Adjusting Nitrogen Rate Recommendations For Agronomic, Forage/Hay, and Vegetable Crops in Delaware

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Recommended Base Nitrogen (N) Rates

The University of Delaware maintains nutrient recommendations (available at http://www.udel.edu/008353) for agronomic, forage/hay, and vegetable crops that are commonly grown in Delaware. Nutrient recommendations for most essential elements are based upon soil test calibration studies. These calibration studies relate the likelihood of a profitable plant response to nutrient addition with the nutrient concentration in the soil as measured by a soil test. However, nitrogen (N) is not included in routine soil analysis because it is not possible to test soils in advance of planting and accurately predict the need for N fertilization. As such, crop N recommendations are based upon field research evaluating plant response to increasing rates of N applied in fertilizers or manures that were historically conducted in Delaware or in nearby states with similar soil types and growing conditions.

Recommended N rates are designed to produce the maximum economic yield, while minimizing the potential for over-application of N. Over-application of N can lead to unnecessary input expense and contribute to serious environmental problems, such as groundwater pollution due to leaching of nitrate-N. Nitrate leaching is a serious concern in Delaware due to the prevalence of sandy, low organic matter soils, surficial groundwater, and artificial drainage. With a few exceptions, the criteria for selecting the recommended base rate of N vary with crop type as follows:

- Agronomic crops: Rates are a function of realistic yield goal, soil type, tillage, and/or irrigation use.
- Field-grown nursery stock: Rates are expressed as an annual application to support good vegetative growth and development.
- Forage crops: Rates are dependent upon the degree of stand establishment and the percentage of legumes in the stand, if applicable. Alternatively, rates for some forage crops are a function of yield goal.
- Fruit and orchard crops: Rates are dependent upon the maturity of the plants.
- Vegetable crops: Rates are expressed as an annual application designed to produce market quality vegetables.

When appropriate, N management guidelines including recommended source, application time, or method for most efficient N use, are specified in each recommendation section.

Nitrogen Rate Adjustments

Base N fertilizer recommendations should be adjusted to account for other sources of N that would be available to a crop. For example, animal manures, biosolids, cover crops, green manures, and legume crops may contribute substantial quantities of plant-available N to the subsequent crops. For that reason, fertilizer N rates should be reduced when planting into fields with a history of manure application, when a cover crop or green manure has been used, or when following a legume crop, such as soybean or alfalfa.

Manures, composts, and organic residuals

In Delaware, animal manures (particularly poultry litter) are commonly applied to agricultural soils to provide essential plant nutrients and as a source of organic matter. In addition, composts or other organic residuals (e.g., biosolids, food processing wastes, etc.) may also be applied to the soil as a nutrient source. Animal manures and other organic residuals contain primarily organic forms of N (e.g., N that is complexed with carbon and not plant available). Inorganic N, primarily in the plant available form of ammonium (NH_4-N), is typically present in small amounts. Over time, soil microbes will use the carbon in manures as an energy source and will convert organic N into ammonium, which is available for plant uptake. The process by which soil microbes convert organic N into ammonium is called mineralization. Mineralization rates are variable in the soil due to many factors including the carbon to nitrogen (C:N) ratio of the organic residual, soil temperature, and soil moisture. For example, N mineralization will be faster for materials with a C:N ratio that is less than 20:1 and under warmer and wetter conditions.

Unlike organic N, ammoniacal N (NH_4-N) is immediately available for crop uptake after land application. However, ammoniacal N is also subject to loss as ammonia gas to the atmosphere (a process called ammonia volatilization) if the manure or residual is not incorporated into the soil soon after application. The potential for ammonia volatilization is increased when manures are surface applied, when applied to soils with a low cation exchange capacity (CEC) or high pH, and under warm and windy conditions. Incorporation of manures and other organic residuals into the soil allows ammonium N to be fixed by soil clay minerals and organic matter, which greatly reduces the risk for ammonia volatilization. However, with the exception of liquid manures, which can be injected with minimal soil disturbance, incorporation of manures and organic residuals may not be compatible with some cropping systems (e.g., no-till or permanent pasture systems).

When applying manures or organic residuals into cropping systems, the amount of plant available N (PAN) that organic residuals will contribute to the crop in the year of application must be estimated. The Delaware Nutrient Management Act requires that all operations managed under a nutrient management plan that apply manures or other organic residuals as a nutrient source must have a recent manure analysis. The Delaware Department of Agriculture Agricultural Compliance Laboratory provides manure analysis to Delaware residents free of charge. A manure analysis will indicate the amount of total N and ammoniacal N (NH_4-N) in a given sample (Figure 1). This information is critical to determine PAN. It is important to remember that the results of manure analysis are only as good as the sample that was submitted. For information about how to take a representative sample of manure (or other organic residual), please refer to [*Know the Value of Manure: Manure Sampling and Analysis*] (available at [http://www.udel.edu/0013476]).

Plant available N in manures or other organic residuals is determined using the following equation:

$$PAN = [(k_m \times N_o) + (e_f \times NH_4\text{-}N)]$$

Where, k_m = organic N mineralization coefficient; N_o = organic N in the manure; e_f = efficiency of ammonium recovery (NH_4-N); and NH_4-N = ammoniacal N from manure analysis.

<u>Step 1</u>: Determine the amount of organic N (N_o) in the sample using the total N and NH_4-N concentrations from the manure analysis report.

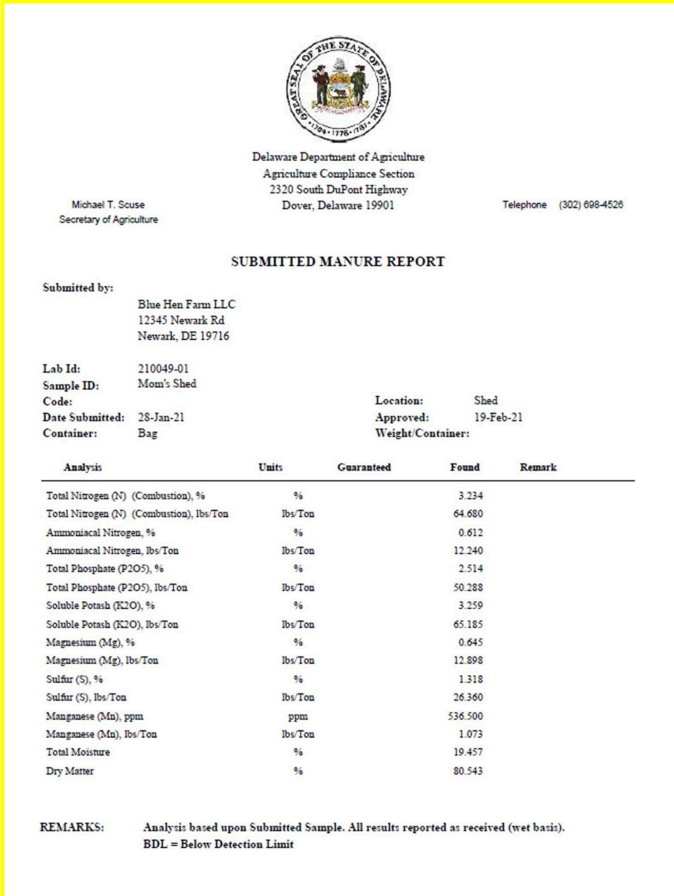
$$N_o = \text{Total N} - NH_4\text{-}N$$

<u>Step 2</u>: Determine the "year of application" manure mineralization coefficient (k_m) for the manure or organic residual type (Table 1).

<u>Step 3</u>: Calculate the amount of plant available N_o in the sample.

$$\text{Plant available } N_o = k_m \times N_o$$

<u>Step 4</u>: Determine the NH_4-N concentration from the manure analysis report.



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SUBMITTED MANURE REPORT

Submitted by:
Blue Hen Farm LLC
12345 Newark Rd
Newark, DE 19716

Lab Id: 210049-01
Sample ID: Mom's Shed
Code:
Date Submitted: 28-Jan-21
Container: Bag
Location: Shed
Approved: 19-Feb-21
Weight/Container:

Analysis	Units	Guaranteed	Found	Remark
Total Nitrogen (N) (Combustion), %	%		3.234	
Total Nitrogen (N) (Combustion), lbs/Ton	lbs/Ton		64.680	
Ammoniacal Nitrogen, %	%		0.612	
Ammoniacal Nitrogen, lbs/Ton	lbs/Ton		12.240	
Total Phosphate (P2O5), %	%		2.514	
Total Phosphate (P2O5), lbs/Ton	lbs/Ton		50.288	
Soluble Potash (K2O), %	%		3.259	
Soluble Potash (K2O), lbs/Ton	lbs/Ton		65.185	
Magnesium (Mg), %	%		0.645	
Magnesium (Mg), lbs/Ton	lbs/Ton		12.898	
Sulfur (S), %	%		1.318	
Sulfur (S), lbs/Ton	lbs/Ton		26.360	
Manganese (Mn), ppm	ppm		536.500	
Manganese (Mn), lbs/Ton	lbs/Ton		1.073	
Total Moisture	%		19.457	
Dry Matter	%		80.543	

REMARKS: **Analysis based upon Submitted Sample. All results reported as received (wet basis).**
BDL = Below Detection Limit

Figure 1. Example of a manure analysis report generated by the Delaware Department of Agriculture's Agriculture Compliance Laboratory, which provides information about the dry matter, total nitrogen, and ammoniacal nitrogen; this information is needed to determine the plant available nitrogen and residual nitrogen from manure applications.

<u>Step 5</u>: Determine the ammonia efficiency coefficient (e_f) for the manure type based on the total dry matter (from manure analysis) and desired application method and planned time to incorporation (Table 2).

<u>Step 6</u>: Determine the amount of NH_4-N that will be plant available based on the manure characteristics and planned application method and timing.

$$\text{Available } NH_4\text{-N} = e_f \times NH_4\text{-N}$$

<u>Step 7</u>: Determine the amount of manure PAN for the year of application.

$$\text{PAN} = \text{Plant available } N_o + \text{Available } NH_4\text{-N}$$

Table 1. Organic manure mineralization rates for common manures and organic residuals applied in Delaware for estimating plant available N.

Manure type	**Organic N Mineralization Coefficient (k_m)**		
	Year of Application	**1st year after application**	**2nd year after application**
Cattle, dairy & beef			
<20% dry matter	0.35	0.12	0.05
>20% dry matter	0.25	0.12	0.05
Poultry (all)	0.60	0.12	0.05
Swine	0.50	0.12	0.05
Horse	0.20	0.10	0.05
Sheep, goat, alpaca, llama	0.30	0.12	0.05
Compost (not mortality compost)	0.05	0.12	0.00

Table 2. Ammonia efficiency coefficients (e_f) for common manures and organic residuals applied in Delaware for estimating plant available N.

Time to incorporation	**Liquid (<10% solids)**	**Semi-solid (10-20% dry matter)**	**Solid (>20% dry matter**
Injected	0.95	--	--
Broadcast with immediate incorporation	0.8	0.8	0.9
1 day	0.75	0.75	0.8
2-4 days	0.65	0.65	0.7
5-7 days	0.4	0.4	0.6
>7 days	0.25	0.25	0.5
Irrigation with no incorporation	0.2	--	--

Here is an example of how to calculate PAN using the information provided in the sample manure report (Figure 1), assuming the poultry litter will be with incorporation by vertical tillage within 4 days of application. Based on this report, the material to be applied is a solid manure (dry matter = 80.54%) with a total N concentration of 64.68 lb/ton and an ammoniacal N concentration of 12.24 lb/ton.

Step 1: Determine the amount of organic N (N_o) in the sample using the total N and NH_4-N concentrations from the manure analysis report.

$$N_o = 64.68 \text{ lb/ton} - 12.24 \text{ lb/ton}$$

$$N_o = 52.44 \text{ lb/ton}$$

Step 2: Determine the "year of application" manure mineralization coefficient (k_m) for the manure or organic residual type (Table 1).

$$k_m = 0.60 \text{ for poultry litter}$$

Step 3: Calculate the amount of plant available N_o in the sample.

$$\text{Plant available } N_o = 0.6 \times 52.44 \text{ lb/ton}$$

$$\text{Plant available } N_o = 31.464 \text{ lb/ton}$$

Step 4: Determine the NH_4-N concentration from the manure analysis report.

$$NH_4\text{-N} = 12.24 \text{ lb/ton}$$

Step 5: Determine the ammonia efficiency coefficient (e_f) for the manure type based on the total dry matter (from manure analysis) and desired application method and planned time to incorporation (Table 2).

$$e_f = 0.70 \text{ for a solid manure incorporated within 4 days of application}$$

Step 6: Determine the amount of NH4-N that will be plant available based on the manure characteristics and planned application method and timing.

$$\text{Available } NH_4\text{-N} = 0.7 \times 12.24 \text{ lb/ton}$$

$$\text{Available } NH_4\text{-N} = 8.568 \text{ lb/ton}$$

Step 7: Determine the amount of manure PAN for the year of application.

$$PAN = 31.464 + 8.568 \text{ lb/ton}$$

$$PAN = 40.032 \text{ lb/ton (round to 40 lb/ton)}$$

In the case where a manure or residual analysis does not provide information about the amount of ammoniacal N in the sample, PAN can be estimated by applying the organic N mineralization coefficient (k_m) to the total N content of the manure. For example, if the sample analysis (Figure 1) did not include the ammoniacal N, we would calculate PAN for this poultry sample as follows:

$$\text{Plant available } N_o = k_m \times \text{total N}$$

$$\text{Plant available } N_o = 0.6 \times 64.68 \text{ lb/ton}$$

$$\text{Plant available } N_o = 38.8 \text{ lb/ton}$$

Once the PAN is calculated for the manure or organic residual that will be applied, the manure PAN rate can be subtracted from the base N rate recommendation provided for the planned crop as found in the *University of Delaware Nutrient Recommendations* (available at http://www.udel.edu/008353). This will determine the amount of supplemental N that should be applied to achieve realistic yield goals. For crops where split N applications are desired, the base N rate can be further adjusted in-season using tools like the pre-sidedress N test for corn (as described in *Nitrogen Management for Corn in Delaware: The Pre-sidedress Nitrate Test*; available at http://www.udel.edu/0013390), in-season N modeling tools, or sensors.

Residual Manure N Credits

Some portion of the organic N applied to soils during land application of manures or other organic residuals will not mineralize during the year of application. In fact, organic N may mineralize over the course of several growing seasons. As such, it may be desirable (based on the planned crop rotation) to estimate the amount of residual N that will mineralize in subsequent growing seasons. We can estimate this based on the amount of organic N that was applied to the field in the year of application. Residual N represents organic N in manure that is more resistant to microbial activity, but that will continue to mineralize slowly over time (Table 1). For example, we estimate that approximately 60% of the organic N applied in poultry litter will mineralize in the year of application (Table 1, PAN example), while an additional 12 and 5% of the organic N will mineralize in the first and second years after application (Table 1).

In the previous example, we estimated that the total organic N content in the poultry litter sample (Figure

1) was 52.44 lb/ton. Using the mineralization coefficient (k_m) in Table 1, we estimated that the amount of organic N that would mineralize from the poultry litter sample in the year of application was 31.46 lb/ton. In the following year (1st year after application), an additional 12% of the organic N applied is expected to mineralize. Therefore, to calculate the residual N credits, we then apply the mineralization coefficients (k_m; Table 1) for the subsequent years as follows:

N credit for first year after application = 0.12 × 52.44 lb/ton

N credit for first year after application = 6.29 lb/ton

As such, the base N rate for a crop grown the year after manure application should be reduced by 6.3 lb for every ton of manure that was applied. Organic N will continue to mineralize in the 2nd year after application at an estimated rate of 5% (Table 1).

N credit for second year after application = 0.05 × 52.44 lb/ton

N credit for first year after application = 2.62 lb/ton

Crop rotations in Delaware often include soybean (a legume crop) following corn or a small grain (double cropped). No N application is recommended for soybean. Therefore, the need to apply manure N credits will be dependent on manure application rates and frequency, as well as the planned crop rotation.

Legume crops

Legumes are specialized plants that form a symbiotic relationship with N fixing bacteria called *Bradyrhizobium japonicum*. These N fixing bacteria form nodules in the roots of leguminous plants and convert atmospheric N_2 gas into ammonium (NH_4-N), which is plant available. The bacteria excrete plant available N from the nodules into the soils, where it can be taken up by the legume plant. In return, the N fixing bacteria receive an energy source (carbon) directly from the plant.

With approximately 150,000 acres planted annually, soybean is the most common legume planted as a cash crop in Delaware, followed by alfalfa for hay, lima beans, peas, and snap beans (approximately 6000, 3000, 1500, and 1200 acres annually). Delaware also leads the nation in planting cover crops, with more than 100,000 acres of cover crops planted. As such, legume plants may be planted alone, or as a mixture with grass species as a cover crop.

The residues of leguminous crops can provide a significant amount of N to subsequent crops. The amount of N left in the soil following a leguminous cash or cover crop is variable and is influenced by factors including species, nodulation, growth stage, biomass production, stand quality, and stand composition. Inoculation with an appropriate *Bradyrhizobia* strain will promote good nodulation and maximize N fixation. Inoculation may provide a relatively large benefit in Delaware soils, as research found that our soils often contain strains of a that are relatively inefficient at N fixation. Termination timing can also impact the amount of N available to subsequent crops when legumes are planted as a cover crop. Maximum N fixation typically occurs at the flowering stage. As such, N credits for legume cover crops (alone or as a mix) will be highest if the cover crop is terminated at the flowering stage.

Determining the N credit for soybean is the most straightforward, as the N credit is a function of the yield (Table 3). For example, the N credit following a 60 bu/ac soybean crop would be 30 lb/ac. As a general rule of thumb, N credits from soybean crops is capped at 40 lb/ac. For crops like Ladino (white) clover, lespedeza, peas, lima beans, or snap beans, the N credit is simply a standard value (Table 3) regardless of stand quality or composition.

Table 3. Estimated nitrogen availability to subsequent crops following a legume crop or cover crop.

Legume Types	Stand Quality	Stand Composition (% legume)	Nitrogen Contribution (lb/A)
Alfalfa	Good (>4 ton/ac)	50-75	90
	Fair (3-4 ton/ac)	25-49	70
	Poor (<3 ton/ac)	<25	50
Red or Crimson Clover	Good (>3 ton/ac)	>50	80
	Fair (2-3 ton/ac)	25-49	60
	Poor (<2 ton/ac)	<25	40
Hairy Vetch or Austrian Winter Pea	Good (>2 ton/ac)	80-100	100
	Fair (1-2 ton/ac)	50-79	75
	Poor (<1 ton/ac)	<50	45
Ladino (White) Clover	--	--	60
Lespedeza	--	--	20
Peas, snap beans, and lima beans	--	--	20
Soybeans	--	--	Up to 40 (apply credit of 0.5 lb N/bu soybean yield)

Yet for many legumes, the N credit will be a function of the stand quality and composition. Stand quality is assessed primarily by determining the amount of biomass generated by the crop. Biomass production can be estimated using the quadrat method, where a frame of known size (e.g., 1 ft × 1 ft) is placed in the field at random locations. Once placed, all aboveground biomass is removed from the area within the quadrat frame. It is important to cut all plants that are rooted within the area of the quadrat, which can be difficult to determine with crops like hairy vetch, which tend to have a vine type growth habit. The cut crops from each location should be placed in a paper bag and weighed to determine the fresh weight. The biomass per unit area can then be calculated based on the size of the quadrat. Dry biomass can be determined by reweighing the sample after it has been oven dried. Alternatively, biomass for some crops can be estimated using sensors, which can be handheld, mounted on equipment, or mounted to unmanned aerial vehicles (i.e., drones). However, obtaining accurate biomass estimates using sensors requires calibration and ground-truthing and the ability to process and analyze the data. In addition, obtaining accurate sensor-based estimates may be difficult if the crop is no longer green or if the crop grows upward after covering the soil.

Stand composition is a measure of the types of species that make up the stand. Stand composition can be assessed using the quadrat method that was mentioned previously for estimating biomass. Determining stand composition using the quadrat method requires that you can accurately identify the legume species and differentiate them from the grass species. Briefly, evaluating stand composition requires counts of the individual grass and legume species that were collected within the area of each quadrat frame. The percentage of the stand that can be attributed to legumes is then calculated by dividing the number of legume plants by the total number of plants in the quadrat and multiplying the result by 100. This process is repeated for all harvested quadrats and the values are averaged. It is important to sample enough quadrats to represent the whole area of interest, as legume composition can vary widely across the field. It may also be more difficult to distinguish between legume and grass species when plants are not mature.

Once biomass and stand composition has been determined for the field, the appropriate legume credit may be selected (Table 3) and the base N recommendation for the following crop should be reduced accordingly.

Other Methods to Estimate N Credits from Cover Crops

Modelling tools are available to predict N release from cover crop to subsequent crops. For example, the Precision Sustainable Agriculture (PSA) group offers a free cover crop N calculator tool (CC-NCALC) that integrates field site data (satellite imagery, real-time weather, and soil data) with details about the cover crop being grown to estimate N release from cover crop residues (e.g., grasses, legumes, and mixes) to the subsequent crop. The PSA tool also can estimate the amount of cover crop residue that will remain over time and corn N uptake. The CC-NCALC tool requires users to provide information about the field location (latitude and longitude), cover crop biomass (dry weight), and cover crop N concentration. The tool's performance is enhanced if information about the cover crop water, carbohydrate, holo-cellulose, and lignin concentrations at termination are also available.

Summary

Manures (and other organic residuals), legume crops, and cover crops can provide a significant amount of N to subsequent crops. These sources of N should be accounted for in nutrient management plans. In-season plant available N and residual N credits should be applied to reduce the base N recommendations for agronomic and vegetable crops to improve N use efficiency and preserve environmental quality. When applied properly, N credits can reduce inputs while maintaining or improving crop yields.

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