Nutrient Management Planning Short Course

Pre-Course Supplemental Learning Material & Knowledge Checks

TEXAS A&M AGRILIFE EXTENSION

The materials in this document are intended to help guide the course registrant to successful completion of the proctored multiple-choice exam held at the end of the in-person short course. It is strongly advised that each registrant read all materials carefully and thoroughly, pausing to review according to the "Learning Expectations & Knowledge Checks" at the end of each section.

NUTRIEN MANAGEMENT POLICY AND CERTIFICATION

1. Nutrient Management Policy and Certification

The documents that cover policy for Nutrient Management Planning are found in Title 190. They included General Manual Title 190, part 402 "Nutrient Management"
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_022546.pdf

and Part 302 "Nutrient Management Policy Implementation".
https://www.crops.org/files/science-policy/testimony/590-part302.pdf

Both documents are provided in full in the pre-course materials and will be included in the hardcopy manuals provided at the in-person course.

Learning Expectations & Knowledge Checks (NMP Policy):

1. Understand A. B. and C. under the 402.1 Policy section.
2. Be prepared to identify any of the definitions under 402.2 Definitions.
3. Understand NRCS' 3 roles in certification – section 402.3
4. Be prepared to answer questions related to the details of nutrient management plans – section 402.4
5. Be prepared to answer questions related to how soil and plant tissue are sampled and how they are analyzed – section 402.5
6. Demonstrate knowledge of the guidance behind recommendations for nutrient and soil amendment application rates – section 402.6
7. Be prepared to answer questions on the special considerations required for NM plans that include manure and other organic materials – section 402.7
8. Understand the guidance in the document related to record keeping – 402.8

SOIL TESTING AND FERTILIZER NUTRIENT RECOMMENDATIONS

1. Soil Testing and Fertilizer Nutrient Recommendations

The website for the Texas A&M AgriLife Extension Soil, Water, and Forage Testing Laboratory is located at the following url…
https://soiltesting.tamu.edu/

The SWFTL website contains published tables of soil fertility recommendations based on soil testing and analysis for nitrogen (N), phosphorus (P), and potassium (K) for most of the major crops, forages, fruits & nuts, vegetables, and ornamental plants grown in Texas.
https://soiltesting.tamu.edu/webpages/recommendations.html

Phosphorus Soil Fertility Recommendations for Texas Grain and Row Crops

	Mehlich III by ICP phosphorus (ppm or mg/kg) in Soil												
	0	5	10	15	20	25	30	35	40	45	50	55	60
updated on 3-30-2012: soiltesting.tamu.edu	------lbs P2O5/acre------												
AFRICAN MILLET	55	50	40	35	30	25	20	15	10	5	0		
BARLEY (HEAVY GRAZING ON SANDY SOILS)	105	95	80	70	60	50	40	30	20	10	0		
BARLEY (HEAVY GRAZING)	105	95	80	70	60	50	40	30	20	10	0		
BARLEY GRAIN (30-40 BU/A)	55	50	40	35	30	25	20	15	10	5	0		
BARLEY GRAIN (70-90 BU/A WITH LIGHT GRAZING)	80	70	60	55	45	40	30	20	15	5	0		
CORN (100 BU/A)	80	70	60	55	45	40	30	20	15	5	0		
CORN (110 BU/A)	105	95	80	70	60	50	40	30	20	10	0		
CORN (120 BU/A)	105	95	80	70	60	50	40	30	20	10	0		
CORN (130 BU/A)	105	95	80	70	60	50	40	30	20	10	0		
CORN (140 BU/A)	105	95	80	70	60	50	40	30	20	10	0		
CORN (150 BU/A)	105	95	80	70	60	50	40	30	20	10	0		
CORN (160 BU/A)	130	115	100	90	75	65	50	35	25	10	0		
CORN (170 BU/A)	130	115	100	90	75	65	50	35	25	10	0		
CORN (180 BU/A)	130	115	100	90	75	65	50	35	25	10	0		
CORN (190 BU/A)	130	115	100	90	75	65	50	35	25	10	0		

The above table taken from the SWFTL website should be read by matching the soil test result (ppm P) across the top with the crop listed in the left-hand column. Note that recommendations are based on realistic yield goals.

Example: The recommendation for 100 bu corn where the soil test was 20 ppm P is 45 lbs P_2O_5 per acre.

By definition, nutrient management applies to all nutrients that are managed for crop production. *In practice, the majority of nutrient management planning is centered around the management of N and P to minimize adverse impacts on water resources while allowing large animal production operations to land-apply (i.e dispose of) animal wastes up to but not beyond a level that is environmentally safe and sound.*

1.1 Sampling Protocols

Soil sampling strategies will take into account the depth of the soil and the historic management of the farm, including

1. Methods of fertilization (e.g. application of animal waste and chemical sources of nutrients, and whether they were surface broadcast, incorporated, or banded)
2. Cultivation practice (e.g. tillage)
3. Irrigation or rainfall – which will affect nutrient leaching and rooting density near soil surface

1.2 Sampling Tools

Hand probes (tube samplers) are most commonly used, though augurs are also effective. Both are effective at collecting routine samples from 0-6". Hand probes are widely available for purchase with attachments that can reach 18" below the surface. For sampling below 18", hydraulic vehicle-mounted probes will are required.

Always use a clean plastic bucket and ensure tools are cleaned before sampling and between fields.

1.3 Taking Good Representative Samples

It is extremely unlikely that you will work in fields that are homogenous with respect to soil type, texture, chemical properties, and fertility. Variability in soil properties occurs at the field level. Overcoming this variability is critical to properly representing the bulk field properties.

Collecting a good representative soil sample cannot be stressed enough. The soil test result is meaningless without a proper sampling procedure.

To overcome the variability in the field

1. An appropriate acreage must be represented by the composited sample
    a. 10 – 40 acres
        i. 10 acres for high producing soils (e.g. hay fields, grain crops)
        ii. 40 acres for pastures and fields where low inputs are applied or removed.
    b. Sample smallest area which could be fertilized separately
2. An adequate number of subsamples must be taken to form the composite samples.
    a. 10 – 15 cores should be composited to represent a 10-40 acre unit
3. All subsamples are taken at the correct depths.
4. Foreign materials should be excluded 'just soil'.

5. Avoid anomalies such as cow pies or oil spills.
6. Keep records of..
    a. sampling units
    b. soil types
    c. slope
    d. historic crops and yields
    e. size and ability to fertilize each area

1.4 Sampling Methods

1. Land Grant University (Texas A&M AgriLife Extension) aka “professional judgement”
2. Simple Random Sampling
3. GPS Grid Method

Learning Expectations & Knowledge Checks (Soil Sampling):

1. Be familiar with recommended tools for soil sampling.
2. Be familiar with protocols for taking representative samples and why this is important.
3. Demonstrate knowledge of general guidelines for soil sampling.
4. Demonstrate knowledge of sampling approaches and when and when not to use them.

2. Soil pH and Limestone Recommendations

Maintaining soil pH in the proper range is critical to ensuring that plants are able to take up and utilize nutrients. The term pH is chemistry shorthand for the "negative logarithm (p) of the concentration of hydrogen (H) in solution. In the soil we assume the solution is mostly water and all potentially soluble constituents, including H+ ions and nutrients are dissolved within it – or in a solid phase in equilibrium with the dissolved phase.

2.1 Water and Soil Solution Chemistry of pH

Pure water participates in a dissolution reaction as follows:

$$H_2O \leftrightarrow H^+ + OH^-$$

The products of the dissolution of water are H^+ and OH^-, making water both a weak acid and a weak base. In pure water the concentrations of H^+ and OH^- are both 10^{-7} M (*where M = moles per liter*).

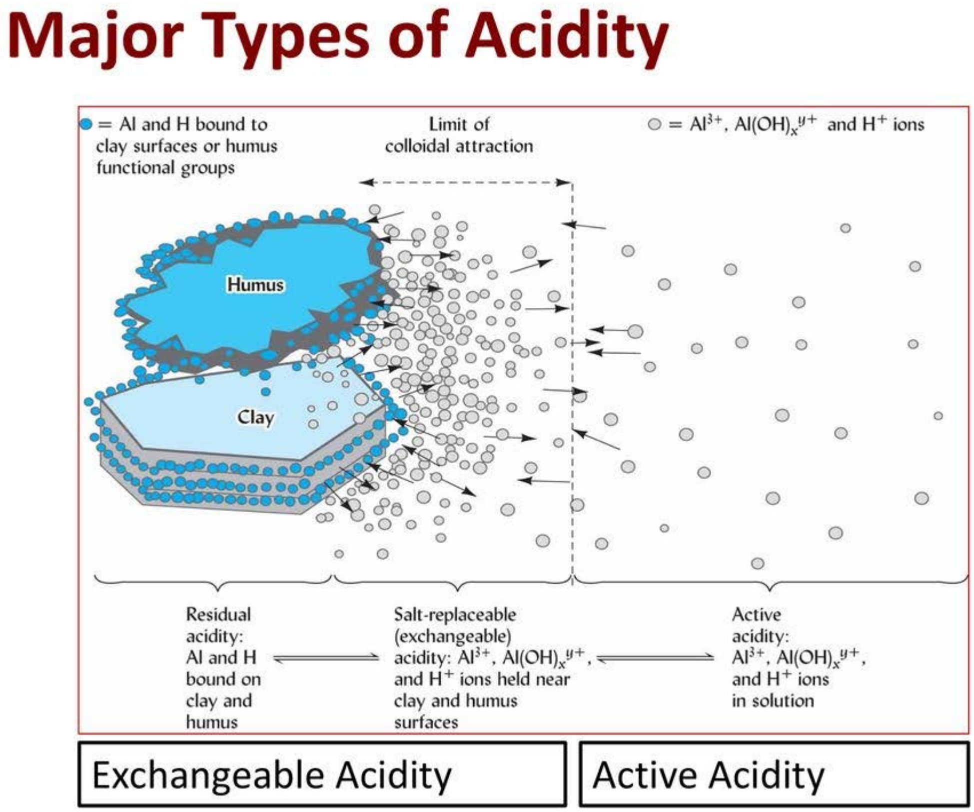
$$[H^+] \text{ x } [OH^-] = [10^{-7} \text{ M}] \text{ x } [10^{-7} \text{ M}] = 10^{-14} \text{ M} = Kw$$

where – Kw is the dissociation constant for water. (i.e. the product of H^+ and OH^- concentrations will always be 10^{-14} M).

$$pH = -\log(H^+) = log\frac{1}{(H^+)}$$

Notice that this equation states that as [H+] increases, the magnitude of the pH value decreases. And because the relationship is logarithmic (base 10), each unit increase in pH represents a 10 x decrease in H^+ or a 10 x increase in OH^-. Solutions with pH < 7 are acidic. Solutions at pH 7 are neutral. Solutions at > pH 7 are alkaline. Soil pH measurements represent H+ in solution and do not measure the undissociated or *potential* acidity.

Soil solution pH range	pH classification
< 4.5	Extremely acidic
4.5 - 5.0	Very strongly acidic
5.1 - 5.5	Strongly acidic
5.6 - 6.0	Medium acidic
6.1 - 6.5	Slightly acidic
6.6 - 7.3	Neutral
7.4 - 7.8	Mildly alkaline
7.9 - 8.4	Moderately alkaline
8.5 - 9.0	Strongly alkaline



2.2 Soil pH Measurement

Different approaches to measuring soil pH will result in different measurements. The use of accurate pH meters and pH electrodes is a standardized practice at soil analysis laboratories, however, the ratio of soil to water may differ. The more water used, the more dilute the concentration of H^+ ions. The three most common approaches used include:

#	Soil : Water Ratio	Considerations
1	1:1	Good for sandy and loam soils. Clayey soils will not be wet enough
2	1:2	Used by Texas A&M SWFTL and provides sufficient water to measure clays in suspension.
3	Saturated Paste	More closely resembles real soil conditions. Requires subjective assessment by technicians (how much is enough?)

Many labs attempt to compensate for the effect of different concentrations of salt in soil by using a solution other than water, such as 0.01M $CaCl_2$ or 0.1 M KCl. Consider the following figures from (Miller and Kissel, 2010 SSSAJ Vol 74:No.1, Left) and (Sonmez et al., 2008 Geoderma 144, Right)

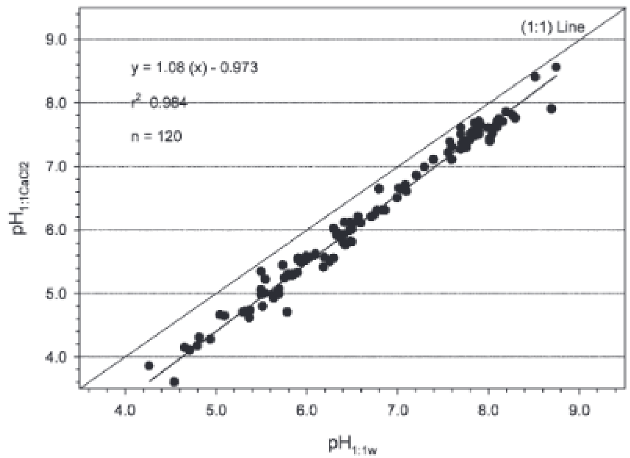


Fig. 1. Relationship between soil pH in a 1:1 water suspension ($pH_{1:1w}$) and pH in a 1:1 0.01 mol L^{-1} $CaCl_2$ suspension ($pH_{1:1CaCl2}$) for 120 soils from the North America Proficiency Testing program, 2000 to 2005.

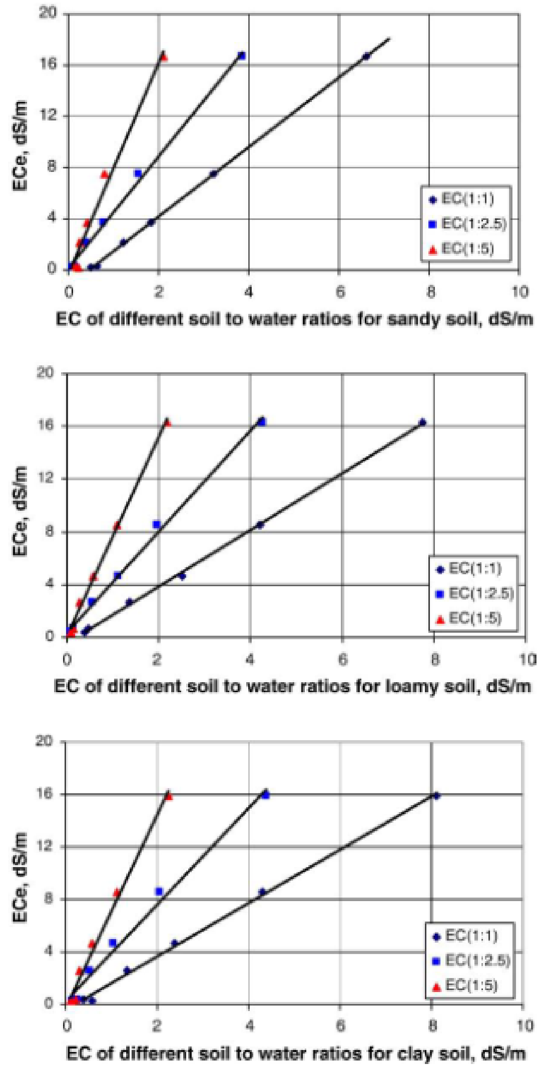


Fig. 1. Relationships of saturated paste electrical conductivity with different soil to water ratios depending on soil texture.

2.3 Soil pH Interpretation

At pH 5.2 and below, aluminum (Al^{3+}) and magnesium (Mn^{2+}) are much more soluble and therefore increase activity in soil solution. Both are toxic to roots. The actual target pH will be crop dependent. Measured values for the same soil often change during the course of year due to different salt contents. Finally, clays have a higher pH buffer capacity than sandy soils and will therefore seasonal changes will appear less substantial.

It is important to manage soil pH to ensure optimized nutrient recover by crops. Although never 100%, nutrient use efficiency can decline sharply as pH values diverge from neutral (pH 7.0). Different nutrients have different optimal pH values at which they are most soluble and accessible to plants.

2.4 Raising Acid Soil pH

Use good quality limestone (high purity and fine particle size) and till in whenever possible. This ensures the most reactive surface area of the particles is exposed to soil solution to dissolve and neutralize acidity. See the included AgriLife Extension publication “Soil Acidity and Liming” for further details.

Learning Expectations & Knowledge Checks (Soil pH and Liming):

1. Understand the dissociation reaction for water and why it is important to pH.
2. Demonstrate knowledge of the major types of soil acidity.
3. Demonstrate knowledge of how soil pH is measured, and the approved method for NM planners in Texas.
4. Understand how pH affects nutrient availability and plant root health.
5. Demonstrate knowledge of liming material types and assessment of lime strength or quality.
6. Understand what electrical conductivity or soil conductivity measures.

3. Nitrogen Testing in Soils

Soils may be analyzed for several forms of nitrogen (N). The most common include ammonium (NH_4^+), nitrate (NO_3^-), and total N. Nitrate is the only form recommended by Texas A&M AgriLife Extension for routine prediction of plant available N. Ammonium N is often rapidly converted to nitrate N in a process called nitrification. Its relative instability, therefore, makes it a poor predictor. Total N is comprised of all forms of N present in the soil, of which most is organic N. The mineralization of organic N is dependent upon many conditions making it also a poor predictor of plant available N.

NO_3-N is measured by first extracting it from the soil using a displacing salt solution. The Texas A&M AgriLife Extension approved extraction is done with 1 M KCl (potassium chloride), which may nearly completely liberate all NO_3-N present. The extract is filtered and then run by photometric or colorimetric determination using the Griess-Ilosvay color forming procedure. In this procedure, all NO_3-N in the filtered extract is chemically reduced to nitrite-N (NO_2-N) by passing through a copperized (reduced) cadmium flow column. The NO_2-N will then form a magenta color when reacted with sulfanilamide and coupled with N-1-naphthyl ethylenediamine dihydrochloride (NED). The color is detected by a detector at 520 nm, and the intensity of the color is linearly related to the concentration of NO_2-N in the extract. Texas A&M AgriLife Extension refers to the procedure as NO_3-N by cadmium reduction colorimetry.

3.1 Considerations for Interpretation

1. Nitrate is also subject to chemical changes in soil, including microbial and plant biomass incorporation, leaching, and denitrification.
2. Should therefore be sampled as near to planting time as possible to avoid miscalculations.
3. In clayey soils and clay loams, NO_3-N leaching is so slow that samples taken to 24" may be used to credit (reduce) fertilizer N applications, *or be used to reduce appropriate land application of manures*.

Learning Expectations & Knowledge Checks (Nitrogen Testing in Soils):

1. Know the forms of N commonly tested for in soil laboratories and the form recommended by Texas A&M AgriLife Extension for use as a predictor of plant available N.
2. Know the approved method by which routine soil N for fertilizer recommendations.
3. Understand the considerations for good sampling timing and N credits.

4. Phosphorus Testing in Soils

Because phosphorus (P) in soils is highly reactive and only sparingly soluble, only a small percentage of the P present will ever become available to plants. Usually <1% of total soil P is found in the soil solution. Therefore, extractants that are more aggressive than simple salt solutions (e.g. 1 M KCl) are required to access potentially plant available P. These extractants are developed according to regional application, usually based on predominant soil characteristics.

The method approved by Texas A&M AgriLife Extension is the Mehlich 3 extraction followed by analysis on inductively coupled argon plasma atomic emission spectrometer (ICP-AES). The Mehlich 3 extractant contains NH_4NO_3 (to provide both cation and anion displacement from the clay colloids for measurement of a number of other nutrients), NH_4F (*fluoride is a selective displacement anion for sorbed* PO_4^-), acetic acid (*to provide moderate dissolution of the P containing mineral apatite (*$\underline{Ca_{10}}(\underline{PO_4})_6(OH,F,Cl)_2$*)*), nitric acid, and EDTA (to chelate other micronutrients). The soil extract is filtered and analyzed on ICP-AES.

This method has performed well across many different soil types in the state of Texas. It is more flexible than Bray (applicable to acid soils) and Olsen (applicable to calcareous alkaline soils). It is very important to note that different extractants will provide different numbers and should therefore not be considered interchangeable… at all.

4.1 Considerations for Interpretation

Crop requirements should be considered carefully as different species have different P needs. Recommendations are to be based on yield goals. P can become stratified (concentrated in the top 2-3"), reducing its availability when upper strata of soil are dry. Tillage and irrigation can affect rooting patterns and distribution of soil P with depth in the soil profile. Disturbance (i.e. tillage) is sometimes required to correct stratification and re-distribute P with depth.

The source of P fertilizer (whether chemical or manure) will affect its use efficiency. Alkaline calcareous soils in the state have high immobilization factors (up to 100%), meaning that applied P may be completely tied up for some period of time in soil reactions that leave it unavailable for plant uptake.

1. P is the most long-term limiting nutrient in Texas soils
2. Critical for early development of plant root and shoot growing points.
3. Critical level for most crops is 50 ppm Mehlich 3 P.

Learning Expectations & Knowledge Checks (Phosphorus Testing in Soils):

1. Know the Texas A&M AgriLife Extension approved method for extracting and measuring soil P and why P extracts are regionally based.

2. Understand the rational behind the extractant used and its basis in soil P behavior.
3. Understand the considerations for interpretation and the critical level for soil P.

5. Potassium Testing in Soils

Though extraction with neutral ammonium acetate has been used in the past, Mehlich 3 extract is the current recommended extractant for soil potassium (K) in Texas. The convenience of using a single extractant to access and accurately estimate multiple plant nutrients' availabilities from soil reduces the time, cost, and labor in soil testing. In fact, Mehlich 3 efficiently extracts P, K, Ca, S, Mg, and Na from soils for analysis by ICP-AES.

Because K is primarily located on cation exchange sites on the surface of clay particles, the component of the Mehlich 3 extract that liberates it from the soil is the cation displacement provided by NH_4NO_3. In certain illitic soils (found in the panhandle) substantial soil K may be located in the interlayers between microscopic crystalline mineral sheets. When this is the case, the Mehlich 3 extract may not access potentially available K. However, interlayer K may *or may not* be liberated in meaningful quantities during the growing season. This will depend on how wet the soil becomes for long periods of time.

5.1 Considerations for Interpretation

Different crops have different needs for K. Forages tend to have high requirements, and removal (i.e. haying) will necessitate replacement at greater rates. Hay harvests may remove 30-50 lbs K_2O per ton per acre. K may leach easily from sandy soils. In clayey soils with substantial CEC, K is conserved on sorption sites. However, high sodium levels in soils can easily displace K from CEC.

Learning Expectations & Knowledge Checks (Potassium Testing in Soils):

1. Know the extractant and analysis method for K in Texas.
2. Understand the rationale behind the use of the extractant and its basis in K behavior in soils.
3. Understand the considerations for interpretation of potassium soil test results.

6. Soil Test Reports and Resources

Learning Expectations & Knowledge Checks (Soil Test Reports and Resources):

1. Understand the layout of a Texas A&M AgriLife Extension soil test report and be prepared to answer questions regarding its interpretation from an example.
2. Know the definition of critical level.
3. Know the units used in the soil test analysis results, and those used in the fertilizer recommendations columns.
4. Understand how to interpret graphic ranking of results in terms of probability of crop yield response to added fertilizer.

SOIL FERTILITY AND FERTILIZERS

1. Introduction

Justus von Liebig (1803-1873), a German chemist considered the father of soil fertility, may have been the first to formally emphasize the role of nitrogen (N), phosphorus (P), potassium (K) and and other 'trace minerals' as essential plant nutrients. It was Liebig who proposed the 'Law of the Minimum' which states that plant growth is not determined by the total resources available, but by the scarcest available resource. In other words, a plant's maximum growth will be determined by the single most limiting nutrient. The corollary to this is that a plant cannot compensate for a limiting nutrient through substitution of another.

Knowledge of plant nutrient requirements is not only crucial to successful crop production, along with the behavior of certain nutrients in soil and water, it is also a central component of protecting natural environmental resources. There are 16 nutrients considered 'essential' to plant growth. Without any one of these nutrients, a plant will either die or fail to complete its life cycle. There are other 'beneficial' nutrients that should not be confused with essential nutrients, as a benefit may be observed when present, but their absence does not cause death or life cycle interruption.

2. Essential Plant Nutrients

What are the criteria for selection as a plant essential nutrient?

1. Plant cannot complete vegetative or reproductive cycles without that nutrient.
2. Nutrient must be directly involved in the nutrition of all plants.
3. In most cases, the deficiency can be corrected by addition of that element only by itself.

The 16 essential plant nutrients consist of a set of elements and molecular compounds that can be grouped into 4 distinct classes:

1) the structural elements,
2) the primary macronutrients,
3) the secondary macronutrients, and
4) the micronutrients.

2.1 The Structural Elements

Carbon	(C)
Hydrogen	(H)
Oxygen	(O)

The structural elements are derived from atmospheric carbon dioxide and water. Plants incorporate these elements through the process of photosynthesis (below). All other nutrients are taken up by plants as minerals dissolved from the soil matrix into the soil solution.

6 CO_2 (carbon dioxide) + 12 H_2O + photons from sunlight (672 Kcal light energy) →

$C_6H_{12}O_6$ (glucose) + 6 H_2O + 6 O_2

2.2 Primary Macronutrients

Nitrogen (N)
Phosphorus (P)
Potassium K)

Primary macronutrients are required by plants in the greatest amounts. They are commonly applied as fertilizer at higher rates than other nutrients.

2.3 Secondary Macronutrients

Calcium (Ca)
Magnesium (Mg)
Sulfur (S)

Secondary macronutrients are generally required in smaller amounts than the primary nutrients.

2.4 Micronutrients

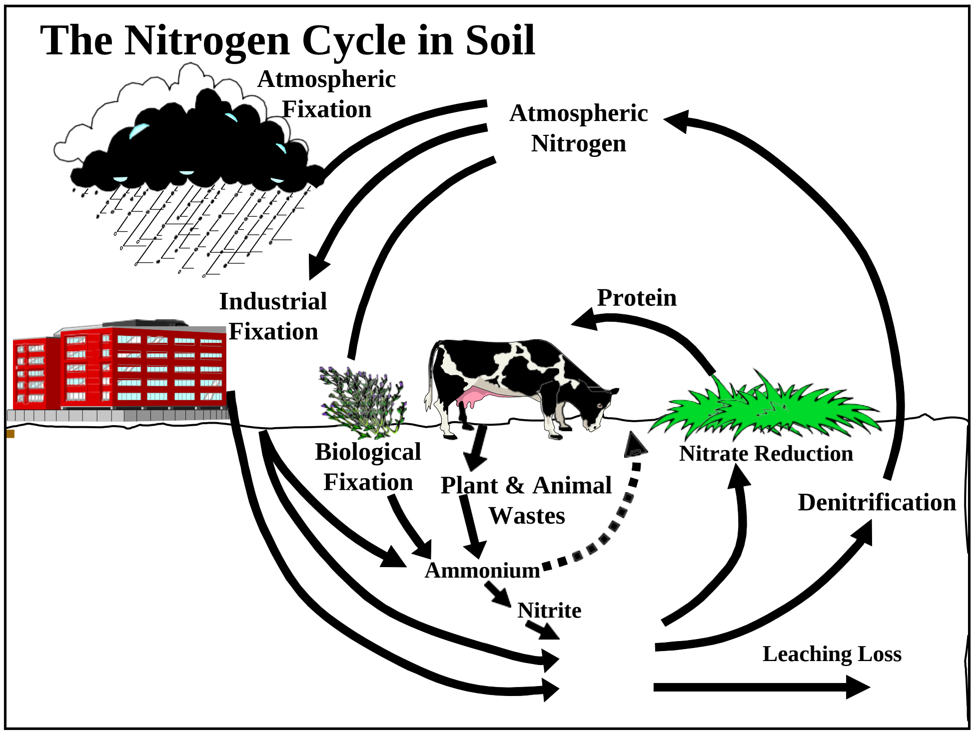
Boron (B)
Chlorine (Cl)
Iron (Fe)
Manganese (Mn)
Molybdenum (Mo)
Copper (Cu)
Zinc (Zn)

Micronutrients are required in very small amounts compared to either primary or secondary macronutrients. They are often supplied in adequate concentrations through the normal turnover of organic matter in soils.

Learning Expectations & Knowledge Checks (Essential Nutrients):

1. Know the 16 essential nutrients for plants and how they are classified/grouped.
2. Understand what Liebig's law of the minimum tells us about plant growth.

SOIL FERTILITY AND FERTILIZERS
3. Nitrogen



Nitrogen is required by plants in the largest amounts behind only water. Nitrogen promotes growth, increases vegetation (leaf size and quality), and hastens crop maturity. Soils in Texas are frequently low in available nitrogen, although high yielding grain crops and legumes may carry over to subsequent crops. Soils with substantial clay contents in the upper Gulf Coast, Blacklands, or Panhandle regions of Texas will undergo very slow leaching of nitrogen, leaving significant amounts of N available to crops within the root zone but below the 6" conventional soil sampling depth. For this reason, sampling for nitrogen to 24" or deeper is recommended for soil nitrogen status assessment.

Total N content ranges from 0.02 - 0.5% in mineral soils, and increases with organic matter content. >95 % of total N in soil occurs as organic N.

Example: If the surface soil (~6" deep) of a field contains 0.2 % N, then:

Assume 1 acre of soil to 6 " is equal to 2,000,000 lbs.

$$\frac{2{,}000{,}000\ lbs\ soil}{acre}\ x\ 0.2\%\ N = 4{,}000\ lbs\ total\ N$$

If all of this N were available to plants, then no fertilizer additions would be necessary. Even the inorganic fraction, which might represent up to 2-5% of total N, would feed a crop (80 -200 lbs N). However, only a small fraction of this N is plant available. Inorganic N compounds include NH_4, NO_3, NO_2, N_2O (gas), NO (gas), and elemental N_2 (gas).

3.1 Characteristics and functions:

- Plant available forms: Absorbed by plants as nitrate (NO_3^-) and to a lesser extent ammonium (NH_4^+).
- Mobility in soil: NH_4^+ not mobile because it is a cation and is attracted to soil particles. NO_3 can leach because it is an anion and not attracted to soil particles.
- Mobility in plants: Readily translocated in plants. Deficiency symptoms show up first in lower (older) leaves.
- Functions in plants: Essential for synthesizing amino acids, the building blocks of proteins. Vital for compounds such as chlorophyll, nucleic acids, and enzymes.
- Deficiency symptoms: Slow growth and stunted plants.
  Yellow-green color (chlorosis).
  V-shaped "firing" of tips and margins of leaves, beginning with older leaves.

3.2 Nitrogen Reactions in the Soil

3.2.a Mineralization: Microbiological breakdown of organic-N to ammonium-N

- Affected by soil factors which influence microbial activity - pH, temperature, moisture
- Occurs readily when C:N ratio of organic material is < 20:1

$RNH_2 + H_2O + H^+ \leftrightarrow ROH + NH^+$ (where R = organic molecule)

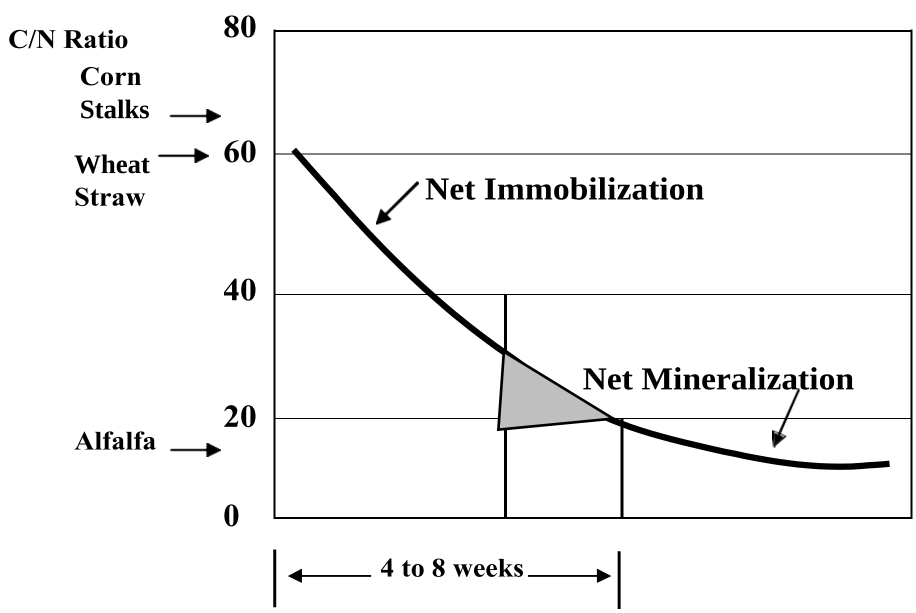
3.2.b Immobilization

Microbiological absorption of plant available N into microbial biomass

- Occurs when C:N ration of organic material is >30:1
- More likely for corn and small grains (C:N 50-70:1) than for legume crops (15-20:1)

$$NH^{+} + ROH \leftrightarrow RNH_2 + H_2O + H^{+}$$

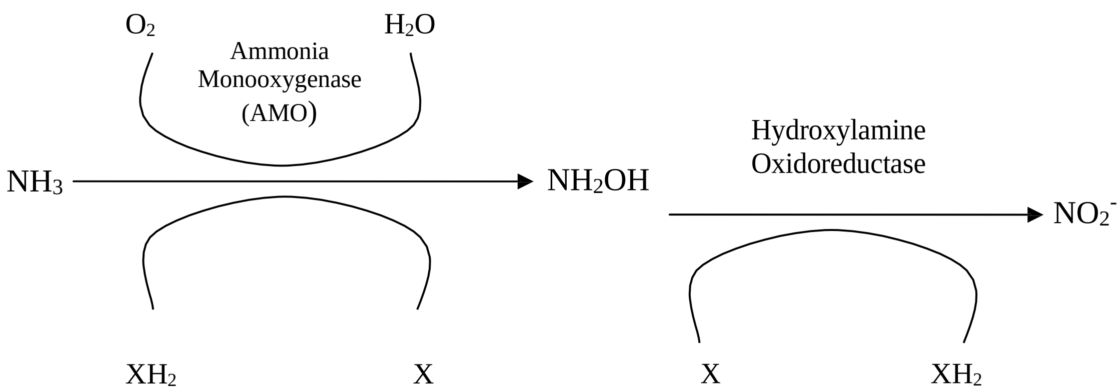
Effects of C:N Ratio on N Mineralization



3.3.c Nitrification:

Two step microbiological oxidation of ammonium (NH_4^+) to nitrate (NO_3^-) through a nitrite (NO_2^-) intermediate.

Overall Reaction:	$NH_4 + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$
Step 1:	$NH_4 + 1½O_2 \rightarrow NO_2^- + H_2O + 2H^+$
Step 2:	$NO_2^- + ½O_2 \rightarrow NO_3^-$



Enzymatic pathway for oxidation of ammonium to nitrite. X and XH_2 are the oxidized and reduced forms of the electron donor. NH_4^+ is oxidized for energy for the fixation of CO_2 via the Calvin cycle

Important to Remember!!

- Oxygen is always required for nitrification to proceed. Therefore, this reaction will become limited in waterlogged or severely compacted soils.
- Nitrifying bacteria are highly sensitive to soil pH (optimum range = 5.5 - 8.8)
- Optimum temperature range = 60ºF to 104ºF. Very little activity near freezing point.

3.2.d Denitrification: Microbiological reduction of nitrate (NO3-) to N2 gas under anaerobic or low oxygen conditions

$$5CH_2O + 4NO_3^- + 4H^+ \leftrightarrow 2N_2 + 5CO_2 + 3H_2O$$

- Some bacteria can use the oxygen from nitrate when O_2 becomes limiting
- Occurs when soils become waterlogged (anaerobic) for extended periods
- Losses of N to atmosphere range from 20% to 40%

3.3 Primary (Chemical) Fertilizer Sources for N

Fertilizer Source	Formula	%N-P-K
Dry Granular or Prilled		
Ammonium Sulfate	$(NH_4)_2SO_4$	21-0-0 (24%S)
Ammonium Nitrate	NH_4NO_3	34-0-0
Urea	$CO(NH_2)_2$	46-0-0
Gaseous		
Anhydrous Ammonia	NH_3	82-0-0
Liquid		
Urea Ammonium Nitrate (UAN)	$CO(NH_2)NH_4NO_3$	32-0-0
Ammonium Polyphosphate	NH_4PO_3	10-34-0 *or* 11-37-0

3.4 Use Considerations for N Fertilizers

1. Ammonia Volatilization - gaseous loss of NH_3 is affected by soil pH, CEC, SOC, texture, mode of application, and fertilizer source

   Occurs when:
   - Ammonium fertilizer is <u>surface</u> applied to high pH and/or calcareous soils
   - Urea is <u>surface</u> applied to any soil
   - Anhydrous ammonia not properly applied to any soil

   Prevention:
   - Proper application/incorporation
     i.e., injection, tillage, irrigation

Examples:

1) Ammonia sulfate applied to calcareous soil
   $(NH_4)_2SO_4 + CaCO_3 \leftrightarrow CaSO_4 + NH_3 + CO_2$

   Ammonium sulfate reacts with calcium carbonate to form calcium sulfate (gypsum), ammonia, and carbon dioxide.

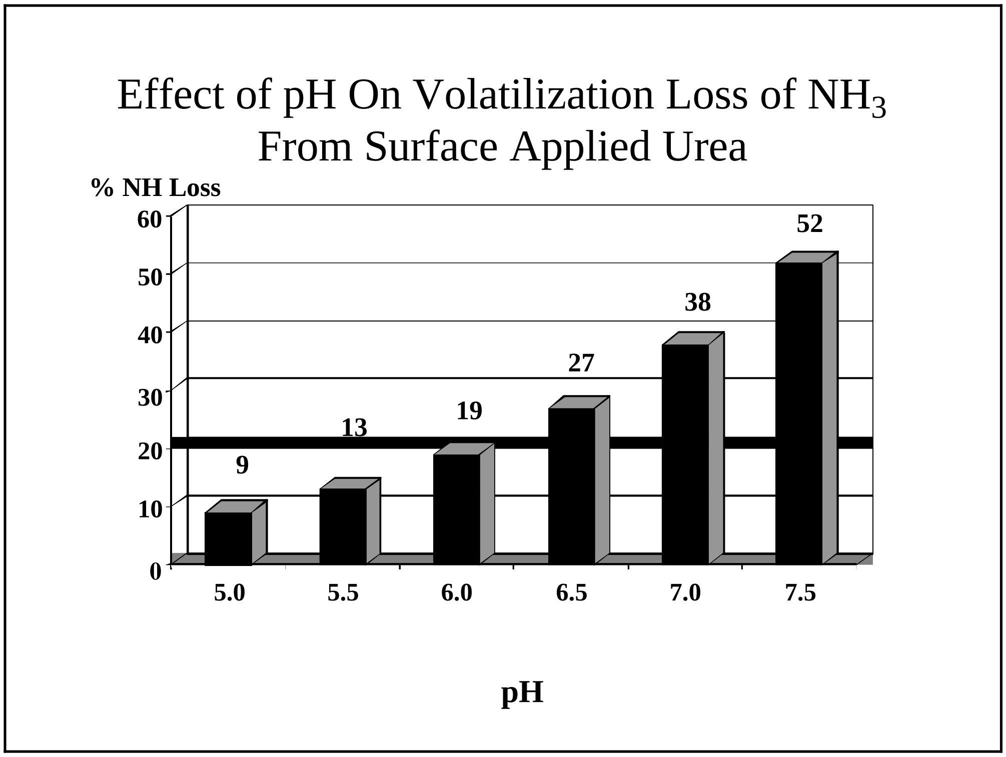
2. Urea hydrolysis
   $CO(NH_2)_2 + H_2O$ (urease enzyme) $\leftrightarrow 2NH_3^+ + CO_2$

   Urea is converted readily in the soil environment when even small amounts of water are present as the urease enzyme is excreted by a wide range of microorganisms

3. Dissociation of ammonium
   $NH_4^+ \leftrightarrow H^+ + NH_3$

This reaction in solution is governed by pH. The rate of volatilization of NH_3 from solution to the atmosphere is governed by:

- Concentration of NH_3 in solution
- Temperature
- Partial pressure of NH_3 gas at the air:soil solution interface



1. Losses by Water Transport

   Occurrence:
   - Surface runoff - all forms/fertilizer sources of N
   - Leaching - nitrate-N

   Management:
   - Method of application - incorporation/injection
   - Timing of application - at time of crop need
   - Rate of application – excess applied an not taken up by plant is vulnerable to all forms of loss

2. Residual Acidity

   Occurrence:
   - All ammonium sources produce acidity during nitrification.
   - Ammonium sulfate {$(NH_4)_2SO_4$} produces 2X as much as Anhydrous NH_3 or Urea.

Management:

- Acid soils - use fertilizer sources other than $(NH_4)_2SO_4$
  Lime as recommended by soil test pH.

Equivalent Acidity of Nitrogen Fertilizer Carriers

Source	**Nitrogen**	**Equivalent Acidity (Per 100 lbs.)**	
		Fertilizer	**Nitrogen**
	%	**…. Lbs. $CaC0_3$ …**	
Ammonium Sulfate	**21**	**110**	**520**
Anhydrous Ammonia	**82**	**148**	**180**
Ammonium Nitrate	**34**	**62**	**180**
Urea	**46**	**71**	**150**
32-0-0 Solution	**32**	**57**	**180**

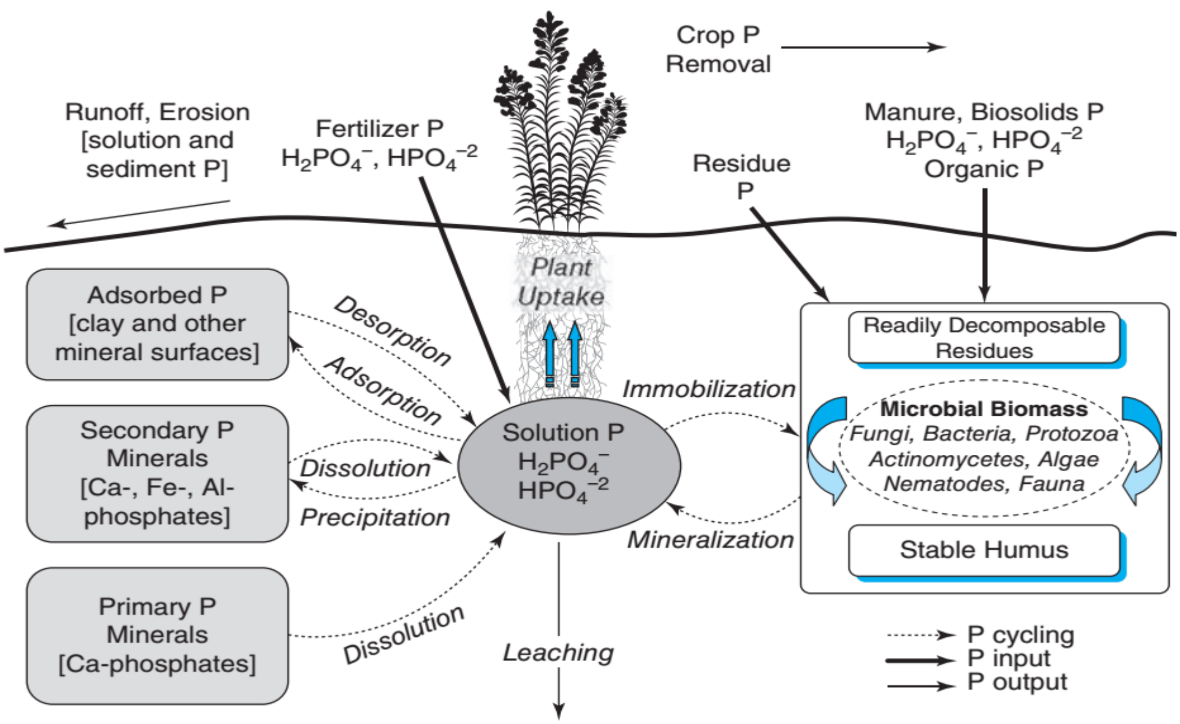
Learning Expectations & Knowledge Checks (Nitrogen):

1. Know the most important forms of N that exist in soils and which forms are plant available.
2. Know different characteristics that affect fate of two plant available forms of N in soil.
3. Know the four major reactions that chemically transform nitrogen in soils and under what conditions each is likely to occur
4. Be prepared to answer questions on use considerations for N fertilizers.
5. Know how N fertilizer inputs can be 'lost'.
6. Understand how different N fertilizer sources cause soil acidification.

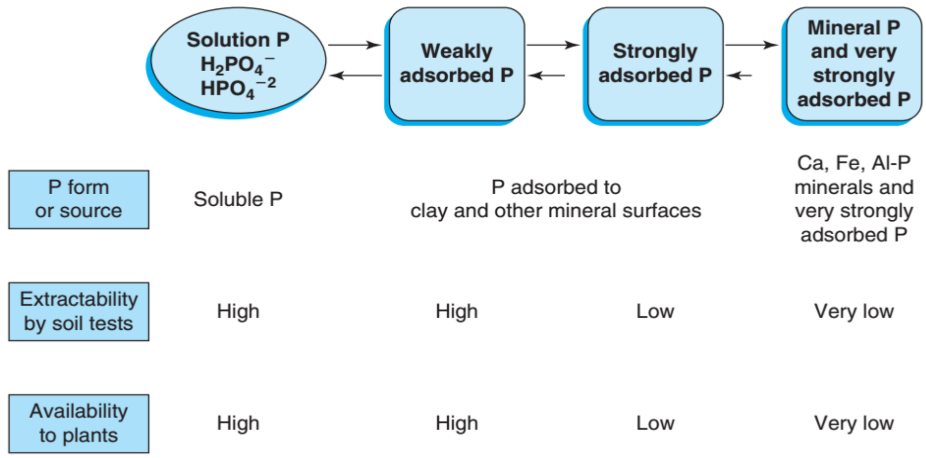
SOIL FERTILITY AND FERTILIZERS
4. Phosphorus

Phosphorus (P) cycling in soil is complex and the majority of reactions favor outcomes other than releasing plant available P into soil solution. The amount and form of P in soil solution depends on the soil pH. $H_2PO_4^-$ and HPO_4^{2-} are the soluble and plant available forms. Soil solution concentrations varies among soil types from 0.003 to 3 ppm P with an average concentration of 0.05 ppm. With such a low concentration available to plants (dissolved and ready for uptake), the soil solution must be replenished in order to supply the quantities of P normally accumulated in plant tissue (~0.3%).

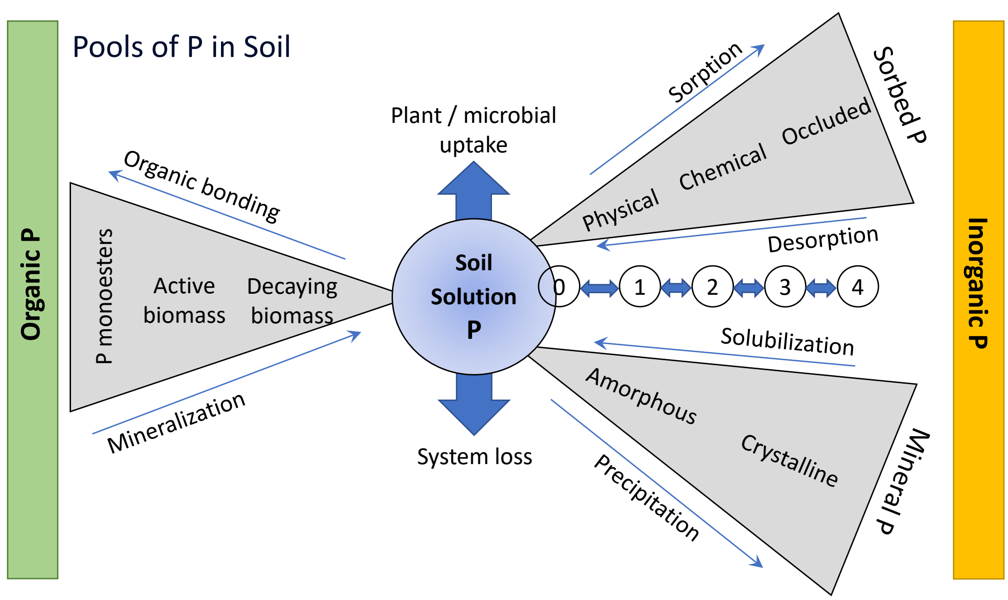
The replenishment occurs as a function of chemical gradient or equilibrium demand on soil P reserves as solution concentrations become depleted. Reserves come from a number of ‘locations’ in the soil matrix, including adsorbed P, sparingly soluble secondary minerals, and mineralization of organic P. However, it is important to understand that resupply is not instantaneous. The diffusion rate for $H_2PO_4^-$ is 0.13 mm / day, whereas the rate for NO_3^- is 3.0 mm / day.



4.1 Forms of P in soil



Reserves of soil P may be in the form of weakly adsorbed P associated with clay and other mineral surfaces. As P becomes more strongly sorbed to soil surfaces, it becomes more resistant to release back into soil solution. At some point, sorbed P may become occluded, or covered over, by amorphous Fe- and Al-hydroxide minerals, preventing access by plants. Soil P may also form very strong mineral complexes such as apatite that are highly unlikely to dissolve. These progress from sparingly soluble amorphous mineral forms to insoluble crystalline minerals.



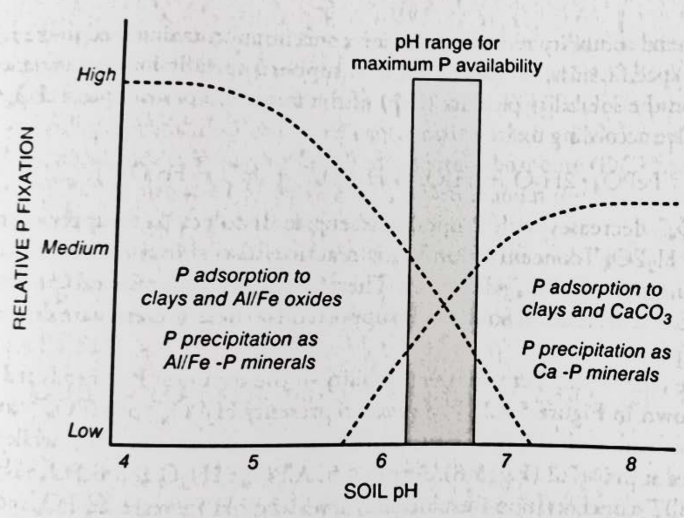


Figure 5-11 *Relative effect of soil pH on P adsorption and precipitation.*

4.2 P Characteristics and Functions

- Plant available forms: Absorbed by plants as primary orthophosphate ($H_2PO_4^-$) or secondary orthophosphate (HPO_4^{2-}).

- Mobility in soil: Not mobile because of reversion to insoluble forms - Ca phosphates in alkaline soils and Fe and Al phosphates in acid soils. Low coefficient of diffusion.

- Mobility in plants: Readily translocated (mobile) in plants. Deficiency symptoms show up first in lower (older) leaves.

- Functions in plants: Essential for energy formation, transfer and storage.
  Stimulates early growth and root formation.
  Hastens maturity and promotes seed production.
  Legume crops such as alfalfa and clover require large amounts of P.

- Deficiency symptoms: Slow growth and stunted plants.
  Purplish coloration, mostly older leaves.
  Delayed maturity.
  Poor grain, fruit or seed development.

4.3 Factors Affecting P Availability

Soil Reaction - optimum pH range is from 6.5 to 7.0

- Acid soils fix P as iron and aluminum phosphates.
- Alkaline soils fix P as calcium phosphates.

Clay Content - rate and amount of fixation greater in fine-textured, clay soils.

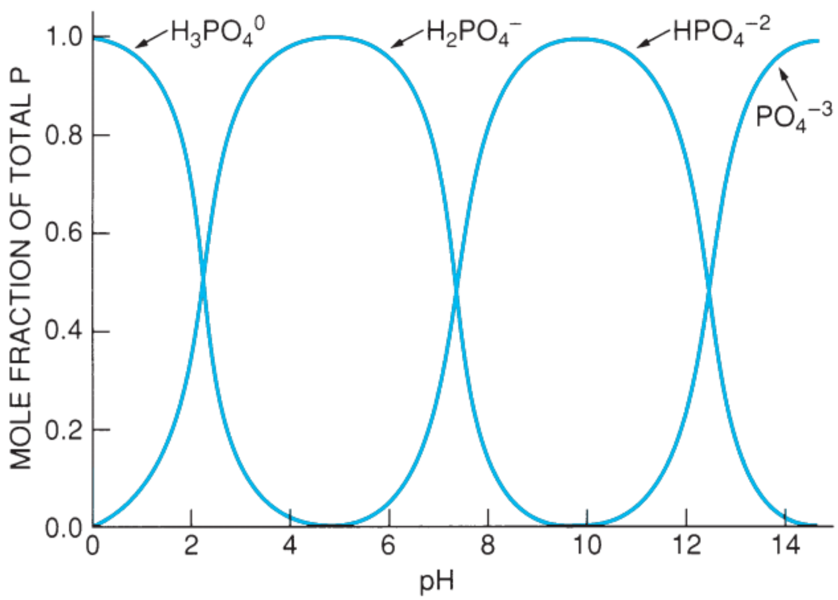
- Greater surface area/CEC for reaction with P fertilizers.

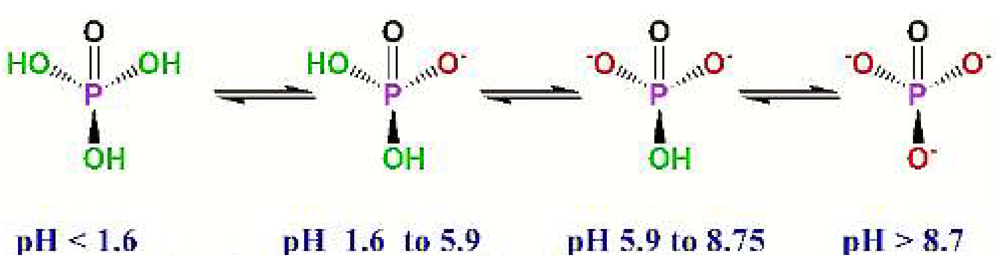
Time of Reaction - the longer that a P fertilizer is in contact with the soil, the more likely fixation into plant unavailable forms will occur.

- Timing application with crop need very important.

Method of Application - surface broadcasting and/or incorporation increase rate of fixation.

- Banding recommended on soils with high fixation potential.





4.4 Primary Fertilizer Sources for P

Source	Formula	N-P-K
Ordinary superphosphate	$Ca(H_2P0_4)_2$	0-20-0 (11% S)
Triple superphosphate	$Ca(H_2P0_4)_2$	0-45-0 (15% Ca)
Monoammonium phosphate (MAP)	$NH_4H_2PO_4$	12-61-0
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	18-46-0
Ammonium polyphosphates	$NH_4 PO_3$	10-34-0 *or* 11-37-0

4.5 Use Considerations for P Fertilizers

1. Reversion/Fixation of P Fertilizers

Occurrence:

- Will occur on acid and alkaline soils.
  Reversion - in alkaline soils P reacts with calcium to form insoluble Ca-phosphates similar to the rock phosphate from which it was produced.
  Fixation - in acid soils P reacts with Fe and Al to form insoluble compounds.

Management:

- Timing of application - match with crop need. Allow minimum time for reversion to occur.
- Band or in-row with seed applications to improve availability.
- Apply NH_4 fertilizer with P fertilizer to improve P availability.

2. NH_3 Volatilization/Seedling Injury

Issue:

- MAP produces soil pH of 3.5 near the fertilizer granule. DAP produces soil pH of 8.0 near the fertilizer granule. On high pH/calcareous soils, DAP can result in NH_3 volatilization/ammonia injury/toxicity to seed.

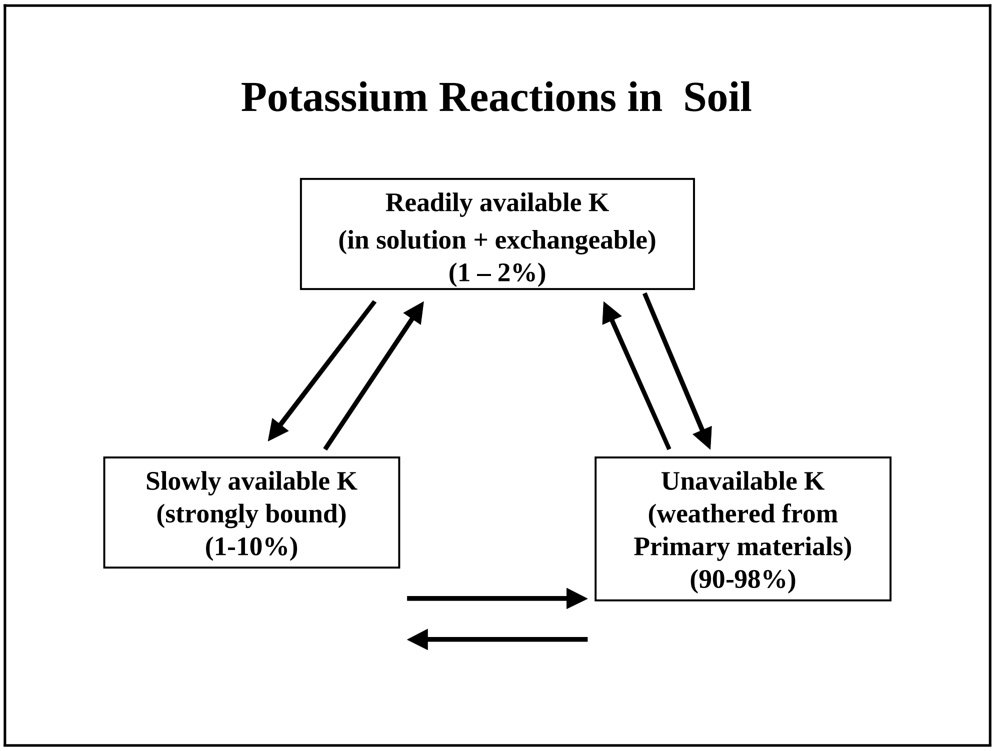
Management:

- MAP recommended for alkaline soils. Acid pH prevents formation of NH_3 and may help with micronutrient availability.
- DAP recommended for acid soils.

Learning Expectations & Knowledge Checks (Phosphorus):

1) Know the forms of P in soil that are plant available.
2) Be familiar with the reactions that limit P availability in soils.
3) Be familiar with use considerations for P fertilizer

SOIL FERTILITY AND FERTILIZERS
5. Potassium



5.1 Characteristics and functions

• Plant available forms:	K taken up by plants in the form of potassium ions (K^+)
• Mobility in soil:	Will not leach in most soil medium and fine-textured soils. Some leaching possible in very sandy soils with low CED.
• Mobility in plants:	Readily tanslocated in plants. Deficiency symptoms show up first in lower (older) leaves.
• Functions in plants:	Controls opening and closing of stomates, regulating transpiration. Essential for translocation of sugars and for starch formation. Increase disease resistance.

Important for stalk strength (reduces lodging).

- Deficiency symptoms: Tip and marginal burn starting with more mature leaves. Weak stalks result in lodging. Small or misshapen fruit.

5.2 Primary Fertilizer Sources for K

Source	Formula	% K_2O
Potassium chloride	KCl	60
Potassium sulfate	K_2SO_4	54
Potassium nitrate	KNO3	46
Potassium-magnesium sulfate	$K_2SO_4MgSO_4$	24

5.3 Use Considerations for K Fertilizers

1. Salt Injury

   - When KC1 applied in row with seed
   - Mainly a problem when there is low rainfall

   Management:
   - Know sensitivity of crop to salt
   - Band applications to the side of seed
   - Limit in-row N+K to 5 (sandy soils) to 10 lbs/A (other soils) for sensitive species

2. K Fixation
   - Most likely in non-swelling clay soils
   - Can reduce K availability

   Management:
   - Time application with crop need
   - Increase rates moderately to offset
   - Band applications

Learning Expectations & Knowledge Checks (Potassium):

1) Know the forms of K in soil that are plant available.
2) Be familiar with use considerations for P fertilizer