was greatest in winter-applied manure	Williams, M. R., Feyereisen, G. W., Beegle, D. B., & Shannon, R. D. (2012). Soil temperature regulates N loss from lysimeters following fall and winter manure application. Trans. ASABE, 55(3), 861-870.
Dairy manure was applied to soil surfaces at temperatures of 15.7 °C, 4.8 °C, and -1.1 °C to analyze how soil temperature affect P losses in runoff and leachate as well as how manure application time impacts overwinter P losses. The loss of DRP, TDP, and total P increased as the soil temperature decreased. Throughout winter, the winter treatment produced 2 times higher total P losses compared to the early fall application. Suggestions include spreading manure when the soil temperature is greater than 10°C. Results displayed that winter manure application creates higher soil P concentrations resulting in more crop-available P.	• As soil temp decreased, loss of DRP, TDP, and total P increased • "Winter treatment had 2 times higher total P losses compared to early fall" • As soil temp decreased, volume of runoff increased • Significantly more DRP runoff lost at 1.1°C than 15.7° and 4.8° • Particulate P was 62%, 65%, 41% of total P runoff losses for 15.7°, 4.8°, and 1.1°C treatments, respectively • Overwinter P losses: » For all P forms, most lost in runoff » 56% increase in runoff volume for frozen soils compared to non-frozen soils » Frozen soil resulted in higher overwinter P losses than early and late fall • Suggest spread when soil temp greater than 10°C: infiltration potential the greatest • Winter application makes higher soil P concentrations and so more crop-available P in spring	Williams, M. R., Feyereisen, G. W., Beegle, D. B., & Shannon, R. D. (2012). Soil temperature regulates P loss from lysimeters following fall and winter manure application. Transactions of the ASABE, 55(3), 871-880.

Summary (100 words)	Bullets	Source
A 28-year study was conducted on double rice fields in Southern Central China where soil characteristics of plots treated with winter green manure were compared to those of fields that ran fallow. By the end, the fields treated with green manure contained higher soil organic C levels, total porosity, capillary porosity, non-capillary porosity, soil permeability, and soil water holding capacity when compared to the winter-fallow plots. Though the researchers tested three different plant species, the differences between them were not significant. Conclusions were drawn that rice fields in this region should be treated with both green manures and chemical fertilizers.	• Double rice fields Southern Central China • Mean weight diameter & normalized mean weight diameter of aggregates with treatment was larger • "Suggest green manures and chemical fertilizers to increase SOC content, improve soil physical properties, soil fertility" • Tested 3 plants in winter • No significant difference • Long-term winter planting green manure: reduced soil bulk density and enhanced total porosity, capillary porosity, non-capillary porosity, soil permeability, and soil water holding capacity, improved 0.25-5 mm water stable aggregates content • Soil organic C with green manure higher than fallow • NMWD positively correlated with content of organic C, amorphous Fe_2O_3, amorphous Al_2O_3, free/weakly combined C, and R_2O_3-combined C	Yang, Z. P., Xu, M. G., Zheng, S. X., Jun, N. I. E., GAO, J. S., Liao, Y. L., & Jian, X. I. E. (2012). Effects of long-term winter planted green manure on physical properties of reddish paddy soil under a double-rice cropping system. Journal of Integrative Agriculture, 11(4), 655-664.
Using the Ohio Natural Resources Conservation Service recommendations on winter manure application, turkey litter or liquid swine manure were added to frozen soil for three consecutive years. Additionally, beef slurry was applied to four grassed plots with either 61x12 m or 30x12 m grassed filter areas. Shortly after manure application, nutrient concentrations were high in runoff. In manure-treated areas, the largest component of N loss was organic N while P losses in surface runoff were greater than in the control. Though the filter strips reduced nutrient concentrations and transport, there was not enough data to differentiate between filter strip effectiveness.	• Shortly after manure application, nutrient concentrations high in runoff • Transport minimal because most events with high concentrations occurred with low flow volumes • Elevated P losses because application rate resulted in excess amounts of P • "Manure-treated watersheds lost 1-2 times the amount of NO_2-N as control (annual basis)" • "Total P unfiltered transported at rates 2-6 times greater than percentage of runoff within 1st 15 days after manure application" • Largest component for N loss was Org N: 35-94% of total N lost	Owens, L. B., Bonta, J. V., Shipitalo, M. J., & Rogers, S. (2011). Effects of winter manure application in Ohio on the quality of surface runoff. Journal of environmental quality, 40(1), 153-165.

Summary (100 words)	Bullets	Source
This study researched the effects of different management practices on nitrate leaching. Thirty-six 0.4 ha plots were utilized in 2001-2004 with 4 different treatments; chisel plow corn with fall manure, chisel plow soybean with no manure, no-till corn with spring manure, and no-till soybean with no manure, and samples were collected from depths of 1.2 m, 1.8 m, and 2.4 m. Manure was applied at a rate of 168 kg N/ha. Average NO_3 concentrations were 16.1 mg/L, 14.4 mg/L, and 11.8 mg/L at 1.2 m, 1.8 m and 2.4 m, respectively. It was also found that spring application of manure was favored over fall application of manure.	• "If manure is not applied in correct time and quantity, even manure applications can lead to increased nitrate leaching to groundwater systems" • "Study was conducted at Iowa State University's Northeast Research Center near Nashua, IA" • "The rate of application of the liquid swine manure was 168 Kg N/ha only to the corn field in corn –soybean rotation" • Groundwater samples were taken at 1.2, 1.8, and 2.4 m • "The NO_3-N concentrations in the water samples were determined spectrophotometrically using a Lachat Model AE ion analyzer" • "The period of active uptake of water by crops played a major role in defining leaching patterns" • "The fall application of swine manure with the chisel plow treatment resulted in higher nitrate leaching into the shallow groundwater than the spring application with no tillage" • "Fall application of swine manure is not suggested"	Rekha, P. N., Kanwar, R. S., Nayak, A. K., Hoang, C. K., Pederson, C. H. (2011). Nitrate leaching to shallow groundwater systems from agricultural fields with different management practices. Journal of Environmental Monitoring 13, 2550-2558.
The P runoff model SurPhos was run utilizing data from 9 previous studies that investigated the effects of time variances between manure application and 1st rainfall events. This paper validates common understandings that the longer the time between manure application and the first rainfall event, the less P is lost. Nevertheless, the modeling demonstrated the importance of examining rain and runoff characteristics as well as timing. Models suggest that runoff dissolved P concentrations decrease with low application rates and increased time between manure application and the first rainfall event; this occurs more frequently in warm conditions.	• "Ran manure P runoff model SurPhos with data from 9 studies that looked at time between application and first rain event on runoff P" • "Soil adsorption of manure P isn't main mechanism to decrease manure P availability to runoff" • "First rain-runoff event usually decreases P loss in runoff" • "Need to simulate interdependent dynamics of manure P availability and rain and runoff in predicting manure P loss in runoff" • "Low application rates and increasing the time between manure application and 1st rainfall runoff event can decrease runoff dissolved P concentration" • "Decreases greater during warm conditions than cold" • "Manure P availability may be more a function of manure decomposition and bioturbation"	Vadas, P. A., Jokela, W. E., Franklin, D. H., & Endale, D. M. (2011). The Effect of Rain and Runoff When Assessing Timing of Manure Application and Dissolved P Loss in Runoff. JAWRA Journal of the American Water Resources Association, 47(4), 877–886.

Summary (100 words)	Bullets	Source
Dairy manure was applied to soil before, during, and directly after an artificial snowstorm to investigate how manure and snowpack interaction impacts nutrient losses. The results demonstrated that manure application preceding snowfall increased the losses of total N and NH_4-N in the snowmelt runoff. Snowfall after manure application might lead to losses of N and P because of decreased infiltration rates. The amounts of NH4-N losses decreased while the amounts organic N, DRP, and total P increased when manure was applied following snowfall. It is thought that placing manure between layers of snow would minimize the amount of nutrients lost.	• "Dairy manure applied before, midway, or directly after an artificial snowfall" • "Application prior to snowfall: increased losses of total N and NH_4-N in snowmelt runoff" » May decrease infiltration during later rainfalls resulting in higher concentration and losses of N and P in runoff » More losses of both N and P during rainfall simulation • "On top of snow: reduced amount of NH_4-N losses but increased losses of Organic N, DRP, and total P in snowmelt runoff"	Williams, M. R., Feyereisen, G. W., Beegle, D. B., Shannon, R. D., Folmar, G. J., & Bryant, R. B. (2011). Manure application under winter conditions: Nutrient runoff and leaching losses. Transactions of the ASABE, 54(3), 891-899.
P and organic matter transport patterns were measured from rainfall-runoff and snowmelt from three different field management systems. Both P enrichment and the organic matter enrichment Ratio (OMER) were larger during snowmelt compared to rainfall-runoff. The TP_{ER} was greater during snowmelt compared to rainfall-runoff due to the frozen topsoil. Throughout snowmelt, P enrichment increased possibly due to the release of dissolved reactive P from plant matter during freeze-thaw cycles. The dominant form of transported P varied depending on the field management system in place; at the corn-grain location, organic P was predominant while inorganic P predominated at the corn-silage sites.	• "Tested various field management practices: corn-grain, corn-silage, manured corn-silage (only field to receive P input during study with fall manure application)" • Total P enrichment ratio greater during snowmelt than rainfall-runoff because of frozen surface soil and snowmelt runoff rates limited transport favored movement of materials like clay & OM • Both Total P and OM enrichment ratio (OMER) increased during snowmelt • P enrichment related to sediment OM concentrations » More P concentration from sediments with high OM seen in snowmelt » No differences in median OMER values during snowmelt because of OM frozen in-place • "OM type influenced form of P transported. Particulate bound P dominated overall loss during rainfall-runoff period"	Panuska, J. C., & Karthikeyan, K. G. (2010). P and organic matter enrichment in snowmelt and rainfall–runoff from three corn management systems. Geoderma, 154(3), 253-260.

Summary (100 words)	Bullets	Source
At varying temperatures, transformations of soil and pig slurry N were measured by monitoring NH_4, NO_3, microbial biomass N (MBN), and ^{15}N. At all measured temperatures, pig slurry increased nitrification. Organic amendments increased net mineralization and nitrification in frozen soils. Immobilization rates were higher in loamy soil compared to clay soil while mineralization and nitrification rates were higher in clay soil than loamy soil. Even with the organic amendments, N immobilization was not detected below 2°C. Nitrification ceased at lower temperatures than N immobilization. At below-freezing temperatures, N mineralization and nitrification are more favorable in fine-textured soils versus lighter-textured soils.	• "Slurry increased nitrification by 3-14 times at all temperatures" • "Straw caused net N immobilization only at temperatures greater than 2 in both soils but rates higher in loam than clay" • "Rate of net mineralization increased with temp: 1.8-3.2 times faster in clay than loamy soil" • "Net nitrification increased with temperatures and higher in clay than loamy soil" • "Below freezing, fine-textured clay more favorable for N mineralization and nitrification than loamy" • "Net N immobilization not detected below 2°C even with straw" • "N immobilization cease at higher temp than nitrification" • "Mineralization and nitrification maintained at higher rates in clay soil than loamy" • "Immobilization rates higher in loamy soil"	Clark, K., Chantigny, M. H., Angers, D. A., Rochette, P., & Parent, L. É. (2009). N transformations in cold and frozen agricultural soils following organic amendments. Soil Biology and Biochemistry, 41(2), 348-356.
Different nutrient fluxes downstream of the Graywood Gully watershed leading to Conesus Lake were measured. Winter manure spreading was halted in 2002-03, resumed in 2005-06 and then halted in 2007. Over the 5 year study, nonevent TP, SRP, TKN, and NO_3 decreased, but events didn't decrease within a year of halting manure application. After only a few days of reinstallment of application, SRP, N, and TP concentrations increased while TSS didn't have a significant impact. TKN was lost from the watershed for 1 week after the application. Timing, topography, and weather conditions dramatically impact the effects of winter manure application.	• All nonevent analytes, except TSS, had significant decreases from 2002–03 to 2006–07, mimicking the results for the combined event/nonevent samples • Reductions of some analyte concentrations occurred quickly, reaching near maximum reductions within a year after the initiation of BMPs • Significant decreases in TP, TKN, and NO_3 occurred with time except for SRP • Focusing on the winter of 2004–05, elevated levels of TKN, TSS, TP, SRP, and NO_3 were observed on 4 January 2005 prior to resumption of winter application of manure	Lewis, T. W., & Makarewicz, J. C. (2009). Winter application of manure on an agricultural watershed and its impact on downstream nutrient fluxes. Journal of Great Lakes Research, 35, Supplement 1, 43–49.

Summary (100 words)	Bullets	Source
After application of swine manure onto fields, the movement of bacteria (fecal coliform - FC, enterococcus - EN, and Escherichia - EC coli) to subsurface tile drains was monitored. The manure was applied in the fall and spring via injection while it was applied broadcast in late winter. Because of higher macropore flow, EN and EC levels in tile water were elevated after late winter application. Though levels of FC were variable, both the highest flow-weighted average and maximum tile water levels for FC resulted from spring injection. The researchers advised against manure application to frozen ground because of increased EN and EC levels in drainage water.	• Movement of bacteria to tile drains after swine manure application » FC, EN, and EC densities in subsurface tile drain water for 3 years » Applied fall & spring (injected), late winter (broadcast) • "EN and EC levels in tile water significantly higher where manure had been applied during late winter because of higher macropore flow and because of broadcast" • "Spring injection treatment yielded highest flow-weighted average and maximum tile water FC levels" • Bacterial densities lower in fall than other plots • Timing only greatly affected EN densities • "Doubling manure application rate had little impact on bacterial densities in water when manure injected due to macropore disturbance" • Manure shouldn't be applied to frozen ground. Especially in excess of crop requirements: Leads to higher EN and EC in water	Pappas, E. A., Kanwar, R. S., Baker, J. L., Lorimor, J. C., & Mickelson, S. (2008). Fecal indicator bacteria in subsurface drain water following swine manure application. Transactions of the ASABE, 51(5), 1567-1573.
This study considered the application of 2 different poultry manures on corn fields during the late fall, winter, and early spring. The resulting N availability, grain yield, grain N uptake, leaf chlorophyll meter, and soil NO_3- N were measured. The soil NO_3- N concentration in late spring was greatest for spring application and smallest for fall application. One explanation for this result is soil nutrient loss. Though manure source and application time differed, the resulting plant N availability, corn grain yield, grain N uptake, and chlorophyll meter reading was constant. The final crop growth was similar for all application times.	• Poultry manure • Late fall, winter, spring application • N availability tested: "Looked at grain yield, grain N uptake, leaf chlorophyll meter reading, soil NO_3-N in June" • NO3-N concentration greater for application in spring compared to fall and winter because of loss from the soil or mvt below the measured top 30 cm of soil • Manure plant N availability, corn grain yield, GNU, CM • No difference in sources or application timing • Corn growth similar all application times • Greater soil NO_3-N concentration for spring-applied manure than fall • "Corn grain yield increased with higher rates of fertilizer N / poultry manure" • Winter manure (incorporated at spring tillage) similar N available to fall and spring application with incorporation	Ruiz Diaz, D. A., & Sawyer, J. E. (2008). Plant-available N from poultry manure as affected by time of application. Agronomy journal, 100(5), 1318-1326.

Summary (100 words)	Bullets	Source
This journal researched the impacts of coupling cover crops (CC) with different manure application timing and rates on nutrient uptake in the fall and spring. The study used 3.8 m by 21.3 m plots and collected corn shoots from 15-35 cm for analysis. It was found that the greatest uptake was in the spring for M 336 with 69.3 kg/ha, M 336 with 10.3 kg/ha and M 336 with 45.5 kg/ha for N, P and K respectively. This was compared to fall uptake for M 336 with 10.1, NM with 1.5, and NM with 7.3 for N, P, and K uptake in kg/ha, respectively.	• "Research site was located at the Agricultural Engineering Research Center, Iowa with a silty clay loam soil composition" • "The 6 treatments were no CC no manure, CC no manure, CC at target manure N rates of 112,224 and 336 kg/ha, and no CC with manure at 224 kg/ha" • pH 6.7 • SOM 37 g/kg • "Liquid swine manure was injected 20 cm deep with a 5.1 cm wide chisel shank mounted on a rear delivery toolbar" • 8x30 cm deep soil cores were taken from the surface of each plot and tested for NO_3-N rates using a Lachat autoanalyzer • Twelve corn stalks from 15 to 35 cm were collected at grain harvest and dried at 60°C for 5 days and tested for NO_3-N using a Lachat autoanalyzer • CC fall shoot DM was greater in the CC no-manure compared to CC manure • "Shoot K uptake was greater in the CC no-m compared to CC manure" • Fall: Highest N uptake for M 336 at 10.1 kg/ha, P uptake for M 224 at 0.4 kg/ha and K uptake in no manure at 7.3 kg/ha • Spring: Highest N uptake in M 336 at 69.3 kg/ha, P in M 224 and 336 at 10.3 kg/ha, K in M 336 at 45.5 kg/ha	Singer, J. W., Cambardella, C. A., & Moorman, T. B. (2008). Enhancing nutrient cycling by coupling cover crops with manure injection. Agronomy Journal, 100(6), 1735–1739.
A 3 year study analyzed the impacts of various soil types, cropping systems, and times of manure application on N losses. The NO_3-N concentration under maize decreased as application time progressed from early fall, to late fall, to early spring. The NO_3-N concentration was almost equivalent among early spring application and split application between early and late spring. Fall manure application resulted in NO_3-N leaching losses above the USEPA Maximum Content Level. These concentrations were seen in greater quantity in sandy soil versus loamy soil and maize crops versus grass crops. NO_3-N concentration was greater in loamy soil than clay soil.	• Flow-weighted mean of NO_3-N concentration averaged 2.5 times greater on loamy than clay • Fall manure application on maize show high NO_3-N leaching risks » Especially sandy soils » Much less concern on grass versus maize » NO_3-N concentration under maize: early fall > late fall > early spring = early + late spring » Results same for both soil types • Fall manure resulted in NO_3-N concentrations above the USEPA MCL of 10 mg L^{-1} • Most concern with coarse-textured soil	Van Es, H. M., Sogbedji, J. M., & Schindelbeck, R. R. (2006). Effect of manure application timing, crop, and soil type on nitrate leaching. Journal of Environmental Quality, 35(2), 670-679.

Summary (100 words)	Bullets	Source
During a 16 day snowmelt period, varying forms of P in runoff waters from grass-clover crop plots and autumn-plowed plots were analyzed. The authors focused on the illite clay soil impacts. High concentrations of molybdate-reactive P and particulate P were found in runoff throughout the study period. High concentrations of colloidal P were found in runoff. Because colloidal P is difficult to trap in grassed buffer strips, the authors suggest P in clay soil runoff be reduced by improving soil structure. Furthermore, research in buffer strips should be based on the mineral composition of the studied soil.	• "Studied 16 day period of snowmelt via surface runoff » Examined grass-clover crop and after autumn ploughing » Measured colloid-bound P" • "High water concentration of dissolved molybdate-reactive P (MRP) and PP detected in surface snowmelt runoff water" • "Colloidal part of PP important in runoff from clay soils » Hard to trap in grassed buffer strips » So in similar soils, P losses reduced at source by improving soil structure" • "Concentration of MRP and PP high all day" • "Little P trapped in grassed buffer strip: uptake of MRP by vegetation minimal during winter" • "Suggest research into P losses and trapping of PP in buffer strips based on mineral comp of soil"	Ulén, B. (2003). Concentrations and transport of different forms of P during snowmelt runoff from an illite clay soil. Hydrological Processes, 17(4), 747-758.
Four plots with varying tillage methods, manure addition, and crop rotation were tested before and after the winter season. Soil cores at 4 depths were analyzed for soil denitrification enzyme activity (DEA), dissolved organic C (DOC), and inorganic N levels (NH_4-N, NO_3-N). Thaw led to great increases in inorganic N and DOC levels at all soil depths. Although DEA decreased after thaw in the 0-5 cm soil depth, it remained unchanged at all greater depths. The researchers concluded that frequent tillage was a contributing factor to decreased DEA levels after frost far more than manure application.	• Soil DEA, DOC, inorganic N levels (NH_4-N, NO_3-N) were examined » Before and after winter » Soil cores gathered at 4 depths • FTCs resulted in significant increases in NH4+-N, NO3--N, and DOC levels at all soil depths • After FTC, DEA remained unchanged in 5-20 cm but low in 0-5 cm • Said tillage instead of manure addition led to more overwinter loss of DEA in top layers of soil with FTCs • Greatest loss of DEA was for most frequently-tilled plots (CC) and plowed in previous season (CS) • "Greatest loss of DEA following FTC was in CC plots and then in soybean plots of CS rotation" • "Large pool of inorganic N in soil in early spring (water quality)"	Jacinthe, P. A., Dick, W., & Owens, L. (2002). Overwinter soil denitrification activity and mineral N pools as affected by management practices. Biology and fertility of soils, 36(1), 1-9.

Summary (100 words)	Bullets	Source
A mechanistic snow ablation model to simulate energy transfers affected by winter manure broadcasting was used. The researchers found that manure application after snowfall led to decreased energy availability to snow and resulted in slower melt. This outcome was seen most when snowmelt was primarily driven by both high solar radiation and turbulent heat fluxes. This phenomenon was demonstrated by surface energy balance estimates of turbulent, shortwave, and longwave fluxes of sensible and latent heat. This decreased snowmelt rate resulted in increased infiltration of meltwater. The researchers concluded that manure application may lead to reduced spring peak outflows.	• Mechanistic snow ablation model • Simulate surface energy balance & snow cover • "Manure on top of snow reduced energy available for melt of snow underneath & slowed melt" • Biggest with snowmelt driven by solar radiation & turbulent heat fluxes • "High absorbed shortwave radiation warmed manure & led to losses in turbulent fluxes and longwave radiation" • "Lower snowmelt rates beneath manure allows more infiltration of meltwater compared to bare snow. Might lower P runoff from winter-spread" • "Higher absorbed shortwave radiation by manure than by the snow surface" • Manure = thermal insulator • All rates of application, manure slows melt • "Spring peak outflows may be decreased/ delayed by manure application"	Kongoli, C. E., & Bland, W. L. (2002). Influence of manure application on surface energy and snow cover: model development and sensitivities. Journal of Environmental Quality, 31(4), 1174–1183.
A Pennsylvania agricultural watershed was studied to understand stormflow and base flow P concentrations. Compared to the uppermost flume (4), the flume near the watershed outflow (1) had the greatest base flow DRP. Nevertheless, DRP and TP concentrations were highest at flume 4 during stormflow. This may have been caused by sediment deposition, resorption of P, and dilution. The P loss during stormflow was possibly caused by the P originating upstream of flume 4. The 2 soil types investigated interacted with the stream very differently. Compared to Typic Dystrochrepts, Typic Fragiudults eroded nearly three times more rapidly.	• "P release from soil and stream sediments in relation to storm and base flow P concentration at 4 flumes (4 farthest away from watershed outflow 1) and in the channel for an ag watershed" • Base flow DRP concentration greater at watershed outflow than uppermost flume • "In-channel decreases in P concentration during stormflow because of sediment deposition, resorption of P, dilution" • "Erosion, soil P concentration, channel sediment P sorption properties influence streamflow DRP and TP" • "90% of overland flow occurs from within 30 m of stream channel" • "Trends in DRP and TP concentration in stream channel show difference between stormflow and base flow conditions" • P lost during stormflow: P upstream of flume 4 (not significant during base flow) accounts for much of P lost during stormflow	McDowell, R., Sharpley, A., & Folmar, G. (2001). P export from an agricultural watershed. Journal of Environmental Quality, 30(5), 1587-1595.

Summary (100 words)	Bullets	Source
Snowmelt runoff, losses of sediment, and P losses were noted after differing tillage treatments were implemented. The treatments included moldboard plow, chisel plow, and ridge till with no fall tillage. Most of the P lost during snowmelt was soluble P. Compared to the other treatments studied, the moldboard plow resulted in less soluble, particulate, and total P loss. The amount of residue coverage decreased from ridge till, to chisel plow, to moldboard plow treatments. More sediment was lost in chisel plow than moldboard plow systems. The researchers concluded that conservation tillage treatments may increase runoff during snowmelt.	• On cropped hillslope: how tillage affects snowmelt runoff/losses sediment, P and COD • Treatments: fall moldboard, fall chisel, and ridge till (no fall tillage) • "P losses in runoff higher for ridge till and chisel than moldboard" • "Soluble P was 75% of total P loss in snowmelt runoff" • Residue cover: 93% for ridge till, 40% for chisel, 10% for moldboard • Increasing roughness: ridge till, chisel plow, moldboard plow • Organic matter at top depth: higher for ridge till than others • Runoff for ridge till and chisel greater than for moldboard • "Moldboard more effective in limiting snowmelt runoff than ridge tilling or chisel plowing" • "Sediment loss: lower for moldboard & ridge till than for chisel" • "Moldboard plow treatment resulted in less soluble, particulate, total P loss than other" • "Soluble P loss was dominant form of P loss in snowmelt runoff" • "Runoff and sediment losses greater for chisel plow than moldboard"	Hansen, N. C., Gupta, S. C., & Moncrief, J. F. (2000). Snowmelt runoff, sediment, and P losses under three different tillage systems. Soil and tillage research, 57(1), 93-100.

Summary (100 words)	Bullets	Source
Two sites in Ontario were investigated over winter to better understand soil and N interactions. Soluble soil N accumulated in early winter and decreased once the soil water was continuously frozen. This phenomenon occurs in seasonally frozen soils, possibly because of the death and lysis of N-rich soil microorganisms during freeze-thaw cycles. No relations between soluble soil N and soil extractable organic C or soil microbial biomass C were found. At one of the sites, denitrification occurred in the shallow soil during thaw. Soil nitrate levels decreased before spring melt while nitrous oxide levels decreased during spring thaw.	• Two sites in Ontario • “Soluble soil N: accumulated in early winter” » “Peaked when soil water frozen” » “Declined during period that frozen soil water was present” • “No correlations between soluble N and soil extractable organic C or soil microbial biomass C” • “Denitrification occurred in shallow soil during thaw period in one site” • “Soil NO_3 levels decreased before thawing” • “Soil ice decreased lethality of soil environment and allowed N dissipation” » “Dissipation because of gaseous losses” » Related to N_2O fluxes found in spring thaw • “Early-winter accumulation of soluble N because of accelerated death and lysis of N rich soil microorganisms during FTCs” • Large N^2O losses during spring melt	Ryan, M. C., Kachanoski, R. G., & Gillham, R. W. (2000). Overwinter soil N dynamics in seasonally frozen soils. Canadian Journal of Soil Science, 80(4), 541-550.
Moldboard plow (MP) and ridge tillage (RT) systems were utilized along with a one-time spring application of beef manure to measure their effects on corn grain yield, runoff, and sediment losses. Though snowmelt runoff was not impacted by manure application, rainfall runoff was reduced. Because of a decrease in rainfall runoff, a reduction in sediment loss was also seen. The ridge tillage system resulted in less rainfall runoff compared with the moldboard plow system. This may be a result of the large amount of residue cover on the ridge tillage plots. Both systems with manure increased the corn yield.	• MP and RT with one-time spring application of soil beef • “MP and RT with manure increases corn yield for 2 subsequent years after manure application” • Snowmelt runoff not affected by manure application • Manure reduced rainfall runoff thus less sediment loss • “RT system resulted in lower rainfall runoff compared with MP system” • Manure pp reduced rainfall runoff and thus sediment loss. • More effective during intense rainfall in RT than MP systems • Tillage system affected rain runoff • Much more from MP than RT plots because of much residue cover in RT plots	Ginting, D., Moncrief, J. F., Gupta, S. C., & Evans, S. D. (1998). Corn yield, runoff, and sediment losses from manure and tillage systems. Journal of environmental quality, 27(6), 1396-1402.

Summary (100 words)	Bullets	Source
Moldboard Plow (MP) and Ridge Tillage (RT) systems were utilized along with a one-time spring application of beef manure to measure their effects on P uptake and losses. Soil P and P uptake were both higher in manure treated plots than non-treated plots. Though particulate P losses by rainfall runoff were lower for the RT system, the dissolved molybdate reactive P losses in snowmelt were lower for the MP system. The authors concluded that the RT system was better for the environment than the MP system because it had less annual particulate P and total P losses.	• "Soil P higher in manure than no manure treated plots" • "P uptake higher for manure than no manure treated plots" • "Annual Particulate P and total P losses similar/ lower from manure than no manure plots" • "For snowmelt, PP loss higher from RT than MP plots" • "Particulate P losses by rainfall runoff lower for RT vs. MP systems" • "Dissolved Molybdate Reactive P losses in snowmelt: Higher for RT than MP" • RT better than MP because of reduces annual PP and TP losses • Possibility that P leaches from corn residues by snowmelt runoff • Corn residue soil surface big source of DMRP during snowmelt	Ginting, D., Moncrief, J. F., Gupta, S. C., & Evans, S. D. (1998). Interaction between manure and tillage system on P uptake and runoff losses. Journal of Environmental Quality, 27(6), 1403-1410.
Two year study investigated the effects of deep tillage channels during winter wheat crop years. During the dry winter, no measurable soil loss was seen on the ripped plots while 2 ha^{-1} soil losses occurred on the control plots. During the wet year, 6.4 t ha^{-1} soil loss was seen for the ripped plots while 20.2 ha^{-1} soil loss occurred on the control plots. Soil loss decreased on tilled plots because tillage channels slow rill erosion. During the wet year, water infiltration increased on the tilled plots compared to the control plots. No change was observed in overall grain yield.	• Inland pacific NW, Washington • Two years, ripped and control plots • Created deep tillage channels on contour in planting wheat on steep slopes in fall • Reduced soil loss because of rill erosion stopped by tillage • Increased water infiltration in wet winter • Didn't change overall grain yield • Suggest to growers to rip wheat stubble with wide shank spacing during crop year • Dry: no soil loss measured in ripped and 3 ha^{-1} soil loss control • Wet: 6.4 t ha^{-1} for ripped and 20.2 t ha^{-1} for control • Ripping helped water infiltration into soil to 180 cm as far as 90 cm downslope from tillage channel • Grain yield reduced in row near tillage channel	Schillinger, W. F., & Wilkins, D. E. (1997). Deep ripping fall-planted wheat after fallow to improve infiltration and reduce erosion. Journal of soil and water conservation, 52(3), 198-202.

Summary (100 words)	Bullets	Source
Between 1979 and 1990 best management implementation on surrounding agricultural facilities impacted sediment, nutrient, and bacteria loads in two watersheds and eventually Lake Champlain and these impacts were studied. In one watershed, up to 15% of P applied in winter manure was lost in runoff. Vegetative filter strips were found to greatly reduce sediment and nutrient losses resulting from milk house waste. Though a 50-75% decrease in indicator bacteria was seen in both watersheds, there was no significant water quality response. The authors offered a few explanations for this including a delay between the studied time period and response occurrence.	• "P export from corn fields up to 1500% higher when winter manure spread" • "Up to 15% P applied in winter-spread manure lost in runoff" • "Vegetated filter strip: retained more than 90% of sediment and nutrients in milking center waste" • "50-75% reduction in indicator bacteria in watersheds studied" • "Tried to reduce sediment, nutrient, and bacteria loads to Lake Champlain by looking at St. Albans Bay and the LaPlatte River Watershed" • St. Albans Bay watershed: total P concentration in runoff more than 2 times observed than when management followed • St. Albans Bay: More than 100% and 500% observed for TKN and NH_3-N concentration when manure winter-spread • No water quality response in Bay	Meals, D. W. (1996). Watershed-scale response to agricultural diffuse pollution control programs in Vermont, USA. Water Science and Technology, 33(4-5), 197-204.
Four sites in Oregon and Montana, ripped with three different tools, were analyzed to better understand frozen soil infiltration. On the sandy loam sites, the infiltration rate on no-rip plots was one mm h^{-1} while the rate on ripped plots was 11 mm h^{-1}. On the silt loam sites, the infiltration rate on no-rip plots was two mm h^{-1} while the rate on ripped plots was 28 mm h^{-1}. Once the depth of freezing was greater than the depth of ripping, no infiltration difference was observed. The authors suggest that ripping along with other beneficial practices can reduce environmental complications.	• "Soil ripping to improve water infiltration into frozen soil" » Plots in Oregon and Montana » 3 different ripping tools • "No difference in infiltration when depth of freezing more than depth of ripping" • "Suggest ripping with other conservation practices to reduce water runoff/soil erosion" • "Ripping can increase overwinter soil water storage with stubble management methods" • Infiltration on sandy loam was 11 m h on rip and 1 mm h^{-1} on no-rip • Silt loam infiltration rate was 28 mm h^{-1} on rip and 2 mm h^{-1} on no-rip • Average depth of frozen soil: .14 m	Pikul, J. L., Wilkins, D. E., Aase, J. K., & Zuzel, J. F. (1996). Contour ripping: A tillage strategy to improve water infiltration into frozen soil. Journal of soil and water conservation, 51(1), 76-83.

Summary (100 words)	Bullets	Source
Analyzed soil properties and corn grain yields resulting from 20 year continuous corn plots subjected to four different rates of N fertilizer and two plowing systems. Bulk density remained constant throughout the experiment. At the depth of 0 - 5 cm, soil pH, soil organic C and N, extractable P, exchangeable calcium, magnesium, and potassium were all higher in no tillage. Below the depth of 5 cm, soil pH, exchangeable calcium, magnesium, and potassium were higher in moldboard plow tillage. The researchers concluded that soil productivity can be sustained with similar maintenance for both no tillage and conventional moldboard plow tillage.	• "Twenty year continuous corn under no tillage or conventional moldboard plow tillage" • "Soil organic C & N, extractable P, exchangeable Ca, Mg, & K, and pH higher in no tillage 0 – 5 cm depth" • "Below 5 cm: pH, exchangeable Ca, Mg, and K were higher with moldboard" • "Organic C and N increased with increasing N rates" • "pH and exchangeable Ca and Mg declined with high N rates" • "Bulk density increased with depth" • BD not changed much since start of experiment • NT had more extractable P 0 - 5 cm • "Exchangeable K not affected by N rate" • "Soil pH decreased with increased rate of N fertilizer" • Yields with N treatments better than without	Ismail, I., Blevins, R. L., & Frye, W. W. (1994). Long-term no-tillage effects on soil properties and continuous corn yields. Soil Science Society of America Journal, 58(1), 193-198.
Three tillage practices (conventional till, reduced till, no till) were utilized to better understand their effects on sediment, N, and P runoff on sorghum plots. Conservation tillage lead to lower mean sediment, total N, and total P loss values than conventional tillage. For example, annual sediment values increased from no till to reduced till to conventional till (281, 523, and 8877 kg ha^{-1} yr^{-1}, respectively). Varying tillage practices had a larger and more predictable impact on particulate nutrients than soluble N and P. Though all N and sediment levels were considered to maintain water quality, soluble P levels exceeded accepted values.	• Looked at sediment, N, and P in runoff • Conventional till, reduced till, no till • Mean sediment, TN, TP loss in runoff from NT and RT were lower than from CT • Conservation tillage good • Tillage effects on soluble N and P losses smaller and less consistent • Soluble P concentration exceeded limits with eutrophication • Critical P concentration exceeded in runoff from unfertilized watersheds at 2/3 sites • Annual sediment: NT: 281, RT: 523, and CT: 8877 kg ha^{-1} yr^{-1} • Total N: NT: 0.76, RT: 0.99, and CT: 7.28 kg ha^{-1} yr^{-1} • Total P: NT: 0.28, RT: 0.37, CT: 2.5 kg ha^{-1} yr^{-1}	Sharpley, A. N., Smith, S. J., Williams, J. R., Jones, O. R., & Coleman, G. A. (1991). Water quality impacts associated with sorghum culture in the Southern Plains. Journal of environmental quality, 20(1), 239-244.

Summary (100 words)	Bullets	Source
A plot with acidic sandy loam soil was tested to understand how thaw affected N_2O production. The researchers found the highest N_2O levels of the year to be during spring thaw. Nitrous Oxide levels during spring thaw were far higher than when the soil thawed mid-winter. This may be because microbial activity increases as temperatures increase. The researchers stated that these conclusions could be reproduced in a laboratory setting. Because similar results were found in other studies, the researchers suggest that N_2O produced from spring thaw may be an important source of atmospheric N_2O in certain regions.	• "In acid sandy loam: field production Of N_2O higher at thaw in spring than any other time" • Soil thaw mid-winter didn't result in increase in N_2O flux • "Microbial N_2O production during thaw important for total annual N_2O emission" • Large increase in N_2O production in spring • "Large difference in N_2O flux after soil thaw in January vs. March could be due to increased microbial activity under warmer conditions" • "Maybe action of extracellular denitrifying enzymes or chemical liberation of N_2O" • Could be reproduced in laboratory setting	Christensen, S., & Tiedje, J. M. (1990). Brief and vigorous N^2O production by soil at spring thaw. European Journal of Soil Science, 41(1), 1-4.
Reviewed the progress of research investigating the impacts of freeze-thaw cycles on soil and their implications for soil agricultural use. At the time of this article's publication, no national procedure to estimate peak volume of runoff from frozen or thawing soils had been set. It is understood that soil erosion is increased by freeze-thaw cycles. Nevertheless, more must be learned about how certain types of erosion resulting from freeze-thaw can be minimized. In summary, more research on certain locations and applications must be conducted to understand the implications of soil freeze-thaw for agriculturalists and all land owners.	• Want more information on soil freeze-thaw implications • Almost half of lands in USA, 4.2 million square km of ag lands impacted by freeze thaw • No national SCS procedure to estimate peak runoff/volume from frozen or thawing soils • Erosion and thawing: freezing of water loosens soil so particles and aggregates more easily carried away • Rates of sheet and rill erosion and amounts of residue/surface roughness for erosion control • Need more quantification for areas and applications	Formanek, G.E., G.B. Muckel, and W.R. Evans, (1990). Conservation applications impacted by soil freeze-thaw. Pp. 108-112. In: Frozen soil impacts on agricultural, range, and forest lands. K.R. Cooley (ed.) Proceedings of International Symposium. Spokane. Washington. CRREL Special Report No. 90-1. Cold Regions Research and Engineering Laboratory. U.S. Army Corps of Engineers. Hanover, New Hampshire.
Data from the Palouse Conservation Field Station collected between 1978 and 1988 were compared with observational data collected by Kaiser from 1939 through 1979. The plots at the Field Station were treated with different tillage management techniques and analyzed for runoff and soil loss while Kaiser researched soil loss. Though the percentage of erosion was partially reliant on crop treatment, erosion in the studied region was greatly caused by runoff events occurring as soil thawed. When runoff and erosion events occurred on any type of frozen soil, the magnitude was greatly impacted by type of crop management system.	• Plots with different treatments and tillage patterns: Winters for ten years in Washington • Also analyzed data looking at soil loss (mostly observational) by Kaiser from 1939-1979 • A lot of erosion in Palouse region of Pacific NW because of frozen and thawing soil runoff events • Percentage dependent on crop treatment • Crop management has large impact on runoff and erosion when events occur on frozen soil or if the soil is only frozen to a shallow depth/thaws rapidly • Also when soil is deeply/impermeably frozen	McCool, D. K. (1990, March). Crop management effects on runoff and soil loss from thawing soil. In Proc. International Symposium on Frozen Soil Impacts on Agricultural, Range, and Forest Lands (pp. 171-176).

Summary (100 words)	Bullets	Source
High frequency automatic sampling was used on 2 agricultural basins to understand the effects of winter runoff events on P and suspended solids concentrations. Suspended solids concentrations were as high as 750 mg L^{-1} during high runoff events. At the beginning of snowmelt, total P concentrations were high compared to that of suspended solids. Total P concentrations varied from 300 mg to 1200 mg L^{-1} during the beginning of snowmelt events. As frost continued to thaw, total P concentrations decreased. Compared with base flow levels, P mean concentration was two to five times higher during snowmelt events.	• Two agriculture drainage basins • Used high frequency automatic sampling • At beginning of snowmelt, concentration of suspended solids low compared to TP concentration and discharge • "Decrease of TP concentration during frost thawing because of gradually increasing proportion of subsurface and groundwater discharge in runoff" • "Max SS concentration (up to 750 mg L^{-1}) found during high runoff peaks because of heavy rainfall on snow-free soil" • "Total P concentration during snowmelt independent of discharge" • Different than during snow- and frost-free periods • Concentration of suspended solids low during snowmelt • "Surface runoff can't erode soil particles from frozen soil surface during snowmelt"	Rekolainen, S. (1989). Effect of snow and soil frost melting on the concentrations of suspended solids and P in two rural watersheds in Western Finland. Aquatic Sciences-Research Across Boundaries, 51(3), 211-223.
Three soil types were used from Utah and Idaho to measure aggregate stability with wet sieving techniques. Soil stability and soil cohesion decreased during the fall and winter and then increased during the spring and summer. The aggregates were most stable at the end of summer since bonding between micro aggregates increased once the freezing season was complete. Aggregate disruption advanced as the water content at the time of freezing increased. Soil disruption through rototilling and compaction led to a decrease in soil cohesion. Aggregates in unconfined soil cores were not as disrupted as those found in confined soil cores.	• Aggregate stability measured » Utah and Idaho soils (three types) » Used wet sieving techniques • "Stability increased during spring and summer" • "Decreases of cohesion: found when minimum daily air temp fell to or below freezing during winter and early spring" • "Disruption increased as water content at time of freezing increased for all soils" • "Disruption of soil (rototilling and compaction) decreased soil cohesion" • "Aggregates from confined soil core disrupted more than those from unconfined soil core" • "Loss of cohesion during fall/winter"	Bullock, M. S., Nelson, S. D., & Kemper, W. D. (1988). Soil cohesion as affected by freezing, water content, time and tillage. Soil Science Society of America Journal, 52(3), 770-776.

Summary (100 words)	Bullets	Source
Literature review investigated storm runoff field studies and connected models. The 3 recognized mechanisms through which storm runoff is generated were referenced. The research completed on the Horton overland, subsurface, and saturation overland flow mechanisms were summarized. The authors insist the necessity of better communication between scientists conducting field studies and those creating related models. Similarly, they urge scientists to complete thorough investigations into models before beginning field experiments. This may keep future research from being too specific toward a certain environment or field. Furthermore, the authors suggest that field research be conducted in diverse environments.	• Storm hydrographs • "Need realistic concepts of runoff processes and variation within drainage basins" • "Reviews connection between modeling and field studies of runoff" • Suggestions to model/fieldwork » Runoff prediction better if cooperation between scientists working on field studies and those interested in modeling » Field research done in varying environments » Field experiments need to be done after models used: Too many data collections done on specific situations that can't be generalized • Mechanisms storm runoff is generated » Horton overland flow » Subsurface flow » Saturation overland flow	Dunne, T. (1983). Relation of field studies and modeling in the prediction of storm runoff. Journal of Hydrology, 65(1-3), 25-48.
In a 6 year study, the effects of chemical fertilizer and liquid dairy manure at varying rates and application schedules were compared. The impacts on crop yield and water quality were investigated. The concentration of nutrients in runoff increased as the rate of manure application during the winter increased. This phenomenon was not as apparent in the other application schedules examined. The authors recommended that manure not be applied during the winter on fields that runoff directly into bodies of surface water. They also suggest that manure applied at or above 560 kg/ha*yr of N may lead to water quality issues.	• Six year study • Applied dairy cattle liquid manure (3 rates and 4 application schedules), chemical fertilizer • "No differences in silage corn yields seen in any manure or chemical fertilizer treatments" • "Don't recommend winter application of manure on areas that send runoff directly to bodies of surface water" • "Non-winter application of manure at/above 560 kg/ha*yr of N leads to water problems" • Snowmelt accounted for over 90% runoff from the plots • "Spring manure application influences runoff quality for June storms" • Concentration of N higher in subsurface flow than surface runoff (all but winter application) • "Higher the rate of winter application, higher the concentration in runoff"	Phillips, P. A., Culley, J. L. B., Hore, F. R., & Patni, N. K. (1981). Pollution potential and corn yields from selected rates and timing of liquid manure applications. Transactions of the ASAE, 24(1), 139-0144.

Summary (100 words)	Bullets	Source
To understand how N is lost when dairy manure is spread during winter months, both lab and field experiments were conducted. Both the field and lab results demonstrated that most N is lost as soluble forms. For example, during the laboratory experiments, 75% of the soluble organic N and 3% of the particulate N was lost during runoff. In the laboratory experiments, most of the soluble N lost was lost during the first runoff event. The authors stipulated that if the soil is frozen and covered with ice or melting snow when manure is spread, high N losses will occur.	• Lab and field experiments • Dairy manure • Results lab: "19% soluble organic N remained in manure after exposure to runoff from melting of 20 cm of snow pack" » Snowmelt runoff transports primarily SN with only a bit of PN » In 20 cm snowpack, 75% soluble organic N removed, less than 3% of particulate organic N lost » Most soluble N lost in 1st runoff event • Field experiments: Loss of PN lower than loss of dissolved forms » "Runoff and N losses higher on manured plots than control" » "Most N lost from manure spread on frozen soils is water soluble" • "Stipulate that manure spread on frozen soil covered ice/melting snow, high N losses expected"	Steenhuis, T. S., Bubenzer, G. D., Converse, J. C., & Walter, M. F. (1981). Winter-spread manure N loss. Transactions of the ASAE, 24(2), 436-0441.

Summary (100 words)	Bullets	Source
The amount of N, P, BOD, COD, indicator organisms, and pathogens found in runoff was investigated. Instead of runoff pollution from pastures and rangelands being dependent on animal density, it is primarily based on land management. The literature reviewed implied that pastured livestock leads to less of a pollution issue than land application. Compared to rainfall runoff, snowmelt runoff from feedlots contains 2 - 3 times more nutrients. For further research, the authors suggested that experiments be conducted on a larger scale instead of small plots. Furthermore, researchers should extrapolate results from edge-of-field studies to receiving waters.	• Looking at N, P, BOD, COD, indicator organisms, and pathogens • Land application sites: "correlations between N and P loading rate and its concentration in runoff water" • Research needs: more data, replications, wider geographical sampling » Relating data on small plots to larger watersheds » Edge-of-field losses to receiving waters • Waste on snow: little or no transformation of applied N and P because of low biological activity • Improved soil structure improves quality of runoff water • Runoff pollution from pastures and rangelands because of management, not number of animals • Pathogen contamination problem in land application sites and feedlots, pastures and rangelands • Pathogen and indicator organisms in pasture and rangeland runoff based on livestock density • Pasture livestock has less pollution than land application • Feedlot runoff data suggest snowmelt runoff has 2 - 3 times more nutrients compared to rainfall-runoff	Khaleel, R., Reddy, K. R., & Overcash, M. R. (1980). Transport of potential pollutants in runoff water from land areas receiving animal wastes: a review. Water Research, 14(5), 421-436.

Summary (100 words)	Bullets	Source
Dairy cattle manure was applied at a rate of 2.25 kg/m^2 to 10 alfalfa plots in late fall, mid-winter, or spring months. The N, total P, and potassium losses were not significantly different between treatment times. On average, N, total P, and potassium losses were greater on manured plots than controls. The average runoff on fall manured plots was less than winter or spring applied plots. Nevertheless, the runoff measurements were greater on control plots when compared to manured land. Though production trends increased on the manured land, there was no significant difference between yields on manured and control plots.	• Dairy cattle manure at rate 2.25 kg/m^2 » Applied each year for 3 years in late fall, mid-winter, spring » 10 alfalfa plots » Runoff analysis • Runoff from control more than manured plots • Average annual runoff from fall less than winter and spring • No significant difference between treatments for N and TP losses • N losses from control plots were 87% of that observed from manure treatments • TP losses from control 66% of those from manure plots • K losses from control 70% of those from treated plots • Largest variation between control and treated was K • Hay yields not significantly increased due to application • Trend towards more production on manured plots	Converse, J. C., Bubenzer, G. D., & Paulson, W. H. (1976). Nutrient losses in surface runoff from winter spread manure. Transactions of the ASAE, 19(3), 517-0519.
Field plots with 3 different rates of winter-applied dairy manure were analyzed for three consecutive years. Resulting inorganic N and total soluble P losses were examined. The 200 metric tons/ha rate resulted in approximately four times the amount of N and P runoff when compared to the 35 metric tons/ha rate. In 1972, the 200 metric tons/ha and 35 metric tons/ha rate were applied before snowfall while the 100 metric tons/ha rate was applied during active thaw. This demonstrated that manure applied during active thaw periods has a higher probability of nutrient loss by runoff than manure applied before snowfall.	• "Surface runoff losses of inorganic N and total soluble P from fields with winter application of dairy manure" » Three rates of manure application » Three consecutive years • Weather responsible for large nutrients in runoff for 1972 • "Manure placement during active thaw periods can result in increased nutrient losses" • "Losses minimized when manure application and then covered with snow" • Snow melted at later date • With least amount of manure application and applied to frozen soil and covered with snow • Nutrient losses similar to areas without manure added • 1972: not much difference in nutrient runoff between control and 25 metric tons/ha • 200 rate resulted in 4 times N and P losses in runoff than 35 rate	Klausner, S. D., Zwerman, P. J., & Ellis, D. F. (1976). N and P losses from winter disposal of dairy manure. Journal of Environmental Quality, 5(1), 47-49.

Summary (100 words)	Bullets	Source
Study started in the winter of 1970 and continued for 4 years. The authors tested stream waters during the winter at multiple points near a cattle and sheep farm in Montana. They altered their experimental methods after the first two years by focusing more on bacteriological analysis than chemical analysis. Most of the chemical data varied because of natural effects. In contrast, the bacteriological data demonstrated that bacterial contamination greatly increased near livestock activity. Nevertheless, the contamination did not spread much downstream. The authors implied that bacteriological analysis is better suited for evaluating livestock pollution than chemical analysis.	• Started in winter of 1970/1971 and continued through spring 1974 • Sampled stream flow at points near wintering operation • First 2 years indicated little change in chemical analysis based on wintering operation • Ion-selective electrodes used in first 2 years • Last 2 years focused on lab bacteriological analysis • "Cattle and sheep wintering operation negligible effect on chemical properties" • Operation increases bacterial contamination • "Contamination appears to be short lived" • "Suggest bacteriological analysis instead of chemical for evaluating pollution potential of livestock operations"	Milne, C. M. (1976). Effect of a livestock wintering operation on a western mountain stream. Transactions of the ASAE, 19(4), 749-0752.
Resulting crop yields, nutrient recovery, soil fertility, and runoff were investigated after dairy and steer manure were applied in a variety of forms. The researchers found that manure application consistently lead to high corn yields. When manure was incorporated into the soil after drying on the surface for a week, the yields were significantly lower than the compared circumstances. After fermented manure application, N recovery values were comparatively high. After anaerobic liquid manure application, P recovery values were comparatively high. In general, winter manure application resulted in increased losses of N, P, and potassium when compared to spring manure application.	• "Dairy-cattle and steer manures in fresh, fermented, aerobic liquid, and anaerobic liquid forms" • "High losses of N from steer manure" • "Application of manure increased dry matter yield of corn" • "Manure dry before incorporation decreased N recovery" • "Application of fresh manure in winter gave lower yields than fermented or liquid" • "Recovery of N and P by crop followed pattern similar to yield" • "Manure to dry for a week before incorporation led to lower yields" • "Higher recovery values by crops obtained for N in fermented manure and P in the anaerobic liquid manure" • "Winter applied: resulted in higher losses of N, P, K than spring-applied"	Hensler, R. F., Olsen, R. J., Witzel, S. A., Attoe, O. J., Paulson, W. H., & Johannes, R. F. (1970). Effect of method of manure handling on crop yields, nutrient recovery and runoff losses. Transactions of the ASAE, 13(6), 726-0731.

Guidance and Policy Documents

Summary (100 words)	Bullets	Source
Reviewed frozen soil characteristics that impact spring and winter flooding. The characteristics include soil structure along with soil frost penetration depth, persistence, and extent. These characteristics are influenced by the type and extent of vegetation and snow cover. The 4 types of frozen soil structure are concrete, honeycomb, stalactite, and granular. The amount of concrete freezing compared to the porous freezing types directly depends on land use. Concrete freezing occurs sooner, is deeper, and is more extensive in open lands than in forested plots. Snow may act as an insulator and slow frost penetration.	• Characteristics of frozen soil that changes flood probability » Structure: fast rain or melting snow can enter » Depth: how fast frost leaves soil during thaws » Persistence: whether soil will remain frozen through periods of snowmelt » Extent: how much of watershed affected • Four soil structure of frozen soil: concrete, honeycomb, stalactite, granular • Effects of soil freezing in slowing percolation greater for heavy than for light-textured soils • Cover of vegetation and snow influences structure/ penetration/ persistence/ extent • Amount of concrete freezing is directly proportional to degree of disturbance of forest floor • Concrete freezing in open lands develops sooner and deeper, more widespread than in forest • Frost forms in granular or honeycomb structure (porous) in soils with considerable humus • Concrete type forms when frost penetrates below humus layer • Light new snow may insulate and retard deep penetration of frost	Storey, H. C. (1955). Frozen soil and spring and winter floods. Water. The Yearbook of Agriculture, 1955, 179-184.

Summary (100 words)	Bullets	Source
To understand the effects of the spread of cattle manure during the winter, 3 field experiments and several laboratory trials were conducted. The authors found that field slope had little impact on runoff losses. The potash runoff losses were greater than N and P losses combined. The addition of superphosphate or hydrated lime to fresh manure increased N runoff losses. Though the addition of straw to the manure lead to decreased N volatilization, this N was then susceptible to runoff losses. Despite the runoff possibilities, the authors suggested that farmers continue spreading manure daily because of their lack of resources.	• Cattle manure on frozen ground » Looked at N, P, and K » Three field experiments and lab tests • With frozen ground, runoff may occur from melting snow during thaw in winter/early spring especially with rain • Highest amount runoff in VT in Feb and March • Steepness of slope not very important • More N losses in volatilization than runoff • Much of ammonia lost in air before runoff • Add of superphosphate or hydrated lime to fresh manure increase runoff losses of N • Straw reduces N volatilization, but this N soluble & subject to runoff • Phosphate losses from untreated manure small • Potash losses greater than losses of N and P combined	Midgley, A.R. and D.E. Dunklee, (1945). Fertility runoff losses from manure spread during the winter. University of Vermont, Agricultural Experiment Station. Bulletin 523:1-19.
The International Plant Nutrition Institute has initiated the 4R Nutrient Stewardship plan. This initiative emphasizes the need for the right source of nutrients along with the correct rate, time, and placement of application. This model will have positive effects on the environment, economy, and community. Right source considers the need to supply nutrients in plant-available forms. Right rate evaluates variables such as plant nutrient demand and soil tests. Right time considers seasonal soil nutrient loss and plant uptake time. Right place examines root location in relation to nutrient placement. This document continues by evaluating example agricultural systems utilizing 4R considerations.	• Source, rate, time, place • Good impacts environmentally, socially, and economically • What impacts it locally: soil, crop, climate, weather, economic, social conditions • Right source: supply nutrients in plant-available forms, suite soil, etc. • Right rate: assess plant nutrient demand, soil analysis, asses all nutrient sources, predict fertilizer use efficiency • Right time: assess plant uptake timing, understand when soil nutrient loss highest • Right place: position nutrients where plant can access them » Variables: plant genetics, tillage, plant spacing, crop rotation, weather variability » Where plant roots are, soil chemical reactions • Contains sustainable examples	The Fertilizer Institute. (2017). The Nutrient Stewardship 4R Pocket Guide. Retrieved from http://www.nutrientstewardship.com/4rs/

Summary (100 words)	Bullets	Source
Agriculture restrictions have been created in Vermont to minimize non-point source pollution. Guidelines have been enacted on various practices including buffer zones, cover crops, agricultural waste storage, farm composting, nutrient management planning, and manure application. Manure may not be applied near water sources or between December 15th and April 1st. Application on perennial grasslands and croplands is restricted when the soil is saturated, frozen, or snow-covered. Manure spreading on cropland, perennial grassland, small grain cropland, and hay land with frequent flooding is banned between October 16th and April 14th. When fields are, or expected to be, flooded, application is prohibited.	• Manure/other ag wastes not applied between Dec 15 – April 1 • Could change via secretary between Dec 1 and Dec 15 and between April 1 and April 30 • Not applied to perennial grasslands, croplands, hay lands when saturated with water or frozen/ snow covered unless exempted • Cannot be applied to cropland, perennial grassland, small grain cropland, hay land with frequent flooding after Oct 16 or before April 14 • Cannot apply to slope more than 10% unless vegetated buffer zone of 100 ft • Winter spreading exemptions possible • Cannot apply mechanically within 100ft of private or 200 ft of public water supply • Cannot apply when field conditions conducive to flooding, runoff, ponding etc. or anticipated	Legislative Committee on Administrative Rules (2016). Required agricultural practices rule for the agricultural nonpoint source pollution control program. Retrieved from http://agriculture.vermont.gov/
Describes the winter fertilizer and manure regulations in Delaware that were put in place in 2007 by the Delaware Nutrient Management Commission. These recently adopted rules prohibit certified nutrient handlers from applying both manure and commercial fertilizer between the dates of December 7th and February 15th. Furthermore, applicators are excluded from applying nutrients on the surface of snow and frozen soil, or on impermeable surfaces. If applicators fail to follow these regulations, they must attend a "compliance and enforcement hearing" before the Delaware Nutrient Management Commission. These regulations affect not only farmers, but also individuals in commercial industries.	• Regulations in place in 2007 • Enforced by Delaware Nutrient management commission • "Prohibit certified nutrient handlers from applying commercial and manure-based fertilizer from Dec 7 – Feb 15" • "Not permitted to fertilize on snow-covered/ frozen ground or on impermeable surfaces like sidewalks roads, etc." • What happens if you do not comply: compliance and enforcement hearing before the commission	Shortridge, D. (2016). Winter application of fertilizer and manure regulated. Retrieved from http://www.news.delaware.gov

Summary (100 words)	Bullets	Source
In Pennsylvania, manure cannot be spread during the winter within 100 feet from water, on slopes greater than 15%, or on fields without cover crops or 25% residue. Spread rates may not be more than 5000 gal/A of liquid manure, 20 tons/A dry non-poultry manure, or 3 tons/A poultry manure unless otherwise specified in the Nutrient Management Plan. This article describes non-regulated suggestions that include avoiding areas where concentrated water is probable, poorly drained fields, and roads. Winter is from December 15th until February 28th, when the ground is frozen at least four inches, or when the soil is snow-covered.	• Pennsylvania regulations: » Need cover crops or 25% residue » Distance from water must be 100 ft » Slopes less than 15% » No more than 5000 gal/A of liquid manure, 20 tons/A dry non-poultry manure, 3 tons/A poultry manure • Avoid poorly drained fields and where concentrated water flow is likely • Don't spread on snow or when rain/melting expected • Avoid roads and ditches • Winter definition: December 15- February 28, when ground frozen 4 inches, or snow covers ground • All PA farmers need manure management plan	Beegle, D. (2015). Late Winter and Early Spring Manure Application Considerations. Retrieved from http://www.extension.psu.edu
Ohio Senate Bill 1 restricts when farmers in the western basin of Lake Erie are permitted to apply manure and fertilizer that incorporates N or P. These nutrients may not be applied when the ground is frozen or snow-covered, or when the top two inches of soil are saturated. Further restrictions have been made around the weather conditions in which granular fertilizer and manure may be applied. Exceptions to these rules can be made if the nutrients are injected or otherwise incorporated into the ground within 24 hours, or applied onto growing crops. Violators risk a $10,000 fine per violation.	• Senate Bill 1 effective July 3, 2015 • In western basin of Lake Erie, can't apply fertilizer (N or P) or manure » "On snow-covered/frozen soil" » "When top 2 inches of soil are saturated from precipitation" » "Fertilizer in granular form when weather forecast has greater than 50% chance of precipitation exceeding 1 inch in 12-hour period" » "Manure when local weather forecast is greater than 50% chance of precipitation exceeding ½ inch in 24-hour period" • "Exceptions: Injected into ground, incorporated within 24 hours of surface application, applied onto growing crop" • Manure: in an emergency that is reported to the correct officials • Risk: penalty amounts may not exceed $10,000 per separate violation	Kirk Hall, P. (2015). Ohio's new fertilizer and manure application restrictions are in effect. Retrieved from http://aglaw.osu.edu

Summary (100 words)	Bullets	Source
The Natural Resources Conservation Service (NRCS) Code 590 articulates guidelines for nutrient application on agricultural soils in the Vermont Conservation Practice Standard. Agriculturalists who apply nutrients or soil amendments to their land are required to maintain a current soil test, Nutrient Management Plan, Vermont Nitrate Leaching Index, Vermont P Index, and detailed records. Soil erosion rates must be kept below tolerable soil loss limits. Nutrients may not be applied to frozen, snow-covered, or saturated soils. Manure application is banned between December 15th and April 1st. Recommendations are included to promote improvements in air quality, nonpoint source pollution, and employee health.	• Applies to all land with nutrients and soil amendments applied • "Soil erosion at or below tolerable soil loss limits" • Vermont Nitrate Leaching Index and Vermont P Index: completed on all fields • "Nutrient sources on organic sites must be consistent with USDA's National Organic Program" • Need current soil test (no older than 3 years) • "Nutrient values of manure/waste, organic by products and biosolids must be determined before application" • Rates of nutrient application not above UVM guidelines • Timing/placement correspond to plant nutrient uptake • No spreading of any nutrients on frozen/snow-covered soils • "Or top 2 inches of soil saturated with rainfall or snowmelt" • Manure spreading ban: Dec 15 to April 1	U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2014). Code 590 Nutrient management practice standard. USDA-NRCS Montpelier, VT.

Summary (100 words)	Bullets	Source
The Natural Resources Conservation Service (NRCS) Code 590 articulates guidelines for nutrient application on agricultural soils in the Delaware Conservation Practice Standard. This document explains that agriculturalists must make a nutrient management plan that describes plans surrounding the variables of nutrient application. Soil tests must be kept current, and generally a N Index and P Site Index must be maintained. Nutrients may not be applied to frozen, snow-covered, or saturated soils. The prior regulation does not apply to the application of liquid manure. Suggestions were included to promote air quality such as incorporation or injection of nutrients and tillage management.	• Need current soil tests: no older than 3 years • Manure/organic amendment testing: manure analyses done before application and at least yearly • Nutrients not applied to frozen/snow-covered soil, or top two inches saturated from rainfall/ snowmelt » Inter application in compliance with DE nutrient management certification program » Not including liquid manure: fields have 30% residue or cover/vegetative cover • P site index and explain P site index rating (organic and manure) • P application can't exceed amount of P removed in the harvesting portion of crops grown for the next 3 years • N leaching Index Rating (organic and manure) • Nutrient management plan: manage amount, placement, timing and application of nutrients » Required for someone with more than 10 acres of land where nutrients applied or 8,000 lbs. of live animals » Describes what to add in nutrient management plan	U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2013). Code 590 Nutrient management practice standard. USDA-NRCS Dover, DE.
The Natural Resources Conservation Service (NRCS) Code 590 articulates guidelines for nutrient application on agricultural soils in the Mississippi Conservation Practice Standard. Agriculturalists who apply nutrients or soil amendments to their land are required to maintain a Nutrient Budget. The Leaching Index for N and the Mississippi P Index must be completed in certain circumstances. Nutrients may not be applied to frozen, snow-covered, or saturated soils. Exceptions to this rule can be made for surface applied manure if certain criteria are met. Recommendations are included to promote improvements in soil nutrient cycling, air quality, nonpoint source pollution, and employee health.	• Applies to lands where nutrients and soil amendments applied • Nutrient budget for N, P, K needed • Leaching Index for N needed unless exempt • MS P Index completed in certain circumstances • Need current soil tests, nutrients of manure, organic by-products, and biosolids determined before land application • Rate of application for N, P, K not exceeding guidelines • Nutrients not applied on frozen/ snow-covered soils or when top 2 inches saturated from rainfall or snowmelt • Exceptions for surface-applied manure possible if slope less than 5%, crops actively growing, minimum forage height of 4 in. maintained, addressed in nutrient management plan, and buffer widths for streams/water 100 ft	U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2013). Code 590 Nutrient management practice standard. USDA-NRCS Jackson, MS.

Summary (100 words)	Bullets	Source
The Natural Resources Conservation Service (NRCS) Code 590 articulates guidelines for nutrient application on agricultural soils in the Iowa Conservation Practice Standard. Agriculturalists who apply nutrients or soil amendments to their land are required to maintain a Nutrient Management Plan for N, P, and Potassium. Nutrients may not be applied to frozen, snow-covered, or saturated soils. Exceptions to this rule can be made for surface applied manure in emergency circumstances. This document explicitly references the 4Rs to nutrient management: right source, rate, timing, and placement. Recommendations are included to promote improvements in soil quality, nonpoint source pollution, and employee health.	• Applies to lands where nutrients and soil amendments applied • Need nutrient management plan for N, P, K • Soil test at minimum every 4 years • Explicitly talk about 4Rs: right nutrient source at right rate at right time in right place • Suggests applying N in spring • Don't apply nutrients when soils frozen, snow-covered, or top 2 inches of soil saturated • Manure may be surface applied on emergency basis • IA P Index required in certain circumstances • Recommendations on how to reduce nonpoint source pollution, control/trap P, trap N • "Must analyze nutrient content of manures, municipal/industrial biosolids, organic by-products before land application"	U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2013). Code 590 Nutrient management practice standard. USDA-NRCS Des Moines, IA.

The National Handbook of Conservation Practices (NHCP) Natural Resources Conservation Service (NRCS) Code 590 articulates guidelines to optimize crop production while protecting waterways and maintaining soil quality. The guidelines describe necessary soil, tissue, and manure analyses. When considering manure application timing, farmers must attempt to correspond with optimum plant nutrient uptake as much as feasible. In regards to winter manure application, the document states that manure should not be applied on frozen, snow-covered, or saturated soil. When amending manure regulations, individual states will take the following into consideration: field slope, organic residue, cover crops, nutrients applied, and proximity of water.	• Manure analyses: include total N, ammonium N, total P, P_2O_5, total K, K_2, percent solids
	• Timing/placement: correspond with plant nutrient uptake
	• "Consider nutrient source, cropping system limitations, soil properties, weather conditions, drainage system, soil bio, nutrient risk assessment results"
	• No surface application when soil frozen/snow-covered and top 2 inches of soil are saturated
	  » Exceptions set by state
	  » "Have slope, organic residue/living covers, amount and form of nutrients applied, distances from water in consideration"
		U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). (2012). Code 590 Nutrient management practice standard. USDA-NRCS Washington, D.C.

Summary (100 words)	Bullets	Source
Reviews winter manure application guidelines in multiple states. In Michigan, it is legal to apply manure during winter conditions, but producers are encouraged to utilize the Manure Application Risk Index. The Right-to-Farm guidelines state that solid manure should be applied to fields with a slope of 6% or less and liquid manure should be applied to fields with a slope of 3% or less. Furthermore, manure must not be applied near surface waters or on flood-prone fields. The article continues by considering variables such as surface water, slope, vegetation type, tillage methods, and storage capacity.	• In Michigan, livestock farmers should use Manure Application Risk Index to find most appropriate plot » Legal to apply manure in frozen and snow-covered fields in MI » CAFOs need comprehensive nutrient management plans that include assessment of winter manure appropriateness » Most have 6 month manure storage, but they can still apply • Right-to-farm guidelines: only applied where slope is 6% or less and liquid manure only applied where slopes are 3% or less • Not applied within 150 feet of surface waters or areas subject to flooding unless injected	Sollman, A. (2011). Winter manure spreading dominates conversations in Midwest. Retrieved from http://animalagteam.msu.edu.
Designed for farmers to better understand when and how to apply manure to Wisconsin lands. The article suggested that manure be incorporated within three days of application and soil tests are conducted every 3 - 4 years. Furthermore, manure should not be applied if soil test P levels reach 150 ppm, on sands or loamy sand until November 1 during the autumn, or if the field slope is above 12%. Manure should not be applied within a 10 year floodplain, 300 feet of a stream, or 1000 feet of a lake.	• Incorporate within 3 days of application » If not, don't apply more than 25 tons/a of solid dairy manure in 1 year » In no-till: don't apply more than 25 tons/a of solid dairy manure in 5 years • Soil test every 3 - 4 years • Avoid fields with high P levels • "If soil test P levels reach 150 ppm, stop applying manure and use runoff reduction practices" • To avoid application that will lead to nitrate-N leaching to groundwater: » In fall, don't apply manure to sands/loamy sands until after Oct 31 » If less than 10 in of soil over bedrock, don't apply • Don't apply manure within 10-year floodplain, 300 ft of streams, 1000 ft of lakes unless incorporated within 3 days • Don't apply when frozen except emergency • When frozen: don't apply to fields with greater than 12% slope • Conservation measures when 6-12% slope	Madison, F., K. Kelling. L. Massie, and L.W. Good. (2003). Guidelines for applying manure to cropland and pasture in Wisconsin. University of Wisconsin Cooperative Extension Publication No. A3392. University of Wisconsin, Madison. Wisconsin.

Summary (100 words)	Bullets	Source
An Iowa law passed the state legislature in 2009 and went into effect on September 15, 2010. The law applies to farmers who have confinement facilities with at least 500 animal units. Farmers may not apply liquid manure on snow-covered soil starting December 21st or on frozen soil beginning February 1st. The restriction ceases April 1st. The only exception is when an emergency out of the owner's control occurs such as equipment failure or natural disaster. The author continues by suggesting to farmers to refrain from applying manure during winter months even if the law does not pertain to them.	• Iowa legislature passed bill in 2009 • Rules went into effect Sept 15, 2010 • "Applies to liquid manure from confinement feed operations that have more than 500 animal units in confinement" • "Cannot apply liquid manure on snow-covered ground from Dec 21 to April 1" • "Except emergency beyond owner's control: natural disaster, unusual weather, equipment/ structural failure"	Rieck-Hinz, A. (2010). Winter application of manure: regulations and common sense. Retrieved from http://crops.extension.iastate.edu