Nutrient Management Guidelines for Agronomic Crops

Grown in Mississippi

MISSISSIPPI STATE UNIVERSITY
EXTENSION

CONTENTS

Introduction to Nutrient Management

Managing plant nutrient inputs to sustain or optimize plant productivity economically while minimizing environmental consequences is the goal of soil fertility management. Nutrient management plans document available nutrients by source (inorganic or organic), crop production practices, and other management decisions that influence nutrient bioavailability, plant growth and productivity, and environmental stewardship**.** This publication integrates many years of research about the economic and environmentally responsible use of plant nutrients in Mississippi.

Nutrient management planning (NMP) is a best management practice, or BMP. It incorporates all nutrient inputs, whether organic materials, livestock production by-products, or commercial inorganic fertilizers.

What Is Nutrient Management Planning?

Nutrient management planning principles are the basic, sound fundamentals of good business management. Nutrient management planning is:

- knowing what you have,
- knowing what you need,
- managing wisely, and
- documenting your management.

Nutrient management plans are site-specific and tailored to the available inputs, soils, landscapes, and management objectives of the farm. They should be a blueprint to implement the four Rs: use the **right amount** of the **right fertilizer** at the **right time** in the **right place**. Following are steps to nutrient management planning:

1. Get accurate soil information for each field or management unit.
   a. Develop farm maps with soil series, surface water bodies, and other management concerns present in the landscape.
   b. Soil sample each field or management unit and process through a reputable soil testing laboratory. Note that some government programs in the state require that testing be done by the Mississippi State University Extension Service Soil Testing Laboratory.
2. Develop fair, realistic yield potential estimates for each field based on recent production history, agronomic practices, and soil potential.
3. Determine what plant nutrients may be required to reach the yield potential based on the soil test results. In some cases, you may need to consider nutrient uptake and removal data for common crops. This information is available from various resources, including this publication. It is important to distinguish between growing crop uptake versus nutrient removal in harvested biomass.

4. Determine plant-available nutrients provided by livestock by-product amendments such as broiler litter that may be used to fertilize the crop. The BMP is to sample the manures that will be used. Table values are available, but the accurate nutrient content of manure is site-, animal-, diet-, and management-specific (see Using Poultry Litter to Fertilize Agronomic Crops on page 23). More information on testing broiler litter is available in MSU Extension Publication 3749 Soil and Litter Testing Basics.

5. If manures were applied to previous crops, estimate any residual nutrient contributions. Usually, 50–60 percent of the nitrogen in animal manures is available to growing plants the first year following application. Subsequent manure nutrient use by plants without additional applications is usually on a declining scale for three growing seasons. The MSU Extension Service credits carryover from previous inorganic fertilizer applications in only specialized circumstances for some crops.

6. Environmental assessment tools such as the Mississippi Phosphorus Index (PI) are available to determine the potential risk of off-site phosphorus movement. Risk is evaluated on a field-by-field basis when animal by-products have been used previously and are being considered for the planning cycle. The PI incorporates site-specific soil conditions and applies BMPs in the evaluation process. Soil test phosphorus levels, soil permeability, field slopes, litter application rates, distance to surface water, and other factors are used to determine the probability of nutrient movement in the landscape. If the PI rating is low, NMPs may be based on crop nitrogen needs. If the PI is medium, additional BMPs may need to be used. If the PI shows a high potential risk for phosphorus movement in the landscape, nutrient management should be based on crop phosphorus requirements as determined by the soil test.

7. Apply rates of commercial fertilizers and/or animal manure to supply nutrients based on the soil test recommendations and the PI risk assessment process. Overapplication does not improve yields and increases the risk of environmental issues.

8. Keep records of nutrient sources, application dates, rates, methods, and climatic conditions. This simplifies future planning.

Nutrient Management

- Know your soils and fields.
- Be realistic about yield potential.
- Determine nutrient removal.
- Find out what is available from this year's application.
- Calculate nutrients available from previous applications.
- Assess the environmental risk of nutrient movement.
- Use common sense when putting nutrients out.
- Keep relevant field records.

This guide is a brief introduction to nutrient management in Mississippi. Practices used on particular farms will vary throughout the state due to soils, weather conditions, and other localized considerations. See MSU Extension Publication 3681 Best Management Practices for Plant Nutrient Management for more information on nutrient BMPs. For crop-specific information, see the MSU Extension Soils page or contact your county MSU Extension office.

The Soils of Mississippi

Soils form from parent materials, climate, biological factors, and topography interacting over time. The diverse factors present in Mississippi yield a wide variety of soils.

Three general land resource regions are recognized in Mississippi (Figure 1):

- An alluvial (water-deposited) flood plain along the current and former channels of the Mississippi River (the Delta).
- A loess region, which is a band of soils formed in windblown material adjoining the Delta.
- Coastal Plain areas, which make up the rest of the state.

The Mississippi loess and Coastal Plain regions have smaller units based on common soils, geology, climate, water resources, and land use.

Soils of the world are classified into 12 soil orders; seven have been found within Mississippi (Figure 2). About 260 individual soil series (the most specific soil classification) have been mapped in the state.

As human land management transitioned from before European colonization to the modern, mechanized era, the predominant surface activities within regions have evolved based on the underlying soil resource. About 75 percent of Mississippi's annually seeded crops, such as cotton, corn, and soybeans, are grown in the relatively flat, deep alluvial soils of the 18 Delta and partial-Delta counties conducive to mechanized farming. Animal production and forestry predominate in the shallower soils of the hills in east and south Mississippi.

Federal soil conservation efforts since the 1980s significantly reduced acreages of tilled crops in the hill regions with very erosive soils. Much of this repurposed acreage is planted in pine trees.

Southern Mississippi Valley Alluvium: The Delta

Mississippi Delta soils originate in sediments left by flooding of the various rivers in the region; it is not a traditional river delta. Much of the Delta region is used to produce annual crops; three-fourths of the total cropland is in the northern counties. Water management issues, including flooding, crop irrigation, and internal field drainage, are critical considerations for soil management in the region.

Delta soils are diverse at small scales due to the alluvial (flooding origin) parent material. Particle sizes within sediment deposits are smaller because they are farther from the originating stream (i.e., soils closer to running water have proportionally more large silt and sand particles than soils farther from the stream). Delta soils also reflect the long-term effects of surface water movement; soils formed under standing water differ from soils formed under running water.

Mississippi Delta soils with more clay particles (the smallest basic soil solid) have unique features. When these soils dry, small, round aggregates form at the surface. These resemble the pellets within shotgun shells and, accordingly, are often called "buckshot." These clay soils have very slow water infiltration rates, making them ideal for aquaculture and rice production.

Southern Mississippi Valley Uplands: Thin Loess Areas and Brown Loam Hills

When floodwaters receded in what is now the Delta, strong west to east winds blew dry sediment deposited by the floods to adjacent uplands. This wind-deposited material is called loess and is the parent material of soils formed in the hilly region along the eastern edge of the Delta. The depth of loess decreases from west to east across the state as the distance from the originating flooded lands increases.

This area, referred to as the Brown Loam region or Bluff Hills, has some very deep deposits, such as the bluffs outside Yazoo City. Natchez silt loam, a soil series found on about 170,000 acres in this area, is designated as the Mississippi state soil. Diverse agriculture is found in the loess region; however, erosion is a significant resource concern because the soils tend to erode when exposed.

Coastal Plain

Mississippi Coastal Plain soils occur on the edge of a soil region that forms an arc along the United States coast from New Jersey to Texas. These soils form on unconsolidated fluvial (stream or river) or marine sediments deposited at the edges of ancient seas. These soils usually are best suited to pastures and forests, but they can support other crops.

The northern portion of the Coastal Plain is commonly called the Mississippi Sand Clay Hills. The Southern Coastal Plain is the Piney Woods region of the state.

Blackland Prairie

Mississippi has two prairie regions: the Blackland Prairie of northeastern Mississippi in the Tupelo, Aberdeen, and Columbus area, and the Jackson Prairie in south-central Mississippi.

Many soils in these areas are very dark and are prone to developing wide cracks when dry. On the surface, they may look like Midwestern prairies. The Mississippi Blackland soils are formed in soft limestone or chalk parent material. Lighter color horizons underlie the very dark surface layers. Midwestern prairie soils form in glaciated areas predominated by grasslands where centuries of nutrient cycling produced soil with very high soil organic matter and dark soils throughout the profile. The Mississippi soils have lower organic matter levels.

The Mississippi prairie soils support a wide variety of agricultural production.

Gulf Coast Marsh

Zones of the marsh along the Gulf of Mexico are almost treeless, have marsh vegetation, and are uninhabited. This area is part of the estuarine complex that supports marine life. Most soils of the Gulf Coast

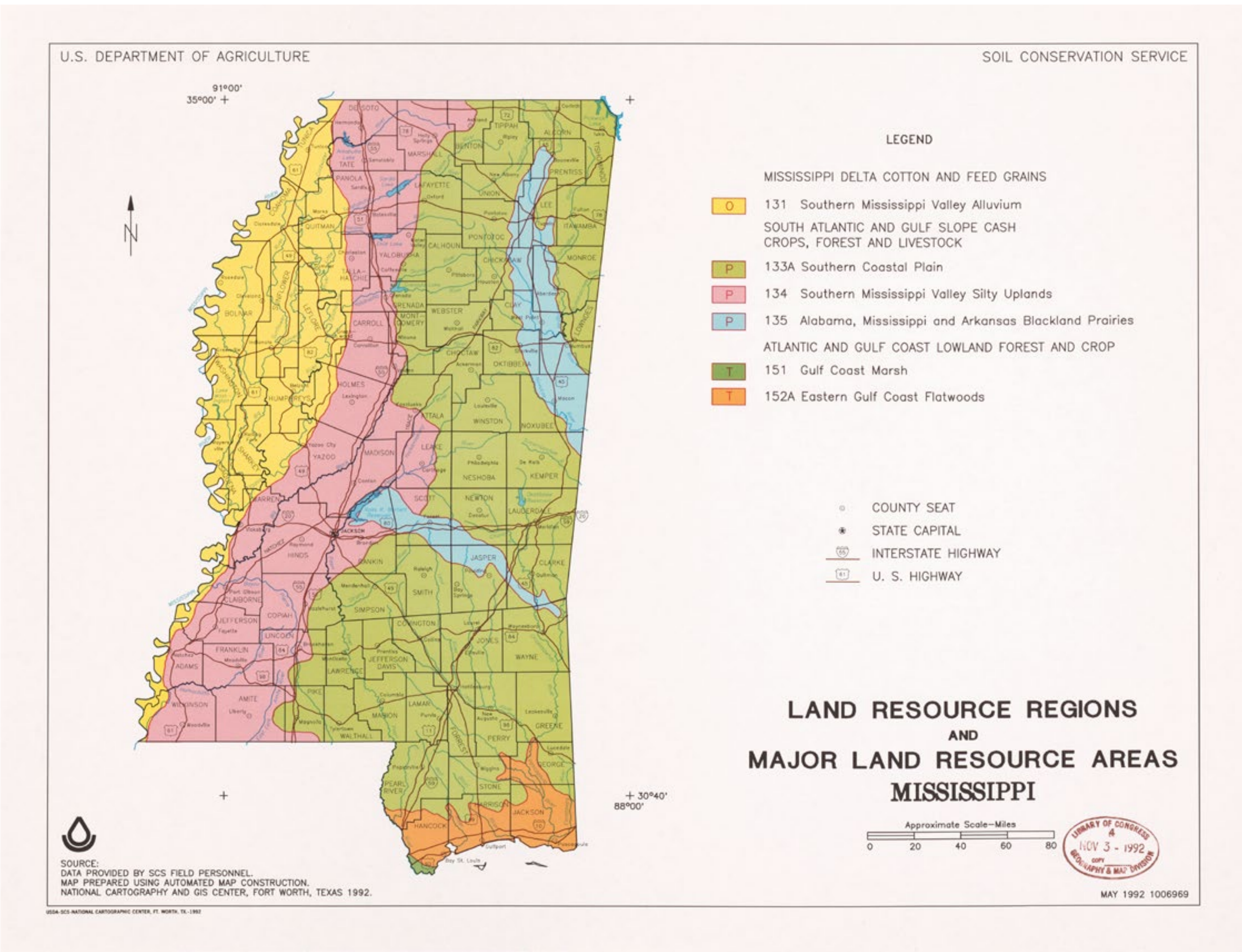

Figure 1. Mississippi land resource regions.

marsh are very poorly drained, with the water table at or above the surface most of the time. These soils are susceptible to frequent flooding. They formed in alluvial and marine sediments and have organic accumulations.

Eastern Gulf Coast Flatwoods

This is flat to gently sloping land along the Gulf of Mexico that includes the highly developed coastal part of the state. Much of the undeveloped land is owned by paper companies and managed as forests. The military also has significant acreage in the region.

For the Soils on Your Farm

This is only a brief introduction to the soil regions of Mississippi, which contains about 260 different soils with a wide range of properties. Site-specific information about the soils in your area is readily available from the U.S. Department of Agriculture's Web Soil Survey.

Web Soil Survey is easy to use to identify the soils of any location and their properties. You can download user-defined reports that inform appropriate conservation or nutrient management plans. Local offices of the Natural Resource Conservation Service and the MSU Extension Service also are available to help identify the soils on your farm.

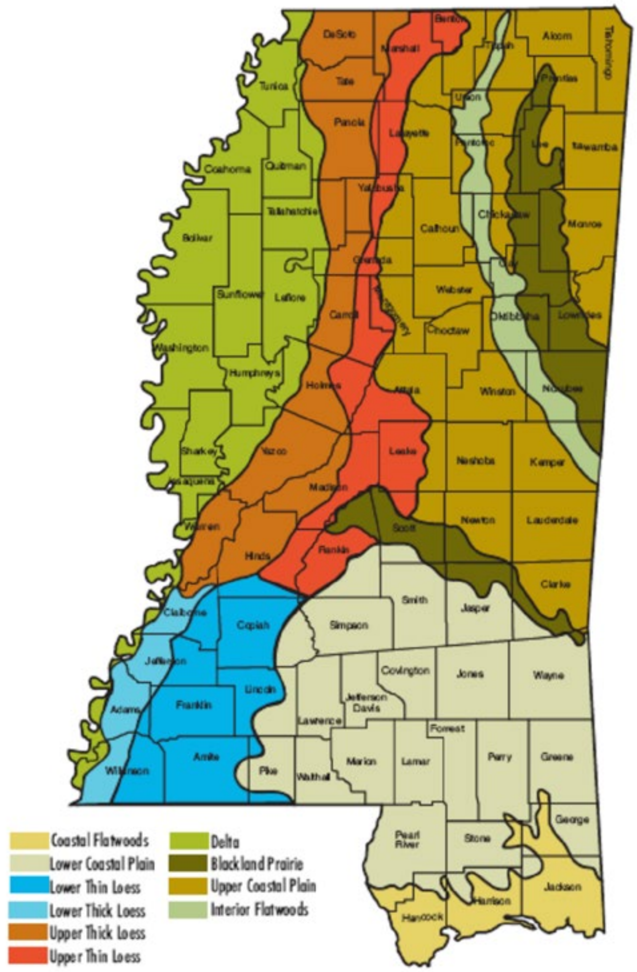

Figure 2. Soils of Mississippi.

Plant Nutrients

The soil provides most nutrients needed by plants. Insufficient nutrients potentially limit or end plant growth, resulting in decreased yields and lower profitability. Excess nutrients can also limit plant development and decrease yields, leading to lower profit and enhanced environmental risks. Nutrient management planners should optimize nutrient relationships to decrease undesirable outcomes.

Essential nutrients are chemical elements required by plants to complete their life cycles. Plant scientists currently recognize 18. Three—carbon (C), hydrogen (H), and oxygen (O)—are assimilated by plants via photosynthesis. The other plant nutrients are overwhelmingly obtained from the soil through root uptake.

In native landscapes, nutrients recycle between plants and soils constantly; however, agricultural crops may use more nutrients than natural turnover can provide. Furthermore, harvested crop biomass removes significant amounts of nutrients from the field. Supplemental nutrients may promote optimal crop development and profitability. These may be provided using inorganic (commercial) fertilizers, animal manures, green manures, and legumes.

Essential nutrients are traditionally classified into three categories: macronutrients, secondary nutrients, and micronutrients. The category names reflect more the nutrient supply characteristics (both in the soil and through amendments) than the actual quantity required by the plants. Remember that an insufficient supply of these nutrients leads to poor plant performance or even death.

Using the **right amount** of the **right fertilizer** at the **right time** in the **right place** is the foundation of nutrient management. See BMPs for Nutrients in Agronomic Crop Production on page 29 and MSU Extension Publication 3681 Best Management Practices for Plant Nutrient Management for more information about economically and environmentally sustainable nutrient management. For more information about fertilizer management in agronomic crops, see Extension Publication 2500 Inorganic Fertilizers for Crop Production and Publication 1466 Fluid Fertilizers.

Macronutrients

Nitrogen

Nitrogen (N) is a component of chlorophyll, which gives the green color to plants and is vital for photosynthesis. It is required for protein production in plants and animals and is a component of the nucleic acids DNA and RNA. Crop nitrogen use efficiency is relatively poor, and significant quantities are often lost via leaching, volatilization, or denitrification. Because of these loss mechanisms, the warm and humid Mississippi environment is not conducive to predictable soil nitrogen carryover from one growing season to the next. Year to year variability may result in some nitrogen carryover in some circumstances.

Highly variable moisture and temperature changes in Mississippi mean the oxidation state of nitrogen transforms continuously. These rapid changes make nitrogen soil testing difficult for most crops, even with a collected sample. Therefore, nitrogen measurements made in the laboratory are not well calibrated with nitrogen available to plants in the rooting zone. More information about nitrogen in Mississippi soils and plant nutrition is available in Extension Publication IS767 Nitrogen in Mississippi Soils.

Legume plants such as soybeans and clovers produce almost all their nitrogen through a symbiotic, or mutually beneficial, relationship with bacteria (*Rhizobium* species) attached to plant roots. *Rhizobium* bacteria convert atmospheric nitrogen (N_2 gas) into plant-usable forms. Because this relationship provides large quantities of nitrogen, legumes with active nitrogen-fixing bacteria rarely need additional nitrogen fertilization. Additionally, if these crops are fertilized with nitrogen, bacterial nitrogen production will decrease. Bacterial populations do not persist longer than a few years in fields where their host legume crop is not planted. In these instances, legumes must be inoculated with the proper nitrogen-fixing bacteria species before planting.

Phosphorus

Phosphorus (P) is integral to converting solar energy to the chemical energy that plants need to synthesize sugars, starches, and proteins. Plant-available phosphorus is usually high or very high in Mississippi Delta soils, so phosphorus fertilization is minimal in those 18 counties. Phosphorus levels in other regions of the state vary but, in the absence of extenuating circumstances (such as long-term application of high amounts of fertilizers), are usually lower than in the Delta region.

Phosphorus is relatively immobile in the soil matrix but can be transported by erosion of soil solids. Phosphorus builds up over time when the phosphorus from fertilizers and organic materials is greater than the amount removed by harvested crops. Early-season plant deficiencies are possible when plant root growth is slow. This is exacerbated by the immobility of the nutrient in the soil.

Phosphorus fertilization is inefficient as it becomes unavailable for plant use through reactions in the soil with iron, aluminum, and calcium. Plant-available phosphorus is much less than the total quantity present in the soil and can only be estimated through soil tests. Additional information on managing phosphorus is available in Extension Publication IS871 Phosphorus in Mississippi Soils.

Potassium

Plants use potassium (K) in photosynthesis, sugar transport, water and nutrient movement, protein synthesis, and starch formation. Adequate potassium plant nutrition improves disease resistance, water stress tolerance, winter hardiness, plant pest tolerance, and uptake efficiency of other nutrients.

Potassium removal by crops under good growing conditions is high, often equal to nitrogen uptake and several times the uptake of phosphorus. Conversely, where levels of soluble potassium in the soil are high, plants may take up more potassium than needed ("luxury consumption") that is not reflected by higher yields.

Potassium mobility in soils is related to soil texture: movement is greatest in soils with more sand content. The buildup of potassium in soils is related to soil texture, with the greatest accumulation generally in clay soils, followed by loam and coarse-textured sands.

Secondary Nutrients

Sulfur

Sulfur (S) is a component of some amino acids used in building proteins. Plants require about the same quantity of sulfur as phosphorus. In Mississippi, soil-test sulfur is reported by the Mississippi State University Extension Soil Testing Laboratory for some crops. The amount of sulfur reported is not a direct measurement; it is based on the soil organic matter content found in the sample.

Like nitrogen, sulfur is mobile in soils and can be lost by leaching. Unlike nitrogen, sulfur is immobile within plants, so deficiency symptoms first present on younger tissues. Nitrogen symptoms are presented in older tissues.

Mississippi soils once received sulfur as an extra nutrient in formerly used fertilizers. For many years, about 25 pounds per acre was deposited in rainfall in the state annually. Neither of these is true as of 2021. When sulfur was added via fertilizer and rainfall, low sulfur issues were confined to coarse, sandy-textured soils prone to leaching already-low organic matter levels. More deficiencies have been diagnosed recently.

More information about sulfur in Mississippi soils and plant nutrition is available in Extension Publication 3669 Sulfur Nutrition for Mississippi Crops and Soils.

Calcium

Calcium (Ca) makes up part of the cell wall and stabilizes cell membranes. Calcium deficiencies are usually manifested in growing points of the plant at the fruit, stem, leaf, and root tips. Calcium deficiency is rare in Mississippi soils, but some crops such as peanuts may use more calcium in one season than the soil can supply.

Magnesium

Magnesium (Mg) is the central part of the chlorophyll molecule where photosynthesis occurs. It is also involved in energy metabolism in the plant and is required for protein formation.

Magnesium deficiency is rare in Mississippi soils but has been diagnosed in some unusual circumstances on sandy soils with low cation exchange capacities and high soil-test potassium. This may lead to a deficiency level for grazing animals. More information on calcium and magnesium nutrition can be found in Extension Publication 3727 Calcium and Magnesium in Mississippi Crop Production.

Micronutrients

This is a brief introduction to micronutrients. More information is available in Extension Publication 3726 Micronutrients in Mississippi Soils and Plant Nutrition.

Copper

Plants require copper (Cu) in very small amounts. It is involved in respiration, protein synthesis, seed formation, and chlorophyll production. Copper is immobile in soils, so it accumulates when application rates exceed use. Copper is also held tightly by organic matter.

Despite being an essential nutrient, copper may be toxic to plants in some situations. Applications of copper-containing municipal biosolids to fields are regulated to manage soil accumulation and other potentially toxic elements. See Extension Publication 3663 Biosolid Applications to Mississippi Soils for more information.

Zinc

Zinc (Zn) is involved in starch formation, protein synthesis, root development, growth hormones, and enzyme systems. As with copper, zinc is relatively immobile in soils and tends to accumulate. Zinc deficiencies are most common on sandy, low organic matter soils with high pH and phosphorus levels, especially under cool, wet conditions. Zinc deficiency symptoms are evident on small plants as interveinal light striping or a whitish band beginning at the base of the leaf.

Manganese

Manganese (Mn) is involved in chlorophyll formation, nitrate assimilation, enzyme systems, and iron metabolism. A high soil pH generally causes manganese deficiency, whereas manganese toxicities occur at low soil pH. Liming programs likely are the best way to address manganese toxicity issues.

Boron

Boron (B) is involved in sugar and starch balance and translocation, pollination and seed production, cell division, nitrogen and phosphorus metabolism, and protein formation. Boron is highly mobile in soils and is not readily retained by sandy surface soils. In contrast, boron has limited mobility in plants. It must be added annually for crops sensitive to boron deficiencies.

In Mississippi, boron is recommended for all alfalfa production and cotton production in all non-Delta areas. In Delta areas, boron may boost yields on non-irrigated soils in dry weather, particularly if the soil has been recently limed. However, excessive rates of boron fertilization should be avoided.

Molybdenum

Molybdenum (Mo) is involved in protein synthesis, legume nitrogen fixation, enzyme systems, and nitrogen metabolism. Deficiencies of molybdenum generally occur on acidic soils with high iron (Fe) and aluminum oxides. The availability of soil reserves of molybdenum to the plant are largely regulated by soil pH. Mississippi State University Extension recommends applying 0.5–1 ounce of sodium molybdate or equivalent annually per bushel of soybean seeds at soil pH less than 7.0.

Iron

Iron (Fe) is used in chlorophyll and protein formation, enzyme systems, respiration, photosynthesis, and energy transfer. Iron deficiency is believed to be caused by an imbalance of metallic ions, such as copper and manganese, excessive amounts of phosphorus in soils, and a combination of high pH, high lime, cool temperatures, and high carbonate levels in the root zone.

Iron deficiency chlorosis in soybeans is a concern in the Blackland Prairie soils of the state where high pH limits iron solubility and, therefore, plant uptake.

Chlorine

Chlorine (Cl) is involved in photosynthesis, water-use efficiency, crop maturity, disease control, and sugar translocation. While chlorine leaches quite readily in coarse-textured soils, deficiencies are not very common and have not been identified in Mississippi.

Nickel

Plants require nickel (Ni) for proper seed germination. Additionally, it is the metal component in urease, an enzyme that catalyzes the conversion of urea to ammonium. Deficiency symptoms are poor germination and chlorosis. It has not been identified as an issue in Mississippi agronomic crops.

Table 1. Macronutrient removal by selected crops.

Crop	Unit	N	P_2O_5	K_2O
Alfalfa	lb/ton	51	12	49
Bahiagrass	lb/ton	43	12	35
Barley	lb/bu	0.89	0.41	0.28
Barley straw	lb/ton	15	5	30
Bermudagrass, common	lb/ton	25	8	34
Bermudagrass, hybrid	lb/ton	50	12	43
Clover, grass	lb/ton	50	15	60
Clover, crimson	lb/ton	47	9	59
Clover, red	lb/ton	41	10	40
Clover, white	lb/ton	56	15	49
Coastal bermuda	lb/ton	50	12	43
Corn, grain	lb/bu	0.90	0.44	0.27
Corn, silage, 67% water	lb/ton	10	3.1	7.3
Corn, stover	lb/ton	22	8	32
Cotton, lint	lb/bale	32	14	19
Eastern gamagrass	lb/ton	40	4	40
Fescue	lb/ton	27	12	54
Lespedeza, Korean	lb/ton	42	10	21
Lespedeza, striata	lb/ton	40	29	22
Oats, grain	lb/bu	0.77	0.28	0.19
Oats, straw	lb/ton	13	8	40
Orchardgrass	lb/ton	36	13	54
Peanuts, nuts	lb/ton	70	11	17
Peanuts, vines	lb/ton	43	6.6	20.5
Rice	lb/bu	0.57	0.30	0.16
Ryegrass	lb/ton	60	16	50
Sorghum, grain	lb/bu	0.66	0.39	0.27
Sorghum-sudangrass	lb/ton	40	15	58
Soybeans	lb/bu	3.8	0.84	1.30
Sweet potatoes	lb/cwt	0.52	0.23	1.00
Tomatoes	lb/ton	3	1.3	6.2
Watermelons	lb/cwt	0.42	0.12	0.74
Wheat, grain	lb/bu	1.3	0.60	0.34
Wheat, straw	lb/ton	13	3	23

Data derived from International Plant Nutrition Institute Nutrient Database, North Carolina State University Extension Service Publication AG-439, Section 4 of the Mississippi NRCS Field Office Technical Guide, and http://plants.usda.gov/.

Introduction to Soil Testing

Soil sampling and testing are critical for successful nutrient management. Soil testing assesses the nutrients available for plant uptake. Soil testing services available through Mississippi State University Extension or commercial laboratories should—

- accurately determine the nutrient status in the soil,
- convey whether a nutrient deficiency or excess is serious,
- serve as the basis for fertilization management, and
- allow an economic assessment of the options.

Soil testing calibration and correlation were developed for crop response. However, soil test-based nutrient recommendations are a foundation for environmentally sensitive stewardship of nutrients. Soil tests alone are insufficient to provide accurate environmental assessment. Soil fertility interacts with other soil-related properties within production systems, including soil series, slopes, and erosion potential.

Representative samples are crucial for reliable test results and interpretation to optimize production, investment return, and environmental quality. Sound field sampling ensures that the soil collected represents the area of interest and improves the relevance of the test results. The soil itself is highly variable, and this variability can increase with vegetation differences, terrain or slope, drainage, organic matter content, texture, and previous fertilizer applications. Errors in test results are usually caused by poor sampling.

Defining Areas to Soil Sample

Soil sampling should always begin with a field plan or map of the different areas to be tested. Knowledge of soils, field acreage, soil characteristics, crop growth patterns, drainage, and other factors can help you identify areas that can be sampled on a "whole field" basis. More intensive sampling schemes such as geometrical grid patterns or user-defined soil management zones often are used within fields. Information about soil series, texture, drainage, yield maps, or use history can help you define and locate soil management zones. Growers may work with crop consultants, Extension Service personnel, or others to determine the best sampling pattern for their situation.

Soil Sampling

Attention to detail provides robust, effective soil sampling that maximizes the quality of the resulting recommendations. Follow these guidelines:

- Use the proper equipment for the situation.
- Random-sample the field, grid, or zone.
- Account for previous banded fertilizer applications.
- Sample the appropriate soil depths for the situation.
- Include an adequate number of subsamples.
- Properly identify and code each sample.
- Consistently sample during the same season from year to year.
- Handle the samples appropriately.

Equipment

Soil may be collected in several ways. Use only stainless steel or other non-reactive metal tools to extract the subsamples in the field. Specialized soil test probes are available but not necessary for soil sampling.

Random Sampling

Sample in whole fields using a random walk pattern across the entire area. Mix the subsamples thoroughly, and transfer the mixture to properly labeled boxes or bags.

Intense soil sampling schemes characterize soil fertility at more detailed levels than whole-field sampling. Grids or management zones are commonly used. The grid cell method considers each grid as a separate whole field and should be sampled with a random walk. Grid point methods sample within a relatively small radius of a midpoint in the grid. In areas where you believe nutrient levels are relatively high and variable, grid cell is the better option. Grid point is the better option when in-field nutrient variability is low. Fields with a history of banded phosphorus and/or potassium fertilizer applications should be accounted for in the sampling plan.

Depth of Sampling

Most agronomic fertilizer recommendations assume samples were collected from the top 6 inches of soil. However, broadcast application of immobile phosphorus and potassium fertilizers leads to the stratification of these nutrients near the soil surface. When minimum or no-till is used, a soil sample depth of 4 inches is typically recommended.

Pastures and hay fields may need double sampling if nutrient or pH stratification is suspected: a 2-inch depth for pH and lime requirements and the regular 6-inch depth for other nutrients.

Number of Cores

Getting a sample that properly represents a field requires multiple subsamples to be mixed thoroughly. Variability of nutrients is typically high due to the lack of uniformity of previous years' fertilizer applications. Surface soil is generally more variable, so more cores should be collected. In general, a composite sample of 20–30 individual borings should be taken to represent a 20-acre area. Take 15–20 cores for 10-acre fields.

Time of Sample Collection

While MSU Extension offers three crop years of recommendations for each sample submitted, it is recommended to collect samples every year in fields that grow multiple crops. This allows you to monitor trends and more accurately manage the fertility program. For less intensive cropping sequences, sampling every 2–3 years is adequate. In either case, for better consistency, fields should be sampled during the same month each time because some nutrient, pH, and lime requirements vary seasonally due to climatic conditions, crop growth, and other factors.

Sample Handling and Record Keeping

Place soil samples into clean plastic buckets and mix well. If testing micronutrients, do not use galvanized metal buckets because samples could be contaminated, particularly with zinc. Break up cores and make sure the mixture is well homogenized before taking a composite subsample for laboratory analysis. Most soil testing laboratories provide small, moisture-resistant containers that hold about a pint of soil. The laboratories prefer these for operational ease, but if none are available, samples may be submitted in plastic bags. Give each sample box or bag a unique name and use the same name on the submission form.

Maintain records of field maps and names; sampling points; timing, cropping, and fertilization history; and other management activities. This information and the soil test reports will allow you to monitor changes in the fertility status of fields and field areas over time.

Soil Test Recommendations

Three growing seasons of phosphorus and potassium recommendations will be generated for the client for each sample submitted to the MSU Extension Soil Testing Laboratory. These recommendations are based on calibration and correlation research by the Mississippi Agricultural and Forestry Experiment Station. The correlations for phosphorus and potassium are summarized in Tables 2 and 3.

The numeric values for each sample are in pounds per acre for phosphorus or potassium; index terms of very low, low, medium, high, or very high are assigned based on the pounds per acre. Potassium values are also evaluated by the soil cation exchange capacity (CEC) as determined from the sample. CEC is a measure of the soil's ability to store positively charged nutrients such as potassium, calcium, magnesium, and sodium. MSU Extension uses CEC to determine soil texture; sandier textures typically have lower CEC. This adjustment is based on research with many Mississippi soils that found that crop response to potash additions differed based on soil CEC.

Note that the units used for the indices are pounds per acre of phosphorus and potassium, but the fertilizer recommendations are given in pounds of phosphate or potash fertilizer per acre. This is because fertilizers are usually marketed using these conventions. Introduction to Inorganic Fertilizers on page 17 has information on converting between the two systems.

More Information

More information on soil sampling is available in the following publications online or from your local MSU Extension office:

IS346 Soil Testing for the Farmer
IS1294 Soil Testing for the Homeowner
P3749 Soil and Broiler Litter Testing Basics

Table 2. Soil testing indices for phosphorus (phosphate equivalent) used by the MSU Extension Soil Testing Laboratory for all crops.

PHOSPHORUS SOIL TEST LEVEL (POUNDS PER ACRE)	INDEX
0–18	very low
19–36	low
37–72	medium
73–144	high
> 144	very high

Table 3a. Soil test potassium levels (pounds K per acre) and indices using the Mississippi soil test extractant for perennial winter grass pasture (fescue or orchard grass); small grains for pasture; peanuts; perennial summer grass pasture (bahia, dallis, or bermudagrass); rice; or annual legumes with ryegrass.

INDEX	CEC < 7	CEC 7–14	CEC 14–25	CEC > 25
very low	0–40	0–50	0–60	0–70
low	41–80	51–110	61–130	71–150
medium	81–120	111–160	131–180	151–200
high	121–210	161–280	181–315	201–350
very high	> 210	> 280	> 315	> 350

Table 3b. Soil test potassium levels (pounds K per acre) and indices using the Mississippi soil test extractant for dryland corn for grain, soybeans, oats, wheat, barley, summer pastures (bahia, dallis, or bermudagrass) with annual legumes (white clover, red clover, lespedeza, arrowleaf clover, ball clover, or subterranean clover); temporary summer grass pastures (millet, sorghum, sudangrass, sorghum-sudangrass hybrids, or Johnsongrass); forage legumes; perennial winter grass pasture with clover (white clover, red clover, subterranean clover with fescue or orchardgrass); pasture grass with annual legumes (crimson clover, annual lespedeza, arrowleaf clover, ball clover, or subterranean clover with bermuda, dallis, or bahiagrass); johnsongrass hay; mixed grass hay; annual or sericea lespedeza hay; or sunflowers.

INDEX	CEC < 7	CEC 7–14	CEC 14–25	CEC > 25
very low	0–50	0–60	0–70	0–80
low	51–110	61–140	71–160	81–180
medium	111–160	141–190	161–210	181–240
high	161–280	191–335	211–370	241–420
very high	> 280	> 335	> 370	> 420

Table 3c. Soil test potassium levels (pounds K per acre) and indices using the Mississippi soil test extractant for alfalfa, cotton, corn or sorghum for silage, sweet potatoes, irrigated corn, or hybrid bermudagrass hay.

INDEX	CEC < 7	CEC 7–14	CEC 14–25	CEC > 25
very low	0–70	0–90	0–120	0–150
low	7–150	91–190	121–240	151–260
medium	151- 200	191–240	241–290	261–320
high	201–350	241–420	291–510	321–560
very high	> 350	> 420	> 510	> 560

Table 4a. Magnesium calibrations for the Mississippi soil test (CEC less than 5).

INDEX	MAGNESIUM (POUNDS PER ACRE)
very low	0–12
low	12.1–24.0
medium	24.1–48.0
high	48.1–96.0
very high	> 96.1

Table 4b. Magnesium calibrations for the Mississippi soil test (CEC greater than 5).

INDEX	PERCENT MAGNESIUM SATURATION
very low	< 0.85
low	0.86–1.75
medium	1.76–3.30
high	3.31–6.60
very high	> 6.61

Table 5a. Zinc fertilizer recommendations for corn and rice.

SOIL TEST RATING	SOIL TEST K RATING	ZINC (POUNDS PER ACRE)
very high	very high	0
high	high	0
medium	medium	1–2
low	low	2–3
very low	very low	3–4

Table 5b. Zinc fertilizer recommendations for pecans.

SOIL TEST RATING	SOIL TEST K RATING	ZINC (POUNDS PER ACRE)
very high	very high	0
high	high	0
medium	medium	10–20
low	low	20–30
very low	very low	30–40

Introduction to Inorganic Fertilizers

A shortage of any soil-provided nutrient limits plant growth. Nutrients are recycled from plants to soil to meet plant needs under natural conditions. Agricultural crops use more nutrients that may be removed in harvested crops than natural vegetation.

Supplemental nutrients ensure optimal crop growth and profitability. The added nutrients may be fertilizers, animal manures, green manures, and legumes. Annual and perennial crops respond to phosphorus (P) and/or potassium (K) fertilization in many situations. Responses to other nutrients have occurred in limited crops and locations.

Supplemental nitrogen is usually needed for almost all non-leguminous agronomic crops grown in the state. However, plant nutrition is just one of many factors that limit potential crop yields. Others include soil physical problems, low or excessive rainfall, other climate issues, poor stands, inappropriate variety selection, weeds, insects and diseases, and crop genetic potential.

The macronutrients, also known as the primary nutrients, are listed on fertilizer labels as elemental nitrogen (N) and the oxide equivalents of phosphate (P_2O_5) and potash (K_2O) in the order N-P_2O_5-K_2O. This is the fertilizer grade or analysis. Numbers in a fertilizer grade such as 10-20-10 indicate that the fertilizer by weight is 10 percent N, 20 percent P_2O_5, and 10 percent K_2O. The relationships to convert between the oxide and elemental forms are:

Phosphorus: $P \times 2.29 = P_2O_5$ and $P_2O_5 \times 0.44 = P$
Potassium: $K \times 1.21 = K_2O$ and $K_2O \times 0.83 = K$

Results from the MSU Extension Soil Testing Laboratory are given in pounds of P or K per acre; however, the fertilizer recommendations from MSU Extension are in pounds of phosphate or potash per acre (see Introduction to Soil Testing on page 12).

Fertilizer Formulations

Various commercial fertilizers are available as solids, liquids, or gases. Each physical form has its own advantages and limitations, which must be considered when selecting the best material for the job.

Granulated fertilizers are solid, homogenous mixtures of fertilizer generally produced from materials such as anhydrous ammonia, phosphoric acid, and potassium chloride. Granulated materials are N-P or N-P-K grades of fertilizer.

The chief advantage of granulated materials is uniform distribution of nutrients. Each fertilizer particle contains all nutrients in the grade. For example, each particle of a 10-20-10 granulated fertilizer theoretically contains 10 percent nitrogen, 20 percent phosphate, and 10 percent potash. Nutrients do not segregate while handling or spreading (ensuring uniform nutrient application), and there is little tendency to cake or dust.

Blended fertilizers are mixtures of materials such as urea and potassium chloride. Granulated compound fertilizer materials can be blended or combined with other mixtures. Be aware that nutrients in a blended mixture may segregate into their individual particles. This directly impacts application rates when spread over a field.

Properly made blends are generally equal in effectiveness to other compound fertilizers and have the advantage of allowing a wide range of fertilizer grades that can match a fertilizer exactly to a soil test recommendation. Blends are often used as starter fertilizers. Urea and diammonium phosphate are not appropriate for use in starter fertilizers because both materials produce free ammonia. This can hinder seed germination and seedling growth when placed near seeds.

Fluid fertilizers are used widely in Mississippi. Fluids can be either straight materials, such as nitrogen solutions (e.g., 32-0-0), or compound fertilizers of various grades. Fluid fertilizers are categorized into two groups: clear solutions and suspensions.

In **clear solutions**, the nutrients are completely dissolved in water and are easy to handle. In addition, phosphorus in these materials is highly water soluble. Only relatively low analyses are possible, especially when the material contains potassium, and the cost per unit of nutrients is generally higher. When equal amounts of plant food are compared, clear solutions are equal in agronomic effectiveness to other types of fertilizers.

In **suspension fertilizers**, solubility of the components has been exceeded and clay added to keep the very fine, undissolved fertilizer particles from settling out. They can be handled like fluids and can be formulated at much higher analyses—even as high as dry materials. Suspensions require constant agitation, even in storage, and suspension fertilizer cannot be used as a carrier for certain chemicals. The agronomic effectiveness of suspensions is equal to other types of fertilizer materials when equal amounts of plant food are compared.

Anhydrous ammonia is a **gaseous fertilizer** that requires special handling and use considerations. It is stored as a compressed liquid that expands during application to a gas that must be injected into the soil to prevent loss to the atmosphere. Special handling methods and safety precautions are required because the material can cause serious chemical burns and asphyxiation.

Fertilizer Properties

Solubility indicates how readily nutrients are dissolved in the soil water and taken up by plants. Solubility usually is not a major consideration, but some materials (e.g., raw rock phosphate) are very insoluble in water.

Particle size of a fertilizer material is important for agronomic and handling reasons. In agronomic applications, particle size is most important for the sparingly soluble materials such as rock phosphate. These materials must be very finely ground to ensure sufficient solubility. For most soluble fertilizers, particle size is not critical for agronomic purposes but is very important in determining ease of handling the materials.

Inorganic Fertilizer Calculations

Proper application rates are critical to optimal economic and environmental management of inorganic fertilizers.

- Fertilizer grade or analysis is always referred to on a ***weight percent basis, not on a volume (i.e., gallon) basis***. Therefore, you must know the weight per gallon of the material to determine the actual plant nutrient content. Most fluids weigh between 10 and 12 pounds per gallon.

  Example: 10-34-0 weighs 11.4 pounds per gallon, so 1 gallon contains:

  11.4 × .10 = 1.14 pounds nitrogen per gallon
  11.4 × .34 = 3.88 pounds phosphate per gallon

  About 9 gallons of this fluid is equal to 100 pounds of fertilizer. To compare fluid fertilizer prices per ton, divide the weight per gallon into 2,000 for the number of gallons per ton.

  For the above example: 2,000 ÷ 11.4 = 175 gallons in each ton. This calculation can be used to compare a liquid priced in dollars per gallon with a solid priced in dollars per ton.

- As above, fertilizer labels identify the percent by weight of N, P_2O_5, and K_2O in the material. To determine how much N, P, or K is in a particular fertilizer:

  70 pounds of a 7-14-7 fertilizer has 4.9 pounds of N (70 × .07), 9.8 pounds of P_2O_5 (70 × 0.14), and 4.9 pounds of K_2O (70 × 0.07).

  40 pounds of a 0-14-28 fertilizer has no N, 5.6 pounds of P_2O_5 (40 × 0.14), and 11.2 pounds of K_2O (40 × 0.28).

- To calculate how much fertilizer to apply to provide a specific amount of nutrient to a given area:

  Amount of fertilizer = amount of nutrient needed ÷ percent nutrient in the fertilizer

  Example 1: How much 34-0-0 is needed to supply 50 pounds of N?

  147 pounds (50 ÷ 0.34) of 34-0-0 supplies 50 pounds of N

Example 2: If 20-10-15 was used to apply 45 pounds of N, how much P_2O_5 and K_2O also would be applied?

It requires 225 pounds (45 ÷ 0.20) of 20-10-15 to apply 45 pounds of N. Therefore, this 225-pound application of 20-10-15 also supplies 22.5 pounds of P_2O_5 (225 × 0.10) and 33.75 pounds of K_2O (225 × 0.15).

- Calculations for liquid fertilizers are similar but require knowing the density of the liquid fertilizer:

Example: How much N, P_2O_5, and K_2O are in a 2.5-gallon jug of a 9-18-6 liquid fertilizer that weighs 11.1 pounds per gallon?

First, calculate the fertilizer in the 2.5 gallons. There would be 27.75 pounds of fertilizer (11.1 lb/gal × 2.5 gal). So, there would be 2.5 pounds of N (27.75 × 0.09), 5 pounds of P_2O_5 (27.75 × 0.18), and 1.7 pounds of K_2O (27.75 × 0.06) in the 2.5-gallon container.

- To calculate the amount of fertilizer needed for a specific area:

Example: How much urea (46-0-0) is needed to apply 135 pounds of N to 25 acres?

First, calculate how much urea will provide 135 pounds of N per acre: 135 ÷ 0.46 = 293.5 pounds. The total urea to apply at this rate on 25 acres is 7337.5 pounds (293.5 × 25), or 3.67 tons.

- To calculate fertilizer costs:

Bulk fertilizer is sold by the ton; converting cost per ton to cost per pound of nutrient allows price comparisons between various fertilizer options.

Example 1: If urea (46-0-0) is $450 per ton, ammonium sulfate (21-0-0) is $380 per ton, and urea ammonium nitrate solution (UAN; 32-0-0) is $350 per ton, what is the price per unit of N of each of these fertilizers?

There are 920 pounds (2000 × 0.46) of N in a ton of urea, 420 pounds (2000 × 0.21) of N in a ton of ammonium sulfate, and 640 pounds (2000 × 0.32) of N in a ton of UAN. This means that the cost per pound of N is $0.49 for urea ($450 ÷ 920), $0.90 for ammonium sulfate ($380 ÷ 420), and $0.55 for UAN ($350 ÷ 640).

Example 2: Diammonium phosphate (DAP; 18-46-0) is $600 per ton. What is the cost per pound of N and per pound of P_2O_5?

There are 360 pounds of N (2000 × 0.18) and 920 pounds of P_2O_5 (2000 × 0.46) in each ton of DAP. The cost per pound of N is $1.67 ($600 ÷ 360), while the P_2O_5 cost is $0.65 per pound ($600 ÷ 920).

DAP is an expensive option if N is the only nutrient needed but would be a good option if P and N were both needed. In practice, DAP is typically used to supply P rather than N. In these cases, N supplied by DAP should be accounted for in the crop's total N fertilizer program.

Example 3: If UAN (32-0-0) is selling for $360 per ton, what is the cost per gallon assuming a weight of 11.06 pounds per gallon?

A ton of 32-0-0 is 180.8 gallons (2000 ÷ 11.06), so 1 gallon of 32-0-0 would cost $1.99 ($360 ÷ 180.8).

The cost per pound of N is $0.56 [$1.99 ÷ (11.06 lb/gal × 0.32)].

Lime, Liming Materials, and Regulations in Mississippi

Soil acidity restricts plant growth and reduces yields. Over half the samples analyzed by the MSU Extension Soil Testing Laboratory from 1989 to 2021 had pH values less than 5.9. Historically, most Delta soils have not been acidic or needed lime; however, 36 percent of the Delta samples over this period had pH less than 5.9.

Phosphorus (P) and molybdenum (Mo) are less available to plants in acidic soils; conversely, aluminum (Al) and manganese (Mn) can be toxic to plants in strongly acidic soils. Some micronutrients, including iron (Fe), manganese, and zinc (Zn) are less available at higher soil pH values. Lime is added to decrease soil acidity and improve plant health. Liming programs can be expensive in Mississippi because the hard lime materials, calcite or dolomite, must be imported from other states. Marl is a softer lime material that is mined in the state.

What Is Soil pH?

Soil acidity is considered the master variable of soil fertility. The term pH refers to the concentration of hydrogen ions on a 0 to 14 logarithmic scale. The number is the negative of the power that 10 is raised: pH 7 means there are 10 to the negative seventh power (10^{-7}) hydrogen ions in the solution. Due to the exponential nature of pH, a soil at pH 6 is 10 times more acidic than a soil with a pH of 7; pH 5 is 100 times more acidic than pH 7; and pH 4 is 1,000 times more acidic than pH 7.

Soil pH is between 4.0 and 8.3 in almost all natural soils in Mississippi. Soils with pH less than 7 are considered acid, and those with pH more than 7 are alkaline. Most Mississippi soils naturally become more acidic over time. Carbon dioxide reacts with water in the soil to form carbonic acid, which then reacts with calcium to form calcium bicarbonate and release two hydrogen ions within the soil. More hydrogen ions result in a lower pH.

Decomposition of organic matter and some fertilizer reactions also increase hydrogen ion concentration in the soil. Cations such as calcium (Ca) and potassium (K) are lost from the soil via leaching (the percolation of water downward through the soil). Cation removal results in a greater percentage of hydrogen in the surface soil and, therefore, a lower pH.

What Is Lime Requirement?

About half the soil samples processed by the MSU Extension Soil Testing Laboratory indicate lime could help plant growth or vigor. Most plants are less productive in acidic soils. Lime may be necessary to—

- prevent aluminum and/or manganese toxicity,
- increase phosphorus and molybdenum availability,
- improve nitrogen fixation by legume crops,
- improve efficiency of applied phosphorus and potassium fertilizers, and
- increase the volume of soil explored by roots.

Lime requirement is a separate measurement than pH and is reported as the amount of lime required to change the soil pH to a specific value. The MSU Extension Soil Testing Laboratory reports it in tons of lime needed per acre. Because lime quality varies, MSU Extension standardized the lime recommendations to assume relative neutralizing value (RNV) is 100. Producers can alter their lime recommendation based on the RNV reported from their lime source.

Some private laboratories may report the buffer pH value used in calculating the lime recommendation. However, most public soil testing laboratories do not report buffer pH to avoid confusion with the lime requirement.

Lime

According to Mississippi regulation, "agricultural liming materials" are calcium and magnesium products capable of neutralizing soil acidity. These primarily consist of calcium carbonate or a combination of calcium carbonate and magnesium carbonate. The lime essentially floods the soil with alternative cations.

Two types of hard limestone are shipped from other states and are widely available in Mississippi:

- Calcitic limestone, or calcite, is calcareous rock composed of calcium carbonate.
- Dolomitic limestone, or dolomite, is calcareous rock containing both calcium and magnesium carbonates. It has at least 6 percent magnesium content.

Marl, or chalk, is a softer rock mined within the state. Marl is granular (loosely consolidated earthy material) and primarily composed of seashell fragments and calcium carbonate.

Alternative lime materials include:

- burnt lime, which is made from calcium oxide or a combination of calcium oxide and magnesium oxide;
- hydrated lime, which is made from burnt lime and consists of calcium hydroxide or a combination of calcium hydroxide and magnesium oxide and/or magnesium hydroxide;
- ground shells, which are ground mollusks;
- basic slag or other industrial byproducts that neutralize soil acidity; or
- pelletized lime, which is finely ground limestone coated with cementing agents.

Lime Neutralizing Value

Hard lime materials are expensive in Mississippi because of transportation costs. They are brought in from quarries in nearby states by truck, rail, or barge.

The quality or value of liming material depends on three factors:

- Purity: Calcium carbonate equivalent (CCE) expresses the acid neutralizing capacity of the material as a weight percentage of pure calcium carbonate.
- Fineness: Calcitic and dolomitic lime sources are not very soluble. Smaller lime particles have more surface area to interact with soil and soil solution and, therefore, more capability to neutralize soil acidity.
- Moisture content of liming materials affects handling and spreading ease and influences the consumer's perceived value of purchased lime.

All liming materials sold in the state are subject to the Mississippi Agricultural Liming Materials Act of 1993. The regulations specify that marl must have a CCE of 70 percent or higher, and 90 percent or more of the material must pass a 10-mesh screen. Calcite and dolomite sold in Mississippi must meet other criteria for fineness of grind and CCE. These quality factors are used to rate limes using the relative neutralizing value (RNV), alternatively known as effective calcium carbonate equivalent (ECCE).

The particle size information and CCE used to estimate lime value is derived from lime samples analyzed by the Mississippi State Chemical Laboratory. Particle size analysis determines the percentage of lime that passes 10-mesh and 50-mesh sieves, and that information is combined with the CCE analysis to determine the RNV.

This calculation is based on research showing that particles larger than 10-mesh generally have no effectiveness in neutralizing soil acidity in an agronomic timeframe. Additionally, it assumes that all particles smaller than 50-mesh will dissolve to neutralize soil acidity, and half the particles in between these two sizes will react. Detailed calculation instructions are available in Extension Publication 3762 Agricultural Limestone's Neutralizing Value. All agricultural liming materials, other than marl, sold in Mississippi must have a minimum RNV of 63.

Comparing Lime Values

The RNV, or ECCE, allows comparison of the value of different liming materials.

> Example: Two agricultural liming materials are available. One has an RNV of 66 percent and costs $45 per ton. The other has an RNV of 85 percent and costs $55 per ton. Dividing the price per ton by the RNV decimal value estimates the agronomic value of the materials:
>
> $45 ÷ 0.66 = $68
> $55 ÷ 0.85 = $65

In this example, the material that is cheaper per ton actually costs about $3 more per ton to neutralize the soil's acidity.

Adjusting Lime Recommendations

Lime recommendations from the MSU Extension Soil Testing Laboratory assume neutralizing value is 100 percent. This should be adjusted at the field level.

Example: Calculate the application rate based on the RNV of the material to be used. The recommendation is 2 tons per acre, and the lime has an RNV of 70 percent.

2 tons / 0.70 = 2.9 tons per acre of material is required to provide the recommended neutralizing value

Most spin spreader trucks used for lime application lack the ability to apply at this level of precision, so the actual application rate is 3 tons per acre. More information is available in Extension Publication 3762 Agricultural Limestone's Neutralizing Value.

Mississippi annually ranks among the top five states in both numbers of broiler chickens grown and quantity of meat produced. In 2018, Mississippi produced 747 million broilers worth $2.68 billion. Approximately 1,400 individual growers contract with six commercial integrators to grow chicks for a specified period (usually 4–9 weeks to reach a targeted slaughter weight). Broiler production is primarily located in south-central Mississippi.

The production houses usually have smoothed soil floors initially covered with 4–6 inches of wood shavings. Wet material ("cake") is removed from the house floor after each flock is removed, commonly five to six times a year. Periodically, all the material is removed in a house "cleanout." This litter is a mixture of bedding material, manure, feathers, and spilled feed.

Poultry litter has long been used to provide nutrients for pastures, hay, and other crops in the south-central Mississippi broiler production region. Interest is increasing in other parts of the state in using broiler litter to fertilize annual agronomic crops. In addition to providing plant nutrients, litter applications to fields can improve soil properties such as tilth, water-holding capacity, and nutrient-holding capacity. There is a tendency to think of litter as a liming material. While there is significant calcium in litter and it seems to positively affect pH over very long periods, it is not a predictable response. Therefore, it is not recommended as a liming material.

Livestock producers develop nutrient management plans (NMPs) in cooperation with the Natural Resources Conservation Service (NRCS) and the Mississippi Department of Environmental Quality (MDEQ); these are required for all livestock operations in Mississippi that operate under general or site-specific operating permits. It is recommended that all producers develop NMPs. The NMP or individual farm management may lead to off-site removal of the litter. The value of the litter is determined by the open market, factoring in nutrient content, demand, supply, transportation, storage, competitive products, and other factors.

Nutrient Content

Litter is an excellent source of plant nutrients; because it is derived from once-living organisms, it contains all the essential plant nutrients. The nutrient content of litter varies, particularly nitrogen, from integrator to integrator based on different bird management techniques (Table 6). There are 12 different divisions among the six broiler integrators doing business in Mississippi. A 2014 study revealed litter nutrient content for these 12 divisions (Table 7). Based on the number of flocks grown on the same litter, concentrations of nitrogen, phosphorus, potassium, and water-extractable phosphorus (WEP) tended to increase until 15 to 20 flocks had been grown and then stabilize (Figures 3–6). Because of this variability, the best management practice is analyzing the actual litter to be used. The Mississippi State Chemical Laboratory or commercial laboratories can conduct this analysis. More information on this process is available in MSU Extension Publication 3749 Soil and Broiler Litter Testing Basics and in the Mississippi State Chemical Laboratory Pricing Guide.

Table 6. Effect of integrator on moisture and nutrient content of fresh Mississippi broiler litter.

INTEGRATOR	MOISTURE (%)	NITROGEN (LB/TON)	PHOSPHATE (LB/TON)	POTASSIUM (LB/TON)
1	21[a]	57[b]	32[a]	55[b]
2	21[a]	50[c]	29[a]	56[b]
3	20[a]	64[a]	30[a]	64[a]
4	19[a]	67[a]	32[a]	64[a]
5	18[a]	43[d]	21[b]	51[b]
6	20[a]	57[b]	28[a]	63[a]

Note: Means within a column not sharing a common superscript differ significantly ($P < 0.05$).

Table 7. Effect of division on number of flocks, litter pH, litter moisture percent, potassium (K_2O), nitrogen (N), phosphorus (P_2O_5), and water-extractable phosphorus.

DIVISION	# OF FARMS	# OF FLOCKS	LITTER PH	LITTER H_2O (%)	K_2O (LB/TON)	N (LB/TON)	P_2O_5 (LB/TON)	WEP (LB/TON)
1	18	7.28^{c}	7.48^{ab}	24.46^{efg}	61.84^{ab}	44.08^{bc}	43.13^{c}	9.58^{bcd}
2	20	7.95^{c}	6.67^{f}	25.35^{defg}	61.94^{ab}	44.42^{bc}	50.78^{c}	6.59^{ef}
3	18	5.94^{c}	7.61^{a}	23.85^{gf}	59.94^{ab}	38.76^{c}	52.53^{c}	4.95^{f}
4	20	8.05^{c}	7.19^{cd}	27.23^{bcd}	60.23^{ab}	46.68^{b}	55.23^{c}	13.38^{a}
5	4	11.25^{c}	7.27^{bc}	27.11^{def}	60.16^{ab}	47.42^{b}	73.49^{b}	9.40^{cd}
6	10	22.40^{b}	7.12^{cd}	26.39^{cde}	57.37^{b}	47.08^{b}	77.24^{ab}	8.00^{de}
7	10	10.50^{c}	6.84^{ef}	28.95^{ab}	59.19^{ab}	49.46^{b}	74.78^{b}	9.52^{bcd}
8	16	12.87^{c}	7.14^{cd}	25.73^{def}	66.86^{a}	45.52^{b}	75.82^{b}	10.83^{bc}
9	7	34.43^{a}	6.81^{ef}	26.71^{cd}	57.02^{b}	46.61^{b}	78.65^{ab}	10.45^{bc}
10	12	12.58^{c}	6.71^{f}	27.92^{ab}	59.67^{ab}	49.84^{b}	85.99^{ab}	10.47^{bc}
11	18	25.22^{b}	6.99^{de}	28.37^{g}	64.73^{ab}	60.85^{a}	89.30^{a}	11.29^{b}
12	5	6.20^{c}	7.10^{cd}	30.26^{a}	67.44^{a}	48.56^{b}	75.78^{b}	6.16^{f}
Average	**13.72**	**13.72**	**7.08**	**26.86**	**61.37**	**47.44**	**69.39**	**9.22**

Note: Means within a column not sharing a common superscript differ significantly ($P < 0.05$).

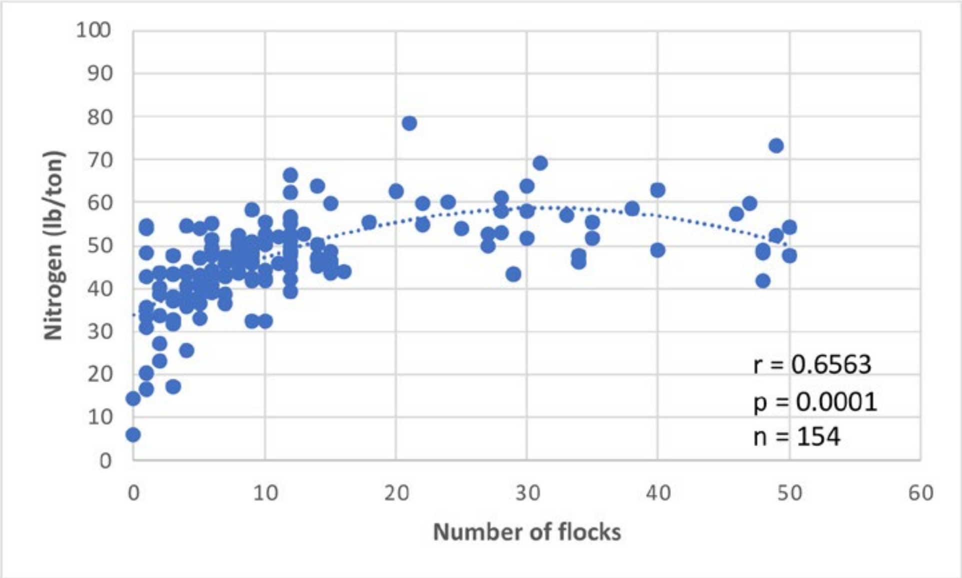

Figure 3. Effect of number of flocks on pounds of nitrogen (N) per ton of litter.

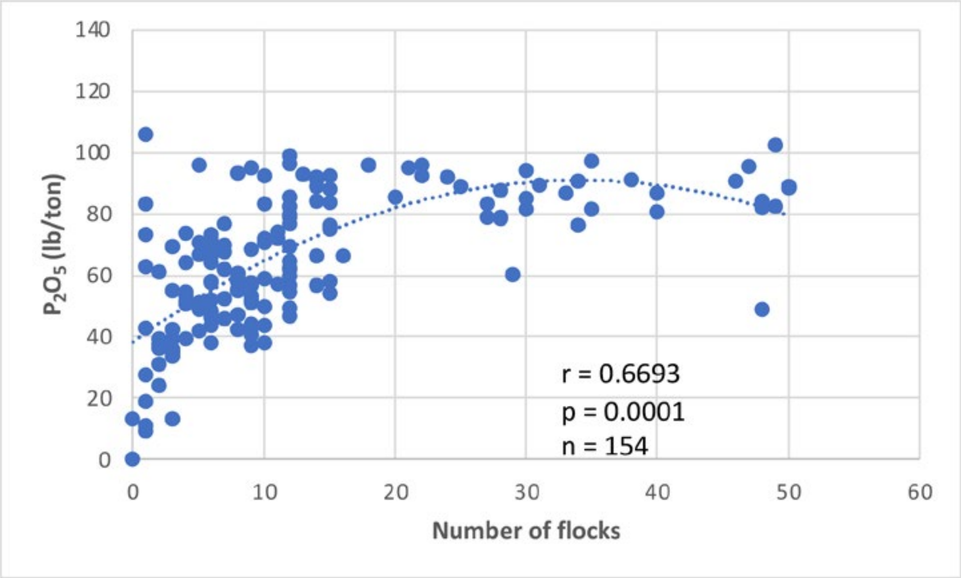

Figure 4. Effect of number of flocks on pounds of phosphorus (P_2O_5) per ton of litter.

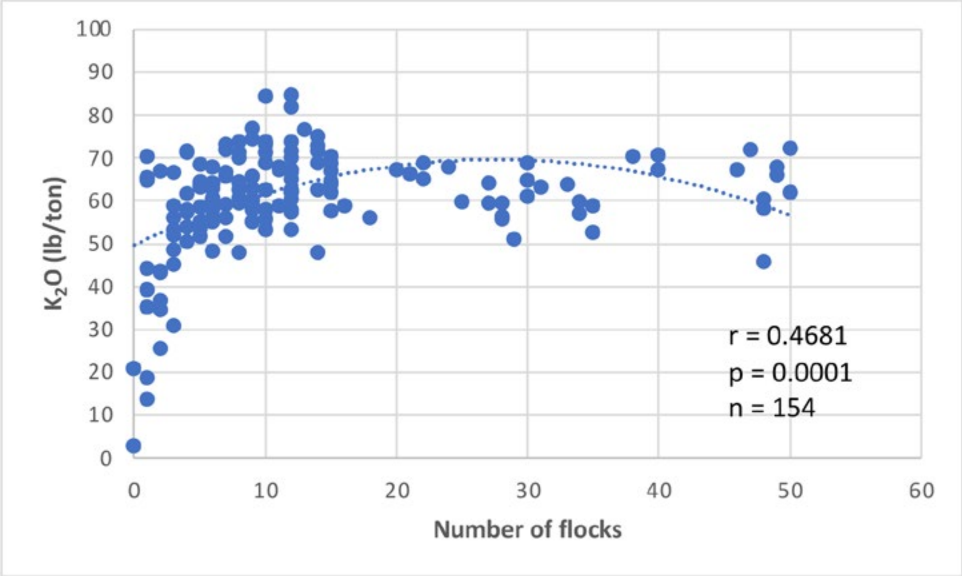

Figure 5. Effect of number of flocks on pounds of potassium (K_2O) per ton of litter.

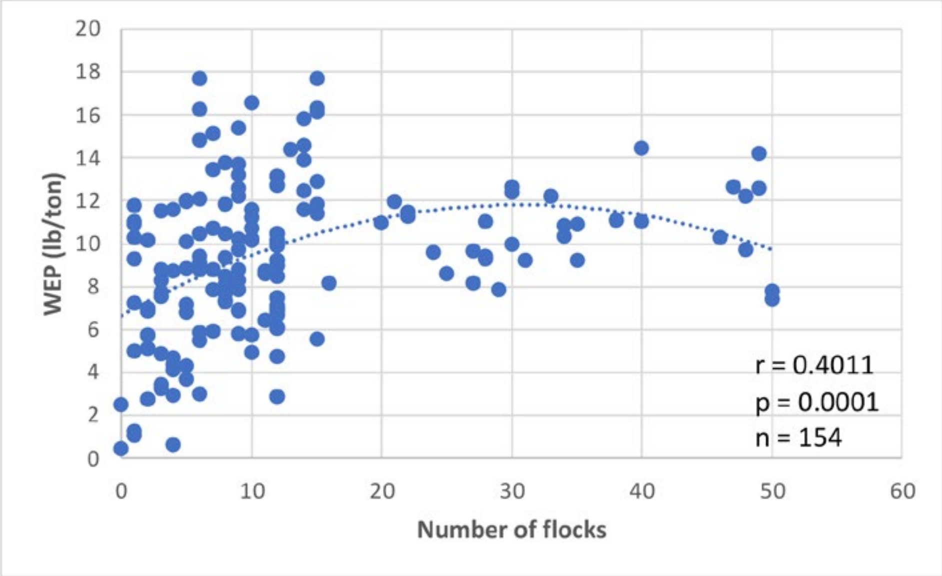

Figure 6. Effect of number of flocks on pounds of water-extractable phosphorus (WEP) per ton of litter.

Litter Transportation

Litter is a relatively light material (31 pounds per cubic foot) compared to inorganic fertilizers (46–70 pounds per cubic foot). However, transport expense must be considered. Some years, financial assistance is available through the NRCS under the Environmental Quality Incentive Program for transporting litter from a poultry production county to a non-poultry county in the state. In April 2019, estimated costs for removing litter from a poultry house and transporting it to a producer's field were as follows:

- Cost for removing from the poultry house = $8/ton
- Cost for loading on a truck for shipment = $8–$12/ton
- Cost for hauling to a producer's field:
    - 50 miles or less = $0.20/ton/mile (so 20 tons × $0.20/ton = $4/mile)
    - 80 miles or more = $0.16/ton/mile
- Cost for spreading on a producer's field = $10/ton

Litter Storage

Many poultry growers have dry stack sheds to store litter, but farmers who purchase litter from a grower or broker may need to temporarily store it. Litter should be covered while stockpiled outside a storage facility. Protect stored litter from any nearby water by placing a berm around the storage area.

Stacking litter in fields for more than a few days is not recommended. Litter loses mass while sitting in storage, which increases phosphorus concentrations. Nitrogen is lost from both covered and uncovered piles, but 50 percent more is lost in uncovered piles. Potash concentrations decrease through leaching.

Litter Application Equipment

Specialized litter spreaders are widely available in the poultry-growing area but may be hard to find in other areas. But proper spreading equipment is necessary and should be calibrated and maintained regularly. For more information on poultry litter spreading equipment, see MSU Extension Publication 2495 Calibrating Poultry Litter Spreading Equipment.

Litter Use in Row Crops

Litter is most effective as a plant nutrient when applied close to the time that the crop will use the nutrients. Nitrogen in the litter takes 1–3 weeks after application to convert to plant-available forms (nitrate or ammonium). Litter is most efficient when applied a few days before planting row crops. With no actively growing cool-season crop, fall applications are inefficient, and there will be no nitrogen from the litter available to a spring-planted crop. Each year, only about 50–60 percent of nitrogen in spring-applied litter is used by plants.

Work in Mississippi by the USDA Agricultural Research Service in cooperation with the Mississippi Agricultural and Forestry Experiment Station has shown broiler litter is most effective as fertilizer for cotton when 2 tons per acre are applied a few days before planting, followed by a side-dressing of an additional 60 pounds of inorganic fertilizer nitrogen. This is equivalent to about 180 pounds of nitrogen applied per acre. If about 120 pounds of nitrogen is added in the preplant litter application, half (or 60 pounds) of it is plant-available over the course of the growing season. Another 60 pounds of nitrogen should be side-dressed using inorganic fertilizers at lay-by; thus, the net application rate is 120 pounds of nitrogen per acre from both sources.

Significant amounts of the phosphorus in the spring-applied litter and practically all of the potassium are plant-available from spring applications. Phosphorus that exceeds the amount used by plants will be stored in the soil. No carryover credit can be given for litter potassium to subsequent crops.

Litter Use in Pasture and Hay Crops

To optimize the efficiency of litter as a fertilizer for pasture and hay crops, it is best to analyze the material before use. Crop-specific application rates are available from the MSU Extension Service. Application rates and management recommendations for the various forages are provided in Appendix A of this publication. Again, it is important to credit for the current crop only half of the nitrogen found by analysis. An example is provided below.

Litter Calculations

The laboratory analysis will report the nutrient contents as percent N (nitrogen), P_2O_5 (phosphorus), K_2O (potassium), and moisture. From this report, it is simple to calculate the macronutrient fertilizer equivalency of the litter on a per-ton basis.

- For an analysis of 3.5% N, 2.1% P_2O_5, and 3.8% K_2O with 20% moisture content:

  $2000 \times (1 - 0.2) = 1600$ lb dry matter per ton of "as is" litter

  $1600 \times 0.035 = 56$ lb N per ton of dry litter

  $1600 \times 0.021 = 34$ lb P_2O_5 per ton of dry litter

  $1600 \times 0.038 = 61$ lb K_2O per ton of dry litter

While it adds error, the fertilizer content can be approximated on an "as is" basis if the moisture content is not readily available:

- "As is" nutrient calculations (no adjustment for moisture) for an analysis of 3.5% N, 2.1% P_2O_5, and 3.8% K_2O:

  2000 × 0.035 = 70 lb N per ton of litter

  2000 × 0.021 = 42 lb P_2O_5 per ton of litter

  2000 × 0.038 = 76 lb K_2O per ton of litter

With the fertilizer content of the litter, and calibrated spreading equipment, application rates can be calculated. It is important to remember that only about 50 percent of the nitrogen in the litter will be available to growing plants during the season of application. (Note that current Mississippi Natural Resources Conservation Service planning standards use 60 percent nitrogen availability.)

- The target nitrogen for bermudagrass pasture is 75 pounds in each of two applications, one in the early spring and one in midsummer. The above litter contains 56 pounds of nitrogen per adjusted ton. The actual target application rate is 300 pounds of nitrogen in two equal applications (because of the 50 percent efficiency factor).

  (150 lb N/ac/application) / (56 lb N/ton) = 2.7 tons per application

- Using the "as is" value for N content:

  (150 lb N/ac/application) / (70 lb N/ton) = 2.1 tons per application

Other Livestock Manure

This section has focused on the use of poultry litter as a crop nutrient. Other species of livestock are grown in the state under general operating permits or other regulations of MDEQ. However, none of the other confined livestock enterprises approaches the production rates of the poultry/broiler industry. Therefore, other livestock operations will be limited to offering manure to producers near the originating location. Information on using those manures is available from local offices of the MSU Extension Service and the Natural Resources Conservation Service.

The authors greatly appreciate the assistance of Tom Tabler, PhD, former Extension Professor, MSU Department of Poultry Science, in the preparation of this material.

Best Management Practices for Nutrients in Agronomic Crop Production

Best management practices (BMPs) are research-proven, achievable management options to protect soil and water resources. BMPs are site-specific, depending on current and past soil management, climate, crops grown, and operator expertise and capability. The four Rs provide a blueprint for fertility management: use the **right source** at the **right rate** at the **right time** in the **right place**. These principles allow you to match nutrient supplies to the needs of growing plants and reduce the potential for off-target nutrient movement in the landscape.

They address the basic questions of nutrient management:

- Are the fertilizers necessary?
- How much fertilizer is economical?
- What fertilizers are available?
- When is the best time to apply any needed fertilizer?
- How can I maximize effectiveness?

Nutrient Management

Using the Right Rate: Nutrient Budgeting

Nutrient inputs are informed by soil nutrient testing, any manure applied, and actual nutrient uptake. Nutrient outflow can be measured through biomass. This information determines application rates and allows "what-if" analysis of different rate application scenarios.

Nitrogen (N) in Mississippi soils is short-lived and prone to rapid transformations in response to climate changes. See Extension Publication IS767 Nitrogen in Mississippi Soils for more information.

MSU Extension agronomic crop recommendations for nitrogen are site-specific and based on realistic yield goals for the field/soil type. Soil texture differences are included in the rate calculations for crops like cotton.

Some states (particularly in the Midwest) no longer use yield goals when recommending nitrogen. However, Mississippi's warm, humid climate and significant annual rainfall make predicting soil residual nitrogen difficult, so yield goals are still important.

Yield goals used to determine nitrogen applications must be realistic. One method is to average your yields from the past 3–5 years for a crop on the same or similar soil and add 10 percent for a realistic projection of the production potential on your specific site. If past yields are not available, contact the local MSU Extension or Natural Resources Conservation Service office for assistance.

Other soil testing laboratories may provide different recommendations.

Animal By-products Testing

Poultry production is the only consistent source of bulk animal by-products in Mississippi. As noted previously, nutrient contents vary based on bird and litter management programs. Application rates should be based on analysis of the actual litter used. The Mississippi State Chemical Laboratory or other public or commercial laboratories can complete this analysis. See Extension Publication 3749 Soil and Broiler Litter Testing Basics for information on sampling litter for nutrient analysis

Plant Nutrient Analysis

Chemical analysis of plant nutrient concentrations in tissue, in conjunction with soil testing, evaluates the soil fertility program and nutrient availability. It is most valuable in problem diagnosis when "good" versus "bad" sections of a growing field can be contrasted.

Fertilizer Management

Soil Test-Based Recommendations

Each soil test phosphate and potash result is rated within a category or index. MSU Extension uses five: very low, low, medium, high, and very high. The category relates the amount measured to whether plants will respond if fertilized. Very high means there is a very small chance of response; conversely, soils testing very low are more likely to respond to addition of the nutrient.

In high or very high soils, phosphorus and/or potassium fertilizers are not needed for almost all Mississippi crops (see Appendices A and B). In soils in the medium category, there may or may not be a response, so MSU Extension recommends maintenance levels of phosphorus and potassium. Soils in the very low or low categories should respond to fertilizer; in these cases, the decision depends on the relative risks of not fertilizing versus fertilizing. In the medium and low groups, phosphorus and potassium recommendations are based on soil fertility maintenance for the next scheduled crop. If the soil tests very low, we recommend a small amount of fertilizer for buildup. Other soil testing laboratories in Mississippi may have different recommendations.

Cotton research concluded that newer varieties experienced potassium stress midway through the growing season, so potash is recommended even if the soil test reports high. This is the only agronomic crop with a potassium fertilizer recommendation in the high category.

The Right Fertilizer for the Situation

Plants do not discriminate between sources of a particular nutrient. Nutrient ions, such as nitrate or phosphate, do not have differentiating characteristics in the soil solution, no matter what their source. In particular, nitrogen fertilizer efficiency depends on the specific product and how it is managed.

MSU Extension recommendations for nitrogen fertilizer management are not based on soil tests. The state is warm and humid, so nitrogen soil testing has had limited usefulness, although research continues. Nitrogen fertilization strategies are crop-specific, and, where applicable, based on attainable yield goals.

Nitrogen volatilization affects management decisions. Urea and urea-ammonium nitrate turn into ammonia gas that can drift away from the field. This volatilization increases when fertilizer is applied at temperatures above 65°F, on high organic matter/surface residues, and in high humidity.

More information on commercial fertilizer properties and management issues is available in Extension Publication 2500 Inorganic Fertilizers for Crop Production.

Proper Placement

Correct fertilizer placement is crucial to efficiency. Avoid broadcast sprays of urea-ammonium nitrate solutions whenever possible on hot, dry days unless the material will be cultivated or irrigated in, or rain is imminent. Incorporating animal manure fertilizers lowers the potential for movement in the landscape. Avoid applying fertilizer materials too near to surface water bodies.

Proper Application Timing

Time applications properly for the crop because plant availability of the nutrients decreases with time. Nitrogen use efficiency is highest when applied close to the time of crop uptake. The greater the time between application and planting, the greater the probability of nitrogen loss from the field. Excessive field losses may necessitate supplemental nitrogen fertilizer later in the growing season. Fall application of nitrogen is not practical in Mississippi for crops seeded in the spring, whether the fertilizer is organic or inorganic. Recent Mississippi research confirmed that nitrogen use efficiency is much lower for fall-applied poultry litter in row crops.

Inorganic phosphorus fertilizers may be field-applied in the fall before a spring-seeded crop because phosphorus is not mobile in the soil. However, note that phosphorus fixation in soils is common, so its use efficiency is not very high whenever it is applied.

In contrast to phosphorus fertilizers, potassium's effectiveness is not affected by soil fixation, except in some high-clay-content soils. Inorganic potash fertilizers for spring crops may be field-applied in the fall if the soil cation exchange capacity (CEC) is 8 or higher; at lower CEC values, it may be lost to leaching.

Equipment Maintenance and Calibration

Equipment maintenance and calibration are fundamental to efficient nutrient applications. Know the correct application width for the equipment and the material being applied; avoid overlaps within the field and onto field borders. Ensure that belts and chains are properly maintained and adjusted. The Mississippi Department of Agriculture and Commerce Bureau of Plant Industry provides education on calibrating commercial spreaders, including aerial equipment.

Precision Technology

Precision technologies may allow more efficient fertilizer management in nutrient-deficient or acid soil areas, or in more responsive zones. However, these tools, which include information management software, equipment, consulting, soil mapping, and training, can be a significant investment.

Runoff Management

Conservation Tillage

Some nutrients, such as phosphorus ions, are closely bound to soil particles, so soil management that minimizes sheet and rill erosion also lowers nutrient movement from the soil surface. These management practices include strip-, mulch-, no-, and ridge-tillage. More information about conservation tillage is available through local Extension or Natural Resources Conservation Service offices.

Proper Animal By-product Storage

Proper storage of poultry litter is important. Many poultry growers have dry stack sheds to store litter and prevent nutrient runoff, but others who acquire litter may need to store it temporarily. Research by Auburn University found that litter should be covered with plastic or other materials to protect the nutrient content of the litter. See page 26 for more information.

Control Water Flow On and Off Fields

Controlling water flow on and off fields with surface and subsurface drainage management reduces nutrient, pathogen, and/or pesticide runoff into downstream waters. Proper water control also reduces wind erosion and dust and may provide seasonal wildlife habitat. More information about conservation tillage is available through local Extension or Natural Resources Conservation Service offices.

Maintain Buffers

Planted buffers between nutrient applications and adjacent water bodies reduce sheet and rill erosion and lower the rate of sediment delivery.

Cover Crops as Nutrient Scavenger and Erosion Control

Cover crops and crop residue on the soil surface reduce soil loss by erosion. In addition, cover crops reduce nitrogen movement in the landscape by "scavenging" nitrogen that may be left in the soil after the previous crop. Using the residual nitrogen increases cover crop dry matter production, enhancing soil quality attributes such as soil organic matter levels and tilth.

Environmental Risk Assessment Procedures

There is an imbalance between the phosphorus content of poultry litters and the requirements of growing plants. Long-term application of litter can lead to buildup of soil test phosphorus to extremely high levels. This buildup increases the probability of phosphorus movement from soils to adjacent water bodies. This phosphorus enrichment of surface waters (eutrophication) can have several negative effects on water quality and aquatic life.

A risk-assessment procedure called the Phosphorus Index (PI) is used to determine the probability of nutrient movement in the landscape. The PI incorporates factors such as soil test phosphorus levels, soil permeability, field slopes, litter application rates, and distance to surface water. Based on this evaluation, further organic or inorganic phosphorus applications may be limited or eliminated in the fields deemed to be high risk.

Appendix A.

MSU Extension Soil Test-Based Recommendations for Hay and Pasture Crops

Table A1. Alfalfa recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	60	120	60	180
low	low	120	120	Year 2: 100 Year 3: 60	Year 2: 200 Year 3: 180
very low	very low	180	180	Year 2: 100 Year 3: 90	Year 2: 200 Year 3: 180

Notes:

Use Table 2 for soil test P rating and Table 3c for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Potassium, boron, and magnesium: Apply 3 lb boron/acre annually. Loss of stand may occur due to K deficiency. Apply additional 40 lb K_2O/acre for each ton of hay harvested. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A2. Recommended fertilizer rate (pounds per acre) for bermudagrass, dallisgrass, or bahiagrass pastures, with perennial or late-maturing annual legumes such as white clover, red clover, and arrowleaf clover.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR OF GRASS COMPONENT)	K_2O (ESTABLISHMENT YEAR OF GRASS COMPONENT)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	90	90	Year 2: 90 Year 3: 60	Year 2: 90 Year 3: 60

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, magnesium, and additional potassium: Where the legume provides less than one-third ground cover, apply 60 lb N/acre each time the forage is grazed down or cut for hay. Loss of stand is sometimes due to K deficiency. If pasture is regularly cut for hay, apply additional 40 lb K_2O/acre for each ton of hay harvested. For reseeding clover or clover seed harvest, apply 1–1.5 lb boron/acre. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A3. Recommended fertilizer rate (pounds per acre) for hybrid bermudagrass hay.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	50	50	50	150
low	low	50	100	63	200
very low	very low	100	100	Year 2: 100 Year 3: 63	200

Notes:
Use Table 2 for soil test P rating and Table 3c for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, potassium, and magnesium: If stand has been established for hay, apply recommended maintenance N, P, and K fertilizer(s) before growth starts (year 2 recommendation in the first year). Apply an additional 60–80 lb N/acre after each successive cutting until the last one. In the establishment year, apply any recommended P and K fertilizer(s), and 60–100 lb N/acre before sprigging. Apply an additional 50 lb N/acre before August 1 if additional growth is desired. Loss of stand may be due to K deficiency. Apply additional 40 lb K_2O/acre for each ton of hay harvested. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A4. Recommended fertilizer rate (pounds per acre) for bahiagrass, bermudagrass, and dallisgrass perennial summer pastures.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	25	25	25	25
low	low	50	50	50	50
very low	very low	100	100	50	50

Notes:
Use Table 2 for soil test P rating and Table 3a for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen and magnesium: Apply all recommended P and K fertilizer(s) and 60–80 lb N/acre before growth starts. Repeat N application by mid-July if more growth is desired. Loss of stand may occur due to K deficiency. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A5. Recommended fertilizer rate (pounds per acre) for perennial winter grass pasture, fescue, and orchardgrass (orchardgrass only in northern Mississippi).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	25	25	25	25
low	low	50	50	50	50
very low	very low	100	100	50	50

Notes:

Use Table 2 for soil test P rating and Table 3a for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, magnesium, and additional potassium: For perennial winter grass pasture (fescue and orchardgrass), 50 lb N/acre and all P and K fertilizer(s) should be applied by Sept. 1. Apply the remainder of the N in two applications, in February and early- to mid-April. If pasture is regularly cut for hay, apply additional 40 lb K_2O/acre for each ton of hay harvested. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A6. Recommended fertilizer rate (pounds per acre) for temporary summer grass pasture: millet, sorghum, sudangrass, sorghum-sudangrass hybrids, and johnsongrass.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR OF GRASS COMPONENT)	K_2O (ESTABLISHMENT YEAR OF GRASS COMPONENT)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	60	Year 2: 120 Year 3: 90

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen and magnesium: Apply recommended P and K fertilizer(s) and 60 lb N/acre preplant. Apply an additional 60–80 lb N/acre after forage is grazed or cut down. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A7. Recommended fertilizer rate (pounds per acre) for small grain winter pasture.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	Year 2: 80 Year 3: 60	Year 2: 120 Year 3: 90

Notes:

Use Table 2 for soil test P rating and Table 3a for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen and magnesium: Apply recommended P and K fertilizer(s) with 60–80 lb N/acre at seeding. Apply an additional 60–80 lb N/acre between mid-January and mid-February. In south Mississippi, increased forage yield and more uniform distribution may be realized with three applications of N: 60–80 lb/acre at planting; 60 lb December 1; and 60 lb February 15. These crops should not be grazed until about 8–12 inches high. They should not be grazed closer than 2–3 inches. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A8. Recommended fertilizer rate (pounds per acre) for forage legumes.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	60	Year 2: 120 Year 3: 60

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Boron and magnesium: For reseeding clover or clover seed harvest, apply 1–1.5 lb boron/acre. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A9. Recommended fertilizer rate (pounds per acre) for annual legumes with ryegrass.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	Year 2: 90 Year 3: 60	Year 2: 90 Year 3: 60
very low	very low	120	120	Year 2: 80 Year 3: 60	Year 2: 120 Year 3: 90

Notes:

Use Table 2 for soil test P rating and Table 3a for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen and magnesium: Apply any recommended P and K fertilizer(s) before seeding. Where the legume provides less than one-third ground cover, apply 60 lb N/acre in late winter or very early spring. Do not graze until grass is about 8–12 inches tall. Do not graze closer than 2–3 inches. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A10. Recommended fertilizer rate (pounds per acre) for fescue or orchardgrass pasture with white clover, red clover, or subterranean clover.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR OF GRASS COMPONENT)	K_2O (ESTABLISHMENT YEAR OF GRASS COMPONENT)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	60	Year 2: 120 Year 3: 60

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, potassium, boron, and magnesium: Where the legume provides less than one-third ground cover, apply 60 lb N/acre each time the forage is grazed down or cut for hay. Loss of stand is sometimes due to K deficiency. If pasture is regularly cut for hay, apply additional 40 lb K_2O/acre for each ton of hay harvested. For reseeding clover or clover seed harvest, apply 1–1.5 lb boron/acre. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A11. Recommended fertilizer rate (pounds per acre) for bermudagrass, dallisgrass, or bahiagrass pasture with annual legumes (crimson clover, annual lespedeza, arrowleaf clover, ball clover, or subterranean clover).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	30	30	30	30
low	low	60	60	60	60
very low	very low	120	120	Year 2: 60 Year 3: 60	Year 2: 120 Year 3: 60

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, potassium, boron, and magnesium: Where the legume provides less than one-third ground cover, apply 60 lb N/acre each time the forage is grazed down or cut for hay. Loss of stand is sometimes due to K deficiency. If pasture is regularly cut for hay, apply additional 40 lb K_2O/acre for each ton of hay harvested. For reseeding clover or clover seed harvest, apply 1–1.5 lb boron/acre. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A12. Recommended fertilizer rate (pounds per acre) for johnsongrass hay.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	50	50	50	150
low	low	50	100	63	200
very low	very low	100	100	Year 2: 100 Year: 63	200

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, potassium, and magnesium: For established stands of johnsongrass, apply any recommended N, P, and K fertilizer(s) before growth begins. Apply 80 lb N/acre after each successive cutting. The recommended N rate assumes an established stand. For the establishment year, use 60 lb N/acre instead. Loss of stand may be due to K deficiency. Apply additional 40 lb K_2O/acre for each ton of hay harvested. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A13. Recommended fertilizer rate (pounds per acre) for mixed grass hay.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	40	80	Year 2: 40 Year 3: 30	Year 2: 80 Year 3: 90
low	low	60	80	60	90
very low	very low	80	120	60	90

Notes:
Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen and potassium: Apply any recommended N, P, and K fertilizer(s) before growth begins. Apply an additional 50 lb N/acre after each successive cutting until last cutting. Loss of stand may be due to K deficiency. Apply additional 40 lb K_2O/acre for each ton of hay harvested.

Table A14. Recommended fertilizer rate (pounds per acre) for annual lespedeza hay.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR OF GRASS COMPONENT)	K_2O (ESTABLISHMENT YEAR OF GRASS COMPONENT)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	35	70	35	70
low	low	70	70	70	70
very low	very low	105	105	70	105

Notes:
Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Boron and magnesium: For annual lespedeza hay, apply any recommended P and K fertilizer(s) plus 1–1.5 lb boron/acre in early spring. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table A15. Recommended fertilizer rate (pounds per acre) for serecia lespedeza hay.

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (ESTABLISHMENT YEAR)	K_2O (ESTABLISHMENT YEAR)	P_2O_5 (MAINTENANCE)	K_2O (MAINTENANCE)
very high	very high	0	0	0	0
high	high	0	0	0	0
medium	medium	40	40	Year 2: 40 Year 3: 30	Year 2: 80 Year 3: 90
low	low	60	60	60	120
very low	very low	90	90	60	120

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Boron and magnesium: For serecia lespedeza hay, apply any recommended P and K fertilizer(s) plus 1–1.5 lb boron/acre in early spring. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Appendix B.

MSU Extension Soil Test-Based Recommendations for Annual Agronomic Crops

Table B1. Cotton recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	40	0	0	0	0
medium	medium	40	60	40	40	40	40
low	low	80	90	80	80	40	80
very low	very low	120	120	80	80	80	80

Notes:

Use Table 2 for soil test P rating and Table 3c for soil test K rating.

Inorganic nutrient management: Use 50–60 lb N per bale of realistic yield goal per acre on light-textured soils; 60–70 lb N per bale realistic yield goal on medium-textured soils; and 70–80 lb N per bale realistic yield goal on clay soils. The yield goal must be realistic; additional N will not increase yields unless N deficiency is the yield-limiting factor. Increase potash rates by 50% from the above if there is a realistic probability of producing more than 2 bales per acre. A recommendation of 40 lb of potash per acre with high soil test K levels is suggested to maintain the existing high soil tests.

For all non-Delta areas: use ⅓ to ½ lb boron per acre annually. In Delta areas, boron may boost yields on non-irrigated soils in dry weather, particularly if the soil has been recently limed.

Table B2. Corn and sorghum for grain (dryland) recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	70	70	35	35	35	35
low	low	100	100	70	70	70	70
very low	very low	140	140	70	70	70	70

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Use maintenance fertilizer rate annually after establishment. Retest soil after year 3.

Nitrogen, magnesium, and additional potassium: Where the legume provides less than one-third ground cover, apply 60 lb N/acre each time the forage is grazed down or cut for hay. Loss of stand is sometimes due to K deficiency. If pasture is regularly cut for hay, apply additional 40 lb K_2O/acre for each ton of hay harvested. For reseeding clover or clover seed harvest, apply 1–1.5 lb boron/acre. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table B3. Corn (irrigated) recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	95	95	60	60	60	60
low	low	130	130	90	90	90	90
very low	very low	170	170	90	90	90	90

Notes:

Use Table 2 for soil test P rating and Table 3c for soil test K rating.

Inorganic nutrient management: Nitrogen rates for corn in Mississippi are 1.3 lb of N per bushel of realistic yield goal. Therefore, apply 260 lb of actual N per acre for a 200-bushel yield goal. Apply all phosphate and potash fertilizers, and one-third to one-half of the N preplant. The remainder of the N should be applied as sidedressing approximately 1 month later or when the corn is 16–18 inches high. If a winter cover crop such as clover or vetch is grown, lower the recommended N rate by 30–60 lb per acre depending on the condition of the cover crop. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Growers using crop rotation should base supplemental fertility needs on the crop with the highest nutrient demand in their rotation system. This may require additional soil sampling or a maintenance application even if one is not recommended for the current crop.

Corn or sorghum grown in fields following rice production or winter flooding/duck hunting often experience serious phosphorus deficiency due to a conversion of soluble ferrous P to insoluble ferric P in flooded soils. The P is unavailable for plant uptake for several months after flood removal.

Table B4. Corn and sorghum for silage recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	60	120	60	120	60	120
low	low	80	120	80	120	80	120
very low	very low	120	120	80	120	80	120

Notes:

Use Table 2 for soil test P rating and Table 3c for soil test K rating.

Inorganic nutrient management: Nitrogen rates for corn in Mississippi are 1.3 lb of N per bushel of realistic yield goal. Apply all phosphate and potash fertilizers, and one-third to one-half of the N preplant. The remainder of the N should be applied about a month later by sidedressing. If a winter cover crop such as clover or vetch is grown, lower the recommended N rate by 30–60 lb per acre depending on the condition of the cover crop. If soil test Mg is low or medium, use 10–20 lb Mg/acre of a Mg source (see Table 4).

Table B5. Soybean recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	30	60	30	60	30	60
low	low	60	90	60	60	60	60
very low	very low	120	120	90	120	60	120

Notes:
Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Inorganic nutrient management: Apply 0.5–1 ounce of sodium molybdate or equivalent annually per bushel of seed if the soil pH is less than 7.0.

Table B6. Soybeans in small grain rotation recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	80	80	80	80	80	80
low	low	80	80	80	80	80	80
very low	very low	120	120	120	120	80	120

Notes:
Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Inorganic nutrient management: The phosphate and potash rates are sufficient for both crops and should be applied in the fall. Where wheat follows soybeans, no preplant N is necessary; otherwise, apply 20–30 lb of N at preplant. In late winter (February), apply 80–100 lb of N. Increase these N rates 20–30 percent on clay soils.

Table B7. Peanut (vines and nuts removed) recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)
very high	very high	0	0
high	high	0	0
medium	medium	60	120
low	low	80	120
very low	very low	120	120

Notes:

Use Table 2 for soil test P rating and Table 3a for soil test K rating. Second- and third-year recommendations are not given because peanuts should not be planted following peanuts because of disease issues. Peanuts should be rotated with non-leguminous crops such as corn or grain sorghum.

Inorganic nutrient management: For Spanish peanuts, include 20 lb N per acre with P and K fertilizer(s). Apply 0.3–0.5 lb of boron per acre in the fertilizer or disease control spray. Fertilizing the previous crop is preferred over direct fertilization of peanuts. For the best production, keep soil test levels at or near the high range.

If lime is recommended, it will increase the calcium level of the soil to an acceptable level for peanuts. If lime is not recommended, apply 250 lb of gypsum per acre at bloom.

Table B8. Rice recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	30	30	30	30	30	30
low	low	40	40	40	40	30	30
very low	very low	80	80	80	80	60	60

Notes:

Use Table 2 for soil test P rating and Table 3a for soil test K rating.

Inorganic nutrient management: Generally, no lime is recommended for rice production regardless of the soil pH. If rice is grown in rotation with soybeans and lime is recommended, a minimum amount (1 ton) should be use for soybeans. Zinc fertilizer may be recommended based on the soil test. Nitrogen fertilizer rates are based on the variety grown. Apply half to two-thirds of the actual N immediately before permanent flood. Apply the remainder at midseason. On leveled soils cut more than 12 inches, an additional 40 lb of phosphate may be beneficial the initial year after the cut was made even though the soil test may indicate an adequate amount.

Table B9. Sunflower (for grain) recommended fertilizer rate (pounds per acre).

SOIL TEST P RATING	SOIL TEST K RATING	P_2O_5 (YEAR 1)	K_2O (YEAR 1)	P_2O_5 (YEAR 2)	K_2O (YEAR 2)	P_2O_5 (YEAR 3)	K_2O (YEAR 3)
very high	very high	0	0	0	0	0	0
high	high	0	0	0	0	0	0
medium	medium	30	30	30	30	30	30
low	low	60	60	60	60	60	60
very low	very low	90	90	60	90	60	90

Notes:

Use Table 2 for soil test P rating and Table 3b for soil test K rating.

Inorganic nutrient management: Apply all phosphate and potash fertilizers and half of the N preplant. Apply the remaining N about 1 month later.

Appendix C.

Nutrient Management Terms

Adopted from the International Certified Crop Adviser performance objectives.

Acidic soil: A soil that has a pH value less than 7.0.

Aerobic: A condition identified by the presence of oxygen.

Aggregate, soil: A mass of fine soil particles held together by clay, organic matter, or microbial gums. Aggregates are part of soil structure.

Agronomic nutrient rate: Amount of nutrients required by a crop for an expected yield after all the soil, water, plant, and air credits are considered. Agronomic rates consider nutrient credits from all soil tests, legumes, manure residuals, and other nutrient credits supplied from any other source.

Alkaline soil: A soil that has a pH value greater than 7.0.

Alluvium: A general term for all eroded material deposited by running water, including gravel, sand, silt, and clay.

Alum: A potassium aluminum sulfate or ammonium aluminum sulfate.

Ammonia (NH_3): See anhydrous ammonia.

Ammonium (NH_4^+): A form of nitrogen that is available to plants from fertilizer and organic matter decomposition.

Ammonium nitrate solution: Non-pressure solution of ammonium nitrate in water; usually standardized to 20 percent nitrogen. Used for direct application or for making multinutrient liquid fertilizer. Analysis is 20-0-0.

Ammonium phosphate: A group of phosphorus fertilizer manufactured by the reaction of anhydrous ammonia with superphosphoric acid to produce either solid or liquid fertilizer.

Ammonium sulfate: Fertilizer material with an analysis of 21-0-0. It also contains 24 percent sulfur.

Anaerobic: A condition identified by the absence of oxygen.

Anhydrous ammonia (NH_3): Fertilizer in pressurized gas form, made by compressing air and natural gas under high temperature and pressure in the presence of a catalyst. Value is 82-0-0.

Animal unit: 1,000 pounds of live animal weight; a term used to determine volumes of animal manure produced.

Anion: An ion with a negative charge.

Application rate: The weight or volume of a fertilizer, soil amendment, or pesticide applied per unit area.

Aqua ammonia: 20 percent anhydrous ammonia dissolved in water.

Aquifer: Layers of underground porous or fractured rock, gravel, or sand through which considerable quantities of groundwater can flow and which can supply water at a reasonable rate. May be classified as perched, confined, or unconfined.

Available nutrient: A nutrient in a form that a plant can absorb.

Available water: Portion of water in soil that can be readily absorbed by plant roots.

Banded nutrients: Fertilizer nutrients placed in a strip near the seed at planting, or surface or subsurface applications of solids or fluids in strips before or after planting.

Base saturation percentage: The proportion of the soil's cation exchange capacity occupied by basic cations.

Biological oxygen demand (BOD): The amount of oxygen required by aerobic microorganisms to decompose the organic matter in a sample of water; used as a measure of water pollution.

Biomass: Plant and plant-derived material, including manure. Includes forestry products; wood-processing wastes; wastes associated with food-processing operations; energy crops, such as switchgrass and poplar trees; and agricultural crop residues, such as corn stover and wheat straw.

Biosolid: Any organic material, such as livestock manure, compost, sewage sludge, or yard wastes, applied to the soil to add nutrients or for soil improvement.

Blocky: Soil structure classification in which aggregates are in the shape of blocks or polyhedrons.

Buffer pH: A soil test procedure where the pH of the soil is measured in buffer solution. This measurement is used in estimating the lime requirement of the soil.

Buffer strip: Areas or strips of land maintained in vegetation and strategically located on the landscape to help control runoff and erosion, and entrap contaminants.

Buffering: The ability of a solution, such as the soil solution or irrigation water, to resist changes in pH when acid or alkaline substances are added. Often used to describe a soil's resistance to pH changes when limed or acidified.

Buildup and maintenance: Nutrients applied to build up a target nutrient level and then maintained by annual addition of the quantity of nutrients expected to be removed in the harvested portion of the crop.

Bulk density: The mass of oven-dry soil per unit volume, usually expressed as grams per cubic centimeter.

Calcitic lime: Limestone consisting of $CaCO_3$-based material with very low magnesium content.

Calcium carbonate equivalent (CCE): The liming potential of a material as compared to $CaCO_3$.

Capillary action: Movement of water in the soil through small soil pores.

Cation exchange capacity: The amount of exchangeable cations that a soil can adsorb at a specific pH, expressed as centimoles of charge per kilogram (cmolc/kg) of soil or milliequivalents per 100 g of soil (meq/100 g soil).

Cation exchange sites: Negative charged sites on the surfaces of clays and organic matter.

Cation: An ion that has a positive electrical charge. Common soil cations are calcium, magnesium, hydrogen, sodium, and potassium.

Chelated molecule: A large, water-soluble organic molecule that binds with a free metal ion to form a water-soluble compound. This process increases the amount of metal ion or atom dissolved in the water and the availability of that ion to plants.

Clay: 1) The class of smallest soil particles, smaller than 0.002 millimeter in diameter. 2) The textural class with more than 40% clay, less than 45% sand, and less than 40% silt.

Colloid: A very tiny particle capable of being suspended in water without settling out. Soil colloids have a charged surface that attracts ions.

Compaction (soil): Increasing the soil bulk density, thereby decreasing the soil porosity, by the application of mechanical forces to the soil.

Composite soil sample: A soil sample resulting from mixing together many individual samples.

Conservation tillage: A general term for tillage practices that leave crop residues on the soil surface to reduce erosion.

Contaminant: Any physical, chemical, biological, or radiological substance that is above background concentration but does not necessarily cause harm.

Contour tillage: Tillage that follows the contours of a slope, rather than running up and down a slope. Helps prevent erosion and runoff.

Contour: An imaginary line perpendicular to the slope that represents the same elevation.

Critical value: The point between sufficiency and deficiency levels for a nutrient.

Crop nutrient requirement: The amount of nutrients needed to grow a specified yield of a crop plant per unit area.

Crop removal rate: The amount of nutrients that are removed from the field in the plant harvest, including harvested fruit, grain, forage, and crop residues that are removed from the field.

Crop rotation: A planned sequence of crops growing in a regularly recurring succession on the same field.

Crop sequence: The order of crops planted and harvested in a field over a period of time.

Crop utilization rate: The total amount of nutrients required by the crop to produce both vegetation and grain, including nutrients used to produce roots, stems, crowns, and other unharvested plant parts as well as the harvested portion that is removed from the field.

Crust: A thin layer of poorly aggregated surface soil formed by wetting and drying.

Deep tillage: Tillage deeper than that needed to produce loose soil for a seedbed, usually used to loosen compacted subsoil.

Denitrification: The transformation of nitrates or nitrites to nitrogen or nitrogen oxide gas, occurring under anaerobic conditions.

Diammonium phosphate (DAP): Fertilizer containing both nitrogen and phosphorus with an analysis of 18-46-0.

Diffusion: The movement of particles from an area of higher concentration to an area of lower concentration.

Discharge: Flow of surface water in a stream or the flow of ground water from a pipe, spring, ditch, or flowing artesian well.

Dolomitic lime: A naturally occurring liming material composed chiefly of carbonates of magnesium and calcium.

Drainage: Rate and amount of water removal from soil by surface or sub-surface flow.

Ecosystem: Community of animals and plants and the physical environment in which they live.

Effluent: Discharge or emission of a liquid or gas.

Elemental sulfur: Sulfur in the elemental form that must be oxidized by soil microbes to the sulfate form for plant uptake.

Environmentally sensitive area: Places on the landscape that are easily degraded by human or natural activity.

Erosion: The wearing away of the land surface by running water, wind, ice, geological agents, or mechanical actions, such as tillage or land leveling.

Essential plant nutrients: Inorganic elements required for growth and development of plants.

Eutrophication: A natural process of enrichment of aquatic systems by nutrients, primarily nitrogen (N) and phosphorus (P). Accelerated, or cultural, eutrophication is caused by the addition of excess nutrients to a system. This results in excessive vegetative growth. Decomposition of this plant material can result in the depletion of oxygen in water, leading to the death of aquatic organisms.

Evapotranspiration (ET): Loss of water to the atmosphere from the earth's surface by evaporation and by transpiration through plants.

Fertilizer: Organic or inorganic material added to a soil to supply one or more nutrients essential to plant growth.

Fertilizer analysis: The composition of a fertilizer, expressed as a percent of total nutrients; for example, total N, available phosphoric acid (P_2O_5), and water-soluble potash (K_2O).

Fertilizer suspension: A fluid fertilizer containing dissolved and undissolved plant nutrients. The undissolved nutrients are kept in suspension, usually by swelling-type clays.

Field capacity: The amount of water a soil holds after free water has drained because of gravity.

Flood plain: Land near a stream that is commonly flooded when the water levels are high. Soil is built from sediments deposited during flooding.

Foliar fertilization: Application of a dilute solution of fertilizer to plant foliage, usually made to supplement soil-applied nutrients.

Friable: The ease by which a moist soil can be crumbled.

Granular: Soil structure where the units are approximately spherical or polyhedral.

Gravitational water: Water that moves through the soil because of gravity.

Green manure: Plant material incorporated into the soil while green or at maturity, for soil improvement.

Groundwater: Water in the saturated zone below the soil surface.

Guaranteed analysis: Minimal percentages of available nutrients as stated on a fertilizer label.

Gully: A large channel in the soil, caused by erosion that is deep and wide enough that it cannot be crossed by tillage equipment.

Gypsum: Calcium sulfate ($CaSO_4 \bullet 2H_2O$) used to supply calcium and sulfur and to improve sodic soils.

Hardpan: A dense, hard, or compacted layer in soil that slows water percolation and movement of air and obstructs root growth. Pans may be caused by compaction, clay, or chemical cementation.

Highly erodible land: A soil-mapping unit with an erodibility index of 8 or more.

Horizon (soil): A horizontal layer of soil, created by soil-forming processes, that differs in physical or chemical properties from adjacent layers.

Humus: Highly decomposed organic matter that is dark-colored and highly colloidal.

Hydrologic cycle: Movement of water in and on the earth and atmosphere through processes such as precipitation, evaporation, runoff, and infiltration.

Hygroscopic water: Water held tightly by adhesion to soil particles. Cannot be used by plants and remains in soil after air-drying. Can be driven off by heating.

Immobile nutrient: A plant nutrient that moves slowly in the soil or plant.

Immobilization: The conversion of an element from the inorganic to the organic form in microbial tissues, resulting in that element not being readily available to other organisms or plants.

Impermeable layer: Soil layers, either natural or manmade, that resist penetration by fluids or roots.

Infiltration: Entry of water from precipitation, irrigation, or runoff into the soil profile.

Injection: Placing something below the surface of soil by mechanical means.

Inorganic nitrogen: Mineral forms of nitrogen.

Inorganic phosphorus: A salt of phosphoric acid or any of its anions, usually orthophosphate or polyphosphate.

Irrigation: Application of water to supplement natural rainfall.

Landscape position: Using topography, slope characteristics, or both to separate a field into different zones that have similar soil characteristics and crop productivity.

Lateral flow: Movement of water horizontally below the soil surface, usually along an impervious layer.

Leaching: The movement of material in solution along with movement of water through the soil.

Lime fineness: The particle size of limestone determined by the fineness of grinding. The finer the grind, the better the material neutralizes acidity.

Lime material: A material capable of neutralizing soil acidity.

Lime purity: The measure of impurities in a given liming material; used to estimate its neutralizing value.

Liming requirement: The amount of liming material required to change the soil pH to a specific value.

Loading: Amount of a substance entering the environment (soil, water, or air).

Luxury consumption: The absorption by plants of an essential nutrient in excess of their need for growth. Luxury concentrations in early growth may be used in later growth.

Macronutrient: A nutrient that a plant needs in relatively large amounts. Essential macronutrients are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulphur (S).

Mapping unit (soil): Basis for setting boundaries in a soil map. May include one or more soil series.

Mass flow: The movement of solutes associated with net movement of water.

Massive soil: A structureless soil.

Micronutrient: Nutrients that plants need in only small or trace amounts. Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn) are considered micronutrients.

Mineral soil: A soil whose traits are determined mainly by its mineral content; mineral soils contain less than 20 or 30 percent organic matter in the U.S. and Canada, respectively.

Mineralization: The conversion of an element by soil organisms from an organic form to an inorganic form.

Minimum tillage: Tillage methods that involve fewer tillage operations than clean tillage does.

Mobile nutrient: A nutrient that moves readily in the soil or plant.

Monoammonium phosphate (MAP): A fertilizer composed of ammonium phosphates, resulting from the ammoniation of phosphoric acid; typically 11 percent N with an analysis of 11-52-0.

Mulch: Natural or artificial layer of plant residue or other material that conserves soil moisture, holds soil in place, aids in establishing plant cover, and minimizes temperature fluctuations.

Mulch till: A full-width tillage and planting combination that leaves some plant residues or other material on the soil surface.

N-based nutrient application: The rate of application of a nitrogen-containing material so the desired amount of nitrogen is applied, regardless of the amounts of other nutrients being applied in the material.

Nitrate (NO_3^-): An inorganic nitrogen form that is very soluble, easily leached from soils, and readily available to plants.

Nitrification inhibitor: A chemical inhibitor that slows the conversion of ammonium to nitrate in the soil, reducing the risk of nitrogen loss from the field.

Nitrification: The microbial process of converting ammonium to nitrite to nitrate.

Nitrite (NO_2^-): A form of nitrogen that is the result of the first step in nitrification in soil as microbes convert NH_4 to NO_2. It is subsequently oxidized to nitrate (NO_3) by microbes.

Nitrogen: An essential plant nutrient that is part of many compounds, including chlorophyll, enzymes, amino acids, and nucleic acids.

Non-point source (NPS) contamination: Water contamination derived from diffuse sources such as construction sites, agricultural fields, and urban runoff.

No-till/direct seeding/zero-till: Method of growing crops that involves no seedbed preparation before planting.

Nutrient buildup: An increase in soil analysis levels of a nutrient due to application of that nutrient at levels that exceed crop removal.

Nutrient drawdown: A decrease in soil analysis levels of a nutrient due to crop removal.

Nutrient management plan (NMP): A written plan that specifies the use of fertilizer, animal manures, and other biosolids.

Organic matter: The organic fraction of the soil exclusive of undecayed plant and animal residues.

Organic nitrogen: Nitrogen that is bound with organic carbon and forms organic molecules.

Organic phosphorus: Phosphorus that is bound with organic carbon and forms organic molecules.

Organic soil: Soil containing more than 20 or 30 percent organic matter in the U.S. and Canada, respectively.

Orthophosphate: Inorganic form of plant-available phosphorus.

P index: An environmental risk assessment tool for assessing the potential for phosphorus movement from agricultural lands. It is usually based on an estimation of potential soil erosion, the phosphorus soil test level, and phosphorus management practices, such as rate of application, source of phosphorus, and timing and method of application.

P_2O_5: Phosphorus pentoxide; designation on the fertilizer label that denotes the percentage of available phosphorus expressed as P_2O_5.

P-based nutrient application: The rate of application of a phosphorus-containing material so that the desired amount of phosphorus is applied, based on balancing the agronomic rate or crop removal rate of the crop with the amount of phosphorus contained in a material. This amount is regardless of the amounts of other nutrients being applied in the material.

Ped: A natural soil aggregate, such as a granule or prism.

Percolation: Downward movement of water through soil or rock.

Permanent wilting point: The soil water content at which most plants cannot obtain sufficient water to prevent permanent tissue damage.

Permeability: Capacity of soil, sediment, or porous rock to transmit water and gases.

pH: Numerical measure of hydrogen ion concentration, with a scale of 0 to 14. Neutral is pH 7, values below 7 are acidic, and values above 7 are alkaline.

Phosphorus: Essential nutrient for plants and animals. Component of cell walls, nucleic acids, and energy transfer molecules.

Plant available nitrogen (PAN): A calculated quantity of nitrogen made available during the growing season after application of fertilizer. PAN includes a percentage of the organic nitrogen, a percentage of the ammonium N, and all the nitrate N in the fertilizer.

Plant residues: Plant material that remains in the field after harvest.

Platy: A soil structure consisting of soil aggregates that are developed predominantly along the horizontal axis; laminated; flaky.

Point source contamination: Water contamination from specific sources, such as leaking underground storage tanks, landfills, industrial waste discharge points, or chemical mixing sites.

Potash (K_2O): Term used to refer to potassium or potassium fertilizers.

Potassium: An essential plant nutrient involved in energy metabolism, starch synthesis, and sugar degradation.

Preferential flow: The rapid movement of water and its constituents through the soil via large and continuous pores.

Prismatic (columnar): Soil structure where the individual units are bounded by flat or slightly rounded vertical faces. Units are distinctly longer vertically, and the faces are typically casts or molds of adjoining units. Vertices are angular or sub-rounded; the tops of the prisms are somewhat indistinct and normally flat.

Recharge area: Land area over which surface water infiltrates into soil and percolates downward to replenish an aquifer.

Recharge: Downward movement of water through soil to groundwater.

Recommended rate: Amount of nutrients recommended on a soil test report or plant tissue analysis for a specific crop that meets but does not exceed the crop nutrient requirements. Recommended rates can also include nutrients used for soil test buildup.

Remote sensing: The collection and analysis of data from a distance, using sensors that respond to different heat intensities or light wavelengths.

Restrictive layer: A nearly continuous layer that has one or more physical, chemical, or thermal properties that significantly impede the movement of water and air through the soil or that restricts roots or otherwise provides an unfavorable root environment.

Rhizobia: Bacteria capable of living symbiotically with higher plants by receiving food and carbon and providing nitrogen to the plant.

Rill: A channel in the soil caused by runoff water erosion that is small enough to be erased by tillage.

Riparian zone: Land adjacent to a body of water that is at least periodically influenced by flooding.

Root interception: Method by which ions in the soil are intercepted by root growth.

Runoff: Portion of precipitation, snowmelt, or irrigation that moves by surface flow from an area.

Saline soil: A non-sodic soil containing enough soluble salt to adversely affect the growth of most crops.

Salinity: An index of concentration of dissolved salts in the soil.

Secondary nutrients: Those macronutrients (calcium, magnesium, and sulfur) used less often as fertilizers than the primary elements.

Sediment: Eroded soil and rock material and plant debris transported and deposited by wind or water.

Sheet and rill erosion: A water erosion process caused by raindrop impact on the soil surface and a thin layer of water (sheet) moving over the soil surface.

Sidedress: To apply a fertilizer, pesticide, or soil amendment to one side of a growing plant, either by surface application or injection.

Single grain: A structureless soil in which each particle exists separately, as in sand.

Sodic soil: Soil high in sodium and low in soluble salts.

Soil analysis: A chemical, physical, or biological procedure that estimates the plant availability of nutrients and soil quality characteristics to support plant growth.

Soil drainage: The process where water is moved by gravity, either by surface channels or internal pores in the soil profile.

Soil organic matter: The organic fraction of the soil exclusive of undecayed plant and animal residues. Often used synonymously with "humus."

Soil pH: The degree of acidity or alkalinity of a soil, expressed on a scale from 0 to 14, with 7.0 indicating neutrality; increasing values indicate increasing alkalinity, while decreasing values indicate increasing acidity.

Soil productivity: A measure of the soil's ability to produce a particular crop or sequence of crops under a specific management system.

Soil reaction: A quantitative term that describes how acidic or alkaline the soil is.

Soil sampling: Process of obtaining a representation of an area of the soil or field by collecting a portion of the soil.

Soil solution: The aqueous liquid phase of the soil and its solutes contained in soil pores.

Soil structure: The combination or arrangement of primary soil particles into secondary soil particle units, or peds.

Soil survey: The examination, description, and mapping of soils of an area according to the soil classification system.

Soil test interpretation: Using soil analysis data to manage soil fertility and monitor environmental conditions.

Soil test level: The nutrient status of the soil, as indicated by analysis of a soil sample.

Soil test recommendation: The suggested amount of nutrients or soil amendment to be added to the soil to achieve expected crop yields.

Soil texture: The relative proportions of sand, silt, and clay in the soil.

Solubility: Amount of a substance that will dissolve in a given amount of another substance, typically water.

Solute: A substance that is dissolved in another substance, thus forming a solution.

Starter fertilizer: A fertilizer applied in relatively small amounts with or near the seed at planting.

Subsurface band: To apply nutrients, pesticides, or soil amendments in narrow bands below the surface of the soil.

Sufficiency level: 1) For interpretation of plant analysis: A nutrient concentration in the plant tissue above which the crop is amply supplied, and below which the crop is deficient. 2) For interpretation of soil analysis: A soil test level above which economic responses to applied fertilizers are unlikely to occur.

Surface band: To apply nutrients, pesticides, or soil amendments in narrow bands over the surface of the soil.

Surface broadcast: To apply nutrients, pesticides, or soil amendments uniformly over the surface of the soil.

Surface creep: Movement of sand-sized particles/aggregates by wind, in which the particles roll along the soil surface. Surface creep may account for 7–25 percent of total transport by wind.

Symbiotic N fixation: Conversion of molecular nitrogen (N_2) to ammonia and subsequently to organic nitrogen forms by organisms.

Tillage erosion: The downslope displacement of soil through the action of tillage operations.

Tillage pan: Also known as a plow pan; a subsurface layer of soil that has a higher bulk density than the layer either above or below it. The compaction is caused by tillage operations.

Tilth: Physical condition of the soil in terms of how easily it can be tilled, how good a seedbed can be made, and how easily seedling shoots and roots can penetrate.

Topdress: To broadcast nutrients, pesticides, or soil amendments on the soil surface after crop emergence.

Total nitrogen: The sum of the organic and inorganic forms of nitrogen in a sample.

Toxicity level: A quantity of a material in plants, soil, or water that can harm or impair the physiological function of plants or soil.

Triple superphosphate: A product that has a guaranteed analysis between 40 and 50 percent available phosphoric acid. The most common analysis is 0-46-0.

Uptake antagonism: When the excess of one nutrient interferes with the uptake of another nutrient. Usually, the nutrients in question have a similar uptake mechanism by the plant.

Urea ammonium nitrate solution (UAN): A non-pressure nitrogen fertilizer solution containing urea and ammonium nitrate in approximately equal proportions dissolved in water. The nitrogen content of the fertilizer solution ranges from 28 percent to 32 percent.

Urea: A nitrogen fertilizer that is a white crystalline solid, is very soluble in water, and has an analysis of 46-0-0.

Volatilization: The loss of a compound in gaseous form from a solid or liquid phase.

Watershed: All land and water that drains runoff to a stream or other surface water body.

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This project is funded partly through U.S. Environmental Protection Agency Nonpoint Source Grant number C9994866-10-0 and Mississippi Department of Environmental Quality, Water Quality Management Branch, under the provisions of Section 319(h) of the Clean Water Act.

Publication 2647 (08-22)

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Produced by Agricultural Communications.