SOIL FERTILITY AND NUTRIENT MANAGEMENT

Content

Competency Areas:

2026 Subject Matter Authors

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CA 1: Basic Concepts of Plant Nutrition

1. List the 17 elements essential for plant nutrition.

	Nutrient	Symbol	Macro/micro	Uptake form	Mobility in plant
1	Carbon	C	Macro	CO_2, H_2CO_3	
2	Hydrogen	H	Macro	H^+, OH^-, H_2O	
3	Oxygen	O	Macro	O_2	
4	Nitrogen	N	Macro	NO_3^-, NH_4^+	Mobile
5	Phosphorus	P	Macro	HPO_4^{-2}, $H_2PO_4^-$	Mobile
6	Potassium	K	Macro	K^+	Mobile
7	Calcium	Ca	Macro	Ca^{+2}	Immobile
8	Magnesium	Mg	Macro	Mg^{+2}	Mobile
9	Sulfur	S	Macro	SO_4^-	Immobile
10	Boron	B	Micro	H_3BO_3, BO_3^-	Immobile
11	Copper	Cu	Micro	Cu^{+2}	Immobile
12	Iron	Fe	Micro	Fe^{+2}, Fe^{+3}	Immobile
13	Manganese	Mn	Micro	Mn^{+2}	Immobile
14	Zinc	Zn	Micro	Zn^{+2}	Immobile
15	Molybdenum	Mo	Micro	MoO_4^-	Immobile
16	Chlorine	Cl	Micro	Cl^-	Mobile
17	Nickel	Ni	Micro	Ni^{+2}	Mobile

2. Classify the plant essential elements as macronutrient and micronutrient.

See Table 1. Macronutrients include the primary macronutrients (N, P, K) and secondary macro nutrients (Ca, Mg, S). These are nutrients taken up in large quantities. Micronutrients (B, Cu, Fe, Mn, Zn, Mo, Cl and Ni) are used in much smaller quantities but equally essential.

3. Recognize the functions of N, P, and K in plants.

Nitrogen is found in chlorophyll, nucleic acids and amino acids and a component of protein and enzymes. Phosphorus is an essential component of DNA, RNA and phospholipids which play critical roles in cell membranes and also plays a major role in the energy system (ATP) of plants. Potassium plays a major role in plant metabolism, and is involved in photosynthesis, drought tolerance, improved winter-hardiness and protein synthesis.

4. Distinguish each macronutrient as mobile or immobile in the plant.

See Table 1. Nutrients that are mobile in the plant will move from the older leaves to new growth areas when the plant experiences a deficiency in the nutrient. Thus, deficiency symptoms for these nutrients will first show up in the *older* leaves. For the macronutrients, this is the case for N, P, K, and Mg. Nutrients that are immobile within the plant cannot move to newly developing tissues, causing deficiency symptoms to appear in the new growth. This is the case with most micronutrients.

5. List the chemical uptake forms for each macronutrient.

See Table 1. Take note: some of the nutrients are taken up in more than one form.

6. Describe how nutrient demands change at different plant growth stages.

In general, nutrient needs increase as the plant grows through the seedling stage, through the vegetative phase, and into the reproductive stage (silking and tasseling, flowering, seed production). For N in corn, uptake increases rapidly between V8 and R1 (silking).

7. List the regional concerns with nutrient deficiencies such as Se, B, Zn, and S.

- Selenium: Deficiencies can be linked to decreased atmospheric deposition, low organic matter, low levels of Se in manure, or reflect soil parent material low in Se. Deficiencies in forage crops and grains play the largest role as they are a key factor in animal nutrition.
- Boron: Deficiencies are most likely to happen on acidic, sandy, low-organic matter soils, especially during dry conditions or after liming. Deficiencies are uncommon but can occur in acidic, sandy, low organic matter soils, especially when there is a prolonged drought. Alfalfa can be at risk due to its high B demand and preferred near neutral soils.
- Zinc: Deficiencies are most likely to happen on high-pH soils (above ~6.5–7.4), cool wet spring conditions, areas with low organic matter, areas of high compaction and in areas with high phosphorus levels. Corn and sorghum are two crops that are particularly Zn sensitive.
- Sulfur: Low organic matter, sandy and acidic soils without a recent manure history can become S limited. Crops like alfalfa, soybeans and other legumes need S for N fixation and are at more risk. Manure application typically supplies sufficient S to meet crop needs.

8. List the regional concerns with nutrient excesses such as Cu and B.

- Copper: Toxicity levels can be reached when fields are repeatedly fertilized with biosolids or sewage sludge high in Cu. A toxic concentration in soil affects seed germination, root system development and plant vigor, but the amount of Cu needed to reach toxic levels depends on the plant species; corn is slightly more sensitive than wheat, barley, and oats. Toxic levels can also impact soil microbes and earthworms impacting soil health and crop production.
- Boron: Excessive concentrations of B can cause reduction of crop yield and loss of quality as well. A B toxicity looks like yellowing of the leaf tips, interveinal chlorosis, and progressive scorching of the leaf margins. Boron toxicity is uncommon in the northeastern region, unless fertilizers or municipal composts high in B have been added in the past. Of the field crops grown in New York, corn and soybeans are most sensitive to B toxicity.

CA2: Basic Concepts of Soil Fertility

9. Recognize the role of the following in supplying nutrients from the soil:

a. Soil solution
b. Cation exchange sites
c. Organic matter
d. Soil minerals
e. Plant residue

a. Soil Solution: The liquid portion of the soil in which nutrients are dissolved, allowing them to move into plants as water is absorbed.
b. Cation exchange sites: Positively charged ions such as Ca, Mg and K that are held on negatively charged exchange sites in the soil. Cation exchange capacity (CEC) is a measure of the amount of cations that can be held by the soil and released into the soil solution. Soils with a greater cation exchange capacity (see PO#12) can hold onto more nutrients.
c. Organic matter: Contains nutrients that are released for plant uptake through microbial decomposition. As soil microbes break down soil organic matter, essential elements like nitrogen, phosphorus and boron are mineralized into plant available forms.
d. Soil minerals: As clays, iron oxides, aluminum oxides, carbonates, etc. weather (breakdown) they release nutrients for plant uptake. A good example of this is K released from feldspars and micas, common in the northeastern US.
e. Plant residues: The breakdown of nutrients in plant residues become available to growing plants. Nitrogen through its cycle is a common example, other essential nutrients in plant residues like P, K and Ca will become available for plant uptake additionally. The speed and degree of the breakdown of residues will depend on environmental factors such as moisture and temperature. Most nutrients are released as the organic molecules in the residue are broken down by microbes. However, some nutrients, like K, are not part of any organic molecules in residues and thus are released much more rapidly.

10. Describe the following nutrient transformations and interactions:
  a. Mineralization
  b. Immobilization
  c. Nutrient uptake antagonism

a. Mineralization**:** Refers to the conversion of organic nutrient sources (plant residues, manures, and biosolids) to inorganic and plant available nutrients. This is accomplished by a wide variety of microorganisms (bacteria, fungi, protozoa, nematodes etc.).
b. Immobilization: Nutrient immobilization is the process by which inorganic nutrients are converted to organic forms by microorganisms, making them temporarily unavailable for plant uptake . Mineralization and immobilization occur at the same time. The net effect of these two processes is typically determined by the ration of carbon to nitrogen in the organic material. For example, a C:N ratio less than ~25 typically results in net mineralization of N while greater than ~25 typically results in net immobilization of N.
c. Nutrient uptake antagonism: Refers to circumstances where, depending on soil conditions and nutrient form and availability, plant uptake is weighted favorably toward some nutrient(s) over others. For example: high soil potassium levels can reduce a plant's uptake of magnesium, even if magnesium is present.

11. Describe how the processes of mass flow, diffusion, and root interception affect nutrient uptake.

- Mass flow: Mass flow of a nutrient occurs when it is dissolved in the soil solution and flows with water into the plant. This is the major process for uptake of N, Ca, and Mg.

- Diffusion: The movement of a nutrient from an area of high concentration to one of lower concentration. Typically, the nutrient will move from the soil solution (high concentration) to the root surface (low concentration). This is an important process for P and K and is a key theory behind the use of banded or starter fertilizer.
- Root interception: Occurs when a root grows into a fresh area or surface of clay or organic matter reducing the distance a nutrient must diffuse and thus increasing absorption of the nutrient. Root interception is extremely important for very immobile nutrients like P and thus having good soil conditions for root growth is essential for good P nutrition.

12. Describe how cation exchange capacity (CEC) influences nutrient mobility and uptake.

Cation exchange capacity (CEC) is a measure of the amount of cations (positively charged ions) that can be held by the soil. As the clay content, organic matter content and pH increase, the CEC will also increase. As CEC increases, so does the ability of the soil to hold nutrients. Since much of the plant uptake (and leaching) of nutrients comes from the soil solution, as the CEC increases, the nutrients in the solution decrease and become less mobile. Having optimum levels of cations on the CEC and low levels of non-nutrient and potentially harmful cations such as aluminum (Al) on the CEC is important for supplying these essential nutrient cations for plant uptake.

13. Distinguish each macronutrient as mobile or immobile in the soil_and recognize the difference in mobility depending on form.

The mobility of N depends on the form it is in. Nitrate (NO_3^-) is very mobile and can be leached easily with significant rainfall. In the ammonium form (NH_4^+) it can be held on cation exchange sites and is not susceptible to leaching. Phosphorus is typically immobile in the soil unless soil test levels rise above the soil's ability to bind it. Calcium, Mg and K are considered immobile in soil because they are held on cation exchange sites. Sulfur (as sulfate SO_4^-) behaves like nitrate (mobile in most soils). For mobile nutrients, application should be timed close to crop needs.

14. Describe how the following soil characteristics affect nutrient uptake:

a. Texture	**d. Moisture**
b. Structure	**e. pH**
c. Drainage/Aeration	**f. Temperature**

a. Texture: Defined as the proportion of sand, silt and clay in the soil. As the clay content increases, so does the CEC, resulting in a greater ability to hold nutrients. Soils with more sand and less clay have lower CECs and cannot hold as many cations. Since sandy soils have large pores, leaching of nutrients is greater than on a soil with more silt and clay.

b. Soil structure: Defined as the arrangement of soil particles into aggregates. Good soil structure is represented by significant aggregation. This allows for optimal root growth, water and nutrient access for any given soil. Destruction of good structure by compaction or tillage can result in an increase in runoff since water cannot infiltrate through the soil profile.

c. Drainage/Aeration: Poor drainage reduces oxygen in the soil leading to limited root growth and nutrient absorption. Highly saturated soil can cause the leaching of nutrients or hypoxia that temporarily immobilizes nutrients or converts nitrate (NO_3^-) to nitrogen gases through denitrification, reducing soil available nitrogen for plants.

d. Soil moisture: Important for root growth, as adequate moisture will improve uptake of nutrients by diffusion and root interaction. Soil moisture is important for organic matter decomposition (which releases N, P, and S).
e. Soil pH: Affects the availability of most nutrients. For example, at low pH and high pH, P is less available than when the pH is around 6.5. At a low pH P is bound by aluminum and iron and at a high pH P is bound by Ca. Many of the micronutrients are also sensitive to pH, being more available in slightly acid soils. At high pH's, Mo can become too available and be toxic to plants. See #46 for more detailed information. Soil pH is also important in N transformations including mineralization of organic materials (biological degradation), nitrification (bacteria responsible for this process are pH sensitive) and N fixation.
f. Temperature: Affects the plant's ability to grow and thus affects nutrient uptake. Temperature also controls the mineralization of organic forms of nutrients to mineral forms that plants can take up. Mineralization and thus nutrient availability is reduced or stopped completely at very low and very high soil temperatures.

15. Describe how the following affect the fate of N in soil:

- **a. Fixation by clay**
- **b. Ammonification/Mineralization**
- **c. Nitrification**
- **d. Volatilization**
- **e. Immobilization**
- **f. Denitrification**
- **g. Leaching**
- **h. Plant uptake**
- **i. Symbiotic N fixation**

a. Fixation by clay: Since the soil has a negative charge, the ammonium ion (NH_4^+) can be bound to soil particles. Depending on the type of clay, this ion can be trapped in the actual structure of the clay mineral and become unavailable for plant uptake.

b. Ammonification/Mineralization: The conversion of organic nitrogen to ammonium-N by microbes as they decompose organic matter. If large amounts of N-rich organic materials with narrow C:N ratios (<25) is added, significant levels of ammonium can be produced. This will then be converted to nitrate (nitrification), absorbed by plants, fixed or held by the soil or converted to ammonia and lost to the air (volatilization). Mineralization readily occurs in warm (68-95°F), well-aerated and moist soils. On average, 60—80 lbs N/acre can be mineralized from soil organic matter each year in the Northeast. Actual mineralization rates can vary greatly depending on organic matter content of the soil, soil biological activity, and weather conditions.

$R\text{-}NH_2$	→	NH_3	→	NH_4^+
organic N		*ammonia*		*ammonium*

Ammonification/Mineralization
R reflects the rest of the molecule.

c. Nitrification: A two-step process that converts ammonium to nitrite (by one species of bacteria) and then to nitrate (by a second species of bacteria). These bacteria are sensitive to temperature, moisture and soil pH. Nitrification is most rapid when soil is warm (67-86°F), moist and well-aerated, but virtually ceases below 41°F and above 122°F.

	Nitrosommas		Nitrobacter	
NH_4^+	→	NO_2^-	→	NO_3^-
ammonium		*nitrite*		*nitrate*

Nitrification

d. Volatilization: The loss of ammonium N through conversion to ammonia. Volatilization losses are higher for manure and urea fertilizers that are applied to the surface and not incorporated (by tillage or by rain) into the soil. Manure contains N in two primary forms: ammonium and organic N. If manure is incorporated within one day, a considerable portion of the ammonium N is expected to be retained; when incorporated after 5 days the ammonium N will have been lost through volatilization. Organic N in manure is not lost through volatilization, but it takes time to mineralize before it becomes plant available.

$H_2N\text{-}\overset{\displaystyle O}{\overset{\|}{C}}\text{-}NH_2$	→	NH_4^+	→	NH_3
Urea		*ammonium*		*ammonia*

Volatilization

e. Immobilization: If there is oxygen in the soil (aerobic soil), nitrate can be used by microbes to break down organic materials. Immobilization refers to the process where nitrate and ammonium are taken up by soil organisms and therefore become unavailable to crops. Incorporation of materials with a high carbon to nitrogen ratio (e.g. sawdust, straw, etc., with C:N>25), will increase biological activity and cause a greater demand for N, and thus result in N immobilization. Immobilization temporarily locks up N. When the microorganisms die, their organic N is converted by mineralization and nitrification to plant available nitrate.

NH_4^+ *and/or* NO_3^-	→	$R\text{-}NH_2$
ammonium *nitrate*		*organic N*

Immobilization
R reflects the rest of the molecule.

f. Denitrification: Once nitrogen in the soil is in the nitrate (NO_3^-) form, several things can happen. Under waterlogged or flooded (anaerobic) conditions, nitrate can be converted to gaseous forms of N. Under typical conditions the majority would be in as N_2 gas. However, a significant amount of N released in this process is in the form of nitrous oxide, a very potent greenhouse gas. This process is called denitrification (see diagram below).

NO_3^-	→	NO_2^-	→	NO	→	N_2O	→	N_2
nitrate		*nitrite*		*nitric*		*nitrous*		*nitrogen*

Denitrification

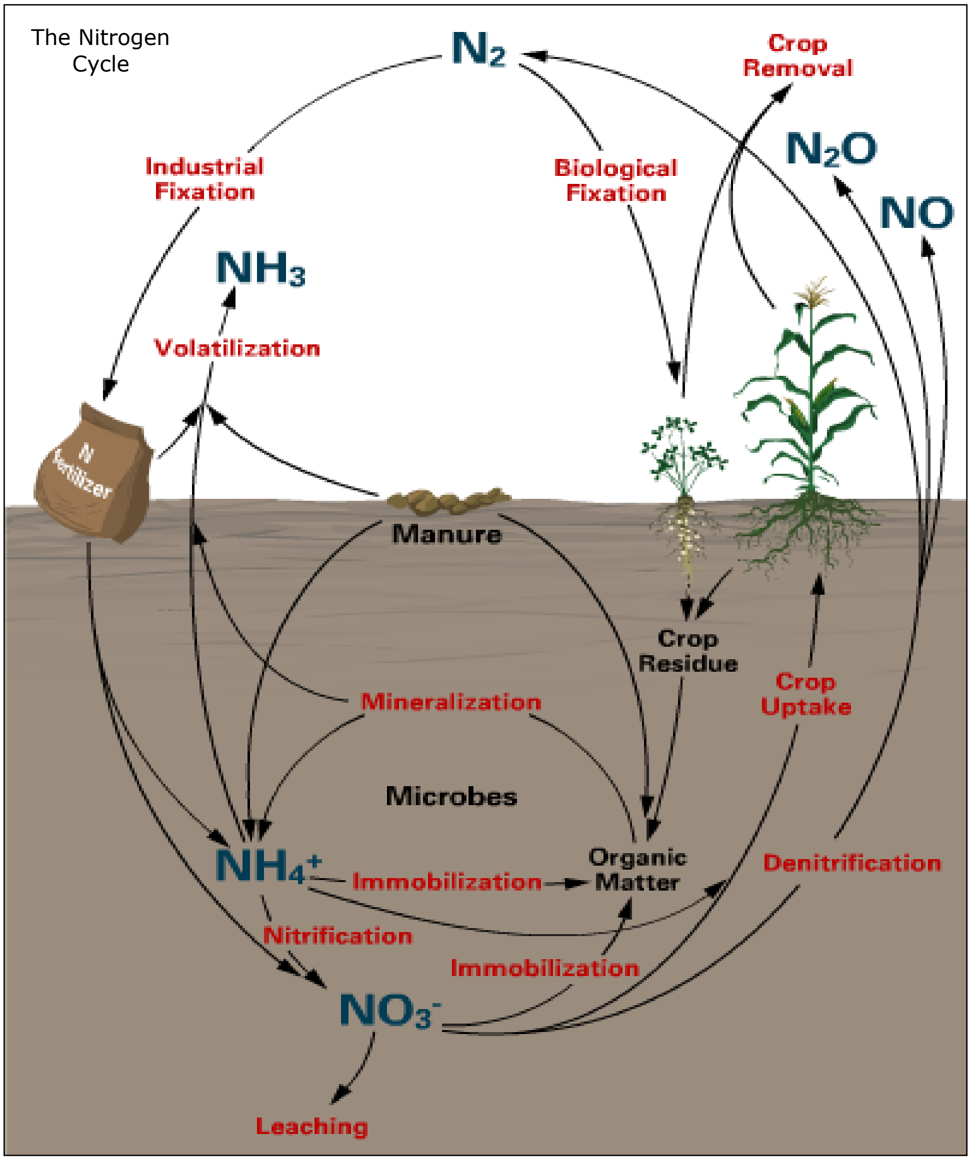
g. Leaching: If sufficient rain occurs nitrate can be lost to groundwater by leaching through the soil profile below the roots of the plants.

h. Plant uptake: If conditions are aerobic (not wet or flooded) nitrate can be taken up by the plants.

i. Symbiotic fixation: Symbiotic fixation of nitrogen is a mutually beneficial process between a legume plant and the associated microorganism (*Rhizobium* sp.). The plant provides the microbe with an energy source to convert N_2 from the atmosphere to ammonium that can be utilized by the plant. Nitrogen fixation requires rhizobia, energy, enzymes and minerals. If a plant available form of N is present, the crop will use it instead of fixing N from the air.

N_2	→	NH_3	→	$R\text{-}NH_2$
nitrogen gas		*ammonia*		*organic N*

N fixation
R reflects the rest of the molecule.



See also: http://nmsp.cals.cornell.edu/publications/factsheets/factsheet2.pdf.

16. Describe how the following soil factors affect symbiotic nitrogen fixation.

- **a. pH**
- **b. Moisture**
- **c. Aeration**
- **d. Nitrogen level**
- **e. Organic matter**
- **f. Population of correct Rhizobia species**

a. pH: The microbes that are responsible for symbiotic nitrogen fixation are very sensitive to pH. As the pH drops, fixation will slow. Very little will occur below a pH of 5.0.

b. Moisture: The Rhizobia species that are responsible for fixation operate under good moisture conditions. If it gets too wet or dry microbial activity will slow down. Under drought conditions, fixation will stop.

c. Aeration: Rhizobia are aerobic bacteria, so adequate aeration is essential. Under very wet conditions they will not fix as much nitrogen. Under wet conditions, leaching and denitrification losses increase.

d. Nitrogen Level: As available nitrogen from (fertilizers, manures, biosolids, organic matter etc.) increases, the amount of nitrogen fixed decreases.
e. Organic matter: If the organic matter content is very high, and the supply of available nitrogen is plentiful, the bacteria will not fix as much nitrogen.
f. Population of Rhizobia: There are numerous species of Rhizobium, and they each require a specific host. The inoculation of the legume seed with the correct species (especially the first time this legume has been in the field) is extremely important to obtaining good levels of fixation. For example, the symbiotic bacteria for soybeans will not fix nitrogen with alfalfa.

17. Recognize how different crops and cropping systems affect soil fertility and fertilization strategies.

Recommendation systems should consider crop rotations. One example is corn in rotation with hay (alfalfa, alfalfa-grass or grass). First year corn after hay typically does not need any additional N, aside a small rate of starter fertilizer. This is because corn benefits from the large amount of N mineralized from the hay's root system and crop residue. Corn after soybeans needs less external N as well as it benefits from the soybean in the rotation. When raw manure is applied to meet N needs of a crop like corn, P and K are typically applied in excess of crop removal, eliminating the need for additional P and K for the crop that follows the corn. Often in winter cereal grain and corn rotations, farmers manage fertility for the corn, while the wheat benefits from nutrients not taken up by the corn at planting, and potentially in the spring as well.

CA3: Soil Testing and Plant Tissue Analysis

18. Recognize how the following effect soil sampling methods:

a. **Method of previous fertilizer application**
b. **Tillage system**
c. **Nutrient stratification**
d. **Within-field soil and crop variability**
e. **Measuring soil health parameters (nutrient analyses vs soil health panel)**

a. Method of previous fertilizer application: Banding of fertilizer applications and manure spreading are known to increase spatial variability within a field. Fertilizer and manure are not evenly distributed across a field causing areas to vary in nutrient levels. The greater the variability the greater the number of samples that should be taken, avoiding fertilizer and manure injection bands when possible.
b. Tillage system: Tillage can impact distribution of nutrients over a field and over depth (deep tillage, zone till, etc.). This can impact sampling density as fewer samples per unit area are needed for less variable fields. However, for practical implications, a reduction in sampling density is not recommended unless intense (grid) sampling shows that a similar reliability can be obtained at a lower sampling density.
c. Nutrient stratification: In no-till systems, nutrient stratification is usually greater than for conventionally tilled fields. Consistent sampling to the recommended depth is critical in no-till systems. For soil pH in no-till systems, two soil samples will be needed, one representing

0-1 inch (for seeding) and one for 1-6 inches depth. If the surface sample (0-1 inch) is below 6.0, lime application should be made even if the deeper sample does not indicate its need.

d. Within-field soil and crop variability: For the best sampling protocol, take 2-3 subsamples per acre and combine into a composite sample. One composite sample should not represent more than 10-20 acres, unless past sampling shows minimal differences. The area to be sampled should be relatively uniform, i.e. similar soil properties and past management. If there are known significant differences within the area to be sampled (e.g. old fence rows, manure or lime stockpile areas, wet spots, etc.) and these areas can be managed separately (variable rate), take a separate sample from these areas.
e. Measuring soil health parameters: Soil health tests often require different sampling and handling procedures than standard nutrient analyses. Soil health analyses may need samples to remain undried and cool, preserving biological activity and may require collecting other parameters other than the soil itself (for example, compaction measurements, etc.). They focus on long-term soil quality, assessing overall soil function and biological activity. Whereas nutrient assessments may require a drying phase with a focus on nutrient needs for a crop, recent nutrients uptake or fertilization and short-term recommendations.

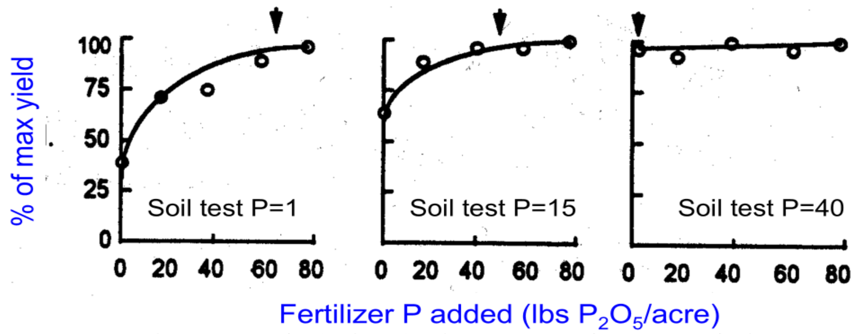
19. Indicate how the following may cause variability in soil test results:

a. Time of sampling
b. Depth of sampling
c. Number of samples taken
d. Sample handling
e. Type of extraction method used (Morgan, Modified Morgan, Mehlich-3, Bray, Olson)

a. Time of sampling: Nutrient content of the soil solution and soil matrix vary depending on the time of year. To minimize variability and build the strongest historic records take samples at the same time of the year.
b. Depth of sampling: Take samples over a constant depth to minimize additional variability and build the strongest historic records. Depth of soil samples depends on tillage used on the field. Samples are normally taken from the surface to the tillage depth (usually 6-8 inches deep). This depth is important because lime and fertilizer are mixed within the tilled layer. For lime recommendations for no-till or minimum-till crops, take a sample from the 0-1-inch depth and one from 0-6 inches. The two samples should be placed in separate plastic bags labeled clearly with “0-1 inch” and “0-6 inch”.
c. Number of samples: For the best sampling protocol, one sample should not represent more than 10-20 acres. One sample should represent one management unit (consider soil type and past management). Test at least once in 3 years or twice in a rotation.
d. Type of extraction and handling: Use the right sampling tools: probe or auger and a clean plastic bucket. Take 2-3 subsamples per acre (with a minimum of 10-15 per field for smaller fields) across a uniform field. Mix subsamples and take a 1 cup subsample. Label the sample and keep a record of the sample and its location. Avoid sampling when the soil is very wet. Scrape away surface litter before inserting the soil probe. Take equal amounts for each subsample. Take cores to plow depth (no-till 0-1 + 0-6 inches, conventional tillage 0-8 inches). Sample between crop rows, avoid fence rows. Remove stones, wood, trash and other debris.

20. Compare and contrast the following approaches for making fertilizer recommendations:
- **a. Sufficiency level**
- **b. Soil buildup and maintenance**
- **c. Cation saturation ratios**

a. Sufficiency level: This is the method used by most land grant universities nationwide. In this approach, the fertilizer rate is based on expected crop response (increased yield) based on the limiting factor concept. The agronomic soil test is an index that can be used, based on local field studies, to determine (1) if a response to extra nutrient is to be expected, and if so, (2) how much of that nutrient needs to be added. Field calibrations are needed to develop guidelines. In the diagram below the arrows indicate the fertilizer recommendation for each of the three different soil test levels in this example based on the calibration data.



b. Soil buildup and maintenance: Approach based on building the soil test level to the optimum range and then maintaining it in the optimum range. In the optimum range, there is a low probability of an additional response to adding fertilizer. The buildup part of the recommendation is determined by the expected crop response to the added nutrients similar to the sufficiency level approach. The maintenance part of the recommendation is based on replacing the amount of nutrient expected to be removed by the crop. This should keep the soil test level from becoming below optimum between soil tests. When the soil test reaches a level where crop removal will not reduce the soil test to below optimum, no additional nutrients are recommended. The crop is allowed to draw the nutrient levels down into the optimum range.

c. Cation saturation ratios: This approach guides management of Ca, Mg and K and suggests benefits of farming at an ideal ratio of Ca, Mg, and K on the CEC. Especially for calcareous soils, adjustments to ratios can be very expensive and saturation estimates based on summation of cations can be inaccurate. Generally, if the soil pH and soil test K and Mg are optimum, the balance of cations on the CEC will support optimum crop production. Further adjustments in cation saturation on the CEC are not economically beneficial.

21. Recognize how the following effect soil test interpretation:
- **a. Probability of crop response to added nutrients**
- **b. Estimate of nutrient sufficiency level**
- **c. Results reported as ppm or lbs/acre**
- **d. Within-field variability**
- **e. Results reported as elemental versus oxide forms (conversion factors)**
- **f. Environmental risk**
- **g. Extraction method**

It is important to recognize that an agronomic soil test is an *INDEX* of nutrient availability. Local field research is needed to calibrate an agronomic soil test for its ability to (1) identify the likelihood of a response to additional nutrients, and (2) accurately predict the amount of nutrient needed to reach sufficiency levels. This research needs to be conducted under local/regional conditions to be applicable, so fertility recommendations are state-specific and sometimes region specific. The agronomic critical soil test level is defined as the soil test level beyond which a response to additional fertilizer is unlikely. Risk of environmental loss increases with increase in soil test result beyond the critical soil test value. Within-field variability needs to be considered in soil sampling protocols (see PO#22). It is important for laboratories to have quality control systems in place. Secondly, it is important to know what type of soil analyses are done. Soil testing laboratories can differ in:

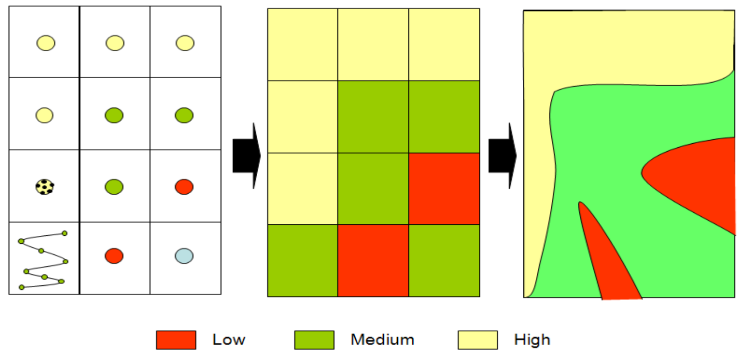
1) Nature of the extract used (e.g. Morgan, modified Morgan, Mehlich-3, Bray-1).
2) Shaking time.
3) Solution to soil ratio.
4) Analytical procedure/instruments used.
5) Way of reporting results (ppm or lbs/acre, P or P_2O_5, K or K_2O):
    - 1 ppm = 2 lbs/acre (7 inches deep)
    - 1 lb P/acre = 2.29 lbs P_2O_5/acre
    - 1 lb K/acre = 1.21 lbs K_2O/acre

Most common extraction methods used in the Northeast include Morgan (sodium acetate), modified Morgan (ammonium acetate), and Mehlich-3. The recommended test for a state or region depends on what test is used to develop the recommendation system. For example, in New York, the Morgan test is recommended. In Vermont, Connecticut, Rhode Island and Maine, Modified Morgan is the recommended test. New Hampshire uses the Mehlich-3 test to derive recommendations. Results from one method can only be equated to those from another method (or laboratory) if reliable conversion equations exist. Even then, converted results are not as reliable as using the recommended test to begin with.

22. Describe soil sampling strategies and know their application:

- **a. Random sampling**
- **b. Grid-based**
- **c. Soil type-based sampling**
- **d. Electrical Conductivity (EC)**
- **e. Yield map based**

Soil type and management impacts soil nutrient levels and crop production. For the most accurate results, take 2-3 samples per acre in a random pattern that covers the field and limit field size to no more than 10-20 acres to reduce the risk of sampling multiple soil types within a field. See PO#19 for more on sampling methods. Grid sampling is useful if there is large within-field variability, if that variability is within the responsive range for nutrients and pH, and if the farmer can manage at the within-field level. In grid sampling a field is divided into small (usually 1-4 acres) blocks (grid cells) and a separate soil sample is taken from each of these grid cells. Typical grid cell size can vary from 2.5 acre/grid to 0.5 acre per grid. Higher intensity sampling (0.5-acre grid cells) gives more information about within field variability but is also much more costly to do. The sample may be 6-10 subsamples taken from a small area at the center of the grid cell or it may be 6-10 subsamples taken randomly throughout the grid cell. Sample results are compiled either directly into a map showing the different soil test levels and recommendations for each grid cell or the test results may be statistically smoothed to create a map (see figure on the right). It is important that appropriate statistical methods are used to create these maps. In recent years, soil sampling based on electrical conductivity mapping or yield mapping has increased in popularity. These approaches both divide fields into zones (typically 2-4 zones) which are then assessed for soil fertility. Such sampling can be more targeted and less time-consuming than grid sampling.



23. Recognize factors that influence the results of the pre-sidedress nitrogen test:

- **a. Timing of sampling relative to weather patterns**
- **b. Depth of sampling**
- **c. Field variability**
- **d. Sample processing**
- **e. Manure history**
- **f. Pre-plant fertilizer**

The Pre-Sidedress Nitrate Test (PSNT) is an in-season soil nitrate test that can be used to determine if soil N supply is sufficient, identifying a possibility to save on fertilizer expenses. This test is taken at sidedressing time just before the period of major N demand by corn. It is useful for fields with a history of manure and/or sod incorporation when predicting available N may be difficult. The PSNT is not a direct measure of available N but is designed to: 1) estimate the soil's nitrate supplying potential, and 2) decide if that is enough N to meet crop needs. The PSNT is particularly useful when it is unclear whether enough manure was applied. Over the course of a few years, carefully compare PSNT results with fertilizer and manure inputs and crop yields.

When to use**:**

- In corn fields, 2nd year or more after a sod and/or where the manure rate is uncertain.
- If not enough manure was applied to meet the expected N needs of the crop.

Where not to use the PSNT**:**

- The test is useless for fields that received pre-plant or early post-plant broadcast fertilizer N applications (other than <40 lbs starter N/acre). Any "leftover" nitrate from broadcast fertilizer will be reflected in the PSNT, resulting in unreliable info on organic N supply.
- First year corn after sod does not need additional N beyond a small starter N application (20-30 lbs N/acre) and PSNT results of first year corn fields tend to underestimate actual N supply making them less reliable as indicators.

How to take samples:

- Limit sampling to areas of 10-20 acres and take a separate sample for areas with different corn stands (different population densities, stage of development, and/or color, crop histories, fertility management, significant changes in slope, etc.).

- Sample between corn rows to a depth of 12 inches (stay away from the starter band).
- Sample when the corn is 6-12 inches tall.
- Do not sample too close to a rain event that could have resulted in nitrate leaching (wait for 2-3 days after significant rainfall).
- Samples should be dried immediately (spread the sample thinly and dry in the sun or under a fan) to stop N mineralization and sent to the laboratory.

Interpretations can be state-specific. Per example: PSNT guidelines for New York are:

PSNT (ppm)	Response to fertilizer N?	N guideline
≥ 25	Low	No additional N needed
21 – 24	About 10%	If uncertain, consider sidedressing 25-50 lbs N/acre.
<21	High	Apply sidedress N according to the guidelines.

For fields with <21 ppm:

- If a PSNT sample is collected from a field expected to need sidedress N (for example a field that received less manure than needed to meet N needs), add the extra N.
- If a PSNT sample is collected from a field that was not expected to require sidedress N the PSNT may be low due to cold and/or wet conditions. No additional N is needed because the field is expected to supply sufficient nitrogen from organic sources once mineralization conditions improve (warm and moist soils).

24. Describe how to properly take a plant tissue sample.

a. Type of crop
b. Part of plant to be sampled
c. Growth stage
d. Timing

Propper plant tissue sampling is essential for accurate nutrient analysis. The sampling method varies by crop type, plant part, growth stage and timing. Each crop has specific sampling guidelines. Corn for example is typically sampled by collecting the uppermost fully developed leaf at the whorl or tasseling stage. The plant part collected must represent the portion of the plant actively engaged in nutrient uptake and growth. Growth stage is equally critical because nutrient concentrations change as plants mature. Sampling should occur at a recommended growth stage (e.g., early vegetative or pre-reproductive) to allow valid comparisons and to establish sufficiency ranges. Sampling should occur when the crop is actively growing and not under severe stress. Collect enough plants from across the field to create a representative composite sample, and avoid unusual spots such as field edges, low areas, or fertilizer bands. Follow the instructions provided by the plant analysis laboratory to ensure accuracy and comparability of results.

25. Describe how to use plant tissue analysis for:

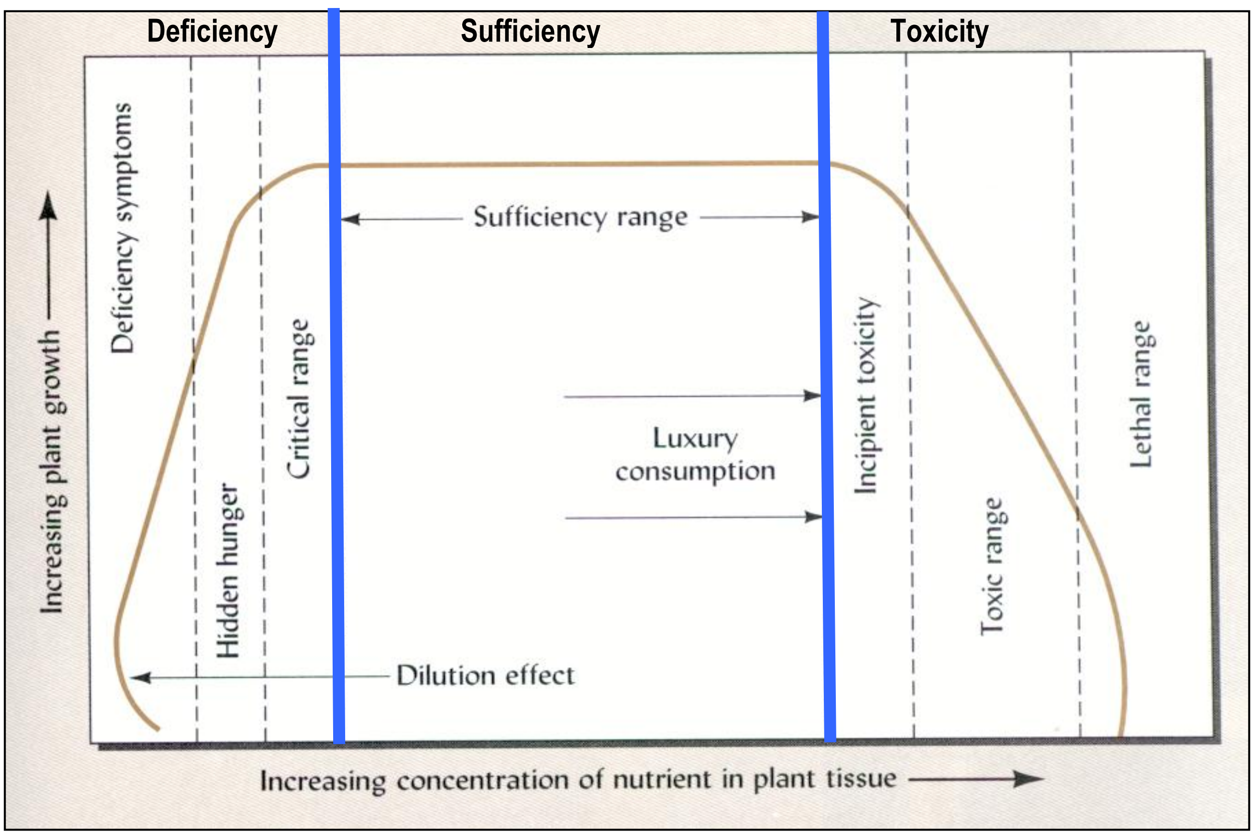
a. Problem solving/diagnosis
b. Nutrient program monitoring
c. In-season nutrient management

Plant tissue analysis can be used for problem solving, nutrient program monitoring, and in season nutrient management. For problem diagnosis, collect tissue from both the affected area and a nearby healthy area for comparison. Use the analysis in conjunction with the visual symptoms, soil test data, and field observations to determine whether the tissue systems are from a nutrient deficiency or another stress factor such as compaction, pest or disease. For nutrient program monitoring, results from multiple years help assess how well a soil fertility program meets crop needs over time, especially for micronutrients that may not be routinely measured in soil tests. In in-season management, tissue analysis provides a real time picture of plant nutrient status, allowing for corrective actions such as foliar feeding or side-dress nitrogen applications before deficiencies limit yield. However, it's important to remember that plant nutrient content reflects not only soil fertility but also environmental and management factors, so results should always be interpreted in context with soil tests and field conditions.

26. Recognize how the following terms relate to plant nutrient level:

- **a. Critical value**
- **b. Sufficiency range**
- **c. Optimum, below optimum, and above optimum soil nutrient levels**
- **d. Luxury consumption**
- **e. Toxicity level**

The critical value (or more often range) of a nutrient refers to the soil or plant tissue concentration below which a deficiency is likely to occur. When nutrient levels fall below this threshold, crop growth and yield can often be improved by adding that specific nutrient. Thus, below the critical value, the nutrient levels are below optimum, impacting crop yield.



Adapted from: Brady and Weil. Properties and Nature of Soils.

Luxury consumption occurs when plants take up more of a specific nutrient than needed for optimum functioning and production. An example of a nutrient that can be consumed in excess of crop needs is K, where K application beyond crop needs results in high K forages. Toxicity is when nutrient levels are so excessive they reduce or inhibit yields and can create other symptoms (leaf burning, curling, stunted growth) by inhibiting the uptake of other essential elements or nutrients. This is more common for micronutrients and when soil pH is outside the ideal ranges.

27. Recognize how the following effect plant tissue analysis results:

- **a. Crop species**
- **b. Growth stage**
- **c. Plant part sampled**
- **d. Crop stress level**
- **e. Time of day sampled**
- **f. Sample handling**

Plant tissue nutrient interpretation depends on (1) species sampled, (2) plant part, and (3) time of sampling.

Examples for sampling timing, parts to collect, and the number of samples for tissue analyses for corn, soybeans and alfalfa.

When to sample	What to sample	How many?
Corn		
Seedling stage	Whole plant 1/2 inch from the bottom up	15 plants
Prior to tasseling	Most recently unfurled leaf below the whorl	15 leaves
Silking	Ear leaf	15 leaves
Soybeans		
Prior to flower	Most recently developed trifoliate	25 plants
Early bloom	Most recently developed trifoliate	25 plants
Prior to pod set	Most recently developed trifoliate	25 plants
Alfalfa		
Early bloom	Top 6 inches or top 1/3 of plant	12 to 30 plants

Sampling is not recommended when the plant part is soil or dust covered, mechanically injured, damaged by insects, or diseased, or under moisture or temperature stress (early morning sampling is preferred). Plants under long periods of stress can develop unusual concentrations which can be misleading. Samples should be cleaned to remove surface contamination. The washing should be quick to avoid leaching of nutrients like potassium and calcium and aways look up the specific sampling instructions prior to sampling.

28. Recognize factors that influence the results of the corn stalk nitrate test:

- **a. Sampling protocol**
- **b. Manure history**
- **c. Crop rotation**
- **d. Fertilizer rate, method of application and timing**

The corn stalk nitrate test (CSNT) is an end-of-season evaluation of the N supply for corn during the growing season. It is useful as a management tool as it helps assess N management at the end of the growing season and can identify if adjustments in N management may be useful in future years. It is recommended for use for 2nd or higher year corn after hay, continuous corn, or corn after soybeans. The interpretations are:

- Low (deficient) = less than 250 ppm N
  - Plants had difficulty accessing enough nitrogen in the sample area. Nitrogen access was hindered by inadequate supply, root restrictions, lack of moisture, or nutrient deficiency interactions. At harvest time, leaves are dead to or above the ear leaf and/or the entire plant has a light green color.
- Marginal (possibly deficient in challenging years) = 250 to 750 ppm N
  - In some years, yields could have increased with some additional N. In those years, plants looked as described as above. In other years, the N supply was sufficient. As it is difficult to predict what kind of growing conditions a season will bring, farmers are advised to target CSNTs in the optimal range.
- Optimal (target) = 750 to 2000 ppm N
  - Nitrogen availability was within the range needed for optimum economic production of corn. In this range, three of the five lower leaves will be dead by harvest time while the top leaves remain medium to dark green.
- Excess (more than the corn needed) = greater than 2000 ppm N
  - If the sample has more than 2000 ppm N, the corn had access to more N than it needed for optimum yield. Most likely, fewer than three leaves from the bottom will have died; the top leaves remain medium to dark green. If manure and/or N fertilizer was applied, the application(s) supplied more N than the crop needed that growing season.

a. Sampling protocol

Timing:
For corn silage, samples could be collected between ¼ milk line, which is just before silage harvest, to about 3 weeks after black layer formation.

Method:
The portion of the stalk used for the test is important. Two methods can be used: (1) sample an 8-inch piece of the stalk, between 6 and 14 inches above the ground; or (2) take a 6-inch sample between 2 and 8 inches off the ground. If the silage cutting height in the field exceeds 14 inches, collect the standard 8-inch section of stalk from the 6-14 inch height. When stubble height is less than 14 inches but greater than 8 inches, stalk samples can be taken between 2 and 8 inches off the ground. This alternative cutting height should be reported to the laboratory when submitting CSNT samples so the laboratory staff can properly adjust the result. This is needed because stalk nitrate levels are higher in the lower portions of the stalk; with 2-8 inch samples, laboratory values need to be divided by 1.5 for the test results to be comparable to the interpretation scale of low (<250 ppm), marginal (250-750 ppm), optimal (750-2000 ppm) and excess (>2000 ppm). Leaf sheaths should be removed and pieces need to be handled carefully to avoid contact with the soil, especially the stalk ends. Also, avoid sampling stalks from corn showing significant damage from disease or insects, such as corn borers. Within-field variability can be large so sampling density should not be less than one

sample per acre. Avoid sampling of diseased or damaged plants, and sampling of unrepresentative areas. Targeted within field sampling could be considered, in conjunction with within field yield mapping and precision application (within-field) or manure and/or fertilizer. Samples should be submitted as soon after collection as possible. Samples should be placed in a paper bag (not plastic). This allows for some drying to occur and minimizes growth of mold. Samples can be stored in the fridge for up to 8 days (recommended if direct mailing is not feasible); freezing should be avoided.

b. Manure history:
This test is most effective when used for multiple years on the same field (or fields with similar histories) to determine how the fields respond to the way N is being managed. However, if fields test 3000 ppm or higher in CSNT, there will be opportunities to cut N application rates without impacting yield after just one year of results. Crop history, manure history, other N inputs, soil type, and growing conditions all impact CSNT results and crop management records that include these pieces of information can be used to evaluate CSNT results and determine where changes can be made. Manure will release N over time and this N supply will be reflected in the CSNT results.

c. Crop rotation:
It is not recommended to take CSNT samples for 1st year corn after hay as 1st year corn fields do not need the extra N while the slower release of N from organic sources (roots and biomass of a hay field), typically results in lower CSNT results. To avoid confusion, sample 2nd or higher year corn fields after hay, continuous corn, or corn after soybean fields only.

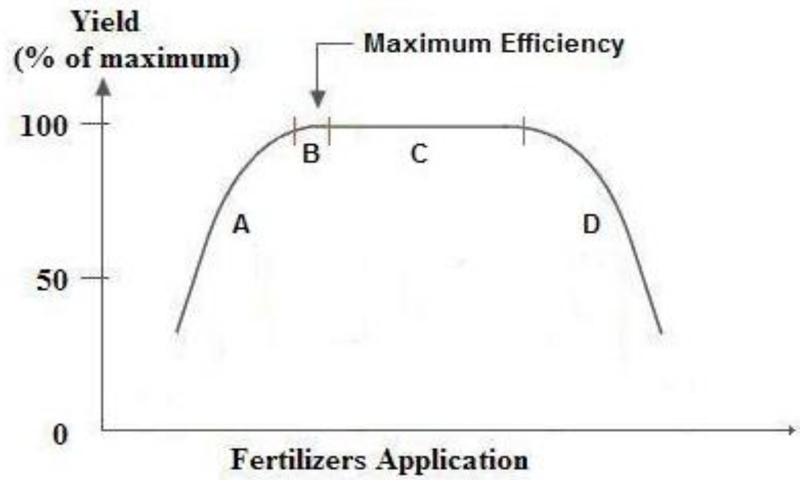
d. Fertilizer rate, method of application and timing
Nitrogen supply is reflected in CSNT results (in addition to weather and other possible stress factors) so fertilizer rate, method of application and timing all impact CSNT results. It is important to apply the 4Rs (see PO#52) for optimum yield, quality and reduced risk of N loss to the environment.

CA4: Nutrient Sources, Analyses, Application Methods

29. Describe the following crop response relationships:

- **a. Diminishing returns response curve**
- **b. Plateau yield**
- **c. Critical response level**
- **d. Economic optimum nutrient rate**

Crop yields depend on many factors including soil properties, genetics, climate, crop management (cultural practices, pest and disease management), and fertility management. Assuming good crop management and reasonable growing conditions, a crop response to fertility management could be expected for soils that are relatively low in a specific nutrient. For example, if N is a limiting yield, addition of N will result in a crop response. Trials with multiple N rates can then be used to determine the economic optimum nutrient rate. Such trials consist of multiple rates of N (typically at least 5 rates) where yield data can be used to determine the plateau yield, the critical response level and the diminishing returns response curve. Applying more fertilizer than needed does not increase yield and could, in some situations, cause a yield decline. Often, additions of excess fertilizer also increase the likelihood of losses to the environment (see PO#56). The crop response curve will be different for each crop and field, so development of a crop fertilizer recommendation system requires assembly of data from many field crop response trials. Together such trials result in identification of critical response levels (critical agronomic test levels) beyond which a response to additional fertility is unlikely to result in a yield increase. The most economic rate of fertilizer is lower than the fertilizer rate at which a maximum yield is obtained.



30. Describe the differences in rates of release of nutrients from the following sources:

- **a. Soil organic matter**
- **b. Commercial fertilizer**
- **c. Soil minerals**
- **d. Animal manure**
- **e. Compost**
- **f. Biosolids**
- **g. Plant residue**

Soil organic matter and organic amendments such as animal manure, compost and biosolids release nutrients over time through microbial mineralization. Soil minerals and organic matter create negatively charged surfaces that attract nutrient cations (cation exchange capacity). Soils differ in their mineral composition and organic matter content, resulting in differences in their capability to provide essential minerals to plants. Commercial fertilizer is recommended only when nutrient supply from other sources is insufficient. Plant residues release nutrients back to the soil. Residue coverage of the soil can furthermore result in moisture conservation and added moisture can make nutrients more available.

31. Identify the physical form and analysis of each of the following nitrogen sources:

- **a. Anhydrous ammonia**
- **b. Urea**
- **c. Ammonium nitrate**
- **d. Urea/ammonium nitrate (UAN)**
- **e. Ammonium sulfate**
- **f. Coated urea products (polymer or sulfur coated)**

See information under PO#33.

32. Describe the physical form and analysis of each of the following phosphorus sources:

- **a. Rock phosphate**
- **b. Triple superphosphate**
- **c. Monoammonium phosphate**
- **d. Diammonium phosphate**
- **e. Ammonium polyphosphate**

See information under PO#33.

33. Describe the physical form and analysis of each of the following potassium sources:

a. Potassium chloride
b. Potassium sulfate
c. Potassium nitrate
d. Potassium-magnesium sulfate

Common forms of N, P and K fertilizers (some have ranges, e.g., UAN is 28-32% N):

N:		N	P_2O_5	K_2O
anhydrous ammonia (gas)	NH_3	82	0	0
urea (granular)	$(NH_2)_2CO$	46	0	0
ammonium nitrate (solid or liquid)	NH_4NO_3	34	0	0
urea ammonium nitrate (UAN) solution	Urea+ NH_4NO_3	28-32	0	0
ammonium sulfate (solid)	$(NH_4)_2SO_4$	21	0	0
P_2O_5:				
rock phosphate (solid)	$Ca(H_2PO_4)_2$	0	18	0
triple super phosphate (solid)	$Ca(H_2PO_4)_2$	0	46	0
monoammonium phosphate (solid)	$NH_4H_2PO_4$	13	52	0
diammonium phosphate (solid)	$(NH_4)_2H_2PO_4$	18	46	0
ammonium polyphosphate (liquid)	$[NH_4PO_3]_n$	10	34	0
K_2O:				
potassium chloride (muriate of potash) (solid)	KCl	0	0	61
potassium sulfate (solid)	K_2SO_4	0	0	50
potassium nitrate (solid)	KNO3	13	0	44
potassium magnesium sulfate (solid)	K_2SO_4 $MgSO_4$	0	0	22

34. Describe the physical form and analysis of the following calcium and/or magnesium sources:

a. Calcitic lime
b. Dolomitic lime
c. Gypsum
d. Potassium-magnesium sulfate

Chemical name	Common Name	Formula	Form
Calcium carbonate	calcitic lime,	$CaCO_3$	solid
Ca,Mg carbonate	dolomitic lime	$CaMg(CO_3)_2$	solid
Calcium oxide	lime, burned lime, quick lime	CaO	solid
Calcium sulfate dihydrate	gypsum	$CaSO_4 \cdot 2H_2O$	solid
Potassium magnesium sulfate	Potassium magnesium sulfate	$K_2SO_4 \cdot 2MgSO_4$	solid
Calcium hydroxide	hydrated lime, slaked lime	$Ca(OH)_2$	Solid

35. Define how the following terms are associated with commercial fertilizer:

a. **Nutrient use efficiency**
b. **Total availability**
c. **Water solubility**
d. **Equivalent acidity**
e. **Prill vs granulated**
f. **Guaranteed analysis**
g. **Salt effect**
h. **Density**
i. **Ammoniated vs blend fertilizer**

a. Nutrient use efficiency: Yield output per unit input (e.g. bushels of corn per lb of applied N).
b. Total availability: The total amount of a nutrient that is expected to become plant-available (could be over many years).
c. Water solubility: Reflects the portion that dissolves in water (more immediately available).
d. Equivalent acidity: A measure of the acidity that is produced from fertilizer application. That is expressed as the pounds of calcium carbonate (lime) required to neutralize the acid-forming effect of 100 pounds of fertilizer. Fertilizers containing ammonium or urea typically have higher equivalent acidity values.
e. Prill Vs Granulated: Prill fertilizers are formed into small, smooth, spherical particles whereas granulated fertilizers are larger, often irregularly shaped particles made by binding smaller particles together. Granulated products often have more uniform nutrient distribution and improved blending characteristics compared to prilled fertilizers.
f. Guaranteed analysis: The minimum amount of %Total N, Available P labeled as % P_2O_5, and soluble K labeled as %K_2O (etc.) in the fertilizer material. By law, fertilizer analyses are always labeled in these terms regardless of the actual chemical form of the fertilizer materials.
g. Salt effect: Soluble salts are salts in the soil solution, in direct contact with roots. High soluble salt content (resulting from e.g. large applications of N (ammonium salts) and K sources) can cause seedling damage (dehydration).
h. Density: For liquid fertilizers where the rate is given in gallons per acre the density of the fertilizer must be known to determine the amount of nutrients applied per acre. For example, if the recommendation calls for 120 lbs N/acre and the source is UAN 30-0-0 with a density of 10.85 lbs/gallon, the rate of application is: 120 lb N/acre ÷ 0.30 lb N/lb UAN ÷ 10.85 lb UAN/gallon = 37 gallons of UAN /acre.
i. Ammoniated vs blend fertilizer: Ammoniated fertilizers are chemically reacted products where nutrients are combined into a single, uniform compound (e.g., monoammonium phosphate—MAP, diammonium phosphate—DAP). Blend fertilizers are physical mixtures of individual granular fertilizers, where each particle contains different nutrients. Blends allow for flexible nutrient ratios; however, ammoniated products ensure uniform nutrient distribution in each granule.

36. Define the following nutrient terms:

a. Total Kjeldahl nitrogen (TKN)
b. Organic N
c. Inorganic N
d. Organic P
e. Inorganic P
f. Dissolved P
g. Particulate P

a. Total Kjeldahl nitrogen (TKN): Total N analytical method that includes organic fraction for soils, plants and water. Soils range from 0.05 to 0.3 % typically but can be several % for mucks. Plants are normally 0.2 to 4 % depending on species, age, plant part, etc.
b. Organic N: Not water soluble, organically bound (e.g. protein), slow to become available. Availability based on mineralization of organic matter.
c. Inorganic N: e.g. ammonium, urea, nitrite, nitrate.
d. Organic P: P bound in organic form, not soluble, most found as phytate. Largest P fraction in animal manure, availability based on mineralization of organic matter.

e. Inorganic P: P not associated with carbon (usually P in solution as PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$).
f. Dissolved P: P in the soil solution (PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$).
g. Particulate P: P attached to soil particles.

37. Calculate fertilizer application rates from fertilizer analysis information.

Example 1:

Needed:	45 lbs N, 45 lbs P_2O_5, 45 lbs K_2O per acre
Determine ratio:	1:1:1 (N: P_2O_5: K_2O)
Apply (example):	e.g. 300 lbs/acre of 15 – 15 – 15

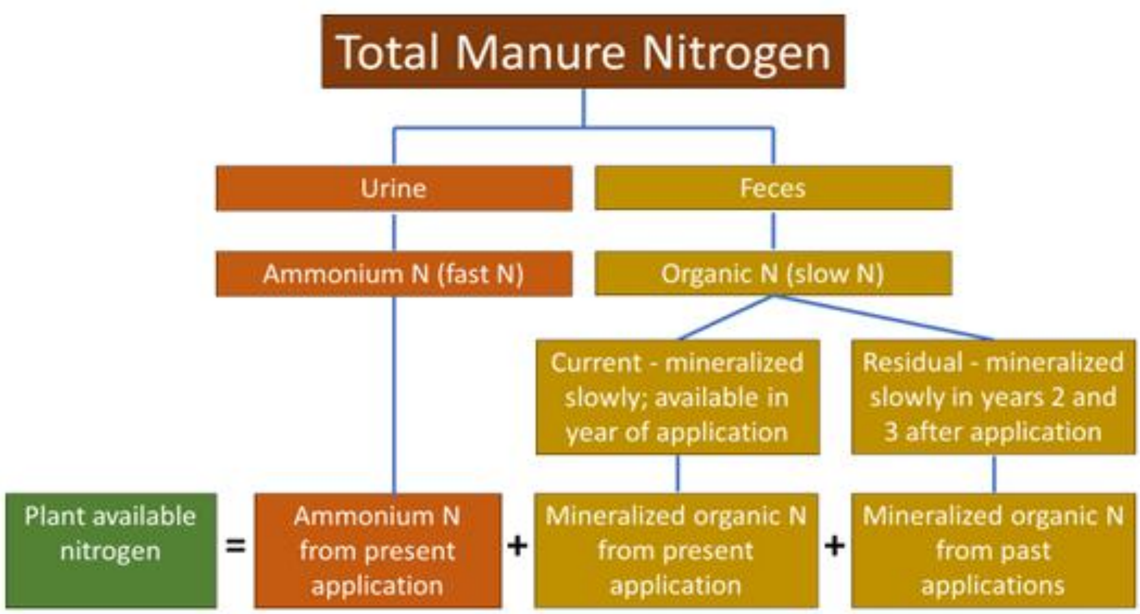
Example 2:

Needed:	150 lbs N, 30 lbs P_2O_5, 120 lsb K_2O per acre				
Apply (example):	*K preplant (broadcast)*	150 lbs/acre 0 – 0 – 61	= 0	0	91
	Starter	200 lbs/acre 15 – 15 – 15	= 30	30	30
	*Sidedress UAN**	37 gallons 30 – 0 – 0	= 120	0	0
	This gives us:		150	30	121

For liquid fertilizers, where the rate is given in gallons per acre, the density of the fertilizer must be known to determine the amount of nutrients applied per acre. In this example, UAN 30-0-0 weighs 10.85 lbs/gallon. Therefore, 37 gallons/acre equals 37 x 10.85 = 401 lbs of UAN/acre and thus at 30% N, this equals 401 x 0.30 = 120 lbs N/acre.

38. Understand how to calculate manure application rates from manure analysis information.

Although concepts of N availability over time are accepted in all states in the Northeast, actual N credits may differ from state to state. Refer to state specific Land Grant University guidance. The following examples represent the New York guidelines for manure N.



Manure contains various N pools that can be separated into a (stable or "slow") organic N fraction and (unstable or "fast") ammonium-N fraction. Both N pools behave very differently (with differences in N release for plant growth) and a manure analysis should be used and include an estimate of both major N pools. These two pools are generally listed as "organic N" and "inorganic N" or "ammonium-N" on manure test reports.

The decay series for stable organic N in manure is by animal type and/or percent dry matter (and in some states soil type and incorporation vs. surface application). To determine the amount of N that is expected to be available to the current crop it is necessary to account for the N from the application to this crop plus any residual N that is expected to be available from manure applications in the recent past. The table below provides the factors to estimate the N from the present and past applications as done in NY. The "present year" factor is multiplied by the amount of organic N applied in the present year. A "last year" factor of 12% indicates that an estimated 12% of the organic N applied in the manure last year is expected to be utilized by the present crop a year after application. Therefore, this factor is multiplied by the amount of organic N applied in the manure last year. Likewise, if manure was applied 2 years ago.

Cornell guidance for manure organic N release by animal type (Ketterings and Workman, 2025).

		Release rate for organic N in manure (%)		
Source	Dry Matter Content (%)	Present Year "Decay_current"	Last Year "Decay_lastyr"	Two Years Ago "Decay_2yrs"
Cows	<18	35	12	5
Cows	≥18	25	12	5
Poultry	<18	55	12	5
Poultry	≥18	55	12	5
Swine	<18	35	12	5
Swine	≥18	25	12	5
Horses	<18	30	12	5
Horses	≥18	25	12	5
Sheep	<18	35	12	5
Sheep	≥18	25	12	5

To calculate a manure rate for a current crop, once the contribution of N from the past manure applications has been estimated this should be subtracted from the current year N recommendation along with any fertilizer N that may be applied in addition to manure (e.g. starter fertilizer N) and any legume credit from a previous legume crop. The result will be the net N requirement that could still be met with the current manure application.

Once the net N requirement is calculated, the availability of the N from the planned application must be estimated. This is determined from the ammonium and organic N analysis of the manure and the application management. The availability of the organic N is determined by multiplying the organic N analysis times the appropriate present year "Decay Current" factor in the table above. The ammonium N availability is determined by multiplying the ammonium N analysis times the appropriate "Ammonium N utilized by the Crop" factor in the table below. The two available N amounts are added together and this is the available N for this manure. This is then divided into the Net Crop N Requirement to determine the N balanced manure rate. This rate should meet the N requirements of the crop. No more than this rate should be applied. If a lower rate is selected additional supplemental N fertilizer may be required.

Cornell guidance for estimated ammonia-N losses as affected by manure application method (Ketterings and Workman, 2025).

Manure Application Method	Ammonium N utilized by the Crop (%)
Injected into a growing crop	100
Spring injected without a growing crop	65
Spring Incorporated within 1 day	65
Spring Incorporated within 2 days	53
Spring Incorporated within 3 days	41
Spring Incorporated within 4 days	29
Spring Incorporated within 5 days	17
No Incorporation or injection	0
Injected or incorporated in the fall	0

Manure rate calculation from manure analysis information using tables above:

- Crop N recommendation: 150 lb N/acre.
- Starter fertilizer: 150 lb/acre 10-10-10 so 15 lb N/acre.
- Legume N credit from previous soybean crop: 30 lb N/acre.
- Residual N from previous manure applications: 20 lb N/acre.
    - Last year:
      20 tons dairy manure/acre, 4 lbs ammonium N and 6 lbs organic N/ton, 15% solids
      20 ton/acre x 6 lbs org. N/ton x 0.12 = *14 lbs N/acre from last year.*
    - Two years ago:
      20 ton dairy manure/acre, 4 lb ammonium N and 6 lb organic N/ton, 15% solids
      20 ton/acre x 6 lb organic N/ton x 0.05 = *6 lb N/acre from 2 years ago.*
- Net crop N requirement: 150 lbs N/acre - 15 - 30 - 20 lb N/acre = <u>85 lb N/acre.</u>
- Planned manure management: applied in the spring and incorporated within 3 days.
- Current manure analysis: 10 lbs total N, 4 lbs ammonium N, 6 lbs organic N/ton, 15% solids.
- Available ammonium N: 4 lbs NH_4-N/ton x 0.41 = 1.6 lbs NH_4-N/ton available.
- Available organic N: 6 lbs organic N/ton x 0.35 = 2.1 lbs organic N/ton available.
- Total available N: 1.6 lbs NH_4-N/ton + 2.1 lb organic N/ton = 3.7 lbs available N/ton.
- N balanced manure rate: 85 lbs N/acre ÷ 3.7 lbs available N/ton = 23 tons/acre.

39. Describe advantages and limitations of the following fertilizer placement methods.

a. Injection
b. Surface broadcast
c. Broadcast incorporated
d. Banding (different depths)
e. Fertigation
f. Foliar application
g. Sidedress
h. Topdress
i. Seed placement (pop-up)
j. Starter band

Method	Advantages	Limitations
a. Injection	Reduce losses.	Slow, expensive.
b. Surface broadcast	Fast, economical.	Higher losses.
c. Broadcast incorporation	Reduce losses.	Slow, erosion.
d. Band application	High nutrient use efficiency.	Costly, slow.
e. Fertigation	High nutrient use efficiency.	Irrigation equipment needed.
f. Foliar	Rapid uptake.	Phytoxicity, expensive, limited to small and/or repeated applications.
g. Sidedress	High nutrient use efficiency as nutrients are applied to a growing crop.	Timeliness, slow, multiple passes
h. Topdress	High nutrient use efficiency as nutrients are applied to a growing crop.	Could result in ammonia loss if urea containing fertilizer cannot be incorporated.
i. Seed placed	Low equipment costs	Phytotoxicity; only small amounts to avoid burn or salt damage to the seedlings.
j. Starter band	High nutrient use efficiency.	Only small amounts to avoid burn or salt damage to the seedlings, slows down planting.

40. Describe how the following nitrogen additives impact N behavior and management:

- **a. Urease inhibitors**
- **b. Nitrification inhibitors**
- **c. Controlled release products**

Various technologies have been developed to minimize the potential for N loss to the environment, including those that delay nitrification (nitrification inhibitors), delay conversion of urea to ammonium (urease inhibitors), and/or employ sulfur or polymer coatings to allow release N over a longer time period (slow or controlled release).

a. Urease inhibitors
Urease inhibitors are substances that inhibit conversion (hydrolysis) of urea to ammonia and carbon dioxide, reducing ammonia volatilization losses. Urease inhibitors can be effective for up to ten to fourteen days. Urease inhibitors especially target N sources that have a high volatilization potential (e.g. urea) in situations in which tillage incorporation is not possible (e.g., no-till, pasture, and grass hay production). Adding a urease inhibitor allows more time (1-2 weeks) for rain to incorporate the N fertilizer. An example of an active ingredient known to inhibit urease is NBPT (N-butyl thiophosphoric triamide).

b. Nitrification inhibitors
Nitrification inhibitors are substances that inhibit conversion (biological oxidation) of ammonium to nitrate. Nitrification inhibitors work by keeping N in ammonium form, which is done by inhibiting *Nitrosomonas* bacteria, delaying conversion for four to ten weeks

depending on soil temperature and pH. These inhibitors can reduce N loss from leaching and denitrification but are only effective on fertilizers that either contain or are converted to ammonium, including anhydrous ammonia, urea, and ammonium sulfate. In humid climates, like the Northeast, nitrification inhibitors have the highest likelihood for a yield response when applied at planting in less well drained soils (where denitrification losses are more likely to occur) or in sandy soils (where the leaching potential is high). Examples of active ingredients known to inhibit nitrification are nitrapyrin and dicyandiamide (DCD). Nitrification inhibitors can be added to solid fertilizers. The mixture should be applied quickly after mixing to avoid volatilization of the inhibitor.

c. Controlled-release fertilizers
Controlled-release fertilizers are usually common fertilizers such as urea, coated with a polymer or sulfur. The coating delays the availability of the nutrients for plant uptake after application and controls nutrient release over time. These enhanced-efficiency fertilizers allow for better timing of N release, consistent with crop growth and N demands. For sulfur-coated fertilizers, N is released upon the physical breakdown of the sulfur coating followed by soil microorganisms completing the degradation and N release process. For polymer-coated fertilizer, N is released when water enters the granule and dissolves the urea or other N forms inside it into a liquid N solution, and the solution diffuses through the coating into the soil solution. The N diffusion rate is influenced by soil temperature; more N is released during warmer, active growing periods and less in cooler, inactive periods. There are advantages and potential disadvantages for the use of controlled-release fertilizers. They can reduce leaching, denitrification and/or volatilization losses, and can result in more uniform growth because of reduced risk of seedling burn or salt damage. However, these products tend to be more expensive per unit of N and are not desirable when a quick release is needed, for example, when sidedressing corn at the 6-leaf stage.

41. Recognize nutrient sources that can be certified organic.

The United States Department of Agriculture (USDA) considers a fertilizer source to be certified organic if it is produced using the USDA organic standards which require that the product is made of natural materials and not treated with chemically synthesized products. In addition to obtaining a certified organic fertilizer label, the nutrient sources need to comply with strict regulations and be verified by an accredited body to ensure their sustainable production. To make sure a product meets the requirements, check with the appropriate organic certification agency. Generally, livestock manure is considered allowable and does not need to be listed or certified. However, producers must follow specific guidelines related to the use of raw and composted manure on organic crop fields.

CA5: Soil pH and Liming

42. Define:

a. **Soil pH**
b. **Buffer pH**
c. **Exchangeable acidity**
d. **Alkalinity**

a. Soil pH

pH is the negative log of the H+ ion concentration

$pH = -Log\ H^+ = log\ 1/H^+$

$pH\ 7.0 = -log\ 0.0000001\ H^+$ or $(H^+) = 1 \times 10^{-7}$

$pH\ 6.0 = -log\ 0.000001\ H^+$ or $(H^+) = 1 \times 10^{-6}$

b. Properties of pH:

pH 7 is neutral - neither acid or basic (alkaline).

pH < 7 is acid and > 7 is basic (alkaline).

1 pH = A 10-fold increase in acidity. pH 5 is 10 times more acid than 6, 100 times more acid than 7

Soils range between pH 3.5 and 9.

a. Hydrogen and aluminum ions and complexes are the two primary sources of soil acidity.

b. pH – Northeastern mineral soils 4.5 – 8.2

c. pH – Northeastern muck soils 3.5 – 8.2

c. Exchangeable acidity is a measure of the soil's ability to withstand a change in pH upon lime addition. The higher the exchangeable acidity of a soil, the more lime is needed for a particular pH change.

d. Buffer pH is used to estimate a soil's exchangeable acidity; the amount of change in buffer pH is related to lime needs.

e. Alkalinity is the term used to describe the amount of base in a soil when the pH is above 7.

43. Describe the long-term change in soil pH from applying N.

Nitrification or the conversion of ammonium N to nitrate N produces acidity ($2\ NH_4^+ + 4\ O_2 \rightarrow 2\ NO_3^- + \boldsymbol{4\ H^+} + H_2O$) and 2 H^+ are produced for every N in the ammonium-N form (NH_4^+). This reaction occurs regardless of the source or the NH_4^+.

N source	Theoretical lb $CaCO_3$/lb N	Official (AOAC) lb $CaCO_3$/lb N
Anhydrous ammonia	3.6	1.8
Urea	3.6	1.8
Ammonium nitrate	3.6	1.8
Ammonium sulfate	7.2	5.4
Monoammonium phosphate	7.2	5.4
Diammonium phosphate	5.4	3.6

The acidity from N fertilizers is often the largest single acidifying addition to agricultural soils. The net amount of acidity created when N fertilizer is applied depends on other reactions that occur with the fertilizer. The acidity created by different fertilizer materials is summarized in the table above. As an example, if 150 lbs N/acre is applied as urea, this will produce the equivalent of 270 lbs of lime requirement (150 x 1.8 = 270 lbs). Similarly, if 150 lbs N/acre are applied as ammonium sulfate, 810 lbs of lime requirement (150 x 5.4 = 810) will be created.

44. Describe how applying N in a no-till or long-term perennial forage crop results in pH stratification (acid roof) and how this impacts root growth, herbicide activity, soil sampling, and liming management.

The reaction of ammonium forming fertilizers (e.g. ammonium nitrate, urea, urea ammonium nitrate, anhydrous ammonia, ammonium sulfate) with oxygen (a process called oxidation) results in the formation of nitrate (NO_3^-) and H^+ ions which lowers soil pH:

$$\underset{\textbf{(ammonia)}}{2\,NH_3} + \underset{\text{(oxygen)}}{4\,O_2} \rightarrow \underset{\text{(nitrate)}}{2\,NO_3^-} + \underset{\text{("acid")}}{\mathbf{2\,H^+}} + \underset{\text{(water)}}{2\,H_2O}$$

$$\underset{\textbf{(ammonium nitrate)}}{NH_4NO_3} + \underset{\text{(oxygen)}}{2\,O_2} \rightarrow \underset{\text{(nitrate)}}{2\,NO_3^-} + \underset{\text{("acid")}}{\mathbf{2\,H^+}} + \underset{\text{(water)}}{H_2O}$$

$$\underset{\textbf{(urea)}}{(NH_2)_2CO} + \underset{\text{(oxygen)}}{2\,O_2} \rightarrow \underset{\text{(nitrate)}}{2\,NO_3^-} + \underset{\text{("acid")}}{\mathbf{2\,H^+}} + \underset{\text{(water)}}{H_2O}$$

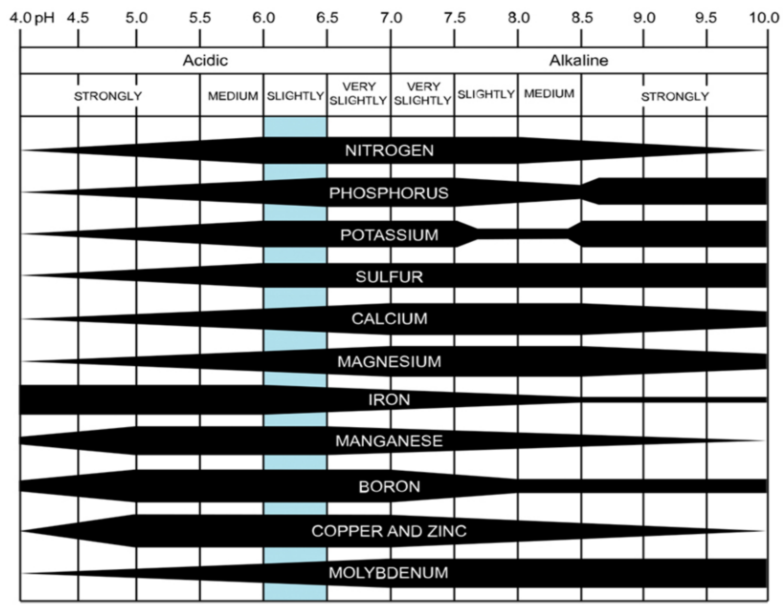
$$\underset{\textbf{(ammonium sulfate)}}{(NH_4)_2SO_4} + \underset{\text{(oxygen)}}{4\,O_2} \rightarrow \underset{\text{(nitrate)}}{2\,NO_3^-} + \underset{\text{(sulfate)}}{SO_4^{2-}} + \underset{\text{("acid")}}{\mathbf{4\,H^+}} + \underset{\text{(water)}}{2\,H_2O}$$

In no-till situations, the fertilizer is not mixed throughout the soil profile, and consequently, the acidity created by this fertilizer remains at the surface, resulting in the formation of an "acid roof" where the surface inch or two of soil is lower in pH than the subsoil. This can impact root growth, especially for new seedings, as well as impact herbicide activity. Under minimum or no-tillage systems, because the surface inch of the soil may become acid more rapidly than the deeper layer, the pH values of two soil layers (0-1 and 0-6 inches) should be determined. If the pH of the surface 0-1 inches is less than desired, but the pH of the 6-inch core is adequate, a small lime addition (1 to 1 ½ tons of lime per acre) is recommended to raise the pH of the soil surface. If both samples are strongly acidic, do not use no-till methods for the establishment of legumes unless lime has been applied and mixed with the soil for at least 6 to 9 months to permit the lime to react with the soil. If the surface pH is adequate, but the pH of the 6-inch core is lower than desired, legumes might be no-till seeded with a slightly lower overall pH or without waiting so long for the applied lime to react as both zones have a low soil pH. Downward movement of lime to subsurface layers is very slow and only occurs after the surface layer has reached >80% saturation which means the pH of the surface needs to be around 7.0 to let lime move downward. If a rapid increase in pH is desired, a very finely ground limestone can be used, or hydroxide sources (hydrated lime or slaked lime) can be considered. Both will be more expensive than planning and maintaining a good pH level over time. As explained, these sources increase the pH of the soil much faster than calcitic or dolomitic limestones. This could be desirable if a quick increase in pH is needed. However, the effects are of shorter duration.

45. Describe how cation exchange capacity (CEC), soil texture, exchangeable acidity and soil organic matter affect lime requirements.

Lime requirements increase with CEC and CEC increases with organic matter and clay content. Thus, clay soils with high organic matter require more lime for a similar pH change than sandy soils low in organic matter. In other words, high CEC soils tend to be well-buffered, meaning they are resistant to pH changes and as a result, require more lime to change the pH. Sandy soil is poorly buffered, requiring less lime per unit pH change. However, because of the greater buffering capacity, the soil pH will decrease slower on higher CEC soils than in poorly buffered sandy soils.

46. Describe how soil pH affects the availability of each nutrient.

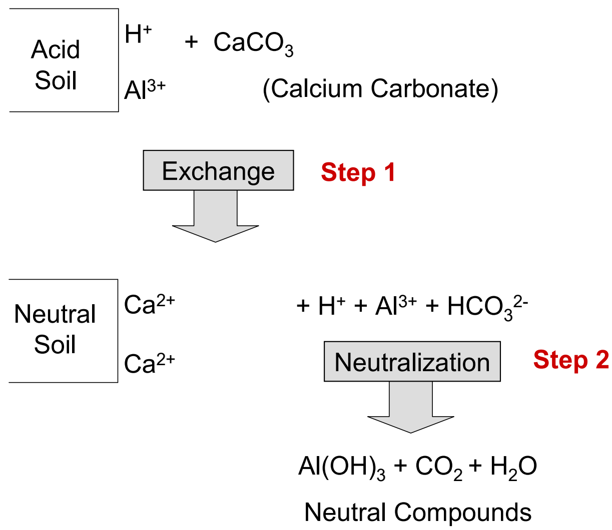


- Most plants grow best at pH values above 5.5.
- Lower pH increase solubility of Al, Mn, Fe.
  a. In excess Al, Mn, Fe are toxic to plants.
  b. A critical effect is that root growth is slowed or stopped by excess soluble Al.
- Extreme pH values decrease the availability of most nutrients. The effect of soil pH on nutrient availability is summarized in the figure below. Low pH reduces the availability of the macro and secondary nutrients. High pH reduces the availability of most micronutrients.
- Soil pH around 6.5 is usually considered optimum for nutrient availability.
- Microbial activity may be affected by very low or very high pH.

47. Describe how liming materials increase soil pH.

- Limestone is calcium carbonate or a combination of calcium and magnesium carbonate ($CaCO_3$ and $MgCO_3$).
- The limestone dissolves in water to form carbonic acid (H_2CO_3) and $Ca(OH)_2$:
  $CaCO_3 + HOH \leftrightarrow H_2CO_3 + Ca(OH)_2$
- H_2CO_3 is unstable and converts to carbon dioxide and water - the CO_2 gas escapes
  $H_2CO_3 \leftrightarrow CO_2 + HOH$
- The remaining $Ca(OH)_2$ dissociates into Ca^{2+} and OH^-.
- The Ca^{2+} replaces 2 H^+ from the soil; increasing the soil base saturation.
- The OH anion reacts with the soil acid cation H+ forming water:
  $H^+ + OH^- \leftrightarrow HOH$ (water)
- For a product to be a liming material, both the exchange and neutralization steps are needed.

Liming consists of two steps, the exchange of acidy on the soil complex and Ca or Mg that results in a solution with H^+ and Al^{3+}, followed by a neutralization step where water and $Al(OH)_3$ (inert) are formed. If either of these two steps cannot be completed, the material is not a liming product.



48. Describe how purity, fineness, and calcium carbonate equivalent (CCE) affect the neutralizing ability of liming materials.

- Calcium Carbonate Equivalent (CCE): the neutralizing value of a liming material compared to pure calcium carbonate. A CCE of 100% indicates the material will neutralize the same amount of acidity per pound as pure calcium carbonate.
- Fineness: Limestones react at rates proportional to the surface area of the particles and the total surface area of the particles is related to the size of lime particles. The finer the limestone is ground, the faster it will react in the soil. Fineness is reported as a particle size distribution usually as the percentage of the material that will pass a 20- and a 100-mesh screen. Material larger than 20-mesh reacts too slowly to be of much value as a liming material. All very fine, less than 100-mesh materials, will react quickly but it will be much more expensive, may be difficult to handle, and the soil pH will decrease faster because there is a lack of larger lime particles available to break down over time.
    - 100% of lime that passes a 10-mesh screen will react in 1 year.
    - 60% of lime that passes 20 but held on 100 mesh will react in 1 yr.

  The fitness factor is derived by subtracting the % passing a 100 mesh sieve from the % passing a 20 mesh sieve and multiply this difference with 0.60, then add the % passing the 100 mesh sieve and divide the sum by 100. Note: fineness does not increase the total neutralizing value of a limestone, just how fast it will react.
- Effective neutralizing value (ENV) is determined by its CCE multiplied by its fineness factor.
- Lime recommendations are reported in 100% ENV and need to be adjusted for the actual ENV of the liming material that is being used.

Example:

- Lime source: CCE = 78.8%, 70% passes a 100-mesh sieve, 97% passes 20 mesh. What is the ENV of this material?

Answer:

- CCE = 78.8%; Fineness factor = {(97-70)*0.60 +70}/100=0.86; ENV = CCE*fineness factor = 78.8*0.86 = 67.8%

49. Calculate lime application rates to meet pH requirements.

Lime recommendations are given in 100% ENV. To convert to lime recommendation for a particular liming material A: Lime rate (tons/acre) = 100 x lime rate for 100% ENV (tons/acre) / ENV of material A. For example, the soil test recommendation is 1.5 tons/acre of 100% ENV and the limestone has an ENV of 70.3, the actual application rate will need to be: 100 x 1.5 ton 100% ENV ÷ 70.3 ENV = 2.1 tons limestone/acre.

50. Describe how soil pH affects availability of heavy metals and other contaminants to plants.

Soil pH influences the availability of heavy metals and other contaminants to plants. In acidic soils (low pH), most heavy metals such as cadmium, lead and zinc become more soluble and in return more available to plant uptake increasing potential toxicity. Rasing the soil pH through liming can reduce metal solubility and thus reduce contaminant uptake. However, some elements like arsenic can become more available at higher pH. Maintaining a soil pH between 6.0 to 7.2 with organic matter can reduce risk of contamination.

51. Describe the need for appropriate incorporation of liming agents to avoid problems with nutrient tie-up, herbicide effectiveness, and crop response.

Lime which is applied to the soil surface (not incorporated or mixed in) in pastures and no-till situations will require more time to react and advanced planning. Surface application in excessive quantities can lead to nutrient tie up, unreliable herbicide performance, and sub optimal crop response (e.g. poor root growth, inefficient fertilizer use, reduced yields). Regardless of crop, when the lime requirement is greater than 4 tons/acre, it is recommended to incorporate half of the lime required into the soil profile and work the remainder into the surface. Generally, for economic returns, apply no more than ~6 tons 100% ENV within a 4- to 5-year rotation. If more is required, apply up to 6 tons in the current rotation and retest the soil again in 3 years.

52. Describe the need for testing contaminants that may be associated with liming materials.

Limiting products need to meet state regulations to be able to be sold. For example, in New York, the New York Agriculture and Markets Law (Article 9-A) states that it is illegal to sell any liming material “adulterated with any substance injurious to the growth of plants, animals, or humans”. Testing ensures that products have not been contaminated with heavy metals or industrial by products and that they meet label guarantees. (e.g. neutralizing value, fineness, Ca or Mg content). In New York liming materials must have 60% CCE with 80% passing a 20-mesh sieve and 30% passing a 100-mesh sieve to ensure both effective application and reduced risk of contamination. See state guidelines for more information.

CA6: Nutrient Management Planning

53. Describe how to set a realistic yield goal by using:

- **a. Production history**
- **b. Soil productivity**
- **c. Management level**
- **d. Soil type/characteristics**
- **e. Artificial drainage**
- **f. Soil drainage class**

Fertility practices should be based on realistic yield goals, also called yield potential, recognizing inherent limitations to yield. A realistic yield potential considers production history, soil productivity, management level, soil type, artificial drainage and soil drainage class. Artificial draining can increase yields for soils that are, by nature, poorly drained. The soil drainage class is a classification of how quickly or slowly water moves through the soil ranging from very poorly drained to excessively drained. Yield potentials are obtained by averaging yields of the past 4 out of 5 years, discarding extreme years (e.g. due to severe drought). Realistic yield goals should consider nutrient use efficiency (ability of the plants to make use of soil nutrients) as it will not be economically or environmentally viable to fertilize fields with very low nutrient use efficiency.

54. Determine crop nutrient needs by using:

- **a. Yield potential**
- **b. Crop population**
- **c. Crop rotation/sequence**
- **d. Soil nutrient supply**
- **e. Soil test information**
- **f. Field history**
- **g. Field-specific N testing (e.g., pre sidedress nitrate test, corn stalk nitrate test, Illinois soil nitrogen test)**

Land-grant university nitrogen guidelines in the Northeast are not based on a soil nitrate test as nitrate is very mobile in the soil. For nitrogen, crop nutrient needs are usually derived based on information about the yield target/potential of a field (ideally based on historic yield data), its place in the crop rotation, estimated soil N supply from mineralization of organic matter, and management history of the field, especially when manure is applied in earlier years. The recommendation is adjusted for N fertilizer uptake efficiency recognizing that not applied N will end up in the crop. Recommendations are not adjusted for crop population density, as that gets accounted for in the yield target/potential.

Nitrogen from sod becomes available over time through mineralization and nitrification. Typically, N needs for a crop are adjusted for up to three years if a sod was in the rotation. Thus, N availability from prior sod crops varies depending on sod species composition and year since termination. Soil nutrient supply of P, K, Mg, etc., is evaluated using a soil test.

For N, several tools can be used to guide decision making beyond the base recommendations developed with the approach outlined above. These tools include the pre-sidedress nitrate test (PSNT), the corn stalk nitrate test (CSNT), and the Illinois soil nitrogen test (ISNT). The PSNT and ISNT are soil-based assessments that guide decisions prior to N application. The CSNT is an end-of-season test equivalent to a report card that allows a producer to evaluate if N applications, as implemented that year, were insufficient, sufficient, or excessive. For more details on PSNT, see PO#23. For details on how to credit past manure applications, see PO#38.

55. Know how to calculate N or P based manure application rates based on:

- **a. Crop requirement**
- **b. Manure analysis**
- **c. Planned application method and timing**
- **d. Linkage with supplemental fertilizer application (e.g., starter)**
- **e. Manure history**
- **f. Soil analysis**

Manure contains all essential nutrients, but in ratios that are not necessarily what plants need. For example, if manure is applied to meet N requirements of a corn crop, P and K will likely be applied beyond crop removal (see PO#60). To determine appropriate manure application rates, it is important to first determine the crop's nutrient needs using soil analysis and nutrient supply from manure using a manure nutrient analysis. The N and P value of the manure can then be determined based on the N and P content of the manure, and the planned application method and timing. Incorporation of manure in spring, prior to planting a corn crop will increase the amount of N that is plant available (due to reduced N volatilization when manure is incorporated). For more details on N credits from manure, see PO#38. To calculate how much P_2O_5 and/or K_2O are applied with a specific rate of manure, multiply the manure application rate in tons or in 1000 gallons by the lbs/ton or lbs/1000 gallons of P_2O_5 in the manure (as is column on the manure analysis report). If an application, for regulatory or environmental risk management reasons, cannot exceed the equivalent of P_2O_5 removed with the crop (P-based manure management), first estimate crop removal of P_2O_5 by multiplying the yield goal by the average P content of the crop. For example: estimated P_2O_5 removal by a 20 ton/acre corn silage harvest at 35% dry matter amounts to 20*2,000*35*0.55/10,000=77 lbs P_2O_5 (an estimated 3.85 lbs P_2O_5/ton of silage). If insufficient N or P is applied with manure, fertilizer applications can be done to ensure sufficient nutrient supply for the crop. Where initial soil fertility levels are low, a starter application of N, P_2O_5 and/or K_2O should be considered as manure nutrients are released more slowly over time.

56. Describe environmental effects and nutrient loss due to:

- **a. Erosion**
- **b. Runoff**
- **c. Volatilization**
- **d. Denitrification**
- **e. Leaching**

a+b. Erosion and Runoff: Because P is held mainly in insoluble forms in the soil the predominant mechanism for P loss is when soil containing these insoluble minerals is eroded. When the eroded soil enters water the dilution effect will solubilize some of this P which can lead to eutrophication. The capacity for soil to fix P is very large, however it is not infinite. It is possible to add enough P to use up most of the available precipitation and adsorption capacity of Fe and Al, at least in the surface soil. When this happens, the soil is saturated with P. Thus, additional P is not fixed, and it remains soluble and can be lost with runoff. This becomes very important when large amounts of P are added to the soil surface. The surface layer of soil can become saturated very quickly and then, when there is runoff over the surface, it interacts with this saturated surface soil layer and picks up significant amount of soluble P and transports it off the field. If this runoff goes into a water body the P is immediately available to cause eutrophication. In very sandy soils with little natural Fe and Al, there is little capacity to hold the P and thus it becomes saturated more quickly. In these soils soluble P loss is an even greater concern and even P leaching can be significant. Management to minimize P loss is a compromise. Incorporating the P positions so that surface runoff and erosion will not have access to the added P thus reducing the potential for loss. The mixing that occurs spreads the P deeper through the soil profile so that it contacts more soil; as a result the soil does not saturate with P as rapidly. However, tillage to incorporate P usually increases the potential for erosion which is the major loss mechanism for P. Ideally place P below the soil surface in a way that minimizes soil and residue disturbance. Direct injection of manure or fertilizer P can be very effective in reducing P loss. Timing can help. Most P sources are highly soluble when first applied. If runoff or erosion occur immediately following application, loss can be very high. However, with time P reacts with the soil and becomes less soluble. Thus, timing P applications when it is less likely that you will have significant runoff or erosion events can reduce losses. Soil properties which control water movement can play a very important role. If soil is compacted or crusted or has a low amount of residue cover, more water will runoff increasing the potential for P loss. Managing soil drainage can have a similar impact.

c. Volatilization**:** Urea nitrogen (Urea fertilizer, UAN solution fertilizer, and manure all contain urea N) is unique in that the available ammonium N (NH4+) from urea can be rapidly converted to ammonia (NH_3) which is a gas. If this reaction occurs on the soil surface the ammonia is lost to the atmosphere. Losses of over a third of the N from urea can occur within one week of surface application of a urea containing material. Tillage or half an inch of rain that incorporates the urea without initiating runoff will minimize this loss. The sooner tillage or rain occurs after application the smaller losses will be. Immediate incorporation or timing application just before rain are important to reducing this loss. Other common N sources such as ammonium sulfate and ammonium nitrate are not susceptible to volatilization. Urease inhibitors have been developed as an additive to urea to effectively reduce the risk of volatilization loss (for up to 14 days) when incorporation is not possible.

d. Denitrification: When soil become saturated with water, another N loss called denitrification occurs. This is especially a problem with poorly drained soils. Denitrification occurs when organisms in a saturated soil begin to run out of oxygen. Some of these organisms have developed the ability to extract oxygen from nitrate (NO_3^-) to survive. In the process, N from nitrate is released as either dinitrogen (N^2) or nitrous oxide (N_2O), gases which are unavailable to plants while N_2O is a greenhouse gas with serious environmental implications.

e. Leaching. Most N sources are rapidly converted to nitrate-N (NO_3^-) by bacteria in the soil. This is an important process because nitrate is the most common form of N taken up by plants. However, since nitrate is an anion (i.e. has a negative charge) it is not held on the soil CEC. Therefore if water percolates through the soil, it can easily carry significant amounts of nitrate with it. If the nitrate is leached below the rooting zone of the crop it is no longer available to plants and if it leaches to the ground water, it represents a pollution risk with public health implications. This is especially a problem with well drained soils.

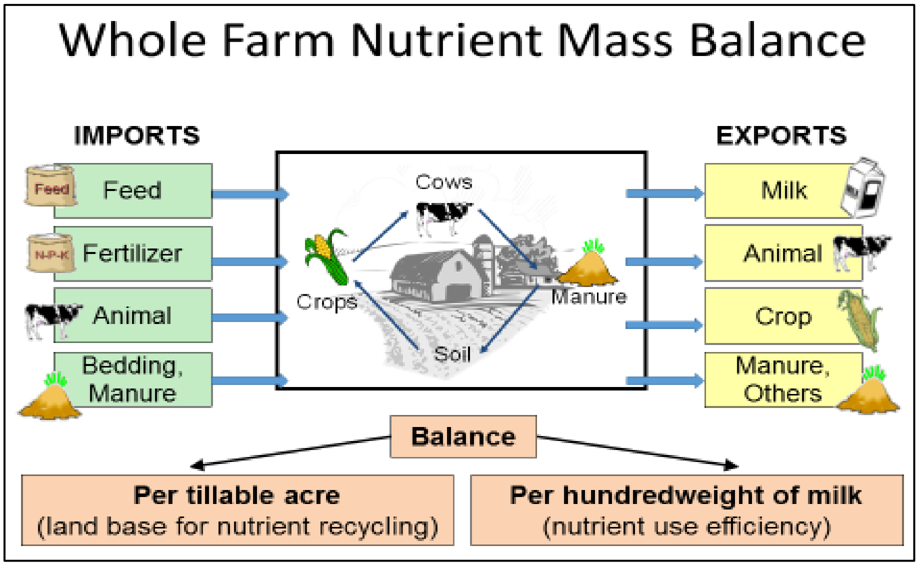
57. Describe how to apply the basic concepts of the 4Rs (right source, right rate, right timing, and right placement).

The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those that produce the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem. The 4R stewardship concept helps crop producers and their advisers select the right source–rate–time–place combination from practices validated by research.

58. Understand the role of the NRCS 590 Nutrient Management Standard in national nutrient management planning policy.

The NRCS 590 Conservation Practice Standard establishes criteria for the nutrient management elements of comprehensive nutrient management plans (CNMPs) for Concentrated Animal Feeding Operations (CAFOs) and other farms receiving state or federal cost sharing for best management practices (BMPs).

59. Define nutrient mass balance and describe why there can be a net excess nutrient mass balance on farms.



A mass nutrient balance can be described as the difference between total amount of nutrients imported onto the farm and nutrients exported via milk, meat, crops, manure, etc. Zero or negative balances are not sustainable as all biological systems have inherent losses. Positive balances are required for long-term sustainability, but balances should not be excessive. Balances can be expressed per unit of cropland (estimate of land base for nutrient recycling) and per unit of product produced. For dairy farms, this second balance is the balance per hundredweight of milk produced on the farm. For more information on whole farm nutrient balances, see http://nmsp.cals.cornell.edu/publications/factsheets/factsheet85.pdf.

60. Distinguish P-based from N-based manure application recommendations and describe implications.

Due to differences in N, P, K ratios of manure versus crop N, P and K needs, it is difficult to achieve acceptable N, P, and K balances simultaneously on dairy and livestock farms; balancing field applications for N with manure will increase soil P and K over time while balancing for P will likely increase the need for purchased nitrogen fertilizer. Rates can typically be higher when recommendations are N-based and may be lower when P-based limits are set (See PO#55).

61. Understand the importance of precision livestock feeding for whole farm nutrient management.

The largest amount of nutrient imported by dairy and livestock farms tends to be purchased feeds. Maximizing forage quality and matching diets with animal specific needs (based on life stage, production capability, and size) can improve animal nutrient use efficiency, thereby reducing nutrients in excreted in manure and reduce feed nutrient imports, improving the farm's overall nutrient balance.

62. Describe various conditions and environmentally sensitive areas associated with an elevated risk for nutrient loss from agricultural fields.

Phosphorus can be lost from agricultural fields as runoff that may be dissolved or sediment bound. Dissolved P (mostly orthophosphate) is available immediately for uptake by algae while sediment-bound P is a more long-term source of P to algae in water bodies. Erosion control is needed to reduce sediment-bound P loss, but it is critical to understand how water moves and where surface runoff occurs as P is lost as dissolved P as well. The total amount of P lost through runoff is typically very small, but it only requires a small amount to cause water quality problems.

High risk conditions for runoff are likely when:

- Significant rainfall or snowmelt is predicted within the next 48 hours.
- Concrete frost, ice layer on soil or in snowpack, deep or dense snow, or water saturated soil is present.
- Tile drains are flowing at least moderately from field drainage (as opposed to ground water interception).
- Nutrient applications occur outside the growing season and/or are not incorporated below the soil surface.

Nitrogen can be lost through volatilization of ammonia, leaching of nitrate, and denitrification which can result in various gasses including nitrous oxide. In addition to the conditions listed above for runoff, high risk conditions for nitrogen loss also include:

- Surface application of unprotected urea containing fertilizer on moist and warm soil.
- Mineralization followed by periods of saturated soils
- High rainfall on coarse textures soils in the presence of nitrate

Manure application under high-risk conditions has a high probability of causing water pollution. Thus, during these conditions, it is generally recommended to avoid spreading on fields with:

- Past runoff problems or groundwater/well problems.
- Significant surface runoff or subsurface flow that can reach a stream or ditch.
- An orientation toward a stream or watercourse with a slope greater than 3-5%; and or
- Concentrated flows.

63. Know the importance of the following components used to develop a nutrient management plan that is economically and environmentally sound:

a. Location of facilities and fields on maps
b. Identify environmentally sensitive areas, including wells, and perform field risk assessments
c. Specify crop rotation
d. Determine expected yields e. Interpret results of soil, plant, and water analyses

e. **Quantification of nutrients from all sources available to the farm**
f. **Develop a nutrient budget for each field**
g. **Make recommendations of nutrient rate, timing, form, and application method (4Rs) based on both agronomic guidelines and environmental risk assessments (NRCS 590) Review and modify plan as needed**
h. **Explain the importance of recordkeeping of nutrient applications and yields by field Describe the difference between routine livestock mortalities and catastrophic livestock mortalities and describe disposal options for both**

a. Location of facilities and fields on maps
- Enhances communication between planner, producer, farm staff and custom applicators and establishes both the facilities and the cropland that must be included in the plan.

b. Identify environmentally sensitive areas, including wells, and perform field risk assessments
- Allows for careful management of nutrients to minimize offsite environmental impacts, often involving the 4Rs and setbacks from sensitive areas. Tools like the Phosphorus Index and Nitrogen Leaching Index can also help identify field-specific risk.

c. Specify crop rotation
- Drives fertility guidelines, especially N.

d. Determine expected yields
- Drives fertility guidelines, especially N, and helps with overall assessment of forage production.

e. Interpret results of soil, plant, and water analyses
- Soil tests drive P, K, Mg, etc. guidelines and manure application rates. Plant and water analysis can be done as diagnostic tools.

f. Quantification of nutrients from all sources available to the farm
- The NRCS 590 standard states that plans need to account for all nutrient sources on a farm. Nutrient sources include soil, manure, compost, biosolids, fertilizer, sod/cover crop/legume N, residual manure N, etc.

g. Develop a nutrient budget for each field
- A field-specific nutrient budget is the amount of each nutrient required for optimum yield. Once it is known what crop needs are, fertilizer and manure can be allocated to meet crop needs and not exceed other environmental goals.

h. Make recommendations of nutrient rate, timing, form, and application method (4Rs) based on both agronomic guidelines and environmental risk assessments (NRCS 590).
- Rate, timing, form and method affect nutrient availability and risk of environmental loss.

i. Review and modify plan as needed
- Annual updates are needed to reflect actual application rates, timing, method etc., rotation shifts, purchase of new land, and other changes that could impact management in the coming year. Plans require annual manure analysis and soil analysis every three years.

j. Explain the importance of recordkeeping of nutrient applications and yields by field
- Recording nutrient applications and yields at the field level allows for the identification of trends and the adjustment of fertilizer or manure applications helping to optimize crop yield and performance. It is also required by most regulatory and/or incentive programs.

64. Understand the factors that are required to estimate manure and waste production volumes on a livestock farm.

- **a. Animal units**
- **b. Species and age**
- **c. Milk production rolling herd average**
- **d. Bedding type and amount**
- **e. Rainfall**
- **f. Impervious area**
- **g. Type of storage**

Manure quantities and analyses are needed to properly allocate manure to cropland on an annual basis. Manure production can be measured based on storage information, from records of how many loads of manure of a given size are hauled each year, or from animal inventories, production levels, and estimated excretion per animal per day. One animal unit is 1000 lbs of live weight. Thus, a mature cow of 1600 lbs equates to 1.6 animal units. Any additions to storage such as rainwater, cooling and wash water, leachate, bedding, etc. should be added to this total for the collection period.

65. Recognize production, environmental and management factors that determine the capacity/duration of manure storage needed on a livestock farm.

Size, type and number of animals affect the amount of manure generated. Land-base and weather determine accessibility in various times of the year. Equipment and labor force might restrict the ability to apply manure in short time frame. Generally, it is advisable to have enough storage capacity on farm to allow the farm to not spread during times that are high risk for runoff.

66. Explain the purpose of the P index and list the four management categories of the P index.

The P index is designed to identify fields at high risk for P loss upon manure application by identifying transport risk of a field (flow distance to streams and absence of presence of vegetation in that flow distance, flooding frequency, hydrologic soil group, erosion, presence of untreated concentrated flows) and then incentivizing beneficial management practices for manure and P fertilizer application to reduce risk. Individual field P index scores can range from low (<50), to medium (50-74) to high (75-99) to very high (>100) and result, depending on soil test P, in one of three management implications for a field: (1) zero P; (2) applications limited to annual P crop removal; or (3) N-based limits. Implementation of beneficial management practices (BMPs) can lower the risk of P loss from a field and will thus lower the transport PI score of a field. In 2022, all states in the northeast region except for Vermont, agreed to use the same transport x BMP approach, resulting in a unified Northeast Region PI (NY, CT, MA, ME, RI, NH). For more detail, see http://nmsp.cals.cornell.edu/publications/extension/NortheastPIndexUserGuide.pdf. For Vermont's PI: https://www.uvm.edu/extension/vermont-phosphorus-index.

67. Describe the impacts of the following manure application practices on the P runoff index score of a field:

- **a. Application rate**
- **b. Application method**
- **c. Application timing**
- **d. Location relative to surface water and groundwater**

a. Upper limits to application rates are defined by the final PI score of a field and its soil test P. There are three categories: (1) zero P; (2) applications limited to annual P crop removal; or (3) N-based limits (See PO #60).
b. Application methods recognized to reduce P loss risk include implementation of no-spreading zones, incorporation of manure or injection of manure.
c. Applications done when crops are actively growing are able to take up the nutrients will be less risky than applications to bare ground outside of the growing season.
d. Flow distance (called the Distance Factor in VT) to streams is an important factor in the P index with high risk assigned to fields that are within 500 feet of a stream.

68. Calculate crop P removal given yield and P concentration.

To determine crop removal, multiply yield (in lbs) times the dry matter content times the P content of the dry matter. For example, 20 tons silage yield at 35% DM and 0.55% P_2O_5 results in a crop P_2O_5 removal of: 20*2000*0.35*0.55/100=77 lbs P_2O_5 (or 77/20=3.85 lbs P_2O_5 per ton silage). See http://nmsp.cals.cornell.edu/publications/factsheets/factsheet28.pdf for crop removal estimates for the most common field crops.

69. Understand the nitrate leaching index principles and interpretations.

The Nitrate Leaching Index (NLI) is an indicator of the potential for nitrate to reach groundwater. The current LI rates leaching potential based on hydrologic soil group (A, B, C, D) and precipitation data. An LI below 2 indicates that the potential for nitrate leaching below the root zone is low. An LI greater than 10 indicates that the potential for nitrate leaching below the root zone is high while LI's between 2 and 10 are considered intermediate. To meet the N leaching requirements of NRCS 590, producers are expected to implement beneficial management practices (BMP) if the LI score for a field is high (>10) and to consider BMPs if the LI score for a field is intermediate (2-10). See http://nmsp.cals.cornell.edu/publications/factsheets/factsheet11.pdf for more detail for New York. Each state has an NLI developed for their specific soil types and climate conditions but will follow a similar approach and interpretation .

70. Describe and understand practices that reduce the risk of nitrate leaching.

Example of practices:

- If pre-plant or early post-plant broadcast application of N fertilizer in corn cannot be avoided, use of an enhanced efficiency N fertilizer (i.e., nitrification and/or urease inhibitors, controlled release fertilizers) is recommended.
- If starter N must be broadcast (e.g., for small grains or new seedings of grass), apply fertilizer as close to expected planting date as possible (ideally within 3 days or less). Consider use of enhanced efficiency N fertilizer.
- For row and cereal crops, including corn, maintain starter fertilizer N rates below 50 lbs/acre actual N under normal conditions.
- Utilize split-applications of nitrogen fertilizer or manure whenever possible, aligning the timing of applications with crop utilization.
- To avoid premature N fertilizer loss and to properly align with crop uptake efficiency for corn, sidedress applications should be made after plants have at least four true leaves.

- Use the pre-sidedress nitrate test (PSNT) to identify fields where sidedress N is unlikely to result in a crop response.
- Manure N application on legumes is acceptable to satisfy agronomic requirements when legumes represent less than 50% of the stand. When legumes represent more than 50% of the stand, manure may be applied at rates no greater than 150 lbs of available N or 85% of the estimated N removal with harvest.
- Minimize fall and/or winter manure application on grass and/or legume sod fields that are to be rotated the following spring.
- Sod crops should not be incorporated in the fall. Chemical sod killing may not be carried out until the soil temperature at four-inch depth is at or below 45°F. Depending on location, this will not likely take place until October.
- Establish winter hardy cover crops (e.g., cereal rye, winter wheat, triticale) whenever possible, but especially when fall manure is to be applied to otherwise bare ground.
- Manure may be applied in the fall where there is a growing crop or in conjunction with seeding of winter hardy cover crops. Applications should generally not exceed the greater of 50 lbs/acre of first year available N or 50% of the expected N requirement of next year's crop.

71. Describe and understand practices that reduce manure odor issues.

Manure treatment like anaerobic digestion or solid-liquid separation and manure incorporation/injection by incorporating manure into the soil during or shortly after application are main ways to reduce odor.

72. Describe and understand practices that reduce agricultural impacts on air quality.

Field level practices that can reduce the impact from land application of manure include incorporation, low splash plates, dribble bars, avoiding aerosolizing manure particles, and applying to fields with growing crops (covers crops, perennials, etc.). Practices related to storage of manure and handling include covered storages, anaerobic digesters, bioreactors/air filters, and establishment of hedgerows and wind breaks around manure storages. Use of enhanced efficiency fertilizer formulations can also increase N fertilizer use efficiency and hence reduce the environmental impact.

73. Describe and understand practices that reduce pathogen concerns from manure.

Improved calf care, herd management factors that reduce pathogen loading, cold temperatures, long storage, methane digestion and composting can reduce pathogen loads.

74. Understand the concepts of adaptive nutrient management and associated tools:

a. **Corn stalk nitrate test, Illinois soil nitrogen test, standard soil fertility testing**
b. **Nutrient mass balance**
c. **Record keeping**
d. **Analysis and adaptation over multiple seasons based on field-specific observations**
e. **Precision agricultural equipment (crop sensors/soil sensors and models)**

Adaptive nutrient management (ANM) is a process where farmers can test input response and adjust field management over time. The process promotes ongoing refinement of nutrient application emphasizing the use of "the right nutrients, at the right rate, timing, and placement" to minimize nutrient losses to the environment (4Rs). The ANM process is field-based and requires the use of assessment tools (measurements, record keeping) combined with learning and adapting management over time. The process allows for continued adjustments of the NRCS-assisted Conservation Practice Standard (CPS) Code 590, Nutrient Management, to achieve better nutrient use efficiency.

A typical ANM process has five steps:

1. Characterize the current condition.
2. Develop a plan for evaluating alternative practice.
3. Implement a comparison of the current practice and a management change.
4. Evaluate results, learn and identify potential management changes.
5. Adjust management based on lessons learned.

The process is implemented over multiple years, to reflect growing season differences, and requires annual determination of yield. Record keeping is an essential component of adaptive management. Evaluation tools may include conducting on-farm research trials, sampling for corn stalk nitrate test, conducting test strips, and conducting field N balances. In New York, the adaptive management process for N allows for field applications of nutrients in excess of land-grant university guidelines for the field, with the requirement to measure yield and evaluate if the additional N benefited the crop that year. Application rates may be informed by specific field observations, soil or plant analyses including standard soil fertility testing, soil N tests such as the Illinois soil N test, or corn stalk nitrate test (CSNT) results, as well as use of crop sensors and models. See PO28 for more information on the CSNT. Independent of what tools are used, enrollment in the adaptive management process for a field requires continued yield documentation and an end-of-season evaluation. For more detail on how this process is implemented in New York, see: AdaptiveNitrogenManagement2025.pdf.