NORTH CAROLINA DEPARTMENT OF TRANSPORTATION

VEGETATION MANAGEMENT MANUAL ROADSIDE ENVIRONMENTAL UNIT

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North Carolina Department of Transportation
Vegetation Management Manual

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ROADSIDE ECOLOGY
Managing North Carolina Department of Transportation's (NCDOT) Roadsides

The primary goal of Departments of Transportation (DOT) is to provide infrastructure that facilitates the movement of people and goods. In North Carolina, the components of aesthetics, tourism and economic development are woven into this commitment. These components make North Carolina's roadsides visually appealing to travelers and distinctly different than those of surrounding states.

Accessibly located in the mid-Atlantic region, North Carolina is considered a drivable destination. According to the Department of Commerce, North Carolina consistently ranks among the top six visited states. Tourism results in a $26 billion economic impact on the State's economy.

North Carolina, with a population of approximately 10 million, continues to rank among the fastest population growth areas in the nation. North Carolina is experiencing tremendous population growth and is expected to become the 8th most populous state in the nation by 2040. As North Carolina's population continues to grow, moving people and goods safely and efficiently while maintaining existing infrastructure will remain a top priority. Since Congress enacted the Highway Beautification Act of 1965, our state has placed emphasis on right of way appearance. Appearance drives tourism and fosters economic development.

Today's driver expects travel corridors that are designed to save time, handle an ever-increasing flow of traffic, and are aesthetically pleasing. A man-made transportation network that fulfills these expectations consequentially disturbs the natural ecology.

Ecology is loosely defined as the interdisciplinary study of how organisms interact and impact their environment. Man is a component of the ecology and is not separated from these interactions.

A quoted key word string search of the term 'ROAD ecology' produced 1,200,000 results focused on the often malign impacts of road construction on the natural environment. Impacts related to water movement, animal migration, and soil profile alterations have been studied by numerous authors. Ecologists have also studied the impacts altered vegetation has on habitat and animal movement.

ROADSIDE ECOLOGY, as practiced in North Carolina, focuses on the amelioration of these impacts. **ROADSIDE ECOLOGY** focuses on the stabilization of soils, stormwater remediation, the protection of federally endangered plant species and beneficial pollinators, wetland mitigation and the aesthetic profile.

In North Carolina, the state maintains control over the entire right of way of state-owned roadways. Many states endorse a 'county-based' maintenance system. North Carolina's is the nation's second largest state-maintained right of way with approximately 80,000 miles of roadway and approximately 300,000 acres within its purview.

FOREWORD

For operational purposes, the transportation rights of way are comprised of several zones. These zones receive varying degrees of maintenance and are subject to different level-of-service expectations. Illustrated in sequence, from left to right, are the operational zone, and the safe recovery zone, the transition/C-ZIP zone and the natural environment zone. Collectively, the operational, safe recovery and transition zones are referred to as the 'built environment'. These zones, from left to right, when considered holistically, have decreasing Level of Service (LOS) expectations, the number of obstacles increase, less funding is appropriated for maintenance, and the zones become less impacted by construction and routine operational activities. The operational zone includes the travel lanes, structures and the array of hidden infrastructure that support the travel way.

From the illustration, the safe recovery zone is the area of mown grass that provides drivers of errant vehicles a safe place to stop or regain control of their vehicle before reentering the travel lanes of the operational zone. For this reason, by design, it is a zone of few obstacles.

To the right of the safe recovery zone is the transition zone. It is also called the C-ZIP area. C-ZIP is an acronym for Clear Zone Improvement Program. This area is traditionally planted in wildflowers, ornamentals, small flowering trees and native grasses. This zone serves a vital purpose by linking remnant farmlands for pollinators. It also provides pollinators with nectar, pollen and habitat. The C-ZIP zone also serves as a transition between the mown area and the natural environment zone. It is the area designated for stormwater remediation devices, bioremediation basins, as well as wetlands and stream mitigation. NCDOT currently manages 31 acres of wetland mitigation on 60 sites and 46,000 linear feet of stream restoration and approximately 1,750 stormwater control measures.

To the right of the C-ZIP zone in the image above is the natural environment zone. This area contains mature trees and most closely resembles the environment prior to road building activities.

ROADSIDE ECOLOGY focuses on activities that ultimately mitigate for the impacts studied in 'Road Ecology'. Let's be clear; how one chooses to manage the built environment ultimately determines the success of these mitigation efforts. The activities associated with roadside ecology are an attempt to recreate the natural environment – not replace it.

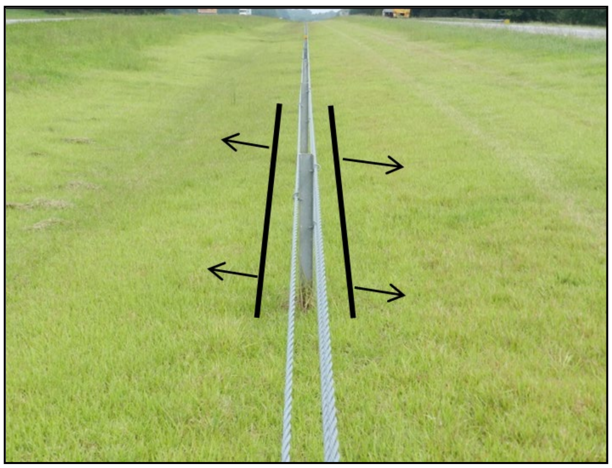
In the publication *Ecology and Society,* Rodney Van Der Ree[1] et al state:

> *"Many road agencies have 'environmental sustainability' as one of their goals and the only way to achieve such goals is for them to support and foster long-term and credible scientific research. Every road project is essentially an experiment and when combined with other road projects, they become replicated. The challenge we*

[1] Effects of Roads and Traffic on Wildlife Populations and Landscape Function: Road Ecology is Moving Toward Larger Scales', Rodney Van Der Ree et al., (Ecology and Society, Vol. 16, #1, Art 48, 2011).

face as researchers is to (1) use good scientific approaches to design studies that are scientifically robust and maximize the individual value of each road project within a larger experimental scope; (2) ensure our research is applied and has tangible value for road agencies and for ecological outcomes; (3) address the higher order effects of roads, traffic, and mitigation measures."

NCDOT is strongly committed to research. As a routine practice, NCDOT commits $8 million annually to research. Part of this commitment focuses on roadside ecology. Beginning in 1962 (Research Project Number ERD-110-S), Dr. Bill Gilbert, North Carolina State University (NCSU), led investigations to determine the best turfgrass for the safe recovery zones and to determine the best management practices to stabilize these areas.



Subsequent research investigated the 'Selection, Establishment, and Maintenance of Vegetation along North Carolina's Roadsides' (Project Number 23241-80-2). Of the numerous vegetative covers studied, this project concluded that Centipede was worthy of consideration and that approximately 60% of the state's rights of way could be established with Centipede.

In 2011, NCDOT began in earnest installing zoysia beside guardrails. Currently, NCDOT is funding zoysia research with Drs. Milla-Lewis and Grady at NCSU (Project Number 2018-8401). The objectives of this investigation are: to determine the best zoysia cultivar for roadside operations, to evaluate reselected first-generation zoysia genotypes, and study installation timing, as well as installation methodologies. The photo (left) indicates how zoysia spreads following an 18 inches wide sod installation beside the guardrail.

By far the program that receives the most notoriety is the North Carolina Wildflower Program. Beginning with 12 acres in 1985, NCDOT has the largest planted wildflower program in the nation in 2017, with approximately 1,500 acres in standard production. Approximately 23 species including annuals, perennials and North Carolina native wildflowers adorn transition zones across the state. Often thought of for its aesthetic value, the program also benefits pollinators. Research conducted in 2015 by NCSU's Dr. Seth-Carley, Horticultural Science Department, shows that compared to adjacent, non-mown rights-of-way, wildflower beds have:

- 6 times more pollinator bees,
- 2.5 times more pollinator flies,
- 5 times more pollinator butterflies, and
- 37 times more pollinator wasps.

Recently, two of NCDOT's rest area facilities – Madison and Wilkes Counties – earned the recognition of certified Monarch Waystations by monarchwatch.org. These facilities incorporated plantings of milkweed and pollinator support species in their facility landscape designs. Travelers are free to explore informational signage and are encouraged to visit our website for more information.

In addition to planting wildflowers, NCDOT also preserves and protects populations of federally threatened and endangered plant species, most of which are wildflowers. Protecting these species embodies the concept of 'roadside ecology' at its core level. In 39 of North Carolina's 100 counties, there are 145 recorded populations of 12 such endangered species. For some of these species, naturally occurring populations are only found on North Carolina rights of way.

The same travelers who demand highway infrastructure that meets their expectations are also becoming increasingly conscious of how transportation corridors are managed from an ecological standpoint. Roadside ecology, as practiced in North Carolina, provides solutions to numerous issues posed by road ecology scholars.

FIGURES

TABLES

LIST OF ACRONYMS

CCE	Calcium carbonate equivalence
CEC	cation exchange capacity
C-ZIP	Clear Zone Improvement Program
DNA	deoxyribonucleic acid
IBDU	isobutylidene-diurea
IPM	Integrated Pest Management
IRVM	Integrated Roadside Vegetation Management
LOS	Level of Service
MASL	Mallinckrodt Ammonium Sulfate Liquid
NCDA&CS	North Carolina Department of Agriculture and Consumer Services, formerly NCDA
NCDEMLR	North Carolina Division of Energy, Mineral and Land Resources
NCDEQ	North Carolina Department of Environmental Quality
NCDOT	North Carolina Department of Transportation
NCSU	North Carolina State University
NRCS	Natural Resources Conservation Service
NVMA	National Vegetation Management Association
PTO	power take off
REU	Roadside Environmental Unit
RLC	reactive layer coating
RNA	ribonucleic acid
USLE	universal soil loss equation
RUSLE	revised universal soil loss equation
NCDMV	North Carolina Department of Motor Vehicles

Introduction

In This Chapter . . .

- *The Soil as a Three-Phase System*
- *The Soil as a Product of the Environment*
- *Physical Properties of Soils*
- *Particle Size Analysis and Textural Class*
- *Effects of Soil Physical Properties*
- *Chemical Properties of Soils*
- *Biological Properties of Soils*
- *Soils of North Carolina*

Soil is a substance of essentially universal occurrence. Perhaps because it is so commonplace, we often fail to fully appreciate the impact it makes on our daily lives. No one, of course, overlooks the dependence we place on soil as a medium for plant growth because it serves as our primary source of food and fiber. Soil is important for many other reasons, however. It is an important consideration for the engineer in the construction of roads, dams, and other works. As a porous mantle over the earth's surface, it acts as a reservoir for the collection and storage of water from rain and melting snow that might otherwise be lost as unrestricted runoff and cause devastating effects. It is essential to understand the soil to the fullest extent possible in order to use and manage it effectively.

Soils vary in their effectiveness when subjected to different uses. For instance, some are excellent media for plant growth yet are totally unsuitable for use in engineering works. Whether or not a soil yields desirable results under a certain application depends upon its properties or the extent to which those properties can be readily modified.

Satisfactory utilization of soils requires an understanding of these properties and their relationship to soil behavior. Equally important is a knowledge of techniques that can be employed to change the soil when it fails to measure up to an accepted standard.

NCDOT Construction Site

The Soil as a Three-Phase System

Defined in simple terms, the soil is a system consisting of three phases: solid, liquid and gas (**Figure 1.1**). The solid phase is a mixture of mineral and organic particles lying in intimate contact so as to provide the skeletal framework of the soil. Enclosed within the framework is a system of pores that not only permeates the soil body but is also continuous with the outer atmosphere. The pore space is shared by the liquid phase, which consists of water with varying quantities of dissolved substances, and by the gaseous phase that makes up the soil air. The solid phase is relatively stable with respect to both composition and organization. The other two phases are in a state of constant change as a result of the virtually continuous interchange of water and air between the soil pores and the outer atmosphere. A typical example of this variability is the loss of water by evaporation or plant use and its periodic replacement by rain or irrigation. In characterizing the soil it is important to consider not only the contribution of the individual phases to overall properties of the soil, but also the way in which the phases interact to determine the final expression of these properties.

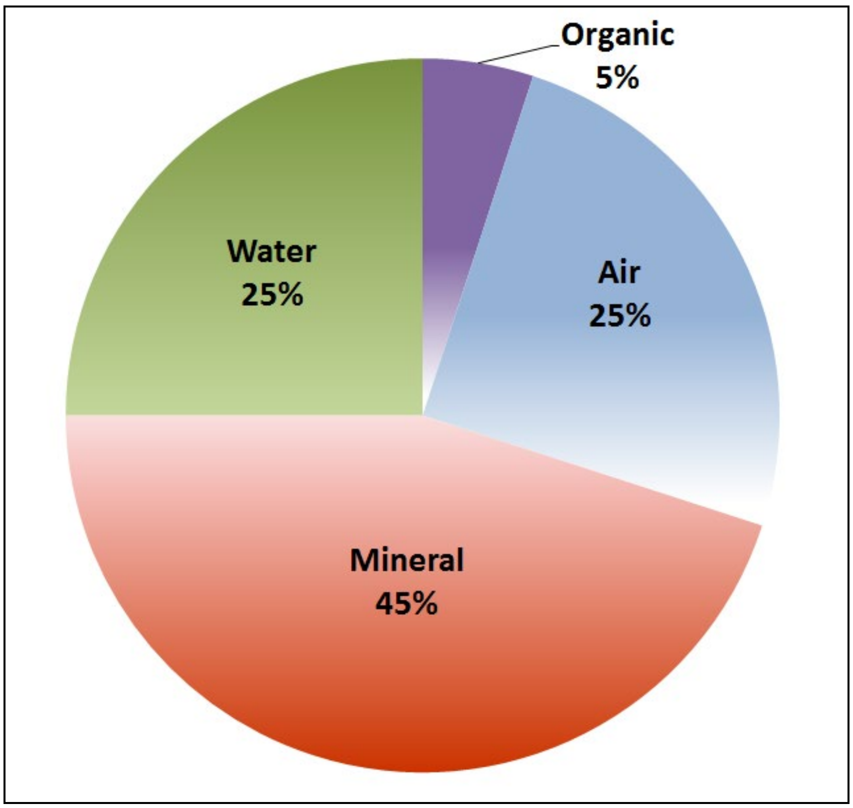


Figure 1.1: Average Composition of a Mineral Soil

Solid Phase of Soils

The major component of the solid phase of soils is fragmented mineral matter derived from the weathering of hard rock at the earth's surface. Mineral particles produced by weathering vary widely in size, but in soils, they occur mainly in the three size groups of *sand*, *silt*, and *clay*. Sand particles are large enough to be seen by the naked eye, whereas silt and clay particles are in the microscopic and submicroscopic ranges of visibility. Larger mineral fragments such as gravels, cobbles, and stones also occur in many soils, but by no means in the majority of them.

The mineral fraction is one of the prime determinants of overall soil properties. Many of these properties relate to the proportions of sand, silt, and clay present. The relative amounts of these particle sizes are described by the term *texture*. Chemical properties of soils are influenced by the specific kinds of minerals present. Since the mineral fraction is relatively stable, many of the properties derived from it are essentially permanent features of the soil.

The organic portion of the solid phase has as its primary source residues from a large variety of plants and animals that inhabit the soil. These residues, once incorporated into the soil, undergo extensive change as they are attacked and decayed by living soil organisms, largely microbial. The products of decay tend to accumulate in the soil, often as a blackish, finely divided substance. Thus, the presence of organic matter is generally evident from the darkening effect it has on soil mineral matter.

Since the bulk of the soil organic fraction initially comes from plant residues, it accumulates for the most part within the surface layer or directly upon the surface of the soil. The amount of organic substance that accumulates relates fairly closely to environmental conditions controlling plant growth and the quantity of residues returned to the soil.

The surfaces of the mineral and organic particles have attractive forces that cause soils to exhibit certain properties. These forces are responsible for the retention of water and chemical elements (as ions) by the soil. They also enable particles to cling to each other, thus causing stickiness in many soils when wet and the formation of hard clods upon drying. Since these properties are associated with the surface of solids, they are most pronounced in soils containing a preponderance of particles of clay. As the average size of clay particles becomes smaller, the total surface per unit quantity of soil increases.

Liquid Phase of Soils

Water is the principal component of the liquid phase and it is important primarily because of its effect on plant growth. It is the major constituent of cell sap and is used directly in the synthesis of important organic constituents required for normal growth of plants to maturity. In the soil, water is involved in the release of essential plant nutrients and other elements from minerals and decaying organic matter. With these dissolved substances, water comprises the *soil solution* and provides the principal pathway for the transfer to plant roots of nutrients necessary for plant growth.

Plants have a comparatively high requirement for water. However, since soil water is lost continuously, and often rapidly, by the combined processes of evaporation and transpiration, i.e., evapotranspiration, it must be replenished frequently to sustain plant growth. *The abundance of vegetation over the surface of the earth is probably limited by the lack of water more than any other factor.*

Living plants can be adversely affected by a surplus as well as by a shortage of soil water. Excesses result in the blockage of soil pores, so that the movement of air within the root zone is restricted. If the supply of oxygen in the soil air is depleted because of limited replenishment, root growth and other essential plant functions are greatly curtailed. Thus, while efforts in dry regions are usually directed toward the conservation of all available water for use by crop plants, water disposal is often a problem in humid areas. Minimal success in the utilization of many agricultural soils relates to our inability or unwillingness to control moisture relationships in these soils.

Gaseous Phase of Soils

Like the outer atmosphere, soil air consists of nitrogen (N_2) and oxygen (O_2) in combination with lesser amounts of carbon dioxide (CO_2) and other gases. Nitrogen is the most abundant gas in soil air just as it is in the atmosphere. It is also an essential plant nutrient but it cannot be used directly in gaseous form by higher plants. However, some soil microbes can utilize N_2 gas, and in so doing, incorporate it into protein-containing substances that ultimately appear in the organic fraction of soils.

Oxygen, the second most abundant element in the soil atmosphere, is essential to all life processes in the soil. It is necessary for root and microbial respiration, an energy-supplying process that normally involves the oxidation of carbonaceous compounds to CO_2 and H_2O. The rate of respiration is thus a function of the concentration of O_2 in soil air, which is, in turn, controlled by the rate of gaseous interchange between the soil and the outer atmosphere. Since gas flow in soils depends on the average size of pores and the extent to which they are filled with water, the state of aeration, as defined by the concentration of O_2, is controlled by the liquid and solid phases of the soil.

The Soil as a Product of the Environment

An important view of soils is that they are natural bodies produced by a set of soil-forming processes acting through time on mineral matter at the surface of the earth. The keynote of soil formation is change. It involves the conversion of previously weathered mineral matter, referred to as the soil *parent material*, into a new product, the soil. Some phases of soil formation are destructive, for they cause the further weathering and wastage of the minerals making up the parent material. Yet, soil formation is also constructive, for it results in the synthesis of new mineral compounds, primarily clays, or of semistable organic substances derived as by-products of the decay of plant and animal residues. Regardless of the specific kinds of change, they introduce new properties that either replace or mask the properties of the parent material. The extent of change depends on the intensity of soil-forming reactions and the time they have to act in soil development.

One of the more obvious effects of soil formation is the development of layers of differing characteristics within the parent material. These layers, called *horizons*, lie roughly parallel to the surface and reflect the variation in soil properties with depth. The kinds and arrangement of horizons determine the nature of the soil *profile* (**Figure 1.2**). The profile, in tum, is the basis for recognizing and classifying individual kinds of soil.

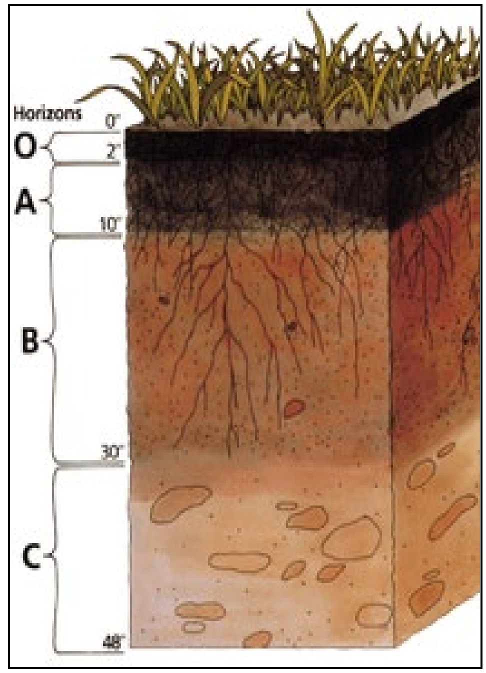


Figure 1.2: Generalized Profile Showing Primary Mineral Horizons (modified from Brady, 1990)

Horizons in soils are products of one or more processes induced by the interaction of soil parent material with imposed climatic or biological influences. Of these processes, the ones that appear to have the greatest impact on horizon formation are (1) mineral weathering, (2) organic matter accumulation, and (3) the downward translocation of colloidal particles, mainly clay, by percolating water, and the accumulation of such particles in a subsurface layer. The tendency for these processes to create horizons in the soil relates to the fact that their ability to produce change in a parent material varies with depth.

Identification of Soil Horizons

Three types of horizons are regularly produced in the mineral section of the soil profile, and they are identified by the letter symbols A, E, B, and C (**Figure 1.2**). The A horizon is the uppermost horizon in most soils. It shows the effects of organic matter accumulation and mineral weathering by its darker color and the presence of resistant minerals such as quartz. The E horizon is the zone of maximum leaching of clay and other materials of very small particle size. The E horizon is generally lighter in color than the A horizon. A mineral soil may contain an A horizon without an E horizon, or it may contain both horizons. In forested regions, a layer of organic litter may also accumulate on the surface of the mineral soil. This layer is called an 0 horizon. It may be directly underlain by either an A or an E horizon.

The B horizon occurs immediately beneath an A horizon or an E horizon, if either or both of these horizons are present. It is the zone of maximum clay accumulation in the profile. In some soils, the accumulation of clay may produce a very dense, almost impenetrable layer; in others, clay accumulation may be so slight as to be barely perceptible. Sometimes a B horizon is recognized by a distinct color change due to colloidal coatings on mineral particles. Common colors of B horizons in well-aerated soils of warm, humid regions are red and yellow due to accumulation of iron oxides. In poorly aerated soils, the B horizon colors decrease in brightness and are often gray. The B horizon is not present in all soils because weathering of minerals and translocation of clay have been insufficient to produce it.

The C horizon is a zone of minimum change. Its normal position is directly beneath the B horizon. If a soil lacks a B horizon, however, the C will lie directly beneath the A. If the A horizon is also absent, the entire profile is classed a C horizon. This latter condition occurs infrequently and is due to low intensity soil development or to severe erosion that has removed the A and B horizons.

Horizon differentiation is not always clearcut and there are often gradual changes in soil properties with depth. Additional designations are used for the transitional horizons, e.g., A3, B1. In some cases, further subdivisions of horizons are necessary, e.g., B21, B22.

The terms ‘topsoil’ and ‘subsoil’ are widely used in practical applications of soils. Although these terms cannot be equated with specific horizons, the topsoil generally includes part or all of the A horizon when that horizon is present. Topsoil is important because it is the major zone of root development for plants. Being at the surface, it can be manipulated to promote vegetation establishment. Where the A horizon has been removed by severe erosion or by human activity, e.g., construction site preparation, the ‘topsoil’ may actually be the B horizon or even the C horizon when the B horizon is missing.

The subsoil generally includes part or all of the B horizon when that horizon is present. Although it is not subject to manipulation like the topsoil, the subsoil is very important in vegetation establishment because it is the medium for deeper root penetration and it serves as a reservoir for moisture and nutrients. Consequently, land use decisions often are based more on the subsoil characteristics than the topsoil features.

Environmental Factors and Soil Formation

Most changes during soil formation are dependent on the availability of water and heat in the soil-forming environment. For this reason, climate is an important, if not the principal, factor of soil formation. A second factor is topography, or lay of the land, which determines the efficiency with which externally supplied moisture and heat are taken up by the developing soil. In addition to climate and topography, the influence of living matter, both plant and animal, and the nature of the parent material have significant bearing on the rate and direction of soil-forming reactions. These four factors: *climate, topography, living matter, and parent material* collectively describe the environment in which soil formation takes place. As environments over the surface of the earth differ, so do their associated soils, provided *time* has been ample to allow for measurable change in the parent material.

The interactions of the variable environmental factors in North Carolina that have produced a diverse array of soils will be described later in the chapter.

Physical Properties of Soils

The term ‘physical properties’ refers to properties (e.g., size, shape, density) that describe the mechanical behavior of the soil mass. Physical properties are extremely important in determining how soils can and should be used. They range from properties that determine a soil’s suitability for a building foundation or a roadbed to its suitability for the growth of different plants. Physical properties relate not only to soil solids but to soil water and air as well. In fact, through their influence on water movement into and through soils, physical properties also exert considerable control on the process of soil erosion by water.

A number of physical properties can be judged by visual observation or by manual sensing. This is fortunate because it enables the soil manager to make immediate judgments and decisions in the field. The following physical properties will be discussed: *texture, structure, density, consistence, and strength.*

Texture

Texture is one of the most important soil properties because it correlates with the chemical, biological, and other physical properties of the soil. Many soil interpretations are made with texture as the main criterion. It is a relatively permanent property because it is based on the mineral fraction only, and it is not influenced by organic matter. It is not subject to change like some of the other properties. Thus, a sandy soil remains sandy, and a clay soil remains clayey.

Texture is defined as the proportionate quantities of *sand, silt, and clay*, which are called the *soil separates*. Sand particles have diameters between 2.0 and 0.05 mm; silt particles have diameters between 0.05 and 0.002 mm; and clay particles have diameters less than 0.002 mm (**Table 1.1**).

Table 1.1: Soil Separates and their Diameter Ranges (Donahue, Miller and Shickluna, 1983)

Soil Separate Name	Diameter Range (mm)	Visual Size Comparison of Maximum Size
very coarse sand	2.0 – 1.0	house key thickness
coarse sand	1.0 – 0.5	small pin head
medium sand	0.5 – 0.25	sugar or salt crystals
fine sand	0.25 – 0.10	thickness of book page
very fine sand	0.10 – 0.05	invisible to the eye
silt	0.05 – 0.002	visible under microscope
clay	Less than 0.002	most are not visible even with a microscope
Coarse Fragments		
gravels	2 – 75 (0.08 to 3 inches)	
cobbles	75 – 254 (3 to 10 inches)	
stones	greater than 254 (over 10 inches)	

Sand grains may be rounded or irregular depending on the amount of abrasion they have undergone. Unless coated with clay and silt, such particles are not sticky even when wet. They cannot be molded as can clay and therefore are not plastic. The water-holding capacity of sand grains is low, and because of the large spaces between the separate particles, water and air pass through rapidly. Hence, soils dominated by sand generally possess good drainage and aeration but may be prone to drought. An exception to this is when sandy soils occur in depressional areas on the landscape.

Silt particles are intermediate between sand and clay in size and properties. They are diverse in shape, and are seldom smooth or flat. The silt separate, because it usually has an adhering film of clay, possesses some plasticity, cohesion (stickiness), and adsorptive capacity, but much less than the clay separate. Silt may cause the soil surface to be compact and crusty unless it is supplemented by adequate amounts of sand, clay, and organic matter.

The surface area per unit mass of clay is very high because of the small size of the individual particles. Fine colloidal clay, i.e., <0.001 mm, has about 10,000 times as much surface area as the same weight of medium-sized sand. The specific surface (area per unit weight) of colloidal clay ranges from about 10 to 1000 square meters per gram (m^2/g) compared to 1 and 0.1 m^2/g for the smallest silt particle and fine sand, respectively. Since the adsorption of water, nutrients, and gas and the attraction of particles for each other are all surface phenomena, the very high specific surface of clay is significant in determining soil properties. This relationship is shown graphically in **Figure 1.3**.

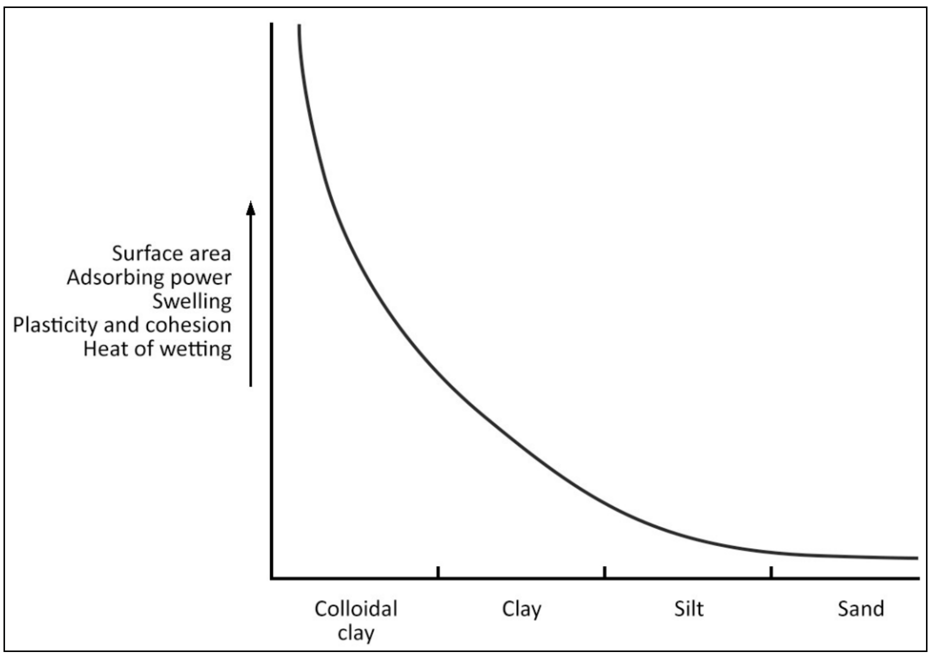


Figure 1.3: Relationship between Soil Particle Size and Several Important Physical Properties (Brady, 1990)

Clay particles vary in shape from plate-like to rounded. When clay is wet, it tends to be sticky and plastic or easily molded. The presence of clay in soil gives it a fine texture and slows water and air movement. While clayey soil becomes sticky when wet, it can also be hard and cloddy when dry unless properly handled. Clay expands and contracts on wetting and drying, and soils with high clay content generally have high water-holding capacity.

Particle Size Analysis and Textural Class

The analytical procedure for determining the amounts of each separate in a soil is called a particle size analysis. It is done by using sieves to mechanically separate out the very fine sand and larger separates from the finer particles. Then the weight of each separate is measured. The silt and clay contents are then determined by measuring the rate of settling of these two separates in a soil-water suspension.

The particle size analysis is the basis for assigning each soil to a textural class. The textural class is a very useful indicator of soil conditions, especially water and air relationships. The relationship between particle size analysis and textural class names is shown diagrammatically in **Figure 1.4**. The diagram reemphasizes that a soil is a mixture of particles of different sizes. To use the diagram, locate the percentage of a given separate (e.g., clay) and project the line inward toward the center of the triangle. Follow the same procedure for another separate. The point at which the two projections cross will identify the class name. Example: Assume that a soil contains 40% sand, 30% silt, and 30% clay. The 30% clay line is parallel to the baseline of the triangle. The 40% sand line intersects the clay line in the section of the triangle designated clay loam. To check the accuracy of the point of intersection, follow the 30% silt line until it intersects with the clay and sand lines. The large dot in **Figure 1.4** marks the intersection of the three percentages.

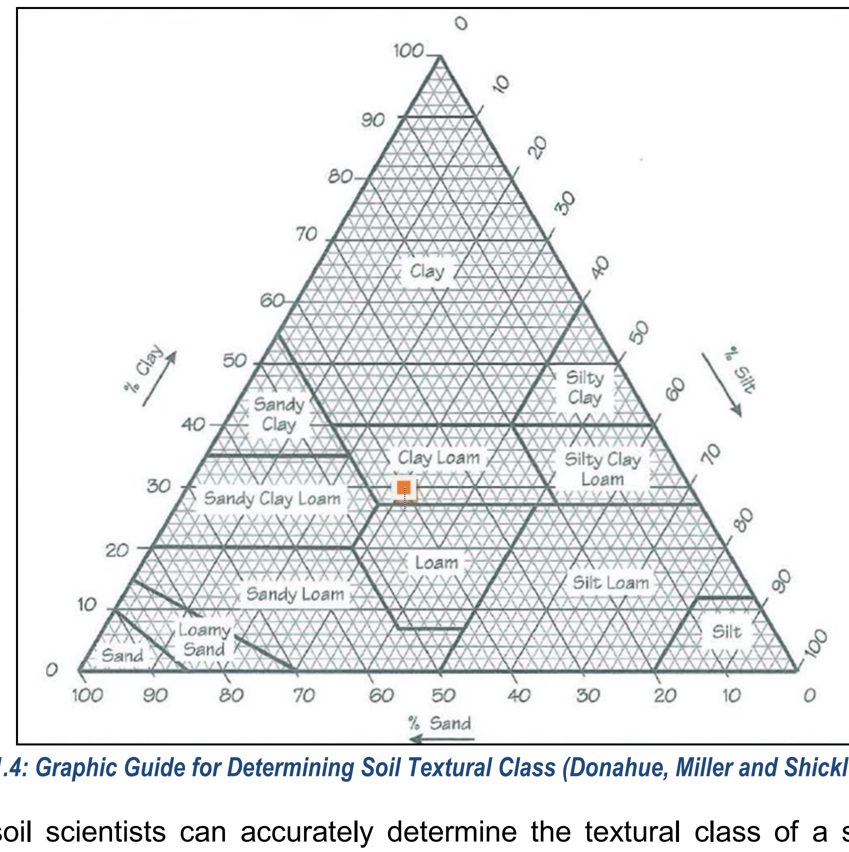


Figure 1.4: Graphic Guide for Determining Soil Textural Class (Donahue, Miller and Shickluna, 1983)

Experienced soil scientists can accurately determine the textural class of a soil by manually squeezing moist soil between the thumb and fingers and noting the "feel" of the soil. Individual sand grains can be felt when rubbed between the fingers and they impart a gritty feel to the soil. Silt particles cannot be felt individually and they produce a soft feel like flour or talcum powder. Clay is sticky and, when present in significant amounts (i.e., > 35%), will allow the soil to form a continuous ribbon when pressed between the thumb and forefinger. Accuracy with the "feel" method is of great practical value in making rapid onsite soil evaluations.

The broad application of particle size analysis and texture by many different users of soil information has led to a variety of terms which can be confusing. The relationship of general texture terms to the more specific textural class names (Brady, 1990) is shown in **Table 1.2**.

Table 1.2: General Terms Used to Describe Soil Texture

U.S. Department of Agriculture Classification System		
General Terms		
Common Names	Texture	Basic Soil Textural Class Names
Sandy Soils	Coarse	Sand Loamy Sand
	Moderately Coarse	Sandy Loam Fine Sandy Loam*
Loamy Soils	Medium	Very Fine Sandy Loam* Loam Silt Loam Silt
	Moderately Fine	Sandy Clay Loam Silty Clay Loam Clay Loam
Clayey Soils	Fine	Sandy Clay Silty Clay Clay

* Although not included as class names in Figure 1.4, these soils are usually treated separately because of their fine sand content.

Structure

The term “structure” is often confused with texture in discussions of soil physical properties but the difference in meaning between the two terms are very distinct. Whereas texture refers to the sizes and distribution of the individual mineral particles in a soil, structure refers to the shape and arrangement of the aggregates formed when mineral particles combine with each other and with organic matter, especially in the upper horizons. The technical term for these aggregates is peds.

A profile may be dominated by a single type of structure. More often, however, several types are encountered in the different horizons. The four principal types of soil structure are *plate-like, prism-like, block-like, and spheroidal*. A brief description of each of these structural types with schematic drawings is given in **Figure 1.5.**

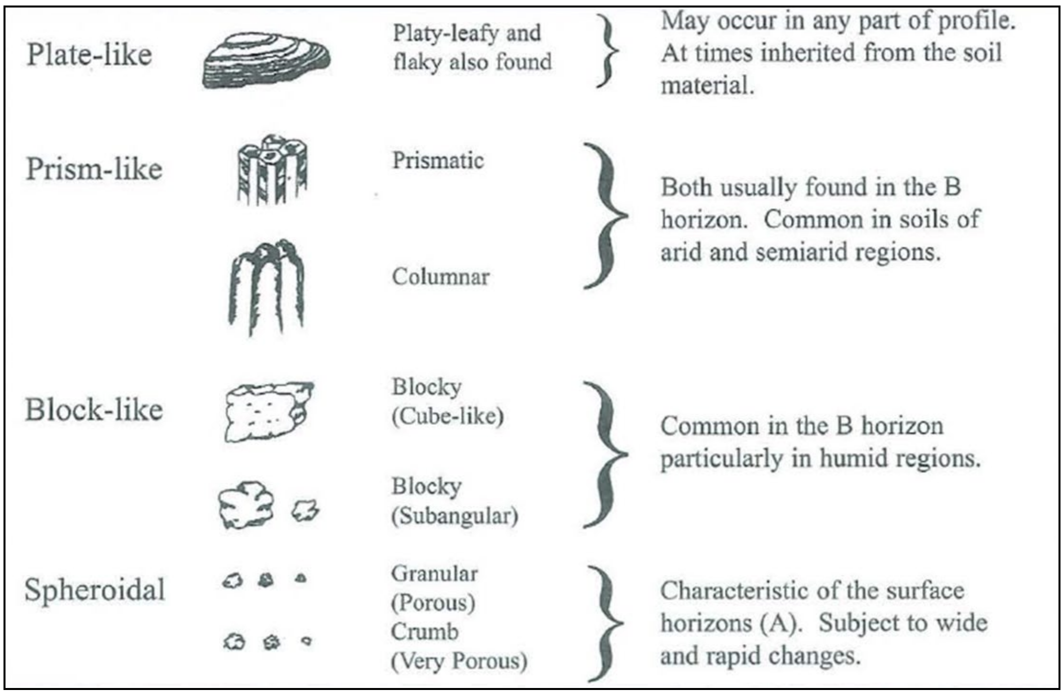


Figure 1.5: Various Structural Types found in Mineral Soils (Brady, 1990)

As already mentioned, two or more of the structural types listed usually occur in the same soil profile. In humid temperate regions like North Carolina, the most common aggregation is spheroidal (granular, crumb) in the surface horizon and block-like in the lower horizons.

Soil structure can, and is frequently changed by natural processes and human activities whereas texture is essentially a permanent unchanging physical property. It follows that a key aim in soil management is to maintain or even enhance the stability of soil structure, particularly in the topsoil where vegetation establishment and maintenance take place. Granules or crumbs are preferred, since their formation introduces an extensive network of large pores that favor the intake and retention of water. Measures that help sustain soil granules and crumbs include the incorporation of residues and other organic matter into the soil and careful tillage operations.

Density

Soil density is measured in several ways. The most valuable density measurement in practical applications is bulk density, also sometimes referred to as volume weight. It is the mass (weight) of a unit volume of dry soil. Bulk density is a useful parameter in describing the relationship between the soil solids and the pore space. Since bulk density relates to the combined volumes of the solid and pore spaces, soils with a high proportion of pore space to solids have lower bulk densities than those that are more compact and have less pore space. Consequently, any factor that influences soil pore space will affect bulk density.

Fine textured surface soils such as silt loams and clay loams generally have lower bulk densities than sandy soils. The solid particles of the fine textured soils tend to be organized in porous granules, especially if organic matter is present. This condition assures high pore space and a low bulk density. In sandy soil, however, organic matter contents generally are low, the solid particles lie close together, and the bulk densities are commonly higher than in the fine textured soils.

Consistence

Soil consistence is a measure of soil workability, and it is expressed in terms of the resistance the soil offers to deformation or rupture when a force is applied to it. Variation in consistence among different soils is primarily due to differences in texture and reflects the influence of the clay fraction. Consistence is also affected by the structural state and by the organic matter content of the soil. For example, well-granulated soils that contain organic matter tend to crumble more readily than do those in a massive, unstructured state or that contain relatively little organic matter.

Consistence is also a function of the water content of soils. Water has a softening effect when it is added to a hard dry clod. Consistence is commonly evaluated at three arbitrarily defined moisture states: wet, moist, and dry. The first of these is represented by recently wetted soil in which little water loss has resulted from plant use and evaporation. Most soils are soft and pliable when wet, and the consistence properties for which they are examined are plasticity and stickiness. Stickiness is judged at a moisture content above that required to produce a plastic condition.

The moist state is defined as a moisture content approximately midway between wet and air-dry. It is intended to represent a soil in suitable condition for tillage operations. Consistence terms used for soils at this moisture content are: loose, friable, and firm. A loose consistence is generally limited to non-coherent, coarse-textured soils. Friable soils tend either to have medium texture or to be very well aggregated if their texture is fine. Soils described as firm when moist are usually relatively dense, often the result of clay content, compaction or limited cementation.

Consistence when dry is determined on air-dry soil. Terms such as loose, soft, and hard are used to describe consistence at this water content. A loose consistence applies to sandy materials. Soft consistence suggests that the soil would crush to a powder when worked in a dry condition. Hard consistence is related to high clay content and is associated with rough, cloddy soil conditions.

Strength

Soil strength is usually regarded as a soil property confined to engineering uses. It is also important, though, in vegetation management because it affects root growth and seedling emergence. Soil strength is defined as the amount of force required to move or rearrange soil particles. It is affected primarily by water content and texture.

Water content is the most important factor determining soil strength. The lower the soil water content, or the drier the soil, the greater the soil strength. Soils that are saturated or waterlogged are weak in soil strength.

In general, soil strength increases with increasing fineness of texture, i.e., more clay. Coarse-textured soils (e.g., sands, loamy sands, coarse sandy loams) usually have the weakest soil strengths unless they are cemented or compacted. Bulk density is a good indicator of soil compaction and, hence, soil strength. As the soil particles are pressed closer together, the bulk density increases and the soil strength also increases.

Effects of Soil Physical Properties

Several important soil properties are directly influenced by the interaction of the physical properties just described. The following properties will be discussed briefly: Soil water; aeration; temperature; and color.

Soil Water

One of the most important soil characteristics is the content and behavior of water within it. We are interested in soil-water relationships for several reasons. First, large quantities of water must be supplied to satisfy the requirements of growing plants because water is continually lost by evaporation from leaf surfaces. Thus, water must be available when the plants need it, and most of it must come from the soil. Second, water is the solvent that together with the dissolved nutrients makes up the soil solution from which plants absorb essential elements. Third, soil moisture helps control two other important factors essential to normal plant growth-soil air and soil temperature. And last but not least, the control of the disposition of water as it strikes the soil determines to a large extent the incidence and severity of soil erosion.

As mentioned earlier, water occupies the pore space in soils. If all the pore space is filled with water, the soil is saturated. If the pore space is not totally filled with water, the soil is unsaturated. Within the unsaturated condition, there are two critical soil water contents: Field capacity and permanent wilting point, or wilting coefficient (**Figure 1.6**). Field capacity is defined as the maximum amount of water a soil can hold against gravity. At field capacity, water has drained from the large pores, the macropores, but the micropores are still filled with water. The permanent wilting point is that moisture content of the soil when insufficient water is available to sustain plant growth and plants wilt beyond recovery. The amount of water that a given soil retains between the field capacity and permanent wilting point is called plant available water. Obviously, this is the quantity of water of greatest concern in vegetation establishment and maintenance. Soil texture is probably the main determinant of available water in a soil through its influence on pore size and configuration. The general relationship between texture and available water is indicated in **Figure 1.7**.

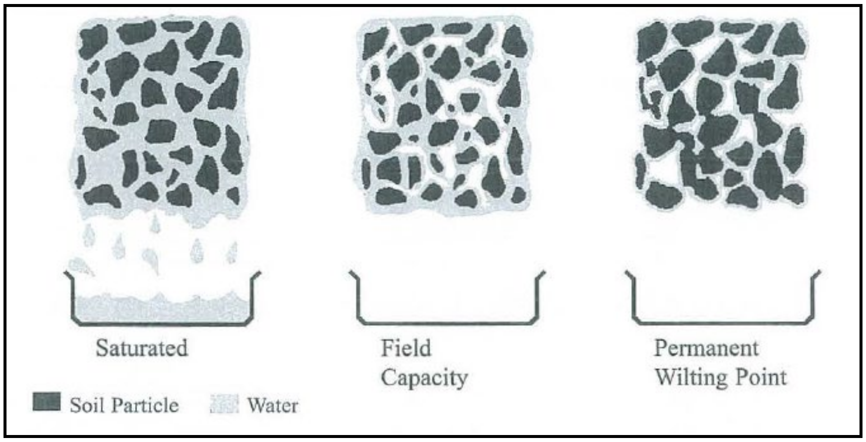


Figure 1.6: Moisture Status in Soil in Relation to Three Major Reference Points (modified from Brady, 1990)

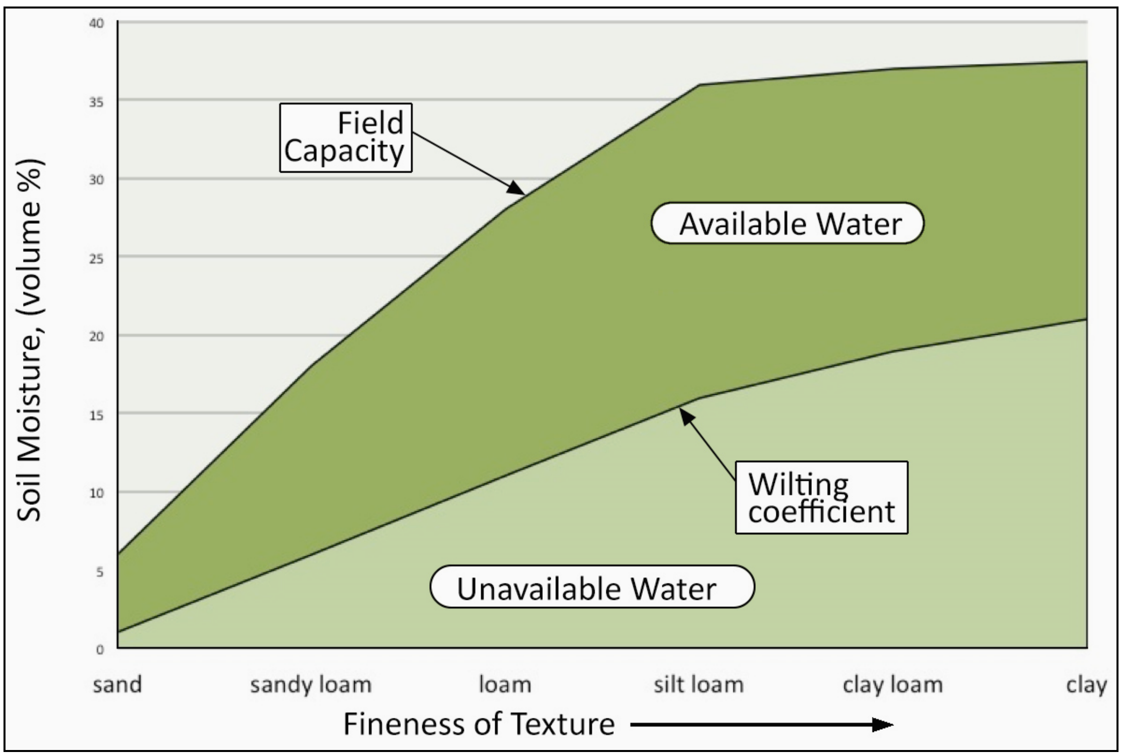


Figure 1.7: General Relationship between Soil Moisture Characteristics and Soil Texture (Brady, 1990)

Note that the wilting coefficient increases as the texture becomes finer. The field capacity increases with fineness of texture until silt loam is reached, then levels off. Thus, the maximum amount of available water occurs in a silt loam, then gradually decreases in clay loam and clay. Other factors (e.g., structure) also influence pore size and configuration. Therefore, one can expect considerable variation in available water from one soil to another even though soil texture may be similar.

Two important aspects of water behavior in soils are the entry of water into the surface layer and the downward movement of water through the underlying soil layers. The entry aspect is called *infiltration*; the vertical movement aspect is called *hydraulic conductivity* (also called permeability in older literature). The infiltration rate of water into a given soil is very important because it governs the amount of water that will enter the soil during a rainfall or irrigation event. The higher the infiltration rate, the faster water will enter the soil and the beginning of runoff will likely be delayed. Conversely, the lower the infiltration rate, the slower water will enter the soil, the more likely runoff will occur sooner, leading to soil erosion.

The movement of water to greater depths at moderate to rapid rates is important for allowing more infiltration to occur and for storing soil water for later use by growing plants. The rate of movement is governed by water content, i.e., saturated or unsaturated conditions, and by pore size. Saturated soils have the highest hydraulic conductivity, i.e., fastest rate of movement, because water movement is primarily in the largest pores. As a soil undergoes wetting, pores at the surface are the first to receive water, and after partial or complete filling, they provide the pathway through which water flows to progressively greater depths in the soil. The advance of water is along a continuous boundary known as the wetting front. An important characteristic of soil wetting is that it slows with time because the friction encountered by water moving through the soil increases as the depth of wetting and the distance to the wetting front increases.

Aeration

Soil aeration is a vital process because it largely controls the soil levels of two life-sustaining gases, oxygen and carbon dioxide. Soil aeration is a critical component of the cycle of photosynthesis and respiration, two essential processes that require oxygen and carbon dioxide for the cycle to be regenerative. Through aeration, there is an exchange of these two gases between the soil and the atmosphere. In a well aerated soil, this exchange is sufficiently rapid to prevent the deficiency of oxygen or the toxicity of excess carbon dioxide. For most land plants, the supply of oxygen in the soil air must be kept above 10%.

The most important factors influencing the aeration of well drained soils are soil texture and soil structure. Organic matter is influential through its role in producing water-stable aggregates. The interaction of texture and structure help determine macropore content and, in turn, soil aeration. Coarse textured soils that are well aggregated are conducive to good aeration. Conversely, dense fine textured soils that are lacking in aggregation are most likely to limit aeration.

Temperature

The *temperature* of a soil greatly affects the physical, biological, and chemical processes occurring in that soil. In cold soils, chemical and biological rates are slow. Biological decomposition can come to a near standstill, thereby limiting the rate at which nutrients such as nitrogen, phosphorus, sulfur, and calcium, are made available. Also, absorption and transport of water and nutrient ions by higher plants are adversely affected by low temperature.

Soil temperature is not subject to radical human regulation. However, two management practices that have significant effects on soil temperature are maintenance of vegetative cover or mulch on the soil and reduction of excess soil moisture. Indeed, water control in soils does more to influence soil temperature than any other soil management tool.

Color

Color has little effect on soil behavior beyond influencing the gain and loss of radiant energy. However, color is particularly useful for making meaningful predictions about the soil. It is a guide to such things as the extent of mineral weathering, the amount and distribution of organic matter in the soil, and the state of aeration.

For the most part, changes in color that result from weathering are due to the formation of secondary iron oxides. The distinct red, yellow, and brown colors in soils are normally attributable to the iron compounds. The coatings of iron oxides over other mineral grains often impart pronounced red and yellow colors, particularly in the B horizons of soils in regions of intense weathering.

Organic matter tends to darken the color of soils but the extent of darkening depends on the chemical nature of the organic material, the quantity present, and its form of occurrence. One cannot equate a particular color with a specific quantity of organic matter. For example, a given percentage of organic matter will produce a much blacker color in grassland soils than the same amount will produce in forest soils.

The interrelationship between color and aeration usually relates to the obstructing influence of water on air flow through the soil. Poor aeration results when pores remain water-filled for prolonged periods. When this occurs, iron and manganese assume chemically reduced forms that impart gray or bluish colorations to the soil body, a condition referred to as *gleying*. If poor aeration is intermittent, the iron and manganese will oxidize in the well aerated zones to produce streaks or splotches of red, yellow, or brown. These bright colored streaks are called *mottles*. Gray splotches in an otherwise bright colored soil matrix are mottles also. The extent and color of the mottles allow an estimate of the drainage status of the soil.

Chemical Properties of Soils

There are several important chemical properties of soils but the two main ones affecting vegetation management are cation exchange and soil reaction (pH). Other chemical effects such as mineral solubility, nutrient availability, and buffering are influenced by the soil reaction and the cation exchange process.

Cation Exchange

Cation exchange is a phenomenon based on the negative charge of clay and organic particles in soils. By virtue of this charge, cations (positively charged ions, e.g., Ca^{++}, K^{+}, Mg^{++}) are adsorbed on the surfaces of clay and organic particles. Cations on these sites are said to be exchangeable in that they may exchange with cations in the soil solution. Once in the soil solution the cations may be taken up by plant roots. Cation exchange is of great importance in plant nutrition, for it means that adsorption keeps nutrient cations in a form that is available to plants but not subject to much loss by leaching.

Only a few cation species make up the bulk of exchangeable cations in soils. Several of these are derived from mineral weathering, including Al^{+++}, Ca^{++}, Mg^{++}, and K^{+}. Ammonium, NH_4^{+}, comes largely from decaying organic matter or from added fertilizer.

The adsorbed cations undergo exchange at different rates and with variable ease because they are held with different strengths on the exchange sites. The relative strength of adsorption is:

$$Al^{+++} > Ca^{++} > = Mg^{++} > K^{+} = NH_4^{+} > Na^{+}$$

Hydrogen, H^{+}, is not included in the series because its adsorption strength differs markedly depending on whether it is adsorbed to clay or to organic matter. With clay, H^{+} appears to have a weak attraction similar to other monovalent cations such as K^{+} and NH_4^{+}. On the other hand, H^{+} is held very firmly to adsorption sites in organic matter.

Soils vary in the amounts of exchangeable cations they contain and that can participate in the cation exchange process. The sum total of exchangeable cations that a soil can adsorb is called the cation exchange capacity (CEC). The CEC is a measure of the negative charge on the soil particles and, thus, is due to the amounts and kinds of clay and organic matter present. In general, the higher the clay and organic matter contents, the higher the CEC. But the type of clay mineral and the degree of decomposition of organic matter also influence greatly the magnitude of the CEC. The variability of CEC is evident from the broad ranges shown in **Table 1.3** (generalized realionship between soil texture and cation exchange capacity (modified from Donahue, Miller and Shickluna).

Table 1.3: Generalized Relationship between Soil Texture and Cation Exchange Capacity

Texture	CEC (meq/100 g.soil)
sand, loamy sand, coarse sandy loam	2 -5
fine sandy loam, loam, silt loam	5 – 15
clay, clay loam	>15

Soil Reaction

Perhaps the most outstanding characteristic of the soil solution is its reaction-that is, whether it is acidic, alkaline, or neutral. Higher plants and microorganisms respond markedly to soil reaction because it tends to control so much of their chemical environment.

The most common way for describing soil reaction is with the term (*potential of hydrogen) pH*. The pH scale goes from 0 to 14 with pH 7 as the neutral point. At pH 7, the hydrogen ion (H^{+}) concentration equals the hydroxyl ion (OH) concentration. From pH 7 to 0 the soil is increasingly more acidic; from pH 7 to 14 the soil is increasingly more alkaline, or basic. The concentration of H^{+}, the chemical element measured in the pH determination, has a tenfold change between each pH number. Thus, a soil of pH 6 is 10 times more acid than a soil of pH 7, and a soil of pH 5 is 100 times more acid than a soil of pH 7.

Soil acidity is a major limitation in many soils. It will be discussed in greater detail in Chapter 2.

Biological Properties of Soils

Biological properties are often overlooked in a soil assessment. This is unfortunate because plant growth, soil fertility, and even soil development depend on the biological activities in the soil. Two major biological considerations are: organisms and organic matter.

Organisms

The soil is teeming with organisms. This feature alone distinguishes it from "dirt". A teaspoonful of soil may contain billions of living organisms. Most soil organisms, both plant and animal, are so small that they can be seen only with the aid of a microscope. Thus, they are called *microorganisms*. But the activities of some larger organisms (*macroorganisms*) have significant effects on soil physical properties. All are significant in the soil biological processes that are so critical for plant and animal life.

Soil biology is too vast and complex to discuss in meaningful detail. A very brief synopsis is presented here. Soil organisms are vital to the cycle of life in earth. They incorporate plant and animal residues into the soil and digest them, returning carbon dioxide to the atmosphere where it can be recycled through higher plants. Simultaneously, they create secondary organic constituents so vital to good physical and chemical soil conditions. During decomposition, soil organisms release essential plant nutrients in inorganic forms that can be absorbed by plant roots or leached from the soil.

Among the macroanimals, *earthworms* stand out because of their beneficial effects on soil aeration and aggregation. Other macroanimals like termites, ants, snails, and rodents produce both positive and negative effects. Nematodes are important microanimals that are generally recognized for their detrimental parasitic effects (e.g., plant root infestation).

The four major groups of microorganisms are: *bacteria, fungi, actinomycetes, and algae*.

Bacteria are single-celled organisms, one of the simplest and smallest forms of life known. They are important in several chemical transformations of essential elements such as nitrogen and sulfur. A critical process that depends largely on bacteria is *nitrogen fixation*-the biochemical transformation of atmospheric nitrogen to organic nitrogen compounds usable by higher plants. Other specific bacteria convert nitrogen from ammonium (NH_4^+) form to nitrate (NO_3^-) form.

Fungi are versatile and persistent in their ability to decompose organic residues. They are especially effective in humus formation and aggregate stabilization. Fungi continue to decompose complex organic materials after bacteria have essentially ceased to function.

Actinomycetes are intermediate between bacteria and fungi in appearance. They are important in the breakdown of soil organic matter and the liberation of its nutrients.

Most algae are chlorophyll-bearing organisms and are capable of performing photosynthesis. Certain blue-green algae are capable of fixing nitrogen in quantities sufficient for production of certain crops (e.g., rice) that are grown in wet soils.

Organic Matter

Soil organic matter consists of decomposing plant and animal residues. It is a very active and important part of the soil. In fact, organic matter influences physical and chemical properties of soils far out of proportion to the small quantities of it that are present. It commonly accounts for at least one-third of the cation exchange capacity of surface soils. It is responsible, probably more than any other single factor, for the stability of soil aggregates. In addition, it is the reservoir for soil nitrogen and it furnishes large portions of the soil phosphorus and sulfur. It loosens up the soil to provide better aeration and water movement.

For maximum benefit, organic matter must be readily decomposable and continuously replenished with fresh residues-roots, tops, and manures. Organic decay is accomplished primarily by bacteria, fungi, and actinomycetes. After the active decomposition has taken place, the organic residues that are left are collectively called *humus*. Humus is the active organic component in soil reactions. It may be considered analogous to clay in the mineral fraction, although humus is generally more active than clay due to its highly colloidal state.

Although all the same nutrients needed by higher plants seem to be needed by the microorganisms that decompose organic matter, nitrogen is the most critical nutrient. Its concentration most often controls the rate of organic matter decomposition because it is needed to build proteins in new bacterial and fungal populations. The nitrogen content in the microorganisms and in organic materials is given in proportion to the carbon content and is called the *carbon:nitrogen ratio (C:N ratio)*. The C:N ratio of organic materials is very important when such materials are added to the soil. If a material has a wide C:N ratio, say 80:1, it means that bacteria, with a C:N ratio of 5:1, would not be able to attack the high C:N material effectively. The process of decay can be speeded up by adding available N to the soil to “feed” the bacteria until their numbers increase sufficiently to bring about organic matter breakdown. **Table 1.4** lists some common organic materials and the percentages of the total weight that are organic carbon and total nitrogen and the C:N ratio of common organic materials applied to or growing on arable soils (Donahue, Miller and Shickluna, 1983).

Table 1.4: Approximate Organic Materials and Percentage Weight

Organic Material	Organic Carbon (C) (%)	Total Nitrogen (N) (%)	C:N Ratio
Crop residues			
Alfalfa (very young)	40	3	13:1
Clovers (mature)	40	2	20:1
Corn stalks	40	1	40:1
Straw, small grain	40	0.5	80:1
Sawdust	45	0.2	225:1
Soil microbes			
Bacteria	50	10	5:1
Actinomycetes	50	8.5	6:1
Fungi	50	5	10:1

Plants can grow well in mineral soils without any organic matter at all and also in “soils” that are 100 percent organic matter. Commercial greenhouses and nurseries use potting soils having as much as 30-60 percent peat moss or other organic materials. The optimum level of organic matter that should be maintained in a soil is not likely to ever be a single value due to the wide variations in climate, soils, and plant adaptation. Key principles to good organic matter management in soils are: (1) Provide a continuous supply of fresh organic matter to the soil in the form of plant residues, animal wastes, composts, and other available materials; (2) Supply additional nitrogen as needed to maintain an adequate C:N ratio of the soil organic matter.

Soils of North Carolina

Soils are a product of their local and regional environment. Geology, geomorphology, and climate, as well as site-specific factors such as moisture and vegetation, collectively influence soil characteristics. Numerous combinations of factors give rise to a large number of diverse soils that fit into locally and regionally recurring patterns.

North Carolina is divided into three major soil regions, the Mountains, Piedmont, and Coastal Plain. Within each region a distinctive group of soil factors exists. These include topography, parent material, temperature, moisture, type of vegetation, and accumulation of organic matter. These factors permit subdivision into distinct soil systems that improve our understanding of the interrelations among the various soils. The soil systems in North Carolina are shown in **Figure 1.8**. Although the array of soils appears bewildering, there is an order to the soils and to their relationships with other soils and soil-forming factors.

The Mountain Region occupies about 15 percent of North Carolina, with altitudes ranging from about 460 meters (1510 feet) adjacent to the Piedmont to about 2035 meters (6675 feet) at Mt. Mitchell in Yancey County. In the Mountain Region, topography, temperature, and bedrock are important in defining the soil systems.

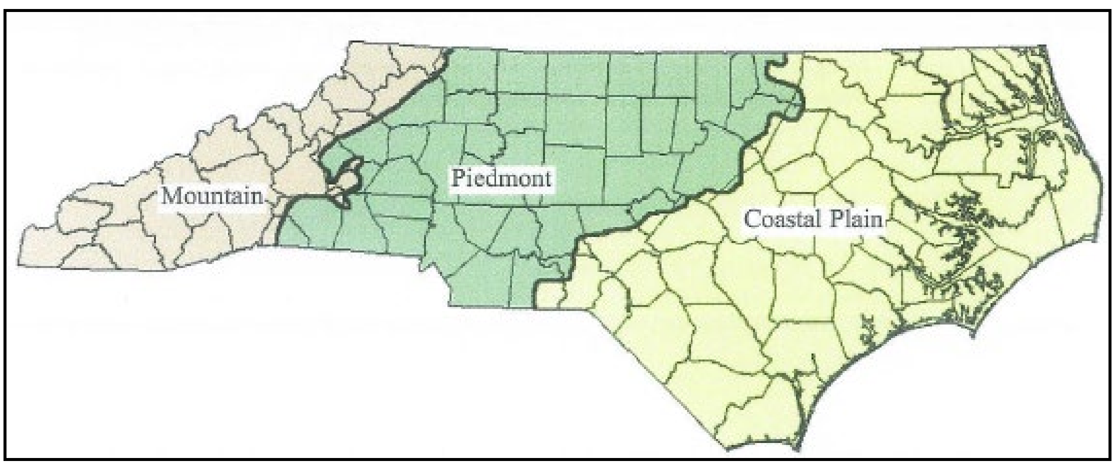


Figure 1.8: Soil Systems of North Carolina

Surface soils of the Mountain Region vary from sandy loam to clay loam, with shallow subsoils varying from silt learns to sandy loams. Steep slopes with shallow, stony, droughty soils are common. Many mountain soils have been severely eroded. On more level topography, deeper profiles provide greater water-storage capacity and room for root growth. Shallow, stony soils and steep slopes present major problems for vegetation establishment in this region. Permanent vegetation is normally selected from cool-season, winter hardy perennials.

The Piedmont Region occupies about 40 percent of the state and is a rolling to hilly area between the Coastal Plain and Mountains. Its altitudes are from about 90 meters (295 feet) on the east where it merges into the Coastal Plain northeast of the Sandhills to about 460 meters (151 feet) near the Mountains. A large variety of parent rocks is particularly responsible for the different soil systems in the Piedmont.

Piedmont soils are similar to those of the Mountains but, in general, are deeper, lower in organic matter, and have subsoils higher in clay. Surface soils vary from sandy loam to clay loam, and subsoils are commonly thick with heavy clay texture. While topography is gentler than in the Mountains, it is mostly rolling to hilly, with well-developed drainage patterns. Soils are generally well to excessively drained.

The sloping terrain and silty subsoils often result in severe erosion potential. As a result of previously poor management practices, many areas are moderately to severely eroded. Piedmont soils generally support a wide variety of plants, including both cool and warm season species. Sites that are steep, shallow, stony, droughty, or severely eroded present problems for establishment of vegetation.

The Coastal Plain occupies about 45 percent of the land area of North Carolina and is composed of sandy to clayey unconsolidated marine and fluvial deposits. Elevations generally range from sea level to about 90 meters (295 feet) but elevations reach 180 meters (590 feet) in a few areas, e.g., the Sandhills. The topography is flat to rolling and has soil systems varying from the sandy, droughty sandhills to the large wet pocosins (*wet pocosins*, a name derived from an eastern Algonquian word meaning “swamp-on-a-hill”). Coastal Plain soils include some of the easiest, and also some of the most difficult, soils to vegetate. The Coastal Plain region has several different subregions.

The Sandhills region of the Coastal Plain is dominated by coarse, deep, excessively drained sand and rolling topography. These soils are extremely low in organic matter and plant nutrients. When disturbed, they are subject to both wind and water erosion. These are some of the most erodible soils in the State and need to be treated with the utmost caution. Due to their low water-holding capacity, revegetation requires highly drought-resistant species.

Upper and Middle Coastal Plain soils generally have well-drained sandy loam surface horizons underlain by sandy clay loam subsoils. Topography is undulating to nearly level. These soils retain more moisture and nutrients than the sands of the Sandhills and coastal dunes, and support a wider variety of vegetation. However, they are still quite erodible when disturbed. The region also includes some poorly drained soils and some excessively drained “Sandhills” soils.

Lower Coastal Plain soils vary from well-drained to poorly drained and from sand to silt loam in texture. The coarser soils are extremely erodible. Poorly drained soils ranging from sands to organics are limited in extent. Along the southern coast both old and young dune sands occur. Choice of species for revegetation is largely determined by moisture retention and drainage conditions. Dune sands require highly specialized plants.

Summary

Soils are very complex bodies and the scientific study of them is fascinating. Although soils in general have a number of common features, individually they tend to differ markedly. Basic differences relate to the composition of the mineral and organic fractions of the soil body and to the proportions and arrangement of these components in the profile. For the most part, the diverse nature of soils arises from the wide range of environmental conditions under which they develop.

Each soil may be viewed as a naturally occurring laboratory where physical, chemical, and biological processes interact simultaneously. These interactions proceed across a wide range of environmental settings resulting in almost limitless combinations of soil characteristics. These characteristics relate to soil behavior and, thus, soil properties are conveniently divided into physical, chemical, and biological groupings. Since soil behavior can be predicted with suitable accuracy from approximate evaluations of its properties, an understanding of these properties enables a soil manager to make many useful practical applications.

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Introduction

In This Chapter . . .

- *Soil Erosion*
- *Physical Obstacles*
- *Chemical Obstacles*
- *Biological Obstacles*

In the academic setting, the term “ideal” soil is often used as a point of reference. In reality, though, one finds very few “ideal” soils. Most soils have one or more limitations that prevent their being used to maximum effectiveness for a prescribed purpose. This is especially true for soils occurring at roadside vegetation sites. Under natural conditions, such sites have often been neglected for a long period of time and their properties, especially chemical ones, have deteriorated. Many other sites have been influenced by construction activities that frequently remove the topsoil and leave an undesirable medium for establishing vegetation. The aim of this chapter is to discuss the most prevalent soils problems encountered in roadside vegetation management. Corrective measures, when applicable, will also be presented.

Soil Erosion

There is little doubt that the most destructive soil menace worldwide is soil erosion. It involves losing not only water and plant nutrients but ultimately the soil itself. Furthermore, the soil that is removed finds its way into streams, rivers, and lakes, and pollutes those water resources. Erosion is a serious problem in all climates because wind as well as water can remove soil. In the southeastern United States, soil erosion due to water is more significant than wind. Thus, the following discussion will focus on erosion due to water. However, wind erosion does occur in localized areas within this warm, humid region, and one should be alert to its occurrence and consequences.

Erosion Process

Erosion is a two-step process. The first step is detachment, the breaking away of particles or small aggregates at the surface of the soil. The second step is transportation, which results in the actual loss of the soil material. Whether or not detachment will occur depends on the ability of erosive agents to overcome forces responsible for maintaining the soil in a coherent state. Thus, well-aggregated, fine-textured soils erode less readily than sandy soils, the latter requiring little energy for detachment. Once detached, however, particles of small size can be transported with less difficulty, which relates to their relatively large surface for receiving energy for each unit of mass being transported.

Wind and moving water provide energy for particle detachment and transportation. The conditions determining the effectiveness of these two agents in erosion differ in many respects, however. For example, a rain will not induce erosion unless there is runoff, and this will occur only if the intensity of rainfall exceeds the infiltration capacity of the soil and if there is slope to the land. Wind, on the other hand, functions independently of slope and infiltration characteristics.

Water Erosion

Erosion due to rainfall is by far the most widespread form of erosion caused by water. Three types of water erosion are generally recognized: sheet, rill, and gully. In sheet erosion, soil is removed more or less uniformly from every part of the slope. However, sheet erosion is often accompanied by tiny channels (rills) that are inegularly dispersed, especially on bare land newly planted or in fallow. This is rill erosion. The rills can be obliterated by tillage operations, but the damage is already done-the soil is lost.

Where the volume of runoff water is further concentrated, the formation of larger channels or gullies occurs by undermining and downward cutting. This is called gully erosion. Gullies are obstacles to tillage and cannot be removed by ordinary tillage practices. While all types are serious, the losses due to sheet and rill erosion, although less noticeable, are responsible for most of the field soil deterioration.

Five major factors contribute to the erosion of land as a result of rainfall. These are: (1) the nature of the rainfall as determined by its frequency, intensity, and seasonal distribution, (2) the soil as it affects infiltration and susceptibility to detachment and transport, (3) the gradient and length of slope, (4) the nature of the cover provided by plants and their residues, and (5) cultural and soil management practices that reduce runoff by modifying soil and cover conditions.

These factors have been integrated into an equation that yields a quantitative evaluation of rainfall erosion for a wide range of climatic, soil, slope, and vegetative cover conditions. This equation, called the universal soil loss equation (*USLE*)[2], is:

$$A = R \times K \times LS \times C \times P$$

where A is the predicted average soil loss in tons per acre per year; R, the rainfall factor or index; K, the soil erodibility factor; LS, the slope factor; C, the cropping, or vegetative cover factor; and P, the practice factor (i.e., the conservation measures that are applied).

Of these factors, the first three are largely fixed by local conditions and together express the inherent potential for a soil to erode under a given set of rainfall, soil, and slope conditions. The last two factors take into account the potential for different plants and cover crops, as well as specific management practices to protect the soil against erosion.

Runoff occurs whenever rain falls on sloping land at a rate that exceeds the rate of infiltration. As either the intensity or frequency of rains increases, so does the potential for runoff and erosion. Particularly important is the number of heavy rains, for they cause most of the erosion even though they may represent only a small fraction of the total precipitation.

For the most part, texture, structure, and organic matter content determine the erodibility of a soil through their influence on infiltration and the ease of particle detachment and transport. Subsoil conditions that affect internal soil drainage are also important. Where internal drainage is poor, infiltration may be retarded and the potential for erosion thereby increased.

The ability of rainfall to erode soils increases with an increase in either the length or steepness of the slope. The principal reason for this is that any change in slope characteristics alters both the volume of runoff and the velocity of flow downslope. Slope length is a factor because it determines the total area from which runoff accumulates. The primary effect of steepness is on runoff velocity; the steeper the slope, the higher the velocity. In addition, as the rate of water that flows off a slope increases, less time is available for infiltration into the soil. As a consequence, the greater the slope the larger the total volume of water lost as runoff.

Plants vary in the protection they offer against the hazard of rainfall erosion. Differences relate primarily to (1) the amount and duration of the cover they provide, (2) the quantity and type of residue left on or incorporated into the soil, and (3) the nature of tillage practices used in seedbed preparation and vegetative maintenance. Plants can be grouped according to their relative ability to protect the soil against rainfall erosion. The greatest protection is afforded by noncultivated plants that provide a good ground cover. Grass provides the highest degree of protection followed by legumes and small grains.

[2] The USLE is continually being refined to enable more accurate prediction of soil loss. This has led to the development of a revised USLE (RUSLE) which is now commonly used.

Any plant cover provides some protection to the land and thereby reduces erosion below that associated with fallow conditions. The degree of protection can often by enhanced where the cover is grown in association with well devised conservation practices. In areas where the risk of erosion is especially high, it is sometimes necessary to employ structures such as terraces to limit the runoff and channel it to a protected outlet offsite.

Consequences of Erosion

The adverse impacts of soil erosion are readily apparent. To summarize several of the important ones related to roadside vegetation management, erosion (1) removes topsoil, which has the highest biological activity and greatest amount of soil organic matter, (2) removes nutrients contained in the topsoil, (3) contributes to the breakdown of soil structure, and, thus, (4) creates a less favorable environment for plant growth. In soils that have restrictions to root growth, erosion decreases rooting depth, which decreases the amount of water, air, and nutrients available to plants.

In addition to the onsite effects listed above, erosion can produce equal or greater adverse impacts offsite. The eroded material, sediment, is transported and deposited somewhere, usually in a stream channel or a water body. The deposition process is called sedimentation. **Sediment is the greatest water pollutant by volume**. It is responsible for such problems as algal blooms and eutrophication. It can damage fish habitat and degrade water quality in streams, rivers, and lakes. In many cases, sediment control is required to minimize the damage caused by sedimentation. If sediment control is needed, it is an indication that erosion control is not being done successfully. Therefore, the aim in effective roadside vegetation management should be erosion control, *not* sediment control!

Erosion Control Practices

There are many specific practices that can be used to control both water and wind erosion. The particular practice or combination of practices selected must be site-specific in order to be effective. Descriptions of practices and their applications may be found in several sources, e.g., the NCDOT Erosion and Sediment Control Guidelines; Erosion and Sediment Control Design Manual, North Carolina Division of Energy, Mineral and Land Resources (NCDEMLR); and the Natural Resources Conservation Service (NRCS) Technical Specifications.

The following general principles underlie the selection and use of any specific practice:

- Maintain a protective cover on the soil.
- Create a barrier to the erosive agent.
- Shorten the length and steepness of slopes.
- Increase water infiltration rates.
- Improve aggregate stability.

Physical Obstacles

Soil Compaction

Soil compaction occurs when soil particles are pressed together, reducing the pore space between them. This increases the weight of solids per unit volume of soil (bulk density).

Soil compaction may occur naturally in the lower A horizon or B horizon as a result of soil-forming processes. In the lower A horizons of certain sandy soils, the size and shape of the sand grains are such that a compact configuration results and it is called an arenapan. In clayey B horizons of certain soils the small clay particles fit closely together to form a compact layer called a fragipan. The compaction of greatest concern to the roadside vegetation manager, though, is that found in the surface horizon resulting from the pressure of vehicle and foot traffic. This compacted zone is often referred to as a traffic pan. The risk for compaction is greatest when soils are wet.

Compaction restricts rooting depth, which reduces the uptake of water and nutrients by plants. It decreases pore size, increases the proportion of waterfilled pore space at field capacity, and decreases soil temperature. This affects the activity of soil organisms by decreasing the rate of decomposition of soil organic matter and subsequent release of nutrients. Compaction decreases infiltration and, thus, increases runoff and the hazard of water erosion.

Compaction can be identified by one or more of the following indicators:

- Platy structure, or a massive ‘structure-less’ condition.
- Greater penetration resistance.
- Higher bulk density.
- Restricted plant rooting.
- Flattened, turned, or stubby plant roots.

The significance of bulk density depends on the soil texture. Sandy loam, loam, and sandy clay loam soils compact more easily than silt, silt loam, silty clay loam, silty clay, or clay soils. Rough guidelines for the minimum bulk density at which a root restricting condition will occur for various soil textural classes (Natural Resources Conservation Service, 1996) are shown in **Table 2.1**.

Table 2.1: Bulk Density Values for Various Soil Textural Classes

Texture	Bulk Density (g/cc)
Coarse, medium, and fine sand and loamy sands other than loamy very fine sand	1.80
Very find sand, loamy very fine sand	1.77
Sandy loam	1.75
Loam, Sandy Clay loam	1.70
Clay Loam	1.65

Table 2.1: Bulk Density Values for Various Soil Textural Classes, cont.

Texture	Bulk Density (g/cc)
Sandy Clay	1.55
Silty clay loam	1.50
Silty clay	1.45
Clay	1.40

Compaction Reduction Practices

Organic matter promotes aggregation of soil particles. This increases porosity and reduces bulk density, thus reducing compaction. Addition of manure, compost, or other organic materials can improve soil structure, helping to resist compaction. Other practical measures include: (1) Reduce the number of trips across the area, (2) work the soils when they are not wet, and (3) lighten the loads or change equipment to reduce the pressure from vehicles and machines.

Soil Crusting

Soil crusts are relatively thin, somewhat continuous layers of the soil surface that often restrict water movement and air entry into the soil, and impede seedling emergence. Soil crusts are characterized by their thickness and strength (air dry rupture resistance). They generally are less than 2 inches thick and are massive. They are created by the breakdown of structural units by raindrops or through freeze-thaw action. Soil crusts are generally only a temporary condition. Typically, the soil immediately below the surface layer is loose.

Crusts reduce infiltration and increase runoff. Rainfall and sprinkler irrigation water impart a large amount of energy upon impact with the soil surface. If the soil is not protected by a cover of growing plants, plant residue or other material, and if soil aggregates are weak, the energy can cause a soil crust to form. When a crust forms, individual soil particles fill the pore space near the surface and prevent the water from entering (infiltrating) the soil. If the infiltration is limited, water accumulates and flows down slope, thus initiating the water erosion process.

The physical emergence of seedlings through a soil crust depends on the thickness and strength of the crust, the size of the broken crust pieces, water content, and the plant species. Seed germination depends on the diffusion of oxygen from the air through the soil. If soil crusts are wet, oxygen diffusion is reduced as much as 50 percent.

Crusting Reduction Practices

The following practical measures will reduce the adverse effects of soil crusts:

- Maintain plant cover or plant residues on the soil surface to reduce the impact of raindrops.
- Adopt management practices that increase organic matter and aggregate stability.

- Shatter crusts with an appropriate implement to increase seedling emergence.
- Employ sprinkler irrigation to reduce restriction of seedling emergence.

Aggregate Instability (Poor Structure)

Soil aggregation was discussed in Chapter 1. Aggregate stability refers to the ability of soil aggregates to resist disruption when outside forces, e.g., falling raindrops, are applied. Aggregate stability is very important in that it affects erosion, movement of water, and plant root growth and proliferation. Desirable aggregates are stable against rainfall and water movement. Aggregates that break down in water or fall apart when struck by raindrops release individual soil particles that can seal the soil surface and clog pores. This breakdown creates crusts that closes pores and other pathways for water and air entry into the soil. It also restricts emergence of seedlings from a soil.

Optimum pore size distribution requires large pores between the aggregates and smaller pores within the aggregates. The pore space between aggregates is essential for water and air entry and exchange. This pore space provides zones of weakness through which plant roots can grow.

The stability of aggregates is affected by soil texture, the type of clay, exchangeable cations and extractable iron, amount and kind of organic matter, and the nature of the microbial population. Sandy soils have low aggregation, but roots can extend and water can move readily. Aggregation is more important in clayey soils to create larger pores to enhance air and water movement. Some clays expand like an accordion as they absorb water. Expansion and contraction of clay particles can shift and crack the soil mass and create or break apart aggregates.

Calcium ions associated with clay generally promote aggregation, whereas sodium ions promote dispersion, or nonaggregation. Soils with over about five percent iron oxides tend to have greater aggregate stability. Additions of organic matter increase aggregate stability, primarily after decomposition begins and microorganisms have produced chemical breakdown products. Soil microorganisms produce many different kinds of organic compounds, some of which help to hold the aggregates together. Fungi produce relatively large thread-like structures called mycelia, which bind soil particles together more effectively than smaller organisms such as bacteria.

Stable Aggregate Promotion

The best way to promote aggregation is to maintain a healthy biological and chemical soil environment that fosters organic matter decomposition and adsorption of calcium on the exchange complex. In addition, tillage operations should be kept to a minimum and the maintenance of a permanent vegetative cover, especially grass, should be encouraged.

Chemical Obstacles

Soil Acidity

Acidity is one of the most limiting factors to plant growth in warm humid areas like North Carolina and throughout the southeastern United States. Acidity influences plant growth through its impact on the overall nutritional environment for plants. Under strongly acid conditions, the acid itself may be toxic to plants. More likely the damaging effect is to render essential nutrients unavailable by removing exchangeable bases, e.g., Ca^{++}, Mg^{++}, from the system or by decreasing the solubility of essential elements such as phosphorus. Acidity has a detrimental effect on beneficial soil microorganisms that are active in organic matter decomposition and nutrient transformation processes, e.g., nitrogen fixation and nitrification.

Soils in warm, humid areas such as North Carolina have a natural tendency to become acid. (1) Most of the soil parent materials in the state are low in bases and contain large amounts of the acid-forming element, aluminum (Al^{+++}). (2) Basic elements, e.g., Ca^{++}, K^{+}, are removed from the plant root zone by the downward movement of soil water. This process is called leaching. (3) Plants take up significant amounts of bases from the soil solution and the basic cations attached to the soil solids are replaced by the acidic cations, Al^{+++} and H^{+}. (4) Organic and inorganic acids form upon the decomposition of organic matter. The simplest and perhaps the most widely found organic acid is carbonic acid (H_2CO_3), a product of the reaction of carbon dioxide and water. Inorganic acids such as sulfuric acid (H_2SO_4) and nitric acid (HNO_3) are formed not only by organic decay processes, but also from the microbial action on certain inorganic sulfur- and nitrogen-containing materials. (5) Many fertilizer materials are acid producing upon their reaction with the soil solution to form nitric and sulfuric acids. (6) Large quantities of sulfuric and nitric acids are formed in the atmosphere from oxides of nitrogen and sulfur emitted from the combustion of fossil fuels at sites near large cities or around industrial complexes. The precipitation of these substances is called "acid rain" since it has a pH value of 4.0-4.5 and, in extreme cases, may be as low as 2.0. This contrasts with "normal" rainfall, with a pH commonly in the range 5.0-5.6. The effects of "acid rain" on soil pH are probably insignificant on soils as a whole, but they may be a factor in localized areas and may have a long-term influence.

Correction of Soil Acidity

Soil acidity is usually decreased by adding carbonates, oxides, or hydroxides of calcium and magnesium, compounds that are referred to as lime. The most widely used liming material is ground limestone. The two important minerals in limestones are calcium carbonate ($CaCO_3$, also known as calcite), and dolomite ($CaMg(CO_3)_2$. Thus, the liming materials produced from these limestones are called, respectively, calcitic lime and dolomitic lime.

Soil acidity and liming have many implications in soil fertility. These topics will be discussed in more detail in Chapter 3.

Nutrient Deficiencies and Losses

Soils vary in their capacity to supply nutrients. Many soils have limited nutrient reservoirs because of low CEC, e.g., sandy soils and soils low in organic matter content. As indicated earlier, most soils in North Carolina are derived from acidic parent materials and, thus, are low in exchangeable bases like calcium and magnesium. The availability of other nutrients, like phosphorus and the micronutrients, are directly related to pH. Thus, pH changes can cause nutrient deficiencies to occur.

In addition to nutrient deficiencies, natural losses of nutrients from the soil system may occur. A major cause of nutrient loss from the root zone is soil erosion which removes the upper part of the upper topsoil, the site of greatest nutrient concentration. Leaching losses may be high when rainfall is heavy. Other “losses” result from nutrient transformation processes associated with certain elements, especially nitrogen. These include volatilization, denitrification, and microbial immobilization. Nutrient management is a subject in itself and is a major thrust of soil fertility. It will be discussed in more detail in Chapter 3.

Soil Contamination

Soils are contaminated by a number of inorganic elements that, in varying degrees, are toxic to humans and animals. Cadmium, arsenic, chromium, and mercury are extremely poisonous; lead, nickel, molybdenum, and fluorine are moderately so; and boron, copper, manganese, and zinc are relatively low in toxicity. Although some of these elements, namely, fluorine and boron, are not metallic, the term ‘heavy metals’ is often used in referring to them.

Two primary methods of alleviating soil contamination due to toxic inorganic compounds are: (1) Eliminate or drastically reduce the application toxins to the soil, and (2) manage the soil chemistry and plant a cover crop to uptake or immoblize toxins thus preventing further cycling of the toxins. Heavy phosphate applications reduce the availability of toxic cations but may have the opposite effect on arsenic, which is an anion. Leaching may also be effective in reducing toxins from the soil but this may increase the likelihood of ground water contamination. Also, plant species differ in their uptake of toxins from the soil and in translocating them within the plant.

Soils have long been used as disposal “sinks” for a wide variety of organic wastes, e.g., animal manures, food and fiber processing wastes, municipal refuse, and industrial sludges. Many organic wastes, especially animal manures, improve the physical and chemical properties of soils and provide nutrients to plants. It is when excess quantities are applied that soil and water pollution can occur.

Biological Obstacles

Loss of Organic Matter

The importance of organic matter to good soil properties has been stated earlier. Thus, the depletion of organic matter has a pronounced effect on both physical and chemical properties, e.g., structure, water holding capacity, and cation exchange capacity.

Soil erosion is a major culprit in organic matter loss. Organic matter is concentrated in the upper few centimeters of most well drained upland soils in North Carolina. Thus, organic matter is affected early in the erosion process. Repeated tillage actions decrease organic matter as a result of aggregate breakdown and faster organic decay.

The soil must receive a continuous supply of organic materials if the soil organic level is to be maintained. Animal manures, composts, organic wastes, and plant residues are the primary sources of these organic materials. In addition, some cover crops or crops grown specifically to supply organic materials are turned into the soil as *green manures*. No attempt should be made, though, to maintain higher organic matter levels than the soil-plant-climate control mechanisms dictate. It would be foolish, for example, to try to maintain as high a level of organic matter in North Carolina soils as is found in Illinois soils.

Inactivation of Microorganisms

Microorganisms are in constant competition for organically combined carbon and other nutrients. Their ability to get these growth materials depends on temperature, moisture, soil acidity, soil nutrient levels, suitable energy sources, and the competition by other microorganisms. It is not possible to define universally favorable conditions for all microorganisms because special groups have different optimal conditions. Generally, microorganisms are most numerous in soils with moisture near field capacity, a pH near neutral, a high nutrient content, and temperatures near 30°C (86°F).

Microorganisms are essentially inactive at the wilting percentage for plants or, at the other extreme, at saturated soil conditions. When the soil becomes extremely dry, many microorganisms develop resistant strains or enter a dormant stage. At saturation, anaerobic organisms, which comprise only a small portion of soil organisms, are most active.

The majority of soil microorganisms grow best at pH 7, which is the pH of microbial cytoplasm (the cell material). Bacteria and actinomycetes are usually less tolerant of acid soil conditions than are fungi and few grow well at a soil pH value below 5.0. Many fungi exist in forested and organic soils with a pH as low as 3.0. Localized micro-environments near roots or decomposing residues can produce locales of lower pH than that of the soil as a whole, sometimes differences of 1 or 2 pH units.

Microbial activity accelerates rapidly as temperature rises. Just as plants are nearly dormant at freezing, so are most microbes. There are exceptions that can exist fairly well at very cold temperatures, and others that exist at relatively high temperatures. The majority of bacteria and actinomycetes have an optimum activity temperature in the range of 25° and 37°C (77°and 99°F).

Microorganisms have high nutritive needs, especially for nitrogen, phosphorus, sulfur, and calcium. The carbon source (from organic substances) is most easily attacked when it is plentiful and from succulent young plants. Organisms compete with other species for nutrients.

Based on the above considerations, the following practical measures should be taken to promote the growth and activity of beneficial microorganisms: (1) Lime the soil to pH 6.0 or higher, but don't overlime, (2) minimize soil fumigation or sterilization, (3) maintain as a soil organic matter level as practical, (4) inoculate with a symbiotic organism, (e.g., Rhizobium) when appropriate, and 5) reduce stress conditions such as drought, water-logging, and excess fertilizer additions.

Summary

A review of the various soils problems described in this chapter reflects the interrelationships among the physical, chemical and biological properties of soils. Soil texture and structure influence aeration and water retention which, in turn, affect biological activity and chemical processes. Soil pH influences nutrient availability and biological activity which, in turn, affect organic matter decomposition and soil aggregation. Soil organisms influence biological and chemical processes which, in turn, affect nutrient availability, organic matter decomposition, and soil structure. That universal nemesis, soil erosion, has a detrimental impact on all soil properties. Conversely, a soil with excellent physical, chemical and biological properties underlying a vigorous plant cover can reduce significantly the adverse impacts of erosion.

The aim, therefore, should be to achieve and maintain a healthy soil system-physically, chemically, and biologically. An imbalance in any component affects the function of the entire system.

REFERENCES

Natural Resources Conservation Service. 1996. Soil Quality Information Sheet: Soil Compaction.

Introduction

In This Chapter . . .

- *Essential Nutrients and Their Functions*
- *Soil Analysis and Interpretation*
- *pH and Liming*
- *Fertilizers*
- *Organic Materials*
- *NCDOT Applications*

The term *fertility* refers to the soil's capacity to supply nutrient elements in amounts, forms, and proportions required for plant growth. It is measured directly in terms of ions or compounds important in plant nutrition and indirectly in terms of the productive capacity of the soil. The fundamental components of fertility are the essential nutrients absorbed by plants and utilized for various growth processes. The nutrients occur in the soil predominantly as constituents of minerals and organic matter and in lesser amounts in exchangeable or soluble ionic form. The soluble and adsorbed forms of the nutrients are extracted easily when contacted by plant roots and provide the active fertility of the soil. Nutrient elements that are not immediately available to plants, such as those in primary and secondary minerals and in organic combination, comprise the potential fertility of the soil.

Soil fertility is amenable, in large measure, to human control. Thus, the ability to assess soil fertility and determine the utilization of fertilizers and soil amendments is essential in order to have a successful vegetation establishment and management program. Soils along transportation routes are selected for their stability in supporting a roadbed. In addition they are usually exposed as a result of highway construction. These soils usually bear little resemblance to what is normally considered good topsoil. As a result, they are usually inadequate media for establishing and maintaining desirable vegetation. Consequently, all plant nutrients and soil amendments necessary for satisfactory vegetation establishment and long term survival must be provided in an appropriate and timely manner.

The scope of soil fertility is much too broad to be treated thoroughly in one chapter. Therefore, the aim of this writing is to present the basic principles of soil fertility, the assessment of the nutrient status of soils, the selection and application of fertilizers and soil amendments, and the Department of Transportation policies regarding fertilizer use.

Essential Nutrients and Their Functions

Essential Nutrients

There are sixteen known essential elements for plant growth (**Table 3.1**). The essential nutrients are categorized into two groups, macronutrients and micronutrients, as shown in **Table 3.1**. The basis for the separation is the relative amounts of nutrients required to sustain normal plant growth. Macronutrients are needed in comparatively large amounts, since they make up the bulk of structural and protoplasmic tissue in plants. Micronutrients are utilized in small quantities, since they are associated with components or systems that comprise very little of the plant. Micronutrients are important to enzymatic, oxidation-reduction, and similar reactions. The designation of nutrients as macro and micro is based solely on amounts of them needed by plants, not their importance. All sixteen are required, and, all are important.

Table 3.1: Eessential Plant Nutrients (by name and chemical symbol)

Macronutrients		Micronutrients	
Carbon (C)	Potassium (K)	Iron (Fe)	Copper (Cu)
Hydrogen (H)	Calcium (Ca)	Manganese (Mn)	Zinc (Zn)
Oxygen (O)	Magnesium (Mg)	Molybdenum (Mo)	Chlorine (Cl)
Nitrogen (N)	Sulfur (S)	Boron (B)	
Phosphorus (P)			

The macronutrients are further subdivided into primary and secondary groups. This division is also based on relative amounts needed by plants. Primary macronutrients are carbon, hydrogen, oxygen, nitrogen, phosphorus, and potassium. Secondary macronutrients are calcium, magnesium, and sulfur. Carbon, hydrogen, and oxygen are supplied by carbon dioxide and water and, thus, are not in mineral forms in the soil. That leaves nitrogen, phosphorus, and potassium as the elements needed in largest amounts in the soil. It is not surprising, therefore, that these three elements are applied most frequently and are present in the largest amounts as commercial fertilizers.

Nitrogen

Nitrogen in plants occurs primarily in protein, which is concentrated in the active tissue, or protoplasm, of plant cells. Nitrogen is also a component of chlorophyll, the green pigment responsible for photosynthesis. When nitrogen is in short supply, chlorophyll formation is reduced, as is the photosynthetic production of carbohydrates needed for energy and for the formation of other essential organic compounds. Retarded growth is therefore likely to result from a deficiency of N.

The chemistry of N is rather complex and it affects the behavior of N in plants and soils. Nitrogen assumes many valence[3] states and occurs in a wide range of ionic and molecular combinations. Changes in valence are the result of oxidation or reduction reactions that are normal to many biochemical functions. Oxidation causes an increase in the positive charge of N; reduction has the

[3] Valence refers to the kind and amount of electrical charge on an ion or molecule. For example, NH_4^+ has a valence of + 1; NO_3^- has a valence of -1.

reverse effect. For example, the nitrification process is an oxidation reaction: $NH_4^+ \rightarrow NO_2 \rightarrow NO_3^-$. In this reaction, the valence of N changes from -3 in NH_4 to +3 in NO_2^- to +5 in NO_3^-. It follows that the state of oxidation of N relates to the ability of N to combine with other positive or negative ions.

Molecular nitrogen, or gaseous nitrogen, is identified symbolically as N_2. Some common forms of N that are more highly oxidized than N_2 are the nitrite (NO_2^-) and nitrate (NO_3^-) ions. The principal reduced forms of N are ammonium (NH_4^+) ions, gaseous ammonia (NH_3), and the amino radical ($-NH_2$) of amino acids, proteins, and similar organic compounds.

The usual forms of N absorbed by plant roots are the NH_4^+ and NO_3^- ions. The greater part of N absorbed by plants is in the NO_3^- form because it occurs in higher concentrations than NH_4^+ and is free to move in solution to plant roots. Ammonium ions are held on exchange sites and thus are not mobile.

The N occurring in organic combination in soil organic matter must undergo change to a chemically available form in order for the plant to use it. This transformation process is called *mineralization*. The process consists of three steps that cause progressive simplification in the form of N. These steps are (1) *aminization*, (2) *ammonification*, and (3) *nitrification*, so named to indicate the form of N each produces. Aminization results in the formation of amino compounds ($-NH_2$ groups) by the enzymatic breakdown of protein. In ammonification, the $-NH_2$ groups are converted to NH_3 which, in turn, is converted rapidly to the NH_4^+ ion. Common general purpose microorganisms are responsible for both aminization and ammonification, and the rate at which these reactions takes place is determined by the same factors that control the general decay process.

Once the N appears as NH_4^+, it can be absorbed by plants or by soil microorganisms, or it can be adsorbed as an exchangeable ion at soil particle surfaces. However, in the soil system, the NH_4^+ ion is usually less stable than the NO_3^- ion, which accounts for its rapid conversion to NO_3^- by nitrification. Two steps are involved in the transformation of NH_4^+ to NO_3^-: (1) the formation of NO_2^- ions by a group of special purpose bacteria, nitrosomonas; 2) the rapid conversion of NO_2^- to NO_3^- by a different kind of special purpose bacteria, nitrobacter.

The transformation of NH_4^+ to NO_3^- is of great importance. It increases not only the potential availability of N to plants but also its susceptibility to leaching loss. Because of the speed with which nitrification takes place, it is safe to assume that the bulk of inorganic N in the soil is NO_3^-, and one should adopt management practices that ensure the retention and availability of this highly mobile ion.

Another important process involving nitrogen in soil-plant relationships is *nitrogen fixation*. Nitrogen fixation is the process of converting atmospheric N into various organic and inorganic forms of N in the soil. There are several mechanisms of nitrogen fixation. The most important one for consideration in vegetation management is the process whereby organisms living in association with the roots of legume plants convert inert atmospheric N to a usable form.

This organism-plant root association is called *symbiosis*, which means a mutually beneficial relationship. The microorganisms provide at least a part of the plant's need for N and, in turn, the organisms obtain soluble food sources from the plant to meet their energy requirements.

A single genus of bacteria, *Rhizobium*, is responsible for the fixation of N in association with legumes. There are several species of *Rhizobium*, each compatible with one variety, or maybe a few varieties, of legumes. For example, the species *Rhizobium trifolii* functions more effectively with clovers than with other legumes. Similarly, *Rhizobium meliloti* is specific for alfalfa. This knowledge has led to the common practice of inoculating legume seed with bacterial cultures prepared especially for the various important kinds of legume plants.

Nitrogen, more than any other major plant nutrient element, is subject to a complex system of gains, losses, and interrelated reactions. Intelligent management demands a working knowledge of these relationships and their comparative magnitudes. These relationships are conveniently shown in a *nitrogen cycle* (**Figure 3.1**).

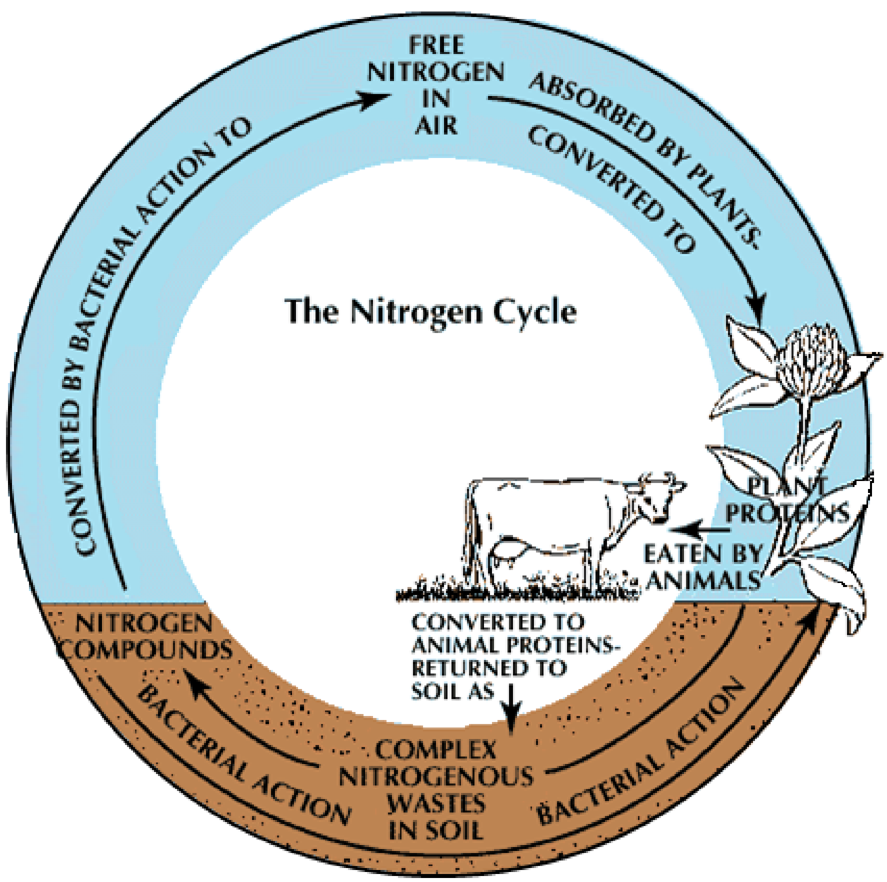


Figure 3.1: Nitrogen Cycle

Phosphorus

Phosphorus (P) is essential to several processes in plants, but two roles illustrate the truly indispensable nature of this element. A very significant function, and one that emphasizes the need for a continuous and adequate supply of P, is as a major constituent of chromosomes in the cell nucleus. As a component of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA), P makes an important contribution to the genetic character of biological matter.

Another highly essential role of P involves the transfer of energy within cellular tissue. The energy is important for several plant functions such as: absorption of nutrients and water; cell division; and sugar development during photosynthesis.

The availability of P to plants depends to a large extent on the solubility characteristics of P-bearing compounds in the soil. The solubility of P compounds is dependent upon many factors, and it is necessary to know the combined effect of all of them before the availability of P can be accurately predicted. The solubility of P in acid soils can often be increased by raising the pH through the addition of lime.

Potassium

Potassium (K) is an unusual nutrient element in that it is required in relatively large amounts by plants but it is not synthesized into compounds as is the case with N and P. Nearly all of the K absorbed by plants remains in a soluble, ionic form. It is not found in the nucleus but occurs in the surrounding cytoplasm of cells. The exact function of K in plants is not known, although it appears to be important in the: (1) synthesis of proteins, carbohydrates, and chlorophyll, (2) transformation of N from nitrate form to amino form in protein synthesis, (3) absorption of nutrients by roots, and (4) translocation and storage of carbohydrate compounds.

Calcium and Magnesium

Calcium (Ca) and magnesium (Mg) are similar chemically and, thus, they behave rather similarly in soil reactions such as cation exchange. However, each has its specific function in plants. Calcium occurs largely in plants as a constituent of the cell wall. The absorption of Ca varies among plant species. Legumes tend to accumulate larger quantities of Ca than do grasses. The high requirement of legumes for Ca is consistent with the sensitivity of these plants to Ca shortages in the soil.

Magnesium is a component of chlorophyll and is thought to aid in both the translocation of starch and the formation of fats and oils. It also appears to affect the absorption and movement of P within the plant.

Sulfur and Micronutrients

Sulfur (S) in soils resembles both the macro-and micronutrients. Like N and P, it is an important constituent of plant cellular materials. But it is similar to several of the micronutrients in terms of its small quantities in soils. Also, an important source of several micronutrients is a group of sulfide minerals present in rocks.

Sulfur is a part of various plant components. It occurs in several amino acids. It is also present as inorganic and organic sulfates. Sulfur contributes to plant functioning in several ways. It is necessary for chlorophyll synthesis and for the production of oils in seed crops.

As previously noted, micronutrients are so named because they are required in relatively small amounts by plants. Yet, a deficiency of any one of them can have as profound an effect on growth as can a shortage of a macronutrient. The low requirement for these elements is explained by their presence in systems that control the functioning of plant processes rather than as constituents of structural and protoplasmic tissue. Nonetheless, the supply of available micronutrients is often as difficult to maintain as is the supply of macronutrients, although deficiencies of the latter elements are generally much more widespread.

Micronutrients make their major contribution to plant growth as constituents of enzyme or hormone systems that control a wide range of biochemical processes. Included in these processes are respiration, energy exchange, and the synthesis of chlorophyll, carbohydrates, and proteins. All such processes are complex in that they involve a series of chemical transformations, each of which is controlled by a specific enzyme or other catalyst. Very frequently, these transformations are oxidation-reduction reactions requiring the presence of a micronutrient element capable of assuming different oxidation states (valences). In this role the micronutrients are referred to as *enzyme activators* and are essential in the functioning of the enzyme.

Nutrient Functions

The functions of the 16 essential elements and selected deficiency and toxicity symptoms are summarized in **Table 3.2**.

Since the majority of plant nutrients are absorbed by the root system, it is important to understand rooting characteristics and the plant-available forms of the essential nutrient elements occurring in the soil solution. Rooting characteristics for the particular types of vegetation managed along North Carolina roadsides will be addressed in the Vegetation Types section of this manual (Chapter 4).

In order to be absorbed by healthy root systems, nutrients must first become soluble, i.e., dissolved, in the soil solution. In general, the more of an element that is in a solution the greater will be its availability for plant root absorption. Thus, it is essential to know the available ionic forms of the nutrient elements and also the properties of the soil solution, e.g., pH, that affect the solubility and, hence, availability of the nutrient elements.

Table 3.2: Functions, Deficiencies and Toxicities of Essential Nutrients

Nutrient	Function	Deficiency Signs	Toxicity Signs
Macronutrients			
Nitrogen	Root absorbed, converted to ammonium and combines with carbohydrates to form proteins. This produces healthy leaves, stems and root systems. Most notable effect is vibrant green color that is produced in plant.	Stunting of shoot growth, decreased leaf size, pale green to yellow in color, copper color in leaf tips if problem continues.	Deep blue green leaves, soft texture, delayed maturity, possible scorching of leaves.
Phosphorus	Root absorbed, plays a role in cell division, helps develop growing point of plant (meristematic tissue), involved in sugar development, found in photosynthesis, involved in flower and seed development.	Slow growth, delayed mantrity, older leaves begin to show dark green discoloring ruming to dull blue green, dwarf growth habits but not to degree of nitrogen deficiency.	Toxicity is rare.
Potassium	Root absorbed, helps regulate osmotic pressure and turgidity of plant, considered a catalyst because it innuences cell division, enzyme activity, & translocation of sugars.	Weak stalks, small fruit or seed, drooping leaves, chlorosis of the leaves, younger leaves will show signs of starvation.	Toxicity is rare.
Secondary Nutrients			
Calcium	Root absorbed, aids in regulating osmotic pressure similar to that of phosphorus.	Death of growing points, abnormal dark green appearance, weakened stems, fruit disorders.	Toxicity is rare.
Sulfur	Involved in protein development similar to tl1at of nitrogen.	Paling of older leaves similar to nitrogen, scorching effect along edges of leaves until it withers up.	Toxicity is rare.

Table 3.2: Functions, Deficiencies and Toxicities of Essential Nutrients, cont.

Nutrient	Function	Deficiency Signs	Toxicity Signs
Secondary Nutrients, cont.			
Magnesium	Root absorbed and aids in movement of phosphorus throughout plant, it is found in the chlorophyll molecule.	Interveinal chlorosis in older leaves, curling of leaves upward, marginal yellowing along mid-rib of leaf.	Toxicity is rare.
Zinc	Essential to enzyme systems, acts as growth regulator.	Stunting growth, thinning, shriveling, & drying up of leaves.	Toxicity is rare.
Iron	Required for chlorophyll production, activator for respiration, photosynthesis & nitrogen fixation.	Young actively growing leaves show yellowing, and eventual ly blades become white or ivory.	Brown leaf spotting at low point of plant.
Manganese	Activator for enzymes in growth processes, assist in chlorophyll production.	Similar to iron deficiency, leaves droop but remain green, localized tissue death.	Yellowing, upward cupping of leaves.
Copper	Possibly plays role in Vitamin A production, enzyme activator.	Bluish discoloration of young leaf tips, death of leaf tips and progression toward stem.	Very rare, chlorosis.
Molybdenum	Helps to transform nitrates into amino acids.	Older, lower leaves begin paling, stunting wi ll develop, localized tissue death along with withering.	Root depression, yellowing, browning of leaves.
Boron	Involved in meristematic cells as a differentiator.	Delayed symptoms, shoots are discolored, sntbby leaf appearance, growth point srunting.	Localized spotty death in veins.
Chlorine	Involved in photosynthesis.	Not often noticed.	Burning of leaf tips. Premarure yellowing.

The available ionic forms(s) of the nutrient elements are shown in **Table 3.3**.

Table 3.3: Principal Ionic Forms of Nutrients Utilized by Plants

Element	Cations	Anions
Macronutrients		
Nitrogen	NH_4^+	NO_3^-
Calcium	Ca^{++}	
Magnesium	Mg^{++}	
Potassium	K^+	
Phosphorus		$HPO_4^=$,$H_2PO_4^-$
Sulfur		$SO_4^=$
Micronutrients		
Copper	Cu^{++}	
Iron	Fe^{+++}	
Manganese	Mn^{++}, Mn^{++++}	
Zinc	Zn^{++}	
Boron		BO_3^{3-}
Molybdenum		$MoO_4^=$
Chlorine		Cl^-

Soil Analysis and Interpretation

The information discussed in the previous section provides a basis for determining nutrient requirements of desirable roadside vegetation. In trying to make this determination, it is necessary to properly evaluate plant health so that any factors limiting plant growth and development can be identified. The first logical step is to look at the vegetation and relate observed symptoms to their probable cause(s). For example, drooping plants may only need water, whereas yellowing plants may need nitrogen. The diagnosis becomes more difficult when plants are not growing properly and there may be multiple causes for it. It is often helpful to have a trained person assess the physical observations because a given symptom may result from several limiting factors that may or may not be nutrient-related.

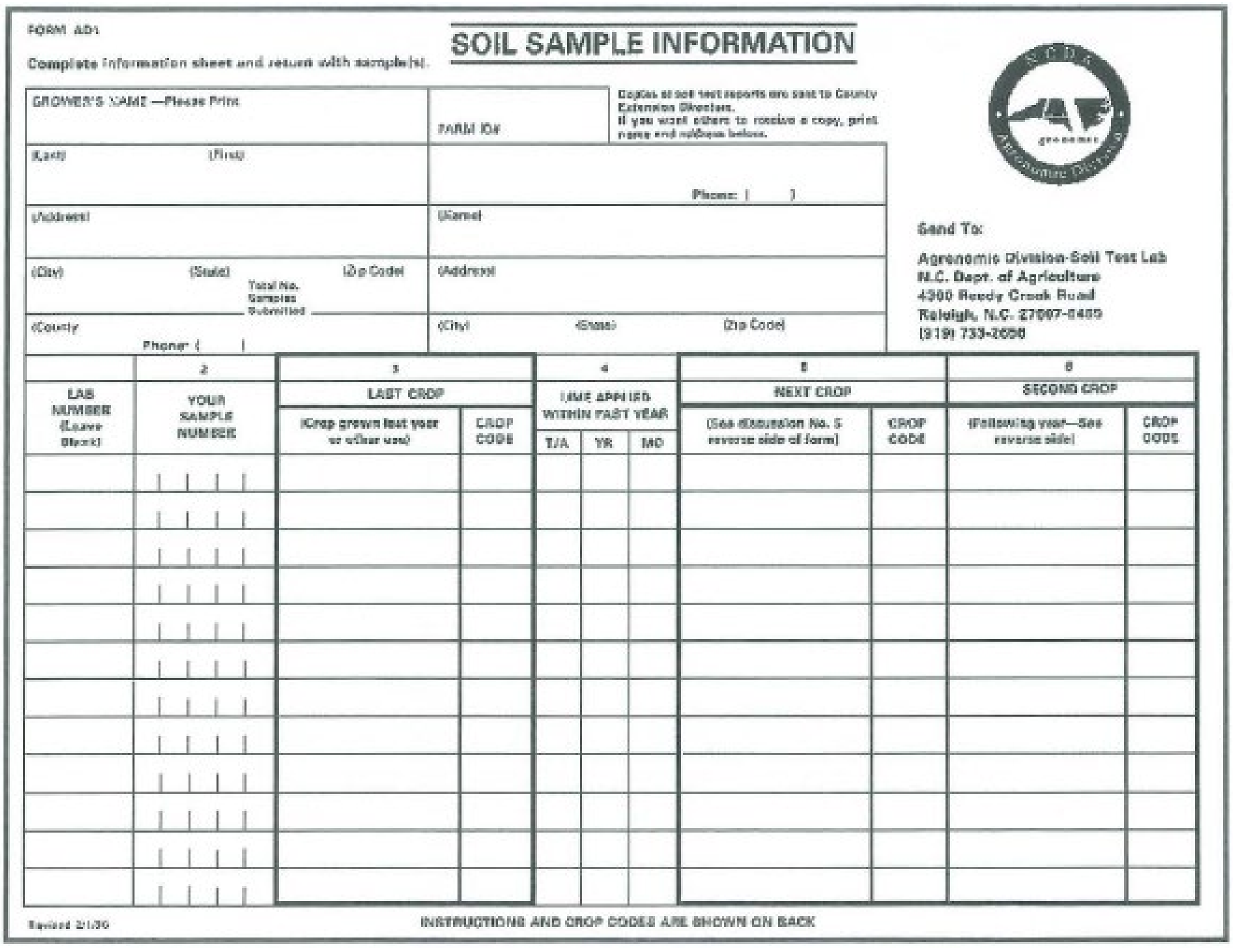
The preferred and most reliable method of diagnosing soil problems and obtaining information on the soil environment is a soil analysis. A soil sample is collected and analyzed in a laboratory, which provides essential chemical information that serves as a basis for making recommendations to optimize plant growth. The reliability of the soil test, however, can be no better than the sample submitted for analysis. For dependable results, it is vitally important to collect samples in a way that accurately represents the chemical status of the soil at a given site.

General guidelines for obtaining a representative soil sample and submitting it for analysis are: (1) Every soil sample should consist of several subsamples, at least 5-10, from the area of concern. The sample should also represent only one general soil type or condition. If the site being sampled contains areas that are obviously different in slope, color, drainage, and texture, a separate sample should be submitted for each area. (2) Samples should be collected three to six months before planting time. This will enable any liming and fertilization to be done before planting. (3) Samples should not be collected when the soil is too wet because it will be difficult to mix the sub samples. As a rule, if the soil is too wet to work, it is too wet to sample.

Samples should be collected with stainless steel or chrome-plated sampling tools and plastic buckets to avoid contaminating the samples with traces of chemicals from the sampling tools. Avoid brass, bronze, or galvanized tools. A suitable soil probe is shown in **Figure 3.2**. Make sure the buckets and sampling tools are clean and free of lime and fertilizer residues. Even a small amount of lime or fertilizer transferred from the sampling tools to the soil can seriously contaminate the sample and produce inaccurate results. For areas where perennial crops such as fescue or turf are being maintained, samples should be taken to a depth of 4 inches. However, if the soil has been tilled to a depth greater than 4 inches for vegetation establishment, samples should be taken to the depth of soil preparation. The individual samples (cores) are mixed thoroughly in the plastic bucket, then a portion of the mixed sample is transferred to a soil sample box.

Figure 3.2: Soil Testing Kit with Soil Probe

The next important step is to completely fill out the soil sample information sheet (**Figure 3.3**). This information sheet provides important data that will allow an agronomist to accurately evaluate the soils information and make recommendations. The soil sample and information sheet are then submitted to the soil testing laboratory. In North Carolina, soil samples are analyzed by the Agronomic Division of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS). Once the tests are completed, a report showing the results and recommendations is provided. A soil test chemically extracts and measures several of the essential elements required for plant nutrition. The test also measures pH and exchangeable acidity, which are used to determine lime requirements. On the Soil Test Report (**Figure 3.4**), the results of the soil analysis are given and also the recommendations for fertilizer and lime are provided. **Figure 3.5** provides a brief explanation of each item on the Soil Test Report.



FORM AD1

Complete information sheet and return with sample(s).

SOIL SAMPLE INFORMATION

GROWER'S NAME —Please Print

(Last) (First)

(Address)

(City) (State) (Zip Code)

Total No. Samples Submitted

(County) Phone ( )

FARM ID#

Copies of soil test reports are sent to County Extension Directors. If you want others to receive a copy, print name and address below.

Phone: ( )

(Name)

(Address)

(City) (State) (Zip Code)

Send To:

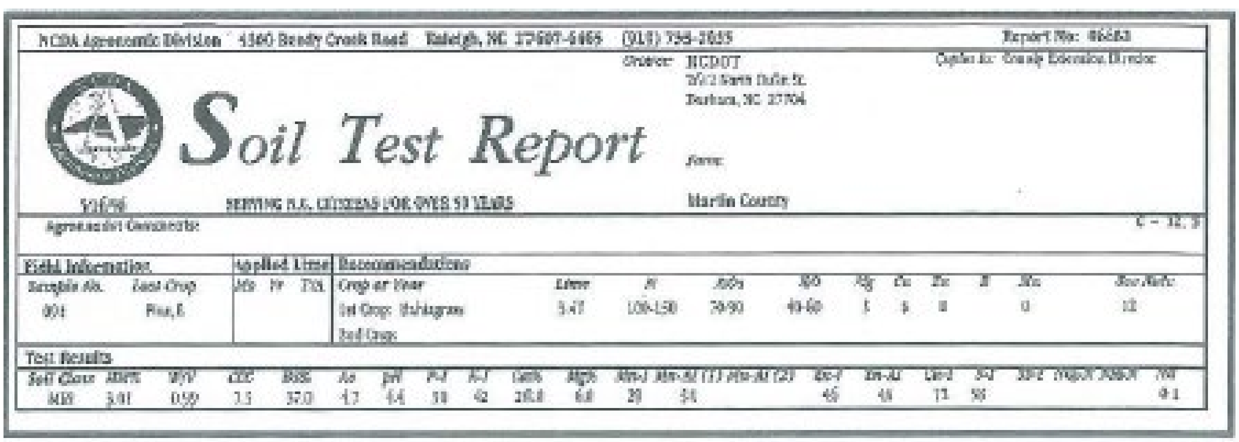
Agronomic Division-Soil Test Lab
N.C. Dept. of Agriculture
4300 Reedy Creek Road
Raleigh, N.C. 27607-6465
(919) 733-2655

	2	3		4			5		6	
LAB NUMBER (Leave Blank)	YOUR SAMPLE NUMBER	LAST CROP		LIME APPLIED WITHIN PAST YEAR			NEXT CROP		SECOND CROP	
		(Crop grown last year or other use)	CROP CODE	T/A	YR	MO	(See discussion No. 5 reverse side of form)	CROP CODE	(Following year—See reverse side)	CROP CODE

Revised 2/1/90

INSTRUCTIONS AND CROP CODES ARE SHOWN ON BACK

Figure 3.3: Soil Sample Information Sheet



NCDA Agronomic Division 4300 Reedy Creek Road Raleigh, NC 27607-6465 (919) 733-2655

Report No: [illegible]

Grower: NCDOT

Copies to: County Extension Director

Durham, NC 27704

Soil Test Report

Farm:

Martin County

SERVING N.C. CITIZENS FOR OVER 50 YEARS

Agronomist Comments:

Field Information		Applied Lime			Recommendations												
Sample No.	Last Crop	Mo	Yr	T/A	Crop or Year	Lime	N	P_2O_5	K_2O	Mg	Cu	Zn	B	Mn			See Note
001	Pine, E				1st Crop: Bahiagrass	3.4T	100-150	70-90	40-60	0	0	0		0			12
					2nd Crop:												

Test Results

Soil Class	HM%	W/V	CEC	BS%	Ac	pH	P-I	K-I	Ca%	Mg%	Mn-I	Mn-AI (1)	Mn-AI (2)	Zn-I	Zn-AI	Cu-I	S-I	SS-I	NO3-N	NH4-N	Na
MIN	3.01	0.59	7.5	37.0	4.7	4.4	19	42	24.8	6.8	29	54		46	46	73	56				0.1

Figure 3.4: Soil Test Report Showing Results and Recommendations

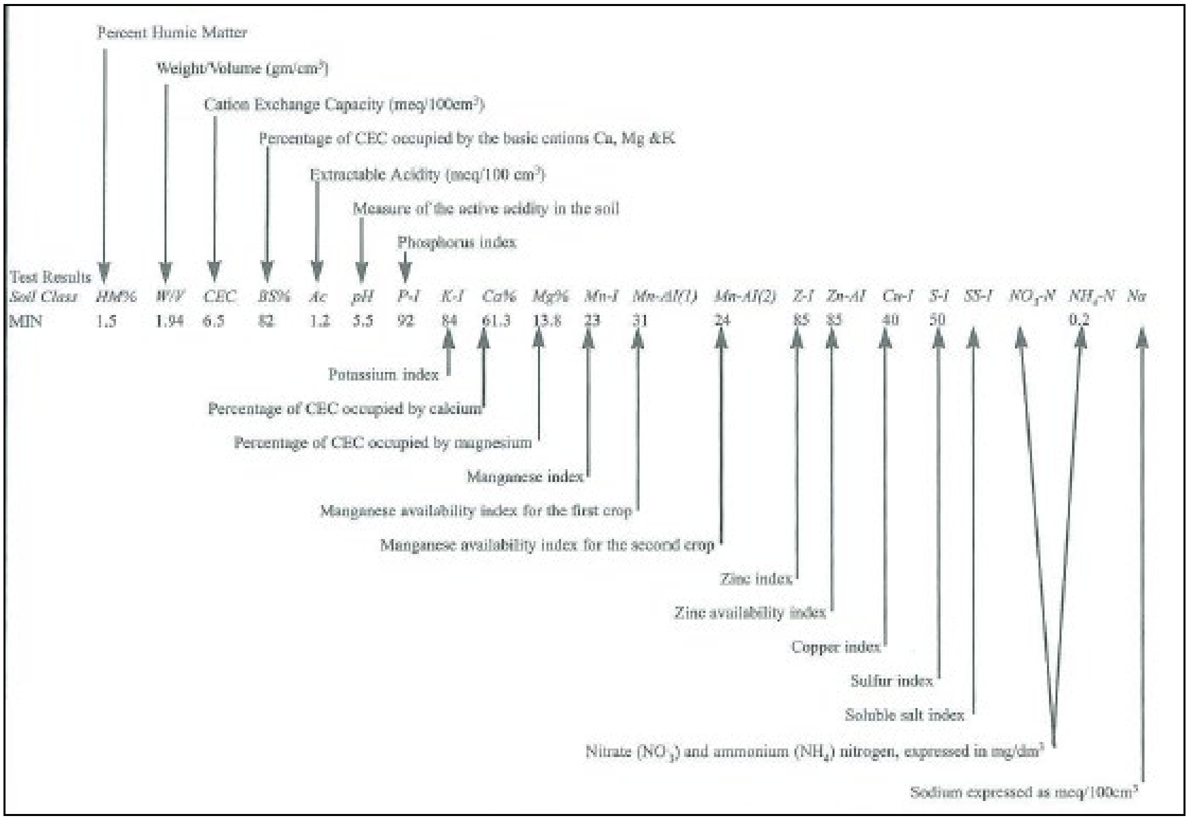


Figure 3.5: Explanation of Soil Test Results

pH and Liming

The soil analysis includes the soil pH, a measure of *active acidity* in a soil. Active acidity is the H^+ concentration in the soil solution. This is a minute amount compared to the *reserve acidity*, i.e., exchangeable acidity. Nevertheless, the very small amount of H^+ in the soil solution, as expressed by pH, has a pronounced effect on the availability of nutrients (**Figure 3.6**).

In determining the amount of lime to bring about a desired pH change, factors other than pH itself must be considered. As indicated above, the amount of acidity measured by pH is very tiny. For example, a solution of pH 6.0 contains only 10^{-6} (.000001) gram of H^+ per liter of solution. It is the reserve acidity that must be neutralized before any significant change in pH occurs. The CEC of the soil and the magnitude of reserve acidity are the important soil factors in calculating the lime requirement. Of course, plants vary in their pH adaptation. Soils containing acid-tolerant plants like azalea and sericea lespedeza may not require any lime whereas acid soils containing clovers and alfalfa will probably have a large lime requirement. Clearly, the lime requirements for an acid, fine textured clay are much higher than those for a sand or a loam with the same pH value.

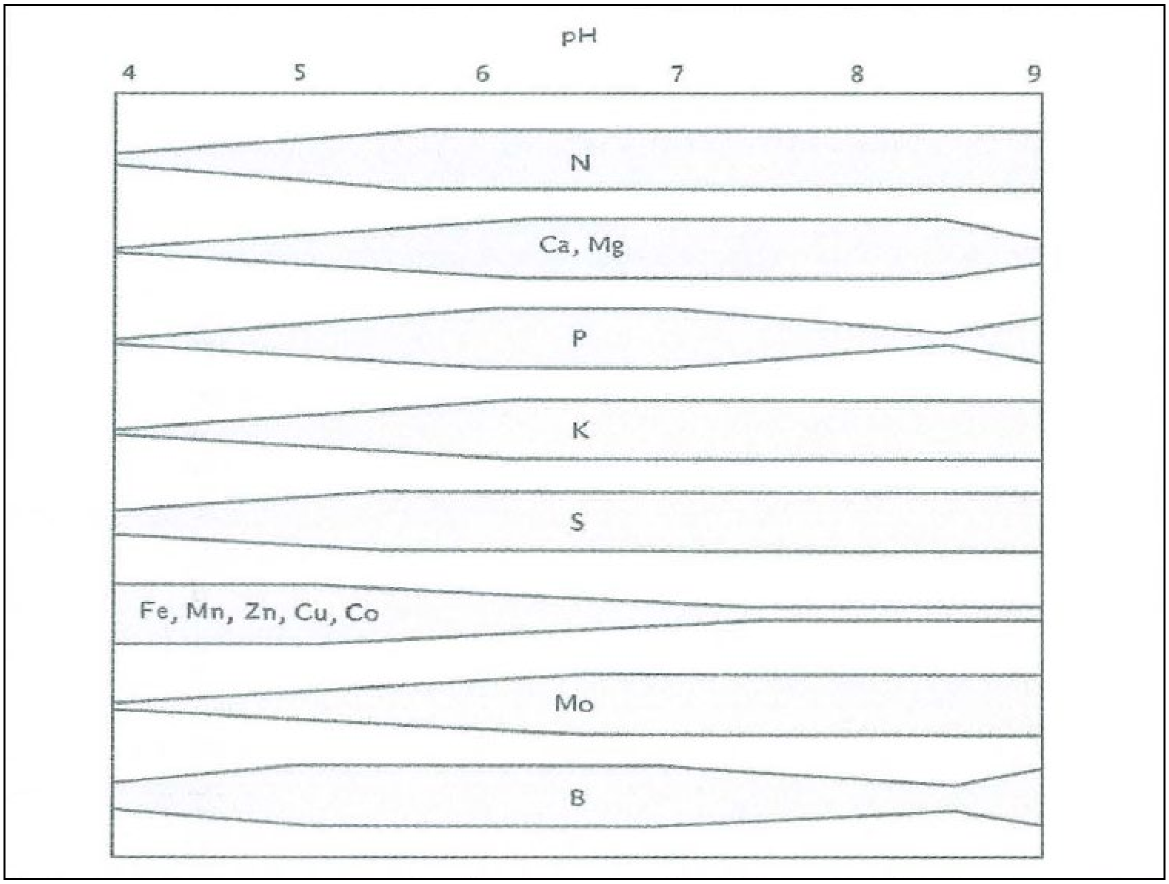


Figure 3.6: pH and Nutrient Availability

Adequate amounts of agricultural lime should be incorporated into the soil at root zone level during seedbed/plantbed preparation because lime dissolves very slowly in water and does not readily move down to the roots from the soil surface. Pure calcium carbonate ($CaCO_3$) is considered as the "standard" lime with a neutralizing value of 100%, and all other liming materials are compared to this compound for their neutralizing values. Other good quality liming materials typically have about 85-90% neutralizing value. **Table 3.4** lists some common liming materials and their neutralizing values compared to $CaCO_3$.

Table 3.4: Liming Materials and Acid Neutralizing Value

Liming Materials	Neutralizing Value $CaCO_3$ Equivalent, %	Equivalent to One Ton of Lime (lb)*
Calcitic lime (Standard Liming Material)	100	2000
Burned lime	178	1120
Hydrated lime	134	1490
Magnesium carbonate	119	1675
Dolomitic limestone	108-95	1850-2100
Calcium silicate slag	80-71	2500-2800

Table 3.4: Liming Materials and Acid Neutralizing Value, continued.

Liming Materials	Neutralizing Value $CaCO_3$ Equivalent, %	Equivalent to One Ton of Lime (lb)*
Marl	70-40	2800-5000
Rock phosphate	7	
Wood ashes	40	5000

*lb divided by 2.2 = kg

Fertilizers

A fertilizer is any inorganic or organic material of natural or synthetic origin added to a soil to supply certain elements essential to the growth of plants. Although the use of animal manure has been common for centuries, chemical fertilizers have been used extensively for a little more than 100 years. They are considered a necessity for many soils. Any inorganic salt, such as ammonium nitrate, or an organic substance, such as urea, used to promote the growth of plants by supplying plant nutrients is considered to be a "commercial" fertilizer. The compound in the fertilizer material that contains a given nutrient element is called *carrier.*

Nitrogen

Most N fertilizers are soluble compounds that release either NH_4^+ or NO_3^- ions very soon after they are added to the soil, and their effects therefore depend on which of these two ions is present. Ultimately, the greater part of fertilizer N is converted to NO_3^-. Under average conditions, NO_3^- is the dominant form of N plants absorb, and fertilizer behavior sometimes reflects this fact. The principal inorganic fertilizer compounds of N are listed in **Table 3.5** along with the total quantity of N they contain. Numerous other sources are marketed and include a variety of N solutions consisting usually of mixtures of ammonium nitrate or urea dissolved in aqua ammonia. Of particular interest are slow-release N fertilizers, such as sulfur-coated urea listed in **Table 3.5**. By dissolving gradually after application to the soil, these materials supply N to plants over periods of several months. Slow-release N fertilizers are of advantage because they reduce N losses by leaching.

Table 3.5: Important Inorganic Nitrogen Fertilizers (percentage N content is on a weight basis)

Name	Chemical Formula	N Content (%)
Anhydrous ammonia	NH_3	82
Aqua ammonia	NH_4OH	25
Urea	$CO(NH_2)_2$	45
Ammonium nitrate	NH_4NO_3	33
Ammonium sulfate	$(NH_4)_2SO_4$	21
Sodium nitrate	$NaNO_3$	16
Calcium nitrate	$Ca(NO_3)_2$	15
Sulfur-coated urea	See urea above	

Phosphorus

Phosphorus is probably second to N as the most widely deficient nutrient in soils. Two principal reasons account for this: (1) it is in low supply in minerals comprising the parent material of many soils; and (2) it is inclined to form compounds of very low solubility with other common ionic soil components. In many soils much of the available P is derived through the mineralization of organic matter. In some soils, the repeated addition of P fertilizer appears to be the only satisfactory way of supplying plant needs for this very important nutrient.

The primary source of phosphorus fertilizers is rock phosphate. When rock phosphate is treated with sulfuric acid, *ordinary superphosphate* is formed. By treating the rock phosphate with phosphoric acid, *triple superphosphate* is formed. These were used widely for many years but they are now less popular than the *ammonium phosphates*. Ammonium phosphates have the additional advantage of containing N as well as P. The most important phosphorus carriers are shown in **Table 3.6**.

Table 3.6: Important Phosphorus Fertilizers (percentage P content is on a weight basis)

Compound	Chemical Formula	Available P_2O_5(%)*
Superphosphates	$Ca(H_2PO_4)_2$; $CaHPO_4$	16-50
Monoammonium phosphate	$NH_4H_2PO_4$	48-55 (11-12% N)
Diammonium phosphate (DAP)	$(NH_4)_2HPO_4$	46-53 (16-18% N)
Steamed bone meal	$Ca_3(PO_4)_2$	23-30
Phosphoric acid	H_3PO_4	52-54

* It should be noted from the chemcial formula that fertilizers do not contain P as P_2O_5. The oxide term (P_2O_5) is used simply because it is the longstanding conventional way of expressing the P content.

Potassium

The chemistry of K fertilizers is comparatively simple. All of the widely accepted materials are readily soluble in water and liberate K rapidly when applied to moist soil. As with P, the content of K in fertilizers is expressed conventionally on the oxide (K_2O) basis.

Unlike nitrogen salts, most K fertilizers have little or no effect on the soil pH. Major K fertilizer materials are listed in **Table 3.7**.

Table 3.7: Important Potassium Fertilizers (the percentage K content is on a weight basis)

Compound	Chemical Formula	Available K_2O (%)*
Potassium chloride	KCl	48-60
Potassium sulfate	K_2SO_4	48-50
Potassium-magnesium sulfate	$K_2SO_4 – MgSO_4$	25-30
Potassium nitrate	KNO_3	44 (13% N)

* It should be noted from the chemical formula that fertilizers do not contain K as K_2O. The oxide term (K_2O) is used simply because it is the longstanding conventional way of expressing the K content.

Calcium and Magnesium

As noted previously, Ca and Mg are supplied to the soil in liming materials. Lime is a soil *amendment*, not a fertilizer. However, because lime has such an effect on soil fertility and plant nutrition, it is included in this discussion of fertilizers.

The two primary sources of Ca and Mg are *calcitic* ($CaCO_3$) limestone and *dolomitic* [$CaMg(CO_3)_2$] limestone. The quality of a liming material is based on its *calcium carbonate equivalent,* i.e., how its chemical composition compares to pure $CaCO_3$ which has a rating of 100. Another consideration in selecting a liming material is its particle size. The smaller the lime particles, the faster they dissolve and release the Ca and/or Mg.

Sulfur

Sulfur deficiencies have not been a widespread problem in the past. Until recent years, demands placed on the native supply of soil S were not great. Considerable S was added to the soil from time to time with fertilizers such as ammonium sulfate and ordinary superphosphate, or from the atmosphere. Soil S is no longer so universally adequate due to several factors: (1) Loss of topsoil and organic matter by erosion; (2) decline of atmospheric S; and (3) changes from older standard fertilizers containing S to high analysis, low-S materials. Some of the more common S fertilizer materials are listed in **Table 3.8**. Since S is often applied to soils in combination with N, the content of the latter element is also shown in the table.

Table 3.8: Important Sulfur Fertilizer Materials

Compound	Formula of S Source	Nutrient Content (%)	
		S	N
Ammonium sulfate	$(NH_4)_2SO_4$	24	21
Gypsum	$CaSO_4 – 2H_2O$	17	-
Potassium sulfate	K_2SO_4	18	-
Sulfur (elemental)	S	100	-
Single superphosphate	$Ca(H_2PO_4)_2 + CaSO_4$	12	-
Sulfur-coated urea	Available from SO_4	10	32

Micronutrients

The amounts of micronutrients in fertilizers must be much more carefully controlled than the macronutrients. The difference between the deficiency and toxicity levels of a given micronutrient is extremely small. Consequently, micronutrients should be added only when their need is certain and when the amount required is known.

When a trace element deficiency is to be corrected, a salt of the lacking nutrient is usually added separately to the soil. Copper, manganese, iron, and zinc are commonly supplied as sulfate salts, and boron as borax. Molybdenum is added as sodium molybdate. Iron, manganese, and zinc are often sprayed in small quantities as chelates or sulfates on the leaves (foliar application) rather than being applied directly to the soil.

Forms of Fertilizers

Fertilizers come in a variety of forms. Some consist of *single* materials or compounds that supply one or more nutrients. Examples of these are NH_4NO_3 and SO_4, or products of more complex composition like the superphosphates. A second category is *mixed* fertilizers produced by combining two or more single materials. Mixed fertilizers that supply all three major nutrients N, P, and K are called *complete* fertilizers.

For many years, essentially all mixed fertilizers were bagged at a central manufacturing plant and shipped to points for distribution. Today, bulk handling and blending of fertilizers are the common procedures. This allows a fertilizer mix to be "customized" to match the plant nutrient needs.

Another innovation in the formulation and handling of mixed fertilizers is the use of liquid fertilizers, sometimes termed *fluid* fertilizers. Nutrients in liquid fertilizers are readily available since they are already in solution. Thus, plant response time is minimized since fertilizers in this form are absorbed by both the above ground portion of the plant and the roots. However, analysis of multinutrient liquid fertilizers are somewhat lower than for solid fertilizers. Other disadvantages of this type of fertilizer are high potential for foliar burn and for leaching, and costs of the materials and their application.

Specialty Fertilizers

Specialty fertilizers are those materials which do not conveniently fit into the categories previously mentioned but which may exhibit one or more of the characteristics that have been described. Specialty fertilizers by this definition include specifically designed slow release materials, manufacturing by-products, and fertilizers specially formulated for particular vegetation types whose nutrient demands cannot be satisfied by generally available analysis.

Two main approaches to achieving slow or controlled release in fertilizers have been: (1) the development of compounds of limited water solubility as a coating; and (2) the alteration of soluble materials to retard their nutrient release to the soil solution. Since nitrogen is the most widely used fertilizer nutrient and is also the most susceptible to loss by leaching or denitrification, this loss has received the most attention. Controlling the solubility and, thus, the release of nitrogen can be accomplished by adding a physical barrier or a coating to water soluble materials. Some commercial coating processes use resins, thermoplastics, polymers and related reactive layer coating (RLC) technology. One of the more common coatings to control nitrogen release is sulfur, a previously discussed secondary nutrient. It is used in the production of sulfur-coated urea. Another way to control nitrogen release is to use materials of limited or controlled solubility which, during chemical or microbial decomposition, release nutrients gradually in forms available to plants. Two of the most common uncoated organic compounds in this category are methylene urea and isobutylidene-diurea (IBDU). The controlled nitrogen release of these products is a function of the ratio of short and long chain polymers that is engineered through the manufacturing process.

Mallinckrodt Ammonium Sulfate Liquid (MASL) is a by-product of that company's acetaminophen (Tylenol) manufacture. This product contains a guaranteed seven percent nitrogen along with a myriad of other materials (including sulfur), most of which are found in very small quantities.

Fertilizer Analysis

The terms *grade, analysis,* and *ratio* are used frequently in the fertilizer industry. Grade and analysis are used interchangeably and refer to the percentage, by weight, of the macronutrients in a sample fertilizer. The numbers on a fertilizer bag (e.g., 10-10-10) indicate the guaranteed grade or analysis. In this example, the fertilizer contains 10% total N, 10% available P_2O_5*, and 10% available K_2O*. Numerous grades of fertilizers exist, all of which follow the same numerical sequence (% N, % P_2O_5, % K_2O) on the label unless otherwise stated.

The term "ratio" is used to express the percentages of N, P_2O_5, K_2O in a given fertilizer in the smallest whole number terms. The fertilizers: 10-10-10, 8-8-8 and 20-20-20 are all 1-1-1 ratio fertilizers. A 16-8-8 fertilizer has a 2-1-1 ratio, and a 12-4-8 fertilizer has a 3-1-2 ratio. These ratios are important when determining which fertilizer to purchase or when discussing fertilizers in broad terms. A balanced fertilizer is one with a 1-1-1 ratio.

The importance of making accurate calculations to determine fertilizer application rates is obvious and needs much emphasis. Accurate calculations will ensure that essential nutrients are provided in correct amounts and proportions to improve plant growth and survivability. They also help prevent environmental damage associated with overfertilization and may preclude the waste of time, money and fertilizer.

Typically, fertilizer rates are expressed as pounds of fertilizer to apply to a given area (either 1,000 square feet or one acre). However, fertilizer rates may be expressed as pounds of a specific element (e.g., N) to apply to a given area.

North Carolina Fertilizer Law

The purpose of the North Carolina Commercial Fertilizer Law (Article 56 of Chapter 106 of the General Statutes of North Carolina) is to "assure the manufacturers, distributors and consumers of the correct quality and quantity of all commercial fertilizers sold in this State, and to assure the safe handling of fluid fertilizers." Licensing, reporting, labeling, inspections, penalties, and associated terminology are discussed in Article 56 and related subchapters of the General Statutes.

The Fertilizer Section within the Plant Industry Division of the NCDA&CS administers the State's fertilizer law. Inspectors from the Fertilizer Section oversee all sampling and reporting. Because of NCDOT's numerous fertilizer delivery points, special sampling procedures have been established to help minimize the time and burdens placed on NCDA&CS. Upon delivery, material which varies more than a reasonable percentage from the labeled analysis or weight and which does not meet specifications in every respect is subject to rejection after delivery and/or an assessment of fines by NCDA&CS.

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* A common misconception is that the % P_2O_5 and % K_2O are the same as % P and % K. % available P = % P_2O_5 x 0.44;% available K = % K_2O x 0.83.

Organic Materials

Prior to the 1920's, compost and organic fertilizers (farm-yard manures) were extensively used in the US. With the development of technologies to derive nitrogen from the atmosphere to produce synthetic ammonia, the use of naturally occurring organic fertilizers declined rapidly. This was primarily because farm-yard manures have very low concentrations of nutrients compared to commercially available fertilizers. However, in recent years there has been a revival in their use because of various environmental concerns. In 1991, North Carolina's House Bill 1109 and Senate Bill 111 helped to pave the way for the use of alternative (recycled or recyclable) products where economically feasible. Although no monies were allocated to assist with this movement, many proactive, progressive units within the Department of Transportation have begun to utilize these products. The Roadside Environmental Unit has utilized a variety of organic recycled products in the installation and maintenance of right of way vegetation.

The addition or incorporation of compost/organic matter to soil provides many benefits which are considerably more important than their nutrient values. When used as a mulch on ornamental beds, organic materials will: (1) help reduce erosion by decreasing the impact of falling water; (2) increase infiltration; (3) decrease evaporative moisture loss; and (4) help reduce weed competition.

Over the last decade numerous research projects have evaluated the effects of organic matter/compost on plants. The loading rate (amount of end-product added to a site) is based on the nutrient content of the product and the physical parameters of the soil. Therefore, each recyclable product type must be evaluated on an individual basis.

Another very important issue to consider is the carbon to nitrogen (C:N) ratio of the product. Available N in the soil is used as an energy source by organisms responsible for biological activity and organic matter decomposition. Therefore, the associated plants may decline due to competition with microorganisms for the available nitrogen. A high C:N ratio means that the product will require N to breakdown carbon compounds present in the material. Thus, available N will be used for organic matter breakdown rather than to support plant life. Some products such as fresh wood chips may have a C:N ratio as high as 600 to 1.

Such products are undesirable for incorporation. It is generally accepted that if the C:N ratio is below 20 to 1, the product is suitable for incorporation because the competition for available N will be low (see **Table 3.9**).

Table 3.9: C:N Ratios of Commonly Used Organic Materials

Raw Material	C:N Ratio (Weight to Weight)
Poultry carcasses	5
Broiler litter	12-15
Cattle manure	19
Turkey litter	16
Sewage sludge	5-6
Wheat straw	100-150
Hardwood bark	116-436
Softwood bark	131-1285
Newsprint	398-852
Leaves	40-80

Sources

There are numerous organic recyclable products available. Many of these are referred to as "natural organic nitrogen sources" and are recommended for landscape use. Three of these sources are: *yard waste debris, sewage sludge,* and *animal manures.*

Yard Waste Debris

In an attempt to conserve landfill space, most cities have diverted yard waste debris such as tree limbs, grass clippings and leaves from their waste treatment flow and have begun to stockpile this debris. Because yard waste has a high C:N ratio, it is not a good product to incorporate into the soil. Some drawbacks that can be experienced when using yard waste include: handling difficulty, bulkiness of the product, product longevity once applied, and the costs of transportation and application.

Sewage Sludge

As the population of our major cities continues to grow, the questions regarding disposal of sewage (municipal) sludge also grows. Processing criteria and product stability are utilized to define the various end products of sewage sludge management. On the whole, sewage sludge is characteristically low in potash (K_2O) and high in certain heavy metals.

In North Carolina, the Department of Environmental Quality (NCDEQ) is responsible for sewage sludge regulations. North Carolina Administrative Code Title 15A 02H .0200 "Waste Not Discharged to Surface Water" is the legislation regulating sewage sludge.

There are four major types of sewage sludge organic end products: digested, activated, composted, and lime-stabilized. Digested sewage sludge is the least stable form of sewage sludge end products and typically has a pH of about 6.5. This product may contain detectable levels of pathogenic bacteria like salmonella (responsible for gastrointestinal disorders), viruses, parasitic eggs, and viable weed seed. Since it is not fully processed, it also emits a strong undesirable odor. In North Carolina, digested sewage sludge is classified as a Class B product and therefore, by law, it is not available for public utilization.

Because of the processing criteria, activated, composted, and lime-stabilized municipal sludge are referred to as Class A (unrestricted use products). These products may be used by the general public provided that the product labeling information is followed. The labeling information provided by the product supplier is intended to protect the user and the environment.

Activated sewage sludge is derived from highly specialized processing. Sewage sludge, once freed of grit and coarse solids, is aerated, inoculated with special microorganisms, filtered/screened, and finally steam sterilized before it is pelletized. The steam sterilization process kills all pathogenic bacteria, viruses, weed seed, and other undesirable microorganisms. Since 1937, the City of Milwaukee, Wisconsin has marketed “Milorganite” (Milwaukee Organic Nitrogen) the most widely utilized form of activated sewage sludge. Other cities sell similar products.

Since the early 1980’s, sewage sludge composting (a process through which microbial activity converts biodegradable organic carbon into carbon dioxide) has gained favor. A process known as aerated static pile composting is most widely utilized. This sludge management technology has grown in popularity because it is economical, environmentally sound, and publicly acceptable. During composting, air is forced through slotted pipes and through the sludge mixture. Internal temperatures often exceed 55ºC (131ºF). All bacteria, weed seed, and disease causing organisms are killed after three days. Composted sewage sludge has N-P_2O_5-K_2O values of 1-1.5, 1.5-2, and less than 1, respectively. For this reason, supplemental K is needed to insure turf and ornamental growth when using composted sewage sludge.

Recently, a new technology known as advanced alkaline stabilization has become popular for processing municipal sludge. The end-product, lime stabilized municipal sludge, is derived from mixing one of several liming agents with wastewater biosolids. Agricultural limestone, kiln dust (a recyclable product from concrete production), or quick-lime (calcium oxide) are the most popular stabilization additives. The resulting product is marketed under several trade names such as: “Lime-Plus,” “Nutrified lime,” and “N-viro soil.” Applications or loading rates of lime-stabilized municipal sludge are based on liming needs of the site, any nutrient limiting factors in the final product, and the calcium carbonate equivalence (CCE) of the product. The CCE can be thought of as the product’s neutralizing power and is always compared to the neutralizing ability of agricultural limestone. Typically, one must apply more lime-stabilized municipal sludge than agricultural lime. However, cost/benefit ratios in some cases have made lime-stabilized municipal sludge an acceptable, cost-efficient alternative to agricultural lime. Characteristically, lime-stabilized municipal sludge has N, P_2O_5, K_2O values of 0-1, 2-3, and 0-0.5.

Lime-Stabilized Sludge

In conjunction with NCDEQ, the NCDOT has developed criteria for utilization of lime-stabilized municipal sludge. The following criteria were generated to formalize the selection process and to promote the use of recycled materials in highway construction and maintenance activities. The alternative of using lime-stabilized municipal sludge is not an attempt to delete the use of agricultural limestone. The contractor can select either material but must adhere to specific application guidelines (see **Table 3.10**). This approach is a more equitable method for lime procurement rather than completely penalizing the agricultural liming industry, which has serviced the Department's needs for many decades.

Table 3.10: Guidelines for Selection of Liming Materials

Project Selection Criteria:
Proximity to the municipal production plant
Watershed impact
Environmental commitments
NCDEQ permit status
Generators' permit performance (compliance vs. non-compliance)
Local ordinance restrictions
NCDOT Permit Restrictions:
Cannot stockpile on job site for more than one week.
Cannot apply within 100 feet of a dwelling, well, stream, or on areas with steep slopes (to minimize run-off).
Cannot have discharge from target application site.

Only recently has NCDEQ permitted NCDOT to utilize lime-stabilized municipal sludge as a top-dressing (non-incorporated) application to turf areas.

Animal Manures

The Roadside Environmental Unit (REU) works closely with the Department's Recycling Task Force, and North Carolina State University specialists to stay informed of possible sources of animal manure compost. To date, poultry litter has been primarily utilized because of application and product storage considerations. Other sources such as dehydrated cow manure, horse manure, and hog waste have been used in limited quantities, usually in roadside evaluation plots.

NCDOT Applications

In the course of establishing and maintaining a wide variety of vegetation along more than 79,585 miles of highway, the Department uses a relatively small selection of fertilizers and soil amendments. The NCDOT utilizes the services of the NCDA&CS Agronomic Division for diagnostic testing. The Agronomic Division staff is knowledgeable of the various soils in the State and has assisted the NCDOT in developing its fertility program. The results of diagnostic tests are carefully reviewed by an NCDA&CS agronomist, who interprets results for the NCDOT and suggests corrective measures. Available fertilizer materials and by-products are listed below with justifications for their use or reasons why the Department is reluctant to use them.

Fertilizers

The fertilizers primarily used are:

- 10-20-20 or other 1-2-2 ratio fertilizers for warm and cool season grass establishment.
- 16-8-8 or other 2-1-1 ratio fertilizers for warm and cool season grass topdressing. (These two ratios are used for their respective purposes as expressly recommended by NCSU Turfgrass Researchers. The comparatively high analysis allows the Department to be very cost effective in purchasing, storage, and application since smaller quantities of the fertilizers need to be purchased and handled to achieve the desired nutrients benefits).
- Ammonium nitrate (34-0-0) is utilized when soil tests or observations indicate that only nitrogen is needed.
- Triple Superphosphate (0-46-0) is utilized when soil tests or other indicators dictate only a required phosphate application.

Other types of fertilizers (water soluble, slow release, etc.) are purchased by the Roadside Environmental Unit for Division utilization as warranted.

Soil Amendments

Soil amendments and by-products commonly considered by NCDOT:

- Yard Waste: The Department has begun to utilize yard waste as mulch in ornamental plant beds. NCDOT is committed to using yard waste debris as a mulch where economically feasible.
- Agricultural (dolomitic) Limestone: This product is used extensively to adjust the pH of acidic soils prior to the establishment of grasses and ornamental plants.
- Composted Poultry Litter: The Roadside Environmental Unit, in cooperation with the NCDA&CS Fertilizer Section, NCSU and NCDEQ, has developed comprehensive specifications for the purchase of composted poultry litter. The specifications are written to describe the minimum requirements of the composting process and to focus specifically on the characteristics of the end product.
- Composted Sewage Sludge: The Department utilizes a limited amount of this material in its vegetation management program as a soil amendment and as a mulch.
- Lime Stabilized Municipal Sludge: The Department currently uses this type of stabilized sludge as an incorporated liming agent in lieu of agricultural limestone in wildflower beds, when the cost is competitive.
- Digested Sewage Sludge: The Department does not apply any of this sludge to the rights-of-way due to this material’s classification as a Class B product not available for public utilization.
- Activated Sewage Sludge: The Department does not utilize activated sludge due to the high cost of this material compared to commercially available fertilizers.

Fertilizer Procurement Process

The Roadside Environmental Unit assesses the Division's granular fertilizer and limestone requirements twice a year. After consulting with the NCDA&CS Fertilizer Section and specialists at NCSU, the Department prepares and mails bid specifications to prospective vendors. Once all bids are returned, officially recorded, and opened by the Purchasing Officer, the bids follow a strict review procedure to determine awards. Contract "certifications" are then issued to successful vendors. The Unit receives copies of the certifications and places orders as needed. Orders are processed by the Purchasing Agent and sent to successful vendors.

In keeping with the recycling efforts, products such as MASL, fly ash, demolition debris mulch, and lime-stabilized municipal sludge are reviewed to determine their suitability as replacements for agricultural-type products typically purchased. When these recyclables meet the previously discussed selection criteria and are economically feasible, individual contracts or bids are awarded. Because of the highly corrosive nature of some of these products, as well as handling and storage difficulties, NCDOT has begun to contract the application of some recyclables. Contract application work is performed under strict guidelines and in the presence of a NCDOT inspector.

Fertilizer Storage and Handling

Safety is the primary concern when storing, handling, and applying fertilizers. There is no substitute for safety because it avoids human suffering, pays dividends in improved efficiency, protects the environment, and results in improved employee morale and performance.
The following guidelines apply to storage of all fertilizer materials:

- Granular fertilizers are hygroscopic; that is, they readily absorb moisture. Thus, they are placed to avoid contact with damp surfaces, moisture, and humidity. Facilities should be dry and free from water seepage. Exposure may be reduced by covering with plastic. Rotate bagged materials to prevent older shipments from caking and becoming unusable.
- Aluminum and wood structures are acceptable for storing fertilizers. Since most fertilizers are corrosive, they should not come in contact with unprotected iron, copper, lead, or zinc materials. Protect wood against impregnation by using treated lumber or paint.
- Bins and storage areas should be kept clean and free of contaminants such as organic chemicals, flammable liquids, corrosive acids, chlorates, and finely divided metals or sulfur, in order to prevent fires.
- Fertilizers are stored away from steam pipes, radiators, light bulbs, and other sources of heat.
- Bagged fertilizers are stored no closer than 30 inches to walls, with adequate aisles for accessibility and ventilation. Piles should not be over 20 feet wide or stacked closer than 36 inches to roof eaves or overhead beams. Keep separate from possible contaminants by a space of 36 inches or a firewall.
- Floors should be dry and clean. They must be of noncombustible material, or protected against impregnation. For bulk fertilizer storage, cover concrete floors with a moisture barrier. Bagged fertilizer should be placed on pallets. Plug all drains which could receive molten nitrate in the event of a fire.

- "No Smoking" rules must be observed and no open flames are allowed.
- Warehouse should be self-ventilating.
- Storage area must be accessible to fire-fighting equipment and hydrants. A fire plan and inventory of materials must be kept on file.
- Fertilizers are not stored with or near explosives or flammable materials unless facilities are designed and approved to store them.
- Spilled material is cleaned up promptly.

Containers and Packaging

NCDOT usually purchases dry granular fertilizers packaged in 40-50 lb plastic or paper bags lined with a moisture barrier to prevent caking. Water soluble liquid fertilizers are usually packaged in 1-5 gallon plastic recyclable containers.

Transporting Fertilizer Products

Fertilizer products are typically shipped from dealers to local NCDOT Roadside Environmental warehouses by flatbed semi trucks. NCDOT employees then transport fertilizer from the warehouse to field operations by flatbed truck as needed.

NCDOT employees are required to become state certified and possess a North Carolina Department of Motor Vehicles (NCDMV) Commercial Driver License to operate flatbeds, hydroseeders and application equipment before transporting fertilizer products. Special care is taken when transporting or loading fertilizer to ensure that the load is secured and the vehicle does not exceed gross vehicle weight limits. Further information on transporting material can be found in two manuals commonly used by NCDOT personnel: North Carolina Commercial Driver's Manual (Sections 3 and 8) and NCDOT Workplace Safety Manual (Chapters 10, 11, and 12).

Fertilizer Application

Two essentials for effective application are proper placement and proper timing. Fertilizer placed in contact with or too close to seeds can cause salt injury or nitrogen burn, resulting in poor stands. If side placement (banding) is not possible or practical, which is the case in many NCDOT operations, incorporation is the preferred method. The use of grain drills and sod seeders for planting grass is desirable, because plants with small seeds respond well to close fertilizer placement. Occasionally it is necessary to apply fertilizer by shoulder-harness spreaders, especially when small, irregular areas need nutrients or topdressing materials. When applying fertilizers with drop, broadcast and hand spreaders, it is best to apply half of the material in one direction and the other half from the opposite direction in order to obtain the most uniform coverage.

When topdressing turf and fertilizing ornamental plants, timing is important. Cool season grasses should be fertilized between September and January. Warm season grass requirements vary, but they should generally be fertilized between May and August. Trees and shrubs should be fertilized in spring and summer. Flowers and grasses should be fertilized when planted. Liquid foliar applications should be made in early morning, late afternoon, or on cloudy days when plants are turgid. More information regarding proper timing and placement can be found in Chapters 5 and 6 of this manual.

Fertilizer Application Equipment

Two additional essentials to effective application are using the proper equipment and calibrating the equipment to apply the proper rates. When selecting equipment to best fit an operation, the acreage, crops, and labor must be considered. Large equipment is impractical in areas along rights-of-way with irregular shapes. Equipment is selected that is convenient to calibrate, hitch, and operate. This can help a busy vegetation manager complete applications on time. Expensive equipment purchases often cannot be justified for infrequent or short term operations. Equipment may be rented if a special type of machine is needed. Adjustments of application equipment are checked carefully. The operator's manual lists recommended equipment settings, which should always be calibrated before beginning any operation. The Department has a wide variety of equipment that is suitable for fertilizer application.

APPLICATION EQUIPMENT

Grain Drill (Class Code 1703) or Sod Seeder (Class Code 4239)

These are granular applicators which usually plant seed and apply fertilizer simultaneously. Most grain drills are pull - type. Most sod seeders are three-point hitch mounted. Both consist of a hopper, metering system, drop tubes, coulters, and drag chains or press wheels. Usually the metering device is a positive displacement type which delivers a fixed volume of material for every revolution it makes. The drive mechanism is connected to the ground wheel so material is delivered whenever the wheel turns and the orifice is opened. This equipment will apply the same rate per acre of seed and fertilizer regardless of ground speed.

Drop Spreader

A drop spreader is used to apply dry fertilizer and lime. It may be three - point hitch or pull type. It consists of a hopper and gravity flow type metering system. With gravity flow, the orifice is adjusted and an agitator ensures smooth delivery. A consistent speed is necessary to provide uniform coverage.

Broadcast Spreader (Class Code 4246)

A broadcast spreader is widely used to apply dry fertilizer and lime. It may be a small handheld or cart-mounted unit for lawn use, or it may be three-point hitch, trailer mounted, or truck mounted for field use. The spreader typically consists of a hopper, drag chain or belt, discharge gate, chute, and one or two spinners. Some units to not use a belt or chain, but relay on gravity flow through an orifice and agitator to achieve the desired discharge rate. Broadcast spreaders are driven by power take off (PTO), ground wheel or manually operated. Most require a consistent speed to provide uniform coverage.

Hydroseeder (Class Code 4170)

A hydroseeder is used to simultaneously apply water, seed, fertilizer, lime, and mulch. It is also used to apply liquid water soluble fertilizers for foliar applications. A hydroseeder may be truck mounted or pull-type. It consists of a tank, agitator, pump, swiveling gun, and nozzle. The hydroseeder is powered by an external engine and pump which are independent of drive wheels. A consistent speed is necessary to provide uniform coverage.

Maintenance of Equipment

Uniform delivery of material is important. Metering devices and discharge mechanisms must be cleaned daily to remove caked material and obstructions. All parts are checked for wear because badly worn parts result in large application errors. The drive mechanism is checked for proper operation because slipping wheels, worn belts, and worn chains also seriously affect performance. All faulty equipment is repaired or replaced. All equipment is operated at designated speeds. Excessively high or low speeds will cause improper application patterns. Most tractor PTO drives are designed to operate at 540 RPM. The operator’s manual lists initial settings and adjustments, which should be calibrated in the field for proper application rate, then any necessary adjustments made accordingly.

Fertilizers are corrosive and in most cases will damage components if left in the equipment overnight. Equipment is washed thoroughly with clean water. Components are protected from corrosion after washing by applying a light oil or other suitable material. These guidelines are standard operating procedures for NCDOT Roadside Environmental personnel. All unit personnel who work with this equipment are responsible for its proper care and maintenance. The maintenance section of the Operator's Manual should be used to locate specific grease points or other scheduled maintenance items.

Summary

In the course of highway construction, soils are selected for the purpose of supporting various pavements and structures. Various soil horizons are exposed during grading operations and little consideration is given to the nutrient requirements for the establishment and long term support of vegetation. This situation is overcome through the prudent use of fertilizers and other soil amendments during vegetation establishment and periodically thereafter to insure its survival.

Research has shown that healthy turf slows the velocity of runoff and allows water to infiltrate. By filtering undesirable particles and assimilating highway contaminants routinely found in runoff, a properly fertilized and maintained utility turf can help prevent soil erosion and other environmental problems. It is apparent when observing roadside vegetation that the NCDOT's fertilization program is below the subsistence level required for good plant health. However, by utilizing the NCDA&CS soil testing services as part of an Integrated Roadside Vegetation Management Program, roadside vegetation can be maintained in a healthy condition that benefits the environment as well as the traveling public.

There are several fundamental steps which are considered necessary for the successful and efficient implementation of a fertilization program. First, collect representative soil samples and follow recommendations closely. Second, thoroughly assess the condition of the target vegetation, including tissue testing if deficiency symptoms are observed. Finally, evaluate atmospheric conditions and the physical condition of the soil just prior to the time of application.

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Introduction

In This Chapter . . .

- *Turfgrasses*
- *Ornamental Plants*
- *Wildflowers*
- *NCDOT Applications*

This chapter presents the various types of vegetation used by NCDOT for eroision control and roadside aesthetic. *Turfgrasses*, *ornamental trees* and *shrubs*, and *wildflowers* are the major kinds of plants grown on rights-of-way. Other important vegetation types are ground covers and nurse plant species.

The general characteristics and functions of each type of vegetation are described. The situations in which they are best utilized are also detailed.



Turfgrasses

Turfgrass is the predominant vegetation type on roadside rights of way. Turfgrass serves a multi-functional purpose by preventing soil erosion, reducing glare and removing dust particles from the air. Turfgrass also significantly enhances the aesthetics of roadside areas.

The management of turfgrass requires knowledge of the characteristics of grass plants, the differences between warm and cool-season grasses, methods of establishing turfgrasses and some basic maintenance requirements.

Grass Plant Characteristics

Grass plants are classified as *monocotyledons*, meaning they have a single seed leaf present when they emerge from the soil. This distinguishes grasses from broad leaf plants, which are *dicotyledons*, meaning they have two seed leaves. The leaf veins in grasses (monocots) are parallel to one another, while the leaf veins in broadleaf plants (dicots) branch from the midrib into a network of finer veins.

Another key difference between grasses and broadleaf plants is the location of the growing point of each type of plant. The growing point of a broadleaf plant is located at the top of the stem. The growing point of a grass plant is at the crown, which is located at the base of the plant near the soil surface where the leaves, roots and stems join. The significance of this difference in growing points is that turfgrass can remain healthy despite frequent mowing because of continued leaf development. Grass grows back after being cut because the growing point is located beneath the path of the mower blade. The tissue removed during mowing is the oldest portion of the leaf. Since the growing point of a broadleaf plant is at the top of the stem, mowing of these plants removes the growing point and may result in serious injury to the plant.

The important structures of a grass plant are shown in **Figure 4.1**. The presence or absence of these structures, their shape and size, and the ways in which they attach to the plant are important characteristics which can distinguish one grass species from another. They also can determine the ability of a grass plant to spread (i.e., if it has rhizomes and/or stolons). It is important to note that grasses have fibrous root systems which give them excellent soil-holding characteristics for erosion control.

Warm and Cool-Season Grasses

Warm-season grasses are generally adapted to the southern United States, which includes the southern and eastern portions of North Carolina. They are considered to be subtropical and they grow best when air temperatures are 80° F (27° C) or higher. Their tolerance of cold weather is poor, and they may be killed by extreme low winter temperatures or late spring frosts. Most of these grasses become dormant when the average daily air temperatures drop to 50° F (10° C).

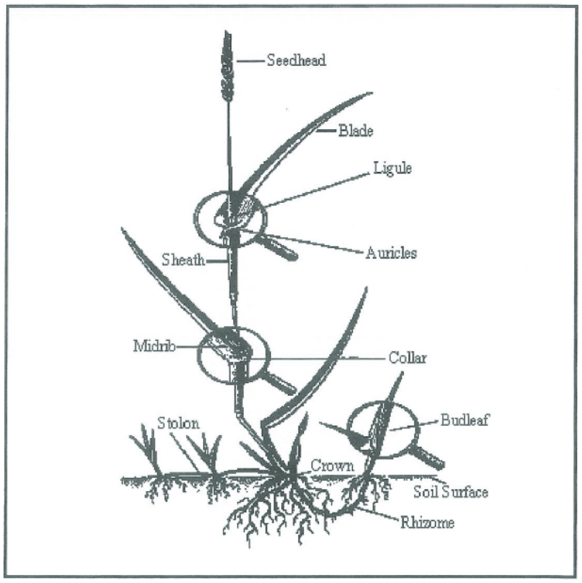


Figure 4.1: Components of a Grass Plant

Some examples of warm-season grasses are bermuda, St. Augustine, bahiagrass, Centipede and zoysia. (The warm-season grasses utilized by the NCDOT will be discussed in more detail in the section entitled NCDOT Applications.)

Cool-season grasses are generally adapted to the northern two-thirds of the United States, as well as the Piedmont and Mountains areas of North Carolina. They grow best in the 60°- 75° F (16° - 24° C) range. All cool-season grasses exhibit above-average low-temperature hardiness, although there is variation between species and cultivars. Heat tolerance is generally poor to fair. Some cool-season grasses can be grown in the northern portions of the warm-season zone, and can be seeded into warm-season turf to provide green color in the winter when the permanent warm-season grasses are dormant.

Some examples of cool-season grasses are Kentucky bluegrass, annual bluegrass, annual and perennial rye, tall fescue and hard fescue. (The cool-season grasses utilized by the NCDOT will be discussed in more detail in the section entitled NCDOT Applications.)

Methods of Establishing Turfgrasses

Proper establishment is the first and most critical step in a turfgrass management program. If the site is prepared and planted correctly with the appropriate species of turfgrass, the result will be a permanent stand of grass that exhibits satisfactory quality. Improper establishment practices often result in a poor stand of grass that is often difficult, time-consuming, and costly to correct.

Turfgrass establishment consists of species and cultivar selection, site preparation, planting, and post-planting care. Performing each of these practices correctly is essential.

There are four methods of turfgrass establishment:

(1) Seeding - applying pure viable seed of the desired species of turfgrass to prepared soil;

(2) Sodding - applying strips or sheets of mature turfgrass and soil to a prepared site;

(3) Plugging - applying small patches of sod at various points in a prepared site;

(4) Sprigging - applying turfgrass stolons and/or rhizomes to a prepared site.

(Proper establishment techniques are discussed in detail in Chapter 5 of this manual.)

Basic Maintenance Requirements of Turfgrasses

The maintenance considerations in a turfgrass management program include the following: soil aeration, liming, fertilization, mowing, irrigation, weed control, disease control and the replenishment of declining, damaged or worn turf. The level of maintenance that a turf area receives depends upon the level of turf quality desired and the resources available for maintenance. Different species of turf have different requirements. (Maintenance of turfgrasses for NCDOT purposes is discussed in greater detail in Chapter 6 of this manual.

Ornamental Plants

Ornamental plants are placed on the landscape to provide screening and shade, prevent soil erosion, and improve aesthetics. Selection of specific plants for a given site should be based on the purpose of the planting as well as the site environment. Some aspects of site environment that are important in the selection of plant material include site altitude, exposure, drainage, soil type, soil pH, and shade. The best practice when selecting plant material is to be aware of the existing conditions and to select plants that will thrive within these parameters.

Trees

Trees are used to provide shade, give screening for privacy, serve as windbreaks, decorate large scale designs, conserve land, and build up forests. Trees are selected based on their suitability for the desired effect and also for their growth habit (shape), flowering, bark characteristics, pest tolerance, longevity, and whether they are deciduous (e.g., maple or oak) or evergreen (e.g., pine or magnolia).

Deciduous - plants that lose their leaves in the winter

Evergreen - plants that keep their leaves throughout the winter

Shrubs

Shrubs are divided into categories based on their mature heights:

1 – 4’	4 – 6’	6 – 10’	10 – 15’
Dwarf	Small	Medium	Large

Shrubs are used for screening, borders, large masses of color, roadbank covering, and their ornamental value. The size, growth habit (shape), flowering, and whether it is evergreen or deciduous aid in selection of shrubs for a particular site.

Ground Covers

Ground covers are used as an alternative to turfgrasses in areas of dense shade and where mowing is not possible, such as steep hills. They also decrease the maintenance requirement since they do not require mowing. Ground covers provide complete coverage of the area, uniform leaf texture, and some have showy flowers.

Ornamental Flowers

Herbaceous annual and perennial plants are often used to provide seasonal color. Annuals must be replaced each year making their use labor intensive, whereas perennials will continue to flower year after year.

Wildflowers

Wildflower species are classified as *annual, biennial or perennial.* Annual wildflowers are planted from seed. They flower, set seed and die in one season. Annual wildflowers may reseed but the resultant stands are often thin and spotty at best. Annuals are usually planted because of their vibrant seasonal colors. Biennials are grown from seed and produce only vegetative growth the first year. They flower and set seed the second year. Perennials are grown from seed and typically produce only vegetative growth the first year and bloom the second and subsequent years.

Wildflower species are selected using various criteria including but not limited to: color, height, length and season of bloom, compatibility, tolerance to weeds, cultural requirements, tolerance of poor soils, and drought tolerance.

NCDOT Applications

For NCDOT purposes there are three primary functions of turfgrass plantings on rights of way: erosion control, safety, and aesthetics.

Turfgrasses

Turfgrass Function

1. Erosion control. Erosion control is an extremely important consideration of the NCDOT for several reasons: Compliance with state sedimentation laws; protection of land, streams and water supplies; and stabilization of areas disturbed by construction activities. Turfgrass, because of its versatility and adaptability, ease of establishment, and fibrous root system, is the single most useful form of vegetation for erosion control.

2. Safety. Turfgrass plays an important role in highway safety by reducing glare and helping to keep the air clean for greater visibility. Turfgrass areas adjacent to travel lanes provide clear, free recovery areas and safe off-highway parking for emergency situations. Turfgrass also provides safe, adequate and unobstructed sight distances along highways and does not obstruct intersections or highway signs.

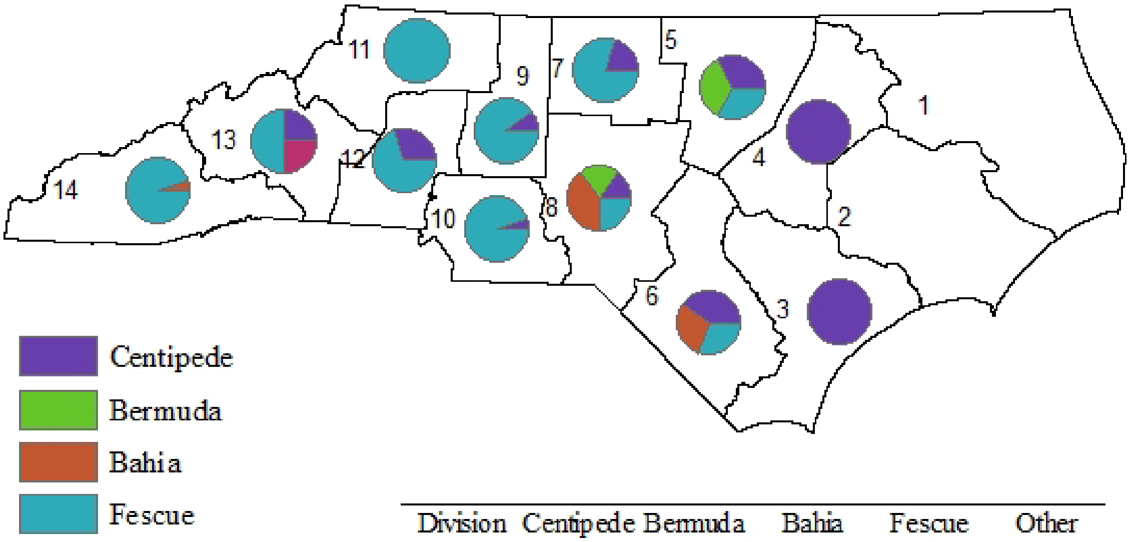
3. Aesthetics. Properly managed turfgrass is visually appealing, and adds beauty to the highway landscape. It has an attractive green color and a uniform appearance. It provides a pleasing and inviting view in the midst of vast expanses of concrete and asphalt.

Turfgrass Selection

The NCDOT uses both warm-season and cool-season grasses. Warm-season grasses grow best during the summer months, go dormant after the first heavy frost and gradually green-up in the spring. Cool-season grasses grow best in the spring and fall, stay generally green in the winter months and are less active during the summer months. The diverse topography and climatic conditions in North Carolina do not allow for one type of grass to do well in all situations. Cool-season grasses are adapted best to the northern and western sections of the state, while warm-season grasses perform better in the southern and eastern sections. The Piedmont area of North Carolina is in a transition zone where neither warm-season or cool-season grasses do exceptionally well. Seed mixtures combining warm-season and cool-season grass species are often used to provide variability and selective benefits that the different species have to offer.

An NCDOT-sponsored research project completed in 2017 (Martin, Bhadury, and Gaustad, 2017) surveyed the Divisions to identify the most common types of grasses used on rights of way. **Table 4.1** shows that both centipede grass and fescue are the most common turf types found along interstates in North Carolina with 10 out of 12 interview participants reported a presence of these species in their Divisions.

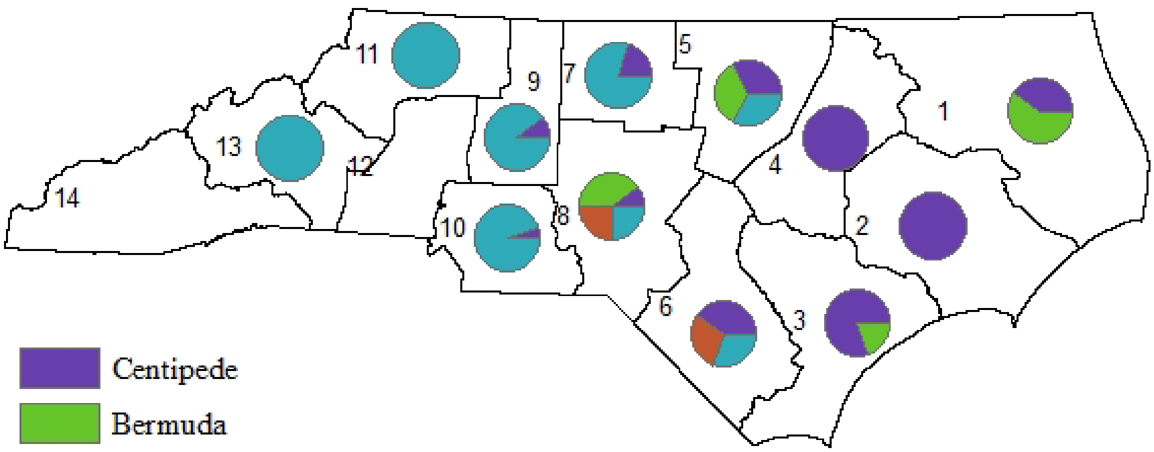
Table 4.1: Turf Types in Interstate Systems(separated by Division number, and associated figure)



Division	Centipede	Bermuda	Bahia	Fescue	Other
1	n/a	n/a	n/a	n/a	n/a
2	n/a	n/a	n/a	n/a	n/a
3	100%	<1%	0%	0%	n/a
4	>90%	0%	0%	0%	n/a
5	33%	33%	0%	33%	n/a
6	40%	0%	30%	30%	n/a
7	20%	0%	0%	80%	n/a
8	15%	20%	40%	25%	n/a
9	10%	0%	0%	90%	n/a
10	<5%	0%	0%	>95%	n/a
11	0%	0%	0%	100%	n/a
12	30%	0%	0%	70%	n/a
13	25%	0%	0%	50%	25%
14	0%	0%	5%	95%	n/a

Along primary routes, centipede grass is the most common type of turf, whith 10 out of 12 interview participants reported a presence of this species in their Divisions, as shown in **Table 4.2**. Fescue is the next most prevalent, followed by Bermuda.

Table 4.2: Turf Types in Primary Roadway Systems (separated by Division, and associated figure)



Division	Centipede	Bermuda	Bahia	Fescue
1	40%	60%	0%	0%
2	100%	0%	0%	0%
3	80%	20%	0%	0%
4	>90%	0%	0%	0%
5	33%	33%	0%	33%
6	40%	0%	30%	30%
7	20%	0%	0%	80%
8	10%	40%	25%	25%
9	10%	0%	0%	90%
10	<5%	0%	0%	>95%
11	0%	0%	0%	100%
12	n/a	n/a	n/a	n/a
13	0%	0%	0%	100%
14	n/a	n/a	n/a	n/a

The NCDOT works closely with North Carolina State University on species selection. The most common turfgrass species utilized by the NCDOT follow.

Cool-Season Grasses

Tall Fescue (Festuca arundinacea)

Tall fescue is a coarse-textured grass with a bunch-type growth habit. It does not spread readily and, therefore, must be overseeded periodically to maintain an adequate stand. It is a deeply rooted perennial with strong wear tolerance, and it is the most heat tolerant of the cool-season grasses. It grows well over a wide range of soil conditions, and tolerates both bright sun and moderate shade. Tall fescue is sensitive to close mowing. The NCDOT uses tall fescue in both cool-season and warm-season grass mixes.

Kentucky Bluegrass (Poa pratensis)

Kentucky bluegrass has a medium-fine texture, a deep blue-green color and the ability to spread by rhizomes. It has moderate wear tolerance with good recuperative ability. Drought tolerance is good but shade tolerance is rather poor. Kentucky bluegrass does not tolerate heat as well as tall fescue and its use in North Carolina is generally restricted to the western Piedmont and Mountain areas.

Hard Fescue (Festuca longifolia)

Hard fescue is a low-growing, non-spreading bunch-type grass. It has a very fine texture and is very drought tolerant. It is also the most shade tolerant of the cool-season grasses. Wear tolerance is moderate and recuperative potential is fair to poor. It grows very slowly and is well adapted to poor soils. The NCDOT uses hard fescue in cool-season mixes from the central Piedmont west to the Mountain areas of the state.

Warm-Season Grasses

Bahiagrass (Paspalum notatum)

Bahiagrass is a low-density turfgrass with coarse, tough leaf blades. It has moderate wear characteristics and spreads by short rhizomes and stolons. It has poor to fair recuperative ability, but tolerates poor soils well. It is deep-rooted and very drought resistant. Bahiagrass is easily identified by its numerous, long V-shaped seed heads. Shade tolerance for Bahiagrass is fair. Prior to repeal of General Statute 136-18.1 in 1999, the NCDOT used bahiagrass in seed mixes throughout North Carolina.

Centipede (Eremochloa ophiuroides)

Centipedegrass is a slow-growing, medium-textured grass that spreads by stolons. It can tolerate a wide range of soil conditions and does well on acidic, infertile soils. Drought tolerance is poor because of a shallow root system. It has the least wear tolerance of the warm-season grasses and has poor recuperative ability. Centipede has fair shade tolerance and a strong tendency to exclude other vegetation. Due to its low-growing nature and inconspicuous seedheads, centipede requires only infrequent mowing. It is well-adapted to the eastern Piedmont and Coastal Plain of North Carolina.

Bermuda (Cynodon dactylon)

Bermuda is a low-growing, dense turfgrass with a fine texture, which spreads by aggressive stolons and, to a lesser extent, by rhizomes. Bermuda tolerates a wide range of soil conditions. It has a rapid establishment rate and excellent recuperative potential because of its ability to spread quickly. Bermuda has excellent drought tolerance but is the least shade tolerant of the warm-season grasses. Prior to the development of chemical controls, its aggressive nature caused damage to cultivated agricultural fields. Therefore, its use on highway rights of way in North Carolina was restricted by state law (see Appendix A for General Statute 136-18.1) until April 1999 when this General Statute was repealed by Session Law 1999-29 Senate Bill 27.

Zoysia (Zoysia japonica)

Zoysia is a low-growing, dense turfgrass with a fine to medium-fine leaf texture. Zoysia spreads by stolons and tolerates a wide range of soil conditions. Because of its growth characteristics, NCDOT began using zoysia beside median cable rail systems in 2011. In 2017, NCDOT initiated a research project (NCDOT Research Project Number 2017-8104) with NCSU to evaluate commercially available and unnamed, experimental zoysia cultivars for roadside use.

Ornamental Plants

It is the goal of the NCDOT to design, locate, and develop highway plantings that are visually acceptable to the user and also to the residents living close to the rights-of-way. Highway appearance is important to the state's economy because it affects activities such as recruitment of new business and industry, travel and tourism, and the attitudes of citizens regarding stewardship of resources. For these reasons, the NCDOT places a high priority on the development and continual improvement of highway aesthetics.

Planting of specific roadside areas is frequently undertaken by the NCDOT and by municipalities, garden clubs, and individuals after permission is granted from the Division of Highways. Many requests are received for permission to plant trees, shrubs, vines, and flowers within highway rights-of-way. In order to protect the public investment and to promote highway safety, utility, economy, and beauty, a state law was enacted to provide protective measures (North Carolina General Statute 136-93).

The highway environment in which landscape plantings are to be established often dictates the choice of plant material and the degree of maintenance. In rural settings the basic emphasis is on the establishment of low-maintenance plantings that project a natural appearance and transition to the rural landscape. More formal landscape treatments are designed for urban areas, rest areas, and governmental buildings where more intensive maintenance is required.

Trees are a vital part of the roadside landscape. Addition of trees to the roadside environment is an element of enhancement programs such as: retention of desirable vegetation during initial highway construction; reforestation or revegetation of cuts, fills, and open areas using native seedlings; and planting of larger native tree species using mechanical tree spades or conventional practices.

Tree seedlings are selected based on their geographic adaptation, bloom, and fall color. They are used for reforestation purposes or departmental programs such as the Dogwood and Redbud Enhancement Program and the Green-Roads Initiative. Larger tree species are selected for their geographic adaptation, flowers, berries, and their contrast of seasonal color.

Ornamental ground covers and shrubs are selected based on their regional adaptation, flowers, berries, and seasonal color. They are used primarily on bridge ends for overpasses, within interchanges, and at rest areas or governmental buildings. Their diversity in sizes, shapes, and textures add definition to any type of landscape planting. An added benefit from ornamental ground covers and shrubs is their soil-holding characteristics that enable them to stabilize vulnerable areas like bridge ends and difficult slopes.

A variety of seasonal colors can be achieved through the use of perennial flowers. Most species tend to produce blooms even during periods of low to moderate rainfall. Annuals are utilized to enhance rest area and governmental facilities. Annuals indeed have their place in specialized situations; however, they are more time consuming, labor intensive, and costly to maintain than perennial flower varieties due to their large water, nutrient, and care requirements.

Several factors influence the choice of plant material. However, the success of any roadside planting depends on the quality of the plant material purchased and utilized. To ensure that plant material meets the minimum requirements for nursery grown stock, it is mandatory that the plant material purchased by the NCDOT conforms to the specifications contained in the American Standard for Nursery Stock regarding root ball size, grading of plants, and the type and minimum dimensions of containers. The following is a list of the most commonly used ornamental tree, shrub, and ground cover species used by the NCDOT.

<u>Ornamental Species</u>

Oak (Quercus sp.)

Several oak species are native to the eastern and southeastern United States. Oaks range in height from 40 to 110 feet at maturity. Tree form is typically rounded with some species being broad and some pyramidal. Foliage varies with some species having willow-like leaves and some having lobed leaves. Most species have leaves alternating on stems. They have catkin-like flowers and all species produce fruit. Size of fruit varies among species ranging from the small acorn of the willow oak to the large acorn of the sawtooth oak. Oaks are selected by the NCDOT based on their growth habit, size, shape, and fall color. The following cultivars are currently utilized:

- Sawtooth Oak (*Quercus acutissima*) - The sawtooth oak is the fastest growing species commercially available. Its leaves tum brown in the fall and may be retained until spring. It matures at a height of 35 to 45 feet and is highly variable in shape.
- Pin Oak (*Quercus palustris*) - This oak grows to a height of 100 feet under ideal conditions and has a pyramidal shape. It develops a broader crown with age. It does not have showy fall color and it may retain brown leaves into winter.
- Willow Oak (*Quercus phellos*) - The willow oak does not grow as fast as a sawtooth oak. It takes on a pyramidal shape when young and broaden as it ages. It may reach a height of 100 feet or greater at maturity.
- Red Oak (*Quercus rubra*) - Under ideal conditions, it can reach a height of 120 feet at maturity. It has a round to oval shape and its leaves turn a reddish-orange during fall months.
- Live Oak (*Quercus virginiana*) - This is a large tree used throughout the Coastal Plain. It is an evergreen that can reach a height of 40 to 60 feet and a spread of 80 to 100 feet at maturity.

Red Maple (Acer rubrum)

This tree species is native to eastern United States. It can range in size from 50 to 80 feet in height, with a spread of 40 to 60 feet. Tree shape is generally rounded but some cultivars are more upright. Red maples have medium green leaves with a powdery silver-white underside, and flower in the leaf axils during early spring. Fruit may be bright red to green. Young twigs are reddish and the bark of the tree is smooth and grey in color. The following cultivars are currently used:

- Bowhall Red Maple (Acer rubrum ‘Bowhall’) - It has an upright form with a symmetrical, narrow pyramidal head. Its leaves are yellow-red in the fall.
- October Glory Red Maple (Acer rubrum ‘October Glory’) - It is an oval-rounded tree with a mature height of 40 to 50 feet. Its leaves are red in the fall.
- Red Sunset Maple (Acer rubrum ‘Red Sunset’) - It has a pyramidal to rounded crown and grows to a mature height of 45 to 50 feet. Its leaves are bright red in the fall.

Pine (Pinus sp.)

Pines range in size from 40 to 120 feet tall at maturity depending on the species. Trees are usually pyramidal in form during young growth and develop a well rounded crown as they mature. Pines produce cones ranging from two inches to 12 inches in size. Their foliage consists of needles in various shades of green. Some of the most commonly used varieties are:

- Loblolly Pine (*Pinus taeda*) - Native to most of North Carolina, the loblolly pine can grow to a height of 120 feet. It has green needles in bundles of three.
- Eastern White Pine (*Pinus strobus*) - Native to the western one-third ofNorth Carolina, white pine may reach a mature height of more than 100 feet. It has a bluish-green foliage with five needles per bundle.
- Virginia Pine (*Pinus virginiana*) - Native to the western half of North Carolina, Virginia pine usually reaches a height of 50 feet or more. Foliage consists of three needles per bundle.
- Longleaf Pine (*Pinus pulustris*) - It grows very rapidly during young seeding stages and will reach a height of 80 feet at maturity. It produces very large cones and will develop a more rounded crown with age.

Flowering Dogwood (Comus florida)

This tree is native to the eastern United States and can be found throughout North Carolina. A small flowering tree, the dogwood takes on a broad crown shape and may reach a height of 20 to 30 feet at maturity. The dogwood produces a white or pink, four petaled-like flower during the early spring prior to leaf development. Foliage is bright green during the summer months and changes to a red to reddish-orange color during the fall. Dogwood fruit is bright red, oval shaped and borne in clusters. Commonly used cultivars are:

- Cloud 9 Flowering Dogwood (Comus *florida 'Cloud 9'*) - This excellent dogwood cultivar is similar in size and color to the native dogwood.
- Cherokee Chief Flowering Dogwood (*Comus florida 'Cherokee Chief'*) - This cultivar has dark pink flowers and matures to the size of native dogwoods.

Cherry (Prunus sp.)

Cherry trees vary in size depending on the cultivar. However, they are usually less than 30 feet in height and can have up to a 30 foot spread. The shape of the tree varies with variety but most are rounded. Some varieties are more spreading. Leaves are alternate on the stems and are generally not showy during the fall. The flowers are the most outstanding feature of this species. Flowering begins in the early spring and the blossoms are usually light pink to white. Cherry varieties used by the Department include the following:

- Okame Cherry (*Prunus okame*) - This is one of the earliest flowering varieties. It has pink flowers, matures at a height of 30 feet and has reddish colored bark.
- Kwanzan Japanese Flowering Cherry (*Prunus serrulata 'Kwanzan'*) - This tree grows to a height of approximately 30 feet and produces double pink flowers in the spring. Its growth habit is a vase or "V" shaped tree.
- Yoshino Cherry (Prunus x yedoensis) - This is a spreading tree that is capable of reaching a mature height of 40 feet. It produces nearly all white flowers during the spring months.

Crapemyrtle (Lagerstroemia sp.)

A native to Japan, crapemyrtle is widely used by the Department due to the large flowers it produces during the summer. The flowers may be white, pink, red, or lavender. It is an upright to rounded tree in shape and may reach a height of five to 40 feet at maturity depending on the cultivar. Its leaves are alternate on the stem and some varieties have attractive orange, yellow, and red fall colors. It produces large seed heads that mature after frost and may remain on the branches until early spring.

Commonly Used Crapemyrtle Cultivars

Common Name	Scientific Name	Mature Height	Flower Color
Victor	Lagerstroemia indica 'Victor'	5 feet	Red
Catawaba	Lagerstroemia indica 'Catawaba'	10 – 20 feet	Dark Purple
Regal Red	Lagerstroemia indica 'Regal Red'	10 – 20 feet	Dark Red
Tuskegee	Lagerstroemia indica 'Tuskegee'	10 – 20 feet	Dark Pink
William Toovey	Lagerstroemia indica 'William Toovey'	10 – 20 feet	Pink-Red
Carolina Beauty	Lagerstroemia indica 'Carolina Beauty'	10 – 20 feet	Brick Red
Potomac	Lagerstroemia indica 'Potomac'	20 – 30 feet	Clear Pink
Miami	Lagerstroemia indica 'Miami'	20 – 30 feet	Dark Pink
Muskogee	Lagerstroemia indica 'Muskogee'	20 – 30 feet	Light Lavendar
Natchez	Lagerstroemia indica 'Natchez'	20 – 30 feet	White
Tuscarora	Lagerstroemia indica 'Tuscarora'	20 – 30 feet	Dark Pink

Glossy Abelia (Abelia x grandiflora)

Glossy Abelia is an oval shaped shrub that can grow six to 10 feet tall and four to six feet wide. It is an upright shrub. The leaves are paired opposite on the stem. It has white to blush pink flowers during late spring and will continue to flower sporadically until the first frost. The most commonly used cultivars are:

- Sherwood Abelia (*Abelia x grandiflora 'Sherwood'*) - It has smaller leaves and it produces more dense growth than Glossy Abelia. Sherwood Abelia can occasionally produce off-shoots reverting to the larger Glossy Abelia.
- Edward Goucher Abelia (*Abelia 'Edward Goucher'*) - This is a hybrid between Abelia x grandiflora and Abelia schumannii. It produces showier flowers than 'Sherwood' but is less hardy.

Holly (Ilex sp.)

Hollies are known for their bright red berries. They may reach heights of four to 20 feet depending on the cultivar. Their shape may be a compact pyramidal tree or a somewhat rounded shrub. Flowers are small and yellowish-green in color, often not showy. The leaves are alternate on the stem and are very shiny. Some of the most often used cultivars are:

- Burford Holly (*Ilex cornuta 'Burfordi'*) - This is a very large holly which may reach a height of 12 to 20 feet. It has one spine at the tip of the leaf, and it will sometimes have an additional pair of spines.
- Dwarf Burford Holly (*Ilex cornuta 'Burfordi Nana'*) - This smaller holly grows slower but it may eventually reach a height of 10 feet.
- Carissa Holly (*Ilex cornuta 'Carissa'*) - This dense-growing shrub will reach three to four feet in height. It has one predominant spine at the tip of the leaf.
- Needlepoint Holly (*Ilex cornuta 'Needlepoint'*) - This is an upright holly that produces fruit. It matures at a height of eight feet. It has long narrow leaves with one spine at the tip.
- Rotunda Holly (*Ilex cornuta 'Rotunda'*) - This dense, spiny shrub will reach a height of three to four feet. Leaves have five to seven spines.
- Helleri Holly (*Ilex crenata 'Helleri'*) - This dwarf, mounded shrub is three to four feet tall. It produces dark green leaves one-half inch long.
- Dwarf Yaupon Holly (*Ilex vomitoria 'Nana'*)-This dwarf, mounded shrub grows three to five feet tall. It also produces small dark green leaves one-half inch long.

Chinese Juniper (Juniperus chinensis)

Junipers vary in size and habit. They can be upright plants growing 30 feet tall or ground covers spreading up to 15 feet. Leaves are usually scale-like on mature foliage and needle-like on young foliage. Cultivars most commonly used are:

- Nick's Compact Chinese Juniper (*Juniperus chinensis 'Nicks Compact'*) - It has a relatively flat-topped, wide-form with green foliage that has a slight blue overcast. Its foliage is more needle-like than scale-like.

- Sea Green Chinese Juniper (*Juniperus chinensis 'Sea Green'*) - This is a compact, spreading shrub with fountain-like arching branches and dark green to light green foliage. It can grow to a height of four to six feet and a width of six to eight feet.

Forsythia (Forsythia x intermedia)

A native of China, forsythia may grow from four to 10 feet tall depending upon the cultivar. Its growth habit may be upright or spreading. Forsythia produces bright yellow, bell-shaped flowers very early in the spring before its leaves appear. Its leaves are opposite on the stem and generally have coarsely toothed margins. Cultivars most commonly used are:

- Lynwood Gold Forsythia (*Forsythia x intermedia 'Lynwood Gold'*) - It has bright yellow flowers which generally spread up and down the stem and a more upright growth habit.
- Spring Glory Forsythia (*Forsythia x intermedia 'Spring Glory'*) - This shrub grows about six feet tall and has sulfur-yellow flowers.

Southern Waxmyrtle (Myrica cerifera)

Waxmyrtle is an upright evergreen to semi-evergreen shrub that is native to North Carolina. It ranges in height from five to 12 feet and tends to form large colonies due to its suckering characteristics. It has small yellow flowers and grayish-white fruit with a waxy coating. It has dark green leaves that alternate on the stem and are aromatic when crushed.

Eastern Redbud (Cercis canadensis)

Prized for their 'heart-shaped' leaves and purple spring flowers, the eastern redbud is a fast growing tree. It is one of the first trees to bloom in the spring and is a true legume producing seed pods 2-3 inches long in late summer. The cultivar used by the Department is 'Forest Pansy'. In addition to the above characteristics, Forest Pansy is characterized by burgundy colored leaves. The pink blooms in the photo are eastern redbuds.

Southern Magnolia (Magnolia grandiflora)

Southern Magnolia is a stately tree reaching heights of 60-80 feet with a spread of 30-40 feet. Summer flowers are very fragrant and can reach 8-12 inches in diameter. During autumn, magnolias produce red fruit in cone-shaped structures. Cultivars: ‘D. D. Blanchard’, ‘Little Gem’, and ‘Bracken’s Brown Beauty’ are most often used by the Department. Southern magnolias require space to grow, Southern Magnolia is a broadleaf, evergreen tree.

Daylily (Hemerocallis sp.)

The daylily is a perennial, semi-evergreen plant that grows in clumps. It has grass-like foliage that grows about two feet tall and it flowers from May to September, depending on the cultivar. The flowers, on stalks above the leaves, range in color from red, orange, yellow, pink or purple and they can be two to seven inches in diameter.

The daylily is used as a ground cover, for naturalizing, as a fire buffer, and for erosion control. It is tolerant of salt and of extremely dry or wet conditions. It has no significant insect or disease problems. Some cultivars commonly used are:

- Orange Vols
- ‘Mary Todd’
- ‘Butter Popcorn’
- ‘Hyperion’
- Mauna Loa

Ornamental Grasses

Large swaths of ornamental grasses adorn North Carolina roadsides. These perennial, clump-forming, upright plants add texture to roadside settings.

- Northern Sea Oats (Chasmanthium latifolium). Northern Sea Oats is a clumping, deciduous grass. It has showy, drooping flowers and rich bamboo-like foliage. Its stems are 2 to 3 feet tall. Its foliage changes from green in the spring to copper in fall to brown in winter. Its salt tolerance makes it a dependable choice for coastal gardens.
- Muhly Grass (Muhlenbergia capillaris). This mound forming grass is typically less than 2 feet tall and is characterized by spine-like leaves. It’s known for its fall color of purple to pink and white seed heads.
- Switch Grass (Panicum virgatum). Switch grass is a warm-season, clump forming grass. Among the varieties used by the Department are: ‘Cloud Nine’, ‘Heavy Metal’, and ‘Shenandoah’.
- Little Bluestem (Schizachyrium scoparium). This warm-season clump forming grass is found throughout the eastern United States. It is generally recognized as an American Tallgrass prairie grass that can grow 2 -5 feet tall.

Wildflowers

The wildflower program in North Carolina originally began in the early 1960's with little success. The program was revitalized in 1985. Today, wildflowers are a tremendous success with approximately 1,500 acres planted statewide. They give much needed visual biodiversity for the traveling public.

Wildflower beds are typically established along the larger, wider margins of major interstate highways, and along US and North Carolina highways. These areas have more exposure to traffic and a sufficient area of right of way to accommodate beds of a half acre to 10 acres or more in size. In other cases, small plots of wildflowers may also be used in conjunction with formal landscape plantings.

The NCDOT utilizes both annual and perennial species. A mixture of annuals and perennials is preferred when trying to establish a permanent wildflower bed. The annuals are used to provide flowers the first year while the perennials are becoming established. Annuals may also be used by themselves to achieve seasonal color in the spring or fall with a single species or in a mixture. Double cropping or sod seeding can be performed to extend the length of bloom or to add color to a wildflower bed. For example, red corn poppy can be sod-seeded into Shasta daisy to create an earlier bloom of red that intermingles with the white Shasta daisy.

Ongoing research involving geographic adaptability, soil fertility and plant compatibility are being conducted by North Carolina State University and the NCDOT to continue the improvement of the cultural practices used for current and potential wildflower species. Approval is obtained from the North Carolina Department of Agriculture and Customer Services before any species is planted on the rights-of-way. North Carolina State University is also consulted to insure that the NCDOT does not introduce a potential weed pest.

The majority of the seed planted comes from commercial sources. Seed is readily available and is usually good to excellent quality. As with turfgrass establishment, the utilization of good quality seed is essential for the success of wildflower establishment. Some native wildflower species are not commercially available and are harvested by the NCDOT to be used in the program. Native wildflowers that occur naturally within the rights-of-way are also utilized. The Department endeavors to reduce mowing and alternate mowing patterns during the bloom season to encourage these native species to become established.

The following is a partial list of wildflower species utilized by the NCDOT.

Annuals

Toadflax (Linaria maroccana) ■ Height: 1 to 2 feet ■ Bloom: Bicolors of yellow, pink, red, white, and purple flowers, March thru May ■ Culture: Full sun or partial shade; tolerates moist soil and drought conditions ■ Miscellaneous: Not winter hardy; poor germination if planted too deep	
Corn Poppy (Papaver rhoeas) ■ Height: 2 to 2 1/2 feet ■ Bloom: Red, pink, or white flowers, April thru July ■ Culture: Full sun or partial shade; prefers well drained soils; drought tolerant ■ Miscellaneous: Does not contain opium; must specify color when purchasing seed	
California Poppy (Eschscholzia californica) ■ Height: 12 to 18 inches ■ Bloom: Orange flowers, spring thru summer ■ Culture: Full sun; drought tolerant ■ Miscellaneous: Very adaptable; flowers close on cloudy days and at night; does not contain opium	

Annuals

Cosmos (Cosmos bipinnatus)

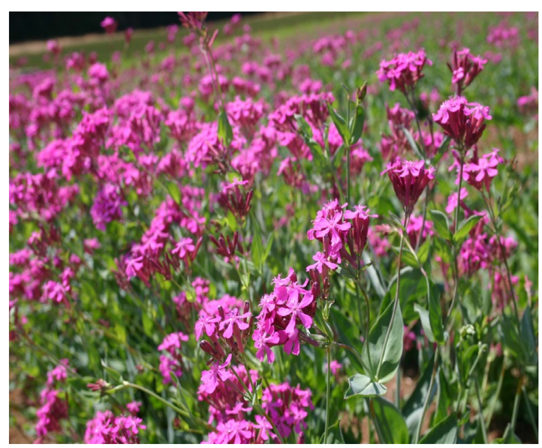
- Height: 3 to 5 feet
- Bloom: Pink, white or reddish-burgundy flowers, June until frost
- Culture: Full sun or partial shade; prefers less fertile soils; drought tolerant
- Miscellaneous: Not winter hardy; should be planted in the summer for a full bloom

Sulphur Cosmos (Cosmos sulphureus)

- Height: 3 to 5 feet
- Bloom: Yellow or mix of yellow, orange and red flowers, June until frost
- Culture: Full sun; prefers sandy, well drained soils; drought tolerant
- Miscellaneous: Not winter hardy; should be planted in spring or summer

Catchfly (Silene armeria)

- Height: 1 to 2 feet
- Bloom: Pink flowers, May to August
- Culture: Full sun or partial shade; prefers clayey soils; tolerates low to moderate moisture
- Miscellaneous: Easy to grow; stem exudes sticky sap which traps insects



Annuals

Calliopsis (Coreopsis tinctoria) ■ Height: 3 feet ■ Bloom: Yellow flowers with maroon centers, May thru August ■ Culture: Full sun or partial shade; prefers sterile soils; requires low moisture ■ Miscellaneous: Prolific bloomer; competes well with grasses; readily reseeds	

Perennials

Ox-Eyed Daisy (Chrysanthemum leucanthemum) ■ Height: 1 to 2 feet ■ Bloom: White flowers with yellow centers, April thru July ■ Culture: Full sun; prefers moderate water and sandy soil ■ Miscellaneous: Attracts birds and butterflies; excellent cut flower	
Lance-Leaved Coreopsis (Coreopsis lanceolata) ■ Height: 3 feet ■ Bloom: Yellow flowers, April thru July ■ Culture: Full sun or partial shade; adapts well to most soil types; very drought tolerant ■ Miscellaneous: Can withstand long periods of wetness; reseeds readily	

Perennials

Purple Coneflower (Echinacea purpurea) ■ Height: 2 to 3 feet ■ Bloom: Purple flowers, May thru August ■ Culture: Full sun; does well on wide range of soil types; very drought tolerant ■ Miscellaneous: Excellent cut flower; prefers relatively high pH	
Dame's Rocket (Hesperis matronalis) ■ Height: 1 to 4 feet ■ Bloom: Violet flowers, May thru August ■ Culture: Full sun or partial shade; prefers well drained soils that are moist to moderately wet ■ Miscellaneous: Excellent cut flower with a sweet fragrance	
Black-Eyed Susan (Rudbeckia hirta) ■ Height: 2 to 3 feet ■ Bloom: Yellow-orange flowers with brown centers, May thru August ■ Culture: Full sun or partial shade; does well on all soils with low to moderate moisture ■ Miscellaneous: Very low maintenance	

Perennials

Narrow-Leaved Sunflower (Helianthus angustifolius) ■ Height: 3 to 6 feet ■ Bloom: Yellow flowers, August until frost ■ Culture: Full sun; prefers loamy soil conditions; can tolerate wet conditions ■ Miscellaneous: Not commercially available; harvested by North Carolina Department of Transportation	
Bur-marigold (Bidens aristosa) ■ Height: 1 to 5 feet ■ Bloom: Yellow flowers, August until frost ■ Culture: Full sun to open shade; prefers loamy soil; moderate to high moisture ■ Miscellaneous: Not commercially available; harvested by North Carolina Department of Transportation	

Other Vegetation Types

The NCDOT utilizes several plant types which are not categorized as turfgrasses, ornamental plants or wildflowers. These various plants and their uses are described below.

Temporary Ground Covers

Sweet Sudan Grass (*Sorghum Saccharum*) - Sudan grass is used for temporary seeding during the summer months in the eastern one-third of North Carolina. It is an annual grass with excellent drought tolerance and an aggressive fibrous root system with good soil-holding characteristics. It will grow in almost any soil and thrives in semi-arid regions.

German Millet (*Setaria italica var. Stramineofructa*) and Browntop Millet (Panicum ramosum) - Millets are members of the grass family. The millet species used by the NCDOT are adapted to hot, dry weather and infertile soil conditions. They are used statewide as temporary ground covers during the summer months. They grow rapidly and range in height from I to 4 feet. They are sometimes included by the NCDOT as supplements to permanent seed mixes.

Rye (*Secale cereale*) - Rye is a grain used for temporary seeding statewide during the cooler months of the year (October - April). It is a member of the grass family and used as a temporary ground cover due to its fibrous roots and ability to grow well in infertile soils.

Nurse Plant Species

Kobe Lespedeza (*Lespedeza striata var. 'Kobe'*) and Korean Lespedeza (Lespedeza stipulacea) - These lespedezas are annual plants used as supplements in permanent seed mixtures. They germinate very quickly and produce rapid growth. They provide soil stability and protection for slower germinating turfgrass species. Kobe and Korean Lespedeza will reseed themselves for years if not mown. They are well adapted to poor, acidic soils.

Perennial Ground Covers

Sericea Lespedeza (*Lespedeza cuneata 'Dumont'*) - Sericea Lespedeza is a perennial legume used widely as a cover crop on poor soils. Its fibrous root system and good soil-holding characteristics make it particularly effective as a ground cover on highway cut-slopes. It grows to a height of three feet, is well adapted to heavy soils, and is essentially weed free.

Crown Vetch (*Coronilla varia*) - Crown Vetch is useful for stabilizing rocky, steep slopes and highway cuts. It spreads by creeping stems and forms a dense cover about two feet tall. It prefers neutral soils but tolerates slightly acidic conditions. Once established, crown vetch provides an attractive cover and prevents erosion while requiring very little maintenance.

Summary

The NCDOT utilizes many types of vegetation to encourage roadside biodiversity. The vegetation types selected for a given site are chosen based on many factors, including purpose and the site environment. Many individual species are available within each type of vegetation. The characteristics and limitations of the site are important factors in determining appropriate plant selection.

The three major types of vegetation utilized by the NCDOT are turfgrasses, ornamental plants and wildflowers. In addition to these, nurse plant species and temporary and perennial ground covers are used in the NCDOT's vegetation management program.

REFERENCES

Martin, James, Joyendu Bhadury, and Brittany V. Gaustad, 2017. Economic Analysis of Vegetation Management Practices. For North Carolina Department of Transportation. Number FHWA/NC/20016-17.

Introduction

In This Chapter . . .

Establishment of:

- *Turfgrasses*
- *Ornamental Plants*
- *Wildflowers*
- *NCDOT Applications*

Timely, successful vegetative establishment is necessary for erosion and sediment control on NCDOT highway roadsides. Whether the vegetation types are turfgrasses, ornamentals, or wildflowers, executing the proper steps in establishment reduces the time and expense required to achieve an acceptable level of plant quality and soil stabilization. This chapter covers the basic tasks associated with establishing various vegetation types on highway rights-of-way including: medians, shoulders, slopes, ditches, and other roadside areas.

Rapid establishment of vegetative coverage after construction is required

Establishing enduring vegetation requires adherence to certain guidelines or steps in order to obtain the desired results. This is true whether establishing turfgrasses, ornamental plantings, trees, or wildflowers. The generally accepted steps for establishment of these types of vegetation are described below.

Turfgrasses

Soil Preparation

Proper seedbed preparation is perhaps the most critical step in the development of vegetative cover because the effectiveness of the succeeding steps depends on the quality of the seedbed. The seedbed is the place where seeds germinate and eventually develop into mature stands. It provides the medium for the resulting plants to take up water and nutrients through their roots. This prepared soil layer allows movement of water, air, and plant nutrients in establishing a favorable biological, chemical, and physical environment for good plant growth. The primary objective of soil preparation is to produce a zone conducive to the development of excellent plant roots and optimum plant growth. The steps in soil preparation are: control of perennial weed pests; removal of rocks and debris; grading; soil modification; and application of fertilizer and lime.

Control of noxious or pestiferous weeds such as kudzu, johnsongrass, and nutsedge should be undertaken as the first step in soil preparation. These weed pests have extensive root and stem systems that can easily invade, proliferate, and overtake desirable vegetation. Careful planning and selective herbicide applications are tools which can be used in dealing with undesirable, persistent weedy species (Chapter 7).

Another step in soil preparation is the removal of roots, rocks, trash, and other debris. All rock and foreign debris three inches or larger should be removed from medians and shoulders, and from ditch cut or fill slopes that have a 3:1 or flatter gradient.

The disturbed area should be graded to provide for removal of excess water during rain events and provide positive drainage for ditch line flow. It should be free of low areas or depressions that collect water. Where possible, topsoil should be removed prior to grading and redistributed over the site after grading and prior to seedbed preparation. This treatment is generally reserved for highly visible areas such as rest areas, roadside parks, and on locations prone to severe erosion.

Assessment of soil fertility and correction of nutrient deficiencies are critical to good vegetative establishment. This is determined from the results of a soil test (Chapter 3). As a general rule, most areas within North Carolina require lime to adjust soil acidity and fertilizer to provide nutrients.

These amendments, tilled into the upper four to five inches of soil, are necessary to ensure healthy turfgrass development in the often adverse and compacted subsoils that characterize many roadway sections. **Table 5.1** gives recommended fertilizer and lime rates for establishing turfgrasses.

Table 5.1: Suggested Establishment Fertilization and Liming Rates for Turfgrasses

(NCSU)				
Turf	**Fertilizer Analysis**	**# of Fert. per acre**	**# Limestone per acre**	**# N per acre**
Centipedegrass	16-4-8	100 – 140	0	15 – 25
All Others	16-4-8	250 – 300	3300	40 – 50
(NCDA & CS)				
Turf	**Fertilizer Analysis**	**# of Fert. per acre**	**# Limestone per acre**	**# N per acre**
All Types	10-20-20	400 – 600	2800 – 3300	40 - 60

The ideal medium for planting is a moist, loamy, granular, friable soil that is free of stones and foreign debris. The soil should be scarified to a depth of about five inches. All clods should be broken and the top two to three inches of soil worked to an acceptable seedbed by the use of a pulverizer, drag, or harrow. Soil scarification adjacent to the edge of pavement should be minimized to avoid disturbance of paved areas. Steep 2:1 cut slopes must be grooved, trenched, or punctured to provide pockets, ridges, or trenches in which seeding materials can lodge. Extreme care must be exercised in seeding operations on shoulders and slopes of ditches to maintain the graded cross section that existed before seeding operations began. In order to prevent compaction, soil preparation should be avoided when soils are frozen, extremely wet, or when other unfavorable working conditions prevail.

Seed Establishment

Seeding

The primary factors affecting turfgrass establishment from seed are the planting procedures, mulching, and maintenance. This assumes adequate soil preparation, selection of the appropriate species or mixture, and obtaining high quality seed.

Specific factors to consider in developing a series of planting procedures include time, rate, placement and equipment selection.

Since disturbed areas must be stabilized within a specified time frame to meet statutory requirements, temporary and permanent seeding occurs throughout the year. North Carolina Administrative Code, Title 15A, Chapter 4B.0107b, states that, to stop erosion, sufficient ground cover must be established within 15 working days or 90 calendar days following the completion of construction. More stringent statutes relate to High Quality Water areas (15A NCAC 04B .0124(e)) which require vegetation establishment within 15 working days or 60 calendar days. Various seed mixtures and application rates address various species that will germinate and become established regardless of the calendar date. Of course, favorable environmental conditions promote desirable results. Most seeds are placed at a fairly shallow depth and cultipacked to provide good seed-to-soil contact. North Carolina's General Permit for Construction Activities (NCG010000) requires quicker seeding times.

Various types of implements can be used to apply seed. The most common seeders in Piedmont and Coastal Plain areas are the rotary or broadcast spreader, and the seed drill. Many mountainous areas use hydroseeders exclusively. Nonetheless, all seed should be applied carefully to provide uniform distribution.

Mulching

Mulching is one of the most important practices in ensuring uniform, rapid turfgrass germination and establishment. There are several benefits for mulching in connection with seeding. Mulch helps prevent erosion on newly prepared and seeded areas by reducing the impact a raindrop when it hits the soil. Mulch also conserves moisture, promotes germination, and enhances growth of grass seedlings.

Grain straw is the most commonly used mulch for turfgrass seed establishment, although wood mulches and erosion control blankets (such as straw and excelsior) are alternatives. Baled grain straw is clean, easily handled, low priced, and is usually more adaptable for application by mechanical mulching equipment. There is no constant ratio between the weight and thickness of vegetative mulch. A guide for applying mulch is that a layer of mulch should provide a minimum of 80 percent coverage, or essentially cover the ground from sight.

Tacking

Mulch must be anchored or tied together in a manner that will prevent it from being blown by the wind or moved by other forces. This is accomplished by applying an asphalt emulsion that binds the mulch particles together, a procedure called *tacking*. Tacking should be performed during or immediately following application of mulch.

Emulsified grades of asphalt containing excessive amounts of water are not satisfactory and do not anchor mulch properly. This may necessitate replacing both straw and asphalt if good binding does not occur. A proper asphalt application should be uniform and black in appearance. A brown asphalt color indicates that the asphalt is too diluted.

Disking the straw lightly into the soil (crimping) is an alternate method of holding straw in place. This works well on flat, sandy sites.

Hydraulic tackifiers (binding agents which may be applied with a hydro-seeder) may also be used to bind straw and should be applied according to the manufacturer's suggested application rates.

The teal coating is a hydraulic tackifier

Vegetative Establishment

There are three types of vegetative establishment: sodding, sprigging, and plugging.

Sodding

Sodding is a method of vegetative establishment where a mature turf is transplanted onto a new site to provide immediate stabilization.

Extreme care should be taken when transplanting sod to prevent it from becoming too dry. Ideally, sod should be installed within 24 hours after it has been harvested. Temporary storage is permissible during fall and winter months provided the sod is kept in a shaded area. Ideally, temporary storage should not last for more than three days.

The sod for clump or bunch-type grasses (e.g., tall fescue) must be grown with netting to hold the sod together. Most of the spreading grasses (e.g., bermuda and centipede) are held together by their rhizomes and/or stolons and generally do not require netting.

Soil preparation for sodding should be similar to that for seeding. The area to be sodded should be brought to a firm uniform surface at such elevation that the surface after sodding will conform to the finished grade of the roadway typical section. Then, if dry conditions prevail, the finished surface may be moistened with water prior to installing the sod. To reduce the demand for supplemental irrigation, dormant warm-season sod can be installed.

Sod can be transplanted at any time during the year, provided adequate moisture can be maintained. Of course, frozen or extremely wet conditions may prohibit sod installation. Sod can be installed by hand or by mechanical means. Each piece of sod must be packed tightly against the edge of adjacent pieces to reduce dessication. Gaps between sod should be avoided. Sod is always installed with the long edge vertical to the slope and in a staggered joint pattern. Where sod is placed on steep roadway slopes, it should be stabilized with 1" x 1" x 12" wooden stakes or U-shaped sod pins driven flush with the sod. After the sod is placed and staked, it should be tamped or rolled to ensure good sod-soil contact.

Once the sod installation is finished, irrigation or watering should be done to thoroughly moisten the soil to a depth of six to eight inches. Subsequently, unless there is appreciable rainfall, the sodded area should be watered sufficiently on a daily basis until the sod becomes established and self-sustaining.

Sprigging

Sprigging involves planting stolons and/or rhizomes in furrows or small holes. This method of vegetative establishment does not involve transporting soil with the vegetation.

Soil preparation for sprigging should be the same as that for seeding. Great care must be taken to keep sprigs cool and well moistened while in transit to the project site and prior to installation. Always ensure that sprigs are protected from drying when kept in temporary storage.

Planting of sprigs can be accomplished by a mechanical planter, a broadcast spreader, or by hand. Typically, a furrow is made and the sprigs inserted at a depth of one to two inches in the soil. Soil is then pushed over the sprigs and firmed. In sandy soils, sprigs may also be broadcast over the area to be planted and then forced into the soil with a crimper, straight spade, or straight-bladed disc harrow. Immediate watering after planting is crucial. Watering should continue until the sprigs become well established.

Transplanting/Plugging

Transplanting utilizes bare root plant material or plugs (small patches of grasses or other herbaceous plants) to establish a site. The plants may come from nursery-grown stock or they may be collected specimens. Transplanting is performed with a mechanical planter or by hand. Transplanting is frequently used to establish coastal grasses on steep slopes or dunes and to establish wetland mitigation vegetation.

Soil preparation for transplanting should be the same as noted for turfgrass seeding establishment with the exception of the soil amendments. Typically, once a hole is made, slow release fertilizer is placed in the plant hole, and the plant is inserted to the proper depth into the soil. The hole is closed and firmed with soil. Great care must be taken to keep transplants well moistened and protected while in transit to the project site and prior to transplanting. Always ensure that plant material is protected from drying when kept in temporary storage. Watering is needed within 30 minutes after planting if the soil is dry. In many wetland sites, ground water or tidal water will be adequate; thus, watering may not be needed.

Ornamental Plants

Soil Preparation

After removing existing undesirable vegetation, the next objective is to perform adequates oil tillage. All plant beds should be tilled to a depth of at least five to eight inches. Several implements are used to accomplish this objective, e.g., chisel plow, disc, and rotovator. After completion of the soil tillage operation, there should not be any remaining clods larger than one inch in diameter.

Use preemergence and postemergence herbicides to remove weeds and unwanted grasses from the plant bed areas. Postemergence herbicides are applied once the weeds and grasses are actively growing and when the desired species are not under stress. To ensure product effectiveness, the herbicides should not be applied when rain is likely within six hours of application. There are three steps in an effective herbicide program for plant beds: (1) Apply a postemergence herbicide to control mature weeds and grasses where the plant bed is to be located; (2) Allow approximately seven days for the herbicide to effectively control weeds. After seven days, the soil should be thoroughly tilled to a depth of five to six inches, as previously discussed in the soil preparation section of this chapter. After the plant bed is leveled to the proper elevation and planted, a preemergence herbicide is applied to maintain a weed-free site.

Planting of Trees and Shrubs

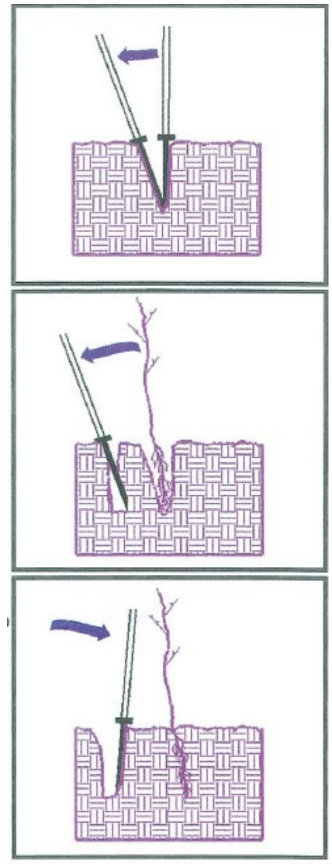
Planting is initiated as soon as possible after soil preparation is completed. The optimum planting time for plant material is in the fall and winter months (October 15 to March 31) when most horticultural materials are dormant. The planting process includes the addition of fertilizer and water at the time of planting. The recommended fertilization of ornamentals at establishment is indicated in **Table 5.2**.

Table 5.2: Fertilization for Establishment of Ornamental Plants (NCSU)

Fertilizer Ratio (N: P_2O_5: K_2O)	# N per 1000 square feet
1 : 2 : 1	1.0

The installation of ball and burlap, bare root, and containerized trees involves several important steps to insure tree survival. These steps range from the actual excavation of the hole to the backfilling, mulching, and guying of the tree. First, a hole should be excavated approximately twice as wide as the root ball and to the depth of the root ball. Fertilizer should be placed in the plant hole before the tree is placed. The fertilizer should be slow release pellets or tablets and should be applied according to the manufacturer's recommendations. By using slow release fertilizers, the nutrients contained in the fertilizer are released gradually over time to provide maximum benefit to the tree. Next, the tree should be placed into the hole such that one-eighth of the root ball is above the ground elevation. The hole should then be backfilled with the previously excavated soil, compacting it as it is backfilled to remove all air pockets. Once the hole is backfilled, a ring of compacted soil (*water ring*), approximately six inches high should be constructed around the base of the tree. The ring should be three to five feet in diameter. Approximately four inches of mulch should then be applied within the water ring. Finally, trees which are greater than six feet in height should be staked and guyed using 1 ¾" x 1 ¾" stakes, 18 to 24" long, and 14 gauge steel wire guys as required to stabilize the tree. Water should then be applied to soak the entire root system. Additional watering should be provided at least once every five days during dry conditions until the trees are established.

Bare root seedlings are often used on wetland hardwood mitigation projects. The two main tools needed to install bare root seedlings are a *planting bag and planting bar* (*or dibble*). The planting bag is a moist canvas bag used during the planting process to prevent the root systems of the seedlings from drying. The dibble is an instrument with a triangular blade 12 inches long, four inches wide, and one inch thick, which is used to dig the hole for planting the seedlings. The following guidelines should be used to install bare root seedlings: (1) Insert a dibble into the soil to a depth of approximately 10 to 12 inches and pull the handle toward the operator. (2) Remove the dibble and insert the seedling into the hole. Be sure the roots of the seedling are enclosed in the hole. It is often necessary to prune the roots of the seedlings so that no roots extend more than ten inches below the root collar. (3) Insert the dibble approximately two inches behind the seedling to create a second hole. The dibble is inserted deep enough to close the bottom of the initial hole containing the seedling and to firm the soil around the roots of the seedling. Care should be taken to eliminate air pockets around the seedling roots. (4) While the dibble remains in hole, push the handle of the bar forward toward the seedling to firm the soil at the top of the root zone. This second hole, called the *compaction hole*, is left open after planting to allow for a water retention area for the seedling roots. Bare root seedlings are generally planted six to ten feet apart. The seedlings are typically planted at a density of 680 plants per acre.


Planting bare root seedlings

Wildflowers

Site Selection

Site selection is the first step in establishing wildflowers. It is desirable to select large sites that can be easily seen by passing motorists. Selecting areas larger than one acre saves time and expense by reducing the number of equipment loadings and the traveling time to varied work sites. Another consideration is to select sites that are easily accessible by tractors and equipment. Highly erodible and poorly drained sites are usually undesirable locations for establishment of wildflowers.

Soil Preparation

The selected sites should be treated with a non-selective systemic or contact herbicide to eliminate existing vegetative growth. The next step is to obtain soil samples to determine nutrient and acidity levels for potential sites. One should also determine if organic materials are needed to improve soil structure in clayey and sandy soils commonly found in roadside situations. Excessive rates of uncomposted materials should be avoided as they tend to make nitrogen fertilizers unavailable to the wildflower seedlings. Application of composted materials for large sites can be accomplished with truck-mounted bulk spreaders or conventional tractor-driven manure spreaders (Chapter 3).

Fertilizer and lime, if necessary, should be applied according to the recommendations given on the soil test report. Equipment used to accomplish these tasks include a farm-type tractor with broadcast spreader or truck-mounted bulk applicator.

After all needed amendments are applied, a good pulverized seed bed five to six inches deep is formed using a chisel plow, disc, and rotovator. This process also incorporates existing residual vegetative cover into the soil.

Next, wildflowers suitable for the geographic area are selected. Some wildflowers are adapted to cool climates while others perform better in warmer climates. Also, different species are suited to different types of soils. Another important point to remember is that most perennial species start to bloom the second year after planting, so it is advisable to add annuals to the initial seed mix to achieve a first year bloom.

Seeds and fertilizer can be applied using a hydroseeder, broadcast spreader, or cyclone-type seeder. It is important that seeds and fertilizer be distributed uniformly across the entire site to achieve optimum results. The seeds are lightly covered with a drag harrow or pea-weeder and this procedure is followed by a cultipacking or rolling to firm the soil. Caution should be observed to prevent seeds from being planted too deeply. To achieve optimum germination, the seed depth should not exceed 1/4 inch below the soil surface.

After beds have been seeded and cultipacked, a light layer of coastal bermuda hay or pine straw (approximately 1 ton per acre) may be applied. Mulch conserves moisture, protects small plants, and also prevents newly seeded beds from eroding after heavy rains. Mechanical mulch spreaders are available to apply mulch to large roadside beds.

NCDOT Applications

The policies of NCDOT on the control of erosion are in compliance with the North Carolina Administrative Code. The NCDOT “Standard Specifications for Roads and Structures” Section 107-12(A) states “Following completion of any construction phase or operation, on any graded slope or area greater, the Contractor shall provide ground cover sufficient to restrain erosion within 21 calendar days or within a time period specified by the NCG010000 Construction Permit.”

There are many ways to establish a vegetative cover, depending largely upon the types of vegetation desired. For turf areas alone, one must decide between seeding, sodding, sprigging, or plugging. Ornamental plantings are usually accomplished by planting cuttings, seedlings, balled & burlap or containerized plant material, or by transplanting larger stock. Wildflowers, like many turf areas, are established by seeding.

NCDOT utilizes proven methods of obtaining proper soil bed preparation, applying soil amendments, and establishing vegetative cover, which are very successful as a result of many years of experience.

Turfgrasses

NCDOT utilizes two main types of turfgrass seed mixes, cool-season and warm-season. The choice of seed mixes is based on the location in the state where the seed is to be planted (**Figure 5.1**). As a general rule, a cool season mix is used throughout the majority of the Mountain region and approximately one half of the Piedmont region. A warm season mix is used in the Coastal Plain region and the remainder of the Piedmont region. The seeding rates and dates for seeding are shown in **Table 5.3**. All seed used on NCDOT roadsides is tested and approved by NCDA&CS and logged by NCDOT's Materials and Test Unit. Seed purity and germination are the criteria used in testing. NCDA&CS standards govern the limitations for these criteria. Seed is then randomly tested to ensure compliance as referenced on the seed label.

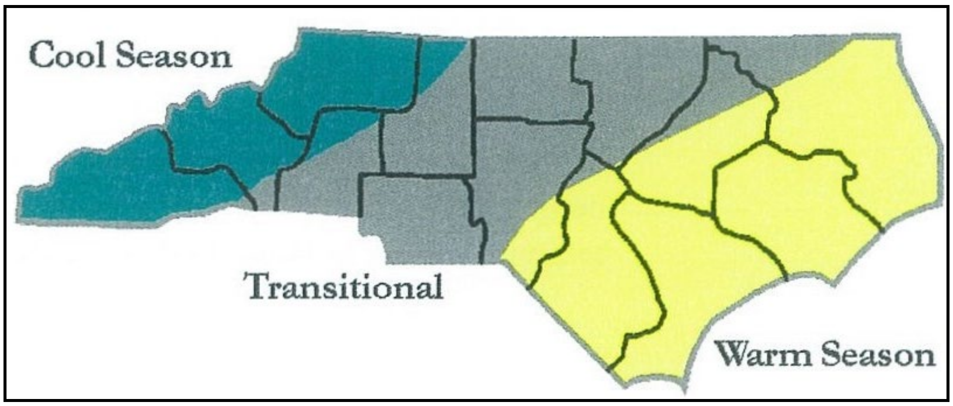


Figure 5.1: Turfgrass Zones in North Carolina

Table 5.3: Seeding Rates and Dates for Cool-and Warm-Season Grasses in North Carolina

Cool Season			
September 1 – April 30		**May 1 – August 31**	
25 #/acre	Rye Grain	20 #/acre	Kentucky Bluegrass
20 #/acre	Kentucky Bluegrass	75 #/acre	Hard Fescue
75 #/acre	Hard Fescue	10 #/acre	German or Browntop Millet
Warm Season			
September 1 – February 28		**March 1– August 31**	
50 #/acre	Kentucky 31 Tall Fescue	50 #/acre	Kentucky 31 Tall Fescue
10 #/acre	Centipede	10 #/acre	Centipede
35 #/acre	Bermuda (unhulled)	25 #/acre	Bermuda (hulled)

Fertilizer and lime are applied at the time of seeding. The actual fertilization and liming application rates used at planting by the NCDOT are shown in **Table 5.4**.

Table 5.4: NCDOT Fertilization and Liming Rates for Establishing Turfgrasses

Turf	Fertilizer Analysis	# of Fert. per acre	# Limestone per acre	# N per acre
All Seed Mixes	10 – 20 – 20	500	4000	50

Note: Although it may appear that NCDOT is applying higher than NCSU recommended rates of fertilizer at time of establishment, the NCSU recommendations are based on a home lawn situation. These sites typically have organic matter and topsoil from which to establish turf. In addition, as noted in Chapter 6, NCSU recommends multi-month fertilizer applications for residential lawns. NCDOT performs only one application at time of seeding. NCDA&CS recommendations are based on years of data collection and analysis of roadside soil samples, and the applications are consistent with soil test information.

Sodding

NCDOT utilizes sodding where an instant cover is needed to stabilize disturbed areas. Typical uses on highway projects include steep slopes on bridge approaches, areas under guardrail, and other areas where quick establishment of turfgrasses is a necessity.

Sprigging

NCDOT infrequently utilizes sprigging to permanently stabilize areas by planting stolons and rhizomes instead of seed or sod. It is mainly used to establish vegetation which may not be available by seed or is very slow to establish by the normal seeding processes. In 2017, NCDOT began sprigging zoysia beside guardrails in experimental plots. Sprigging will allow NCDOT to vegetatively expand its use of zoysia at a reduced cost compared to sodding.

Transplanting/Plugging

NCDOT utilizes transplanting instead of seed or plants where the aim is to permanently stabilize or colonize areas by planting nursery stock or collected bare root transplants. It is mainly used to establish vegetation on coastal dune and wetland areas (**Table 5.5**). Transplanting is a common practice on shoulders and slopes of roadways within coastal counties and within marsh-type wetland mitigation sites.

Table 5.5: Types of Vegetation Transplanted by NCDOT

Coastal (Dune) Plants	Wetland Plants
American Beachgrass (*Ammophila breviligulata*)	Smooth Cordrass (*Spartina alterniflora*)
Sea Oats (*Uniola paniculata*)	Saltmeadow Cordgrass (*Spartina patens*)
	Black Needlerush (*Juncus roemerianus*)
	Common Rush (*Juncus effusus*)
	Bulrush (*Scirpus sp.*)
	Sawgrass (*Cladium jamaicense*)
	Tall Cordgrass (*Spartina cynosuroides*)

Ornamental Plants

Design and Stakeout of Landscape Planting Projects

Once a landscape planting plan is designed, the first objective of field personnel is to make the plan fit the natural topography as close as possible under actual field conditions. During this phase, individual plants and plant bed areas are measured and marked according to the planting plan. Wires with plastic flags are typically installed to designate individual plants in major planting areas. Plastic flags are color coded to represent various types of plant material. For example, white flags are used for deciduous trees, red flags for evergreen trees, yellow flags for flowering trees, and green flags for shrubs. Parameters that must be considered while staking out a landscape planting design include: safety set-backs, sight distances, effects on mowing and drainage, utility lines, and soil conditions in the plant root zone.

NCDOT has developed guidelines governing the set-back distances of trees and shrubs that are planted on highway rights-of-way. **Table 5.6** lists the minimum safety set-back distances for curb/gutter sections and shoulder/ditch sections, which are dependent on the posted speed limit along the proposed planting route.

Table 5.6: Minimum Set-Back Distances for Various Posted Speed Limits

Section	35 mph or less	35 mph – 45 mph	45 mph or more
Curb/Gutter Section			
Large Tree	10’	15’	25’
Small Tree/Large Shrub	5’	8’	20’
Small Shrub	1’ to foliage line	6’ to foliage line	10’ to foliage line
Shoulder/Ditch Section			
Large Tree	12’	20’	30’
Small Tree/Large Shrub	8’	10’	20’
Small Shrub	6’ to foliage line	8’ to foliage line	15’ to foliage line

Sight distances are another important consideration during the stake out phase. Plants are selected based on height at maturity. Shrubs must be kept low, while trees and large shrubs must be selected that will permit clear sight distances between two and six feet above the roadway elevations. Pruning may be required. Proper pruning cuts are illustrated in **Figure 5.2**. Care must be taken not to plant any material on the highway rights-of-way which will interfere with sight distances, vehicular or pedestrian traffic, or the natural flow of water off of the site.

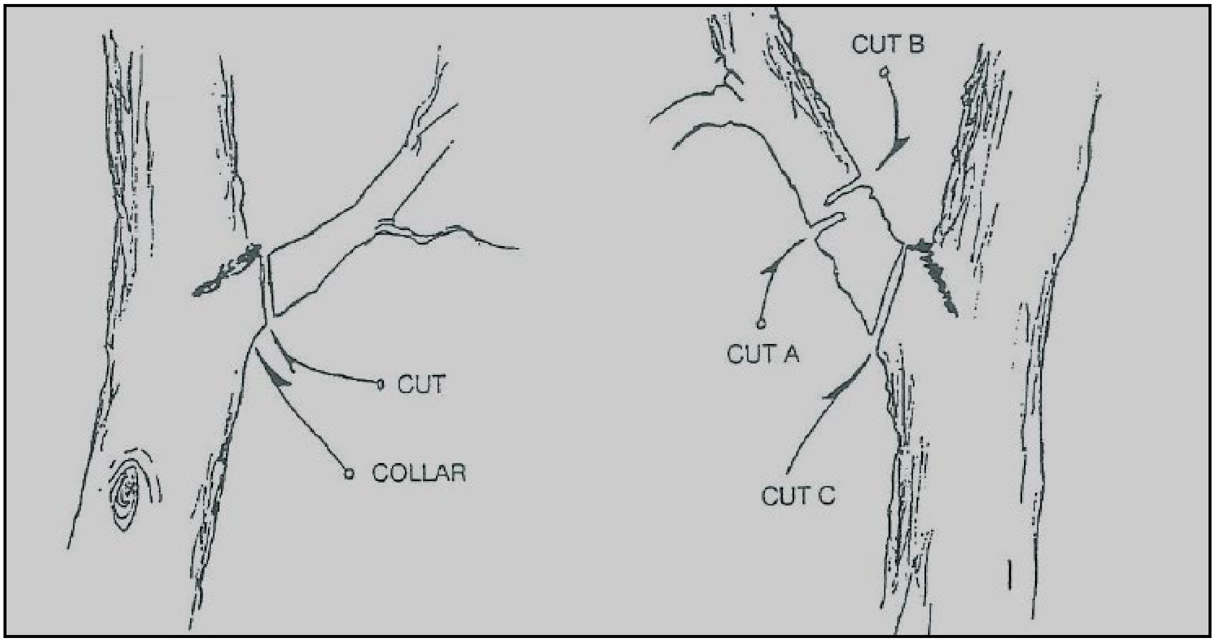


Figure 5.2: Proper Pruning Cuts

While staking for the landscape planting plan, it is also important to consider the effects that the planting will have on mowing. Plant beds and tree mulch rings should be constructed in a shape that will facilitate mower operation and will avoid excessive mower maneuvering or hand trimming. Plantings should also be a minimum of two feet behind the ditch line in cut sections and two feet outside the shoulder break point in fill sections.

All underground utility lines should be located and marked before staking out the landscape planting plan. Underground utility lines should be avoided during staking and plants should be relocated, if necessary, so that utility lines are not disturbed. Also, tall growing trees should not be placed directly under overhead utility lines. Wide-spreading trees should not be used unless there is sufficient width of planting area to accommodate them without continued severe pruning. NCDOT prefers to use large mulched areas for plantings to reduce areas which require mowing and to protect plants from mechanical damage.

Soil Preparation

Once the preliminary staking is complete, there are several pre-planting activities that must be performed before transplanting trees/shrubs. These activities include proper soil tillage and plant bed weed control. NCDOT utilizes many types of trees, shrubs, grasses and other ornamental plants on highway rights of way. Installation may include ball and burlap, bare root, or containerized plant material. The optimum planting time for relocating plant stock is in the fall and winter months. NCDOT fertilization practices for establishing ornamentals are shown in **Table 5.7.**

Table 5.7: NCDOT Fertilization for Establishment of Ornamentals

	Fertilizer Ratio (N: P_2O_5: K_2O)	# N per 1000 square feet
State Forces Planting	n/a	None at time of planting
Contract Planting	Varies	1.0

Wildflowers

Wildflowers can be seeded in mono-culture stands or in mixes. The combinations are practically limitless. Refer to *Wildflowers on North Carolina Roadsides* (published by NCDOT Roadside Environmental Unit) for further information.

To aid in the establishment of wildflowers, NCDOT utilizes composted animal litters on some of the wildflower beds throughout the state. The use of these organic materials requires the Department to adhere to certain guidelines and policies. Best management practices (BMPs) for the utilization of animal wastes are discussed in detail in Chapter 3 of this manual.

NCDOT often uses methods of seeding wildflowers called *double-cropping* and *interseeding*. Double-cropping occurs when two different annual species are planted in the same bed in the same year (usually one is planted to bloom in spring and another in fall). Interseeding involves planting annuals into established perennial wildflowers to add another season of bloom. These methods of seeding are valuable components of NCDOT's overall wildflower program.

The successful establishment of wildflowers along roadsides is not a simple process. Long range planning and extensive work are necessary. It is not possible to simply "throw seeds on the ground" and have a successful wildflower establishment program.

Equipment

The types of equipment used for vegetation establishment by NCDOT are listed below. A brief description of their usage is also given.

Chisel Plow - The chisel plow typically has "C" shaped shanks, mounted on dual coil springs. The frame, shanks and springs are of sufficient weight, size, and strength to provide an eight to twelve inch cutting depth. The chisel plow is used to break up hard pans and compacted areas.

Disk Harrow - A tandem disk harrow or an offset disk harrow of sufficient weight and size to provide a six to eight inch cutting depth is normally used.

Cultipacker - The cultipacker consists of heavy-duty smooth spoke or crowfoot rollers to provide clod breaking and smoothing capabilities. It is used by NCDOT to ensure good seed-to-soil contact.

Drop Spreader - The drop spreader consists of a spreader hopper (approximately eight foot in width), with a spreader plate and ground driven wheels. The drop spreader delivers a uniform application of material by literally dropping material such as limestone or fertilizer onto the soil.

Broadcast Spreader - The broadcast spreader consists of a unit with a hopper for holding seed, fertilizer, pelletized limestone, or other granular products, and a mechanism which will spread the product uniformly over a swath approximately three to four times the width of the equipment.

Seed Drill - The seed drill can be used for seeding various species of grasses and grains. It generally has a minimum width of 10 feet and contains a seed hopper capable of seeding an eight foot width, with row spacing approximately seven and a half inches. The unit also contains discs equipped with springs to aid in loosening the soil. Also, the seed drill usually contains a fertilizer box capable of distributing fertilizer while seeding.

Hydroseeder - The hydroseeder combines water, seed, fertilizer, and sometimes hydromulch into a slurry. The mixture is then pumped through a nozzle and sprayed uniformly over the area to be seeded. Typical hydroseeders can distribute this slurry up to 150 feet or more, depending on the size of the pump. This allows for seeding on terrain which may not be accessible by other broadcasting or drill seeding methods.

Straw Blower - The straw blower or mulch blower is used to distribute mulch over a previously seeded area. It consists of a slide or chute for inputting the mulch, chopper blades for chopping and breaking up the mulch, and a blower to spread the mulch up to 50 feet depending upon the size of the equipment.

Tack Applicator - The tack applicator consists of an emulsified asphalt distributor capable of keeping the asphalt particles suspended in water, either by heat or a combination of heat and agitation. It also has a pump and spraying system which provides a uniform spray over straw or hay mulch to hold it in place until the vegetation is established.

Crimper - The crimper usually consists of a straight disk harrow which “cuts” the straw into the soil, leaving the straw partially exposed to protect the seedbed from the elements. This alternate method of holding straw in place is effective in loose, sandy soil but may require higher rates of straw.

Tiller - The tiller is used to pulverize soil and incorporate soil amendments. This unit is PTO driven and usually has blades capable of tilling to a depth of approximately four to six inches.

Mulch Blower - The mulch blower, usually truck-mounted, is used to spread bulk materials such as bark, limestone, compost, or other materials. Typical units can uniformly distribute products up to 150 feet.

Wildflower Seeder - The wildflower seeder is basically the same as a seed drill except that a specialized seed box (sometimes referred to as a native grass seed box) is required. This specialized seed box is made for handling small or fluffy seed like that of many wildflowers and native grasses.

Sod Roller - The sod roller is used to firm sod after it has been put on an appropriate seedbed. This rolling is necessary to ensure that proper contact between the soil and the sod roots has been accomplished. The roller is usually filled with water for additional weight to achieve this contact and to avoid bridging (or air pockets) that would cause the roots to dry.

Summary

Vegetation performs many important functions, including erosion control, property enhancement, air purification, and stormwater pollutant prevention. It is very important to establish a healthy community of vegetation with timely planting. Through years of field experience, research, and cooperation with other agencies, NCDOT has established many techniques and methods for establishing and maintaining vegetation on 79,585 miles of North Carolina roadsides. These roadsides contain turfgrass and thousands of ornamental and wildflower plantings.

Several important steps must be followed in establishing turfgrasses, ornamental plantings, and wildflowers. These include proper seed bed preparation, timely seeding and planting schedules, recommended fertilizer and soil amendment application rates, wise choices of plant material, and selection of appropriate equipment selection to perform this type of work.

Introduction

In This Chapter . . .

Management of:

- *Turfgrasses*
- *Ornamental Plants*
- *Wildflowers*
- *NCDOT Applications*

The roadsides of North Carolina are enriched by the presence of large amounts of vegetation. As detailed in Chapter 4, this vegetation is in various forms. All of it serves functional and/or aesthetic purposes. The enormous amount of this vegetation on NCDOT rights-of-way represents a major investment by the taxpayers of North Carolina. In order to protect this investment and ensure that the vegetation serves the purposes for which it is intended, proper management is crucial.

This chapter describes the management practices which the NCDOT employs in maintaining roadside vegetation. These practices have been developed through many years of experience and with much input from experts at North Carolina State University. Many aspects of maintenance must be considered due to the large variety of vegetation types and the specialized situations which exist on roadsides and at Department facilities.

The Department does not seek to develop vegetation management standards of golf course or arboretum quality. Rather its goal is to provide a level of care that is appropriate and adequate to ensure long-term survival of roadside vegetation.

Turfgrasses

Mowing

The primary maintenance procedure required for turf is mowing. Mowing should begin when the grass is 50 percent higher than the desired height. For instance, if one desires a 3-inch height of turfgrass, mowing should begin when the turfgrass reaches 4 1/2 inches. The frequency of mowing or the number of mowing cycles in a given season is regulated by the amount of turf growth. The amount of growth is dependent upon temperature, fertility, moisture status, season, and natural growth rate of the grass species. As a general rule grass should be mown so that no more than 50 percent of the leaf surface is removed.

Mowing operations should be performed when the soil and grass are dry. This helps prevent the spread of disease and injury to the turf. Grass clippings should be left to decay and release their nutrients back to the turf, thus minimizing the need for fertilizer. Grass clippings should be removed if they are heavy or thick enough to damage the turf.

Another factor affecting mowing is the quality of the turf. High quality turfgrasses, like those on golf courses, are often mowed very short and very often. These turfgrasses require more fertilization and weed control to maintain their appearance. Utility turfgrasses, like those found on roadsides, do not require as much maintenance, but they do not offer the same appearance as high quality turf.

Mower Types

Either a rotary/flail (impact) or reel (sheer) mower can be used to mow turfgrass. The sheer mowers are preferred for turf requiring a height of one inch or less. Impact mowers are generally used on turf requiring heights greater than one inch. Mower blades should be sharp to obtain the best results. Dull mower blades “tear” the grass blade instead of cutting it, thus reducing the quality of the turf. Grass tearing results in poor turf appearance and allows disease to enter the plant. Well-sharpened mower blades will also reduce mower vibration, lengthen mower life, and reduce fuel consumption.

Mowing Heights

The height of the mower blades is dependent on the type of turf present and the desired appearance of the site. Mowing heights are related to the desired appearance and the purpose of the turf. High quality turfgrasses are cut frequently enough that less than 50 percent of the leaf surface is removed with each mowing. The height that utility turf is mown is affected by the species of grass present. Cool-season grasses typically are mown to a height of six inches, while warm season grasses are mown to a height of four inches.

Liming

Lime is required when the soil is acidic, i.e., pH below 5.5. The pH of the soil is usually determined through soil analysis (Chapter 3). When the soil pH is low, phosphorus and several of the micronutrients become unavailable for plant use. Lime raises the pH of the soil and, thus, the availability of those nutrients to the plant increases. Liming is important in the maintenance of a healthy turf and it should be done whenever soil test reports indicate a need for lime.

The amounts of clay and organic material greatly affect liming rates. The lime requirement increases with increasing amounts of clay and/or organic matter. **Table 6.1** shows the amount of lime needed to raise the pH from 5.5 to 6.5 in soils with various textures.

Table 6.1: Effect of Soil Texture on Lime Requirement

Soil Texture	Lime Requirement
Sandy Loam	60 lbs. per 1,000 square feet
Loam	100 lbs. per 1,000 square feet
Clay Loam	150 lbs. per 1,000 square feet

Lime does not move readily through the soil. Therefore, it should be mixed well with the top 4-5 inches of soil during seedbed preparation. On established turf, a centrifugal spreader or a drop spreader is used to evenly broadcast lime and, thus, increase its effectiveness.

Fertilization

Plant nutrients are essential for turf growth. Thus, they must be present in adequate amounts in the soil for optimum turf growth. The primary nutrients - nitrogen, phosphorus, and potassium - are used by turf in large quantities, and they are likely to be deficient in most soils. Nitrogen gives the turf a dark green color and promotes rapid vegetative growth. Phosphorus promotes root formation, and potassium aids in translocation of food and increases disease resistance and health (Chapter 3).

Fertilizer is applied according to the type of turfgrass that is present. Warm-season grasses are fertilized at a different time of the year than cool-season grasses due to their growing cycle. The fertilizer that is applied is often selected on availability but it should have a nutrient ratio of 2-1-1 (N-P_20_5-K_20). This ratio covers the typical nutrient requirements that are needed to support the growth of turf in North Carolina (**Table 6.2**).

Table 6.2: Suggested Maintenance Fertilization for Turfgrasses (NCSU)

Monthly Application Rate – pounds of N per 1000 sq. ft.												
Turf	J	F	M	A	M	J	J	A	S	O	N	D
Bahia					0.5		0.5					
Bermuda					1	1	1	1	0.5			
Kentucky Bluegrass		0.5 -1							1		1	
Centipede						0.5						
Tall Fescue		0.5 – 1							1		1	

Sod Seeding

Sod seeding is the placement of grass seed into an established turf with minimum soil disturbance. The sod seeder uses a system of discs to slice through the turf and soil to allow for proper soil-to-seed contact. This method of seeding supplements poorly established turf that does not need to be completely reseeded. Furthermore, sod seeding decreases soil disturbance that could result in an erosion problem. The equipment used for this operation ranges in size and function and will be configured to best suit the soil conditions and topography of the site.

Supplemental Seeding

Turfgrass is constantly threatened by drought, disease, insects, and erosion. Where turf is damaged, the affected area is repaired and the site is seeded and mulched according to the parameters of turfgrass establishment (Chapter 5). Sometimes it is necessary to use a form of mechanical stabilization to prevent erosion from occurring on the recently reseeded area until the site has been stabilized. Some forms of mechanical stabilization consist of polypropylene roving and cellulose matting.

Ornamental Plants

Fertilization

There are many suggested fertilization programs for ornamental plants. The type and quantity of fertilizer should be based on soil test recommendations. Recommendations of NCSU researchers are shown in **Table 6.3**. A fertilizer containing 10% to 16% nitrogen should be used if the soil has not been tested. Further, 30 to 40% of this applied nitrogen should be in the ammoniacal or urea form. These forms of nitrogen will release nitrogen slowly to the plant and not leach from the soil as readily as nitrate nitrogen. Generally two to four pounds of a complete fertilizer per 1000 square feet per year are recommended for optimum growth, depending on the plant species. The fertilizer is applied by broadcasting. One application may be all that is needed on mature plants while more than one application may be required on young plants. Fertilizer should be applied before spring growth if possible. Watering after fertilization is recommended. Ornamental plants vary in their pH requirements. Most plants grow best if the pH is maintained between 6.0 and 7.0. Some exceptions are azaleas, camellias, pieris, and rhododendrons, which grow well in the pH range of 5.0 - 6.0.

Table 6.3: Suggested Maintenance Fertilization for Ornamental Plants (NCSU)

Application Rates		
	Fertilizer Ratio ($N:P_2O_5:K_2$)	**#N/1000 sq. ft./year**
New Transplants (first year after planting)	3 : 1 : 2	1.0
Growth Phase (2 – 4 years after planting)	4 : 1 : 2	2.0 – 4.0
Maintenance Phase (>4 years after planting)	3 : 1 : 2	1.0

Pruning

Tree pruning is performed for four purposes: tree training, sanitation, restoration, and hazard prevention. Each purpose represents a solution to problems that occur throughout the development of trees.

Tree training is the pruning of crossing branches or double leaders. Tree training attempts to produce a healthy, structurally sound and biologically efficient tree. Training does not focus on aesthetics but focuses on long term viability, function, and value. Tree training should be done by professionals who are knowledgeable in tree biology, structure, and growth characteristics.

Sanitation is the removal of undesirable limbs produced by the tree due to stress or growth patterns. Basal sprouts produced at the base of crape myrtles are an example of unwanted tree limbs. The sprouts are natural but undesirable if the crape myrtle is being utilized as a tree-form instead of shrub-form. Water sprouts are soft, fast growing branches that usually grow vertically from large limbs or the trunk. They may appear after a tree suffers an abrupt major change such as heavy pruning. They rarely make good substitutes for slower growing branches, and, unless they fill a large hole in the tree structure, they should be removed.

Restoration is the removal of broken or damaged limbs caused by ice storms, strong winds, mechanical means, or insects and diseases. These limbs need to be removed before the damage endangers the development of the tree.

Hazard prevention is the removal of tree parts which show evidence of potential failure and may result in risk and liability. An example would be a large dying limb on a mature oak overhanging a roadway. The dying limb has the potential to fall and result in an accident and personal injury. Hazard prevention is the removal of the limb before it falls, thus eliminating the risk of personal injury and decreasing liability. Hazard prevention applies to property liability as well as personal liability.

Shrubs are pruned to aid the development of the plant's growth and structure. The shrub's structure can be improved by removing the crossing or entwined branches, dead or broken branches, and stems which could damage or weaken the development of the plant. Pruning may also involve the removal of undesirable stems such as basal sprouts and suckers that can affect the growth of the plant.

Shrubs are pruned to improve the appearance of the plant through shaping and by rejuvenating plant growth. The shrub's shape can be controlled by either cutting back top growth to initiate branching or eliminating overgrown branches that affect the shape of the plant. Shrubs are sometimes pruned to allow tall, straggly shoots to grow according to the desired shape.

Some shrubs need to be rejuvenated by the routine removal of a portion or all of its main stems to initiate new, more desirable growth. This ensures the proliferation of the desired trait exhibited by the shrub. Shrubs such as Buddleia (Butterfly Bush), Oleander, and Caryopteris (Bluebeard) are marginally hardy in North Carolina and tend to suffer die-back in the winter. The plants are treated as if they are herbaceous and are pruned back to within about 6 inches of the ground each winter to maintain maximum flower show and performance.

Most shrubs are chosen and utilized in a planting based on their natural growth habit and form. Except for the above described rejuvenation practices, pruning of shrubs should be rarely required.

Mulching

A good mulch cover serves many purposes. Mulch helps conserve moisture within the soil and, hence, reduces the amount of water that must be applied. Mulch helps regulate soil temperatures to prevent plants from beginning their growth too early in the spring and thus reduces the likelihood of early frost damage. It also minimizes soil temperature fluctuations and this protects tender roots from the danger of freeze and thaw damage. It improves soil structure and suppresses weed growth. Mulch helps to reduce erosion by shielding the soil particles from wind and water impact.

Types of mulch include: shredded hardwood, pine needles, pine bark in various sizes, leaf litter, and recycled materials. The type of mulch selected is based on the type of plant material, the desired finished look, availability, and cost. Shredded hardwood mulch works well in most highway situations and exhibits good bonding between particles so that it holds well on slopes. Pine bark nuggets give a more polished appearance and may be desirable at rest areas and around office buildings where beds are in close view. Aged fines or probase-type mulches work well when mulching plantings of perennials and annuals.

Mulch should be applied immediately after planting or whenever the depth of mulch on an existing plant bed becomes insufficient. New plantings should not be left unmulched more than 24 hours. Mulch should be installed and maintained at a consistent finished depth of four inches in most applications. Some perennial plantings and ground covers, as well as annuals, require only a two inch depth.

Mulch should not be placed in contact with the trunk of the tree when mulching around the base of the tree. The mulch should slope down to ground level at this point. Any depth of mulch extending up the base of the trunk encourages the development of adventitious roots which can be harmful and lead to the death of the tree.

Wildflowers

Wildflowers are a popular alternative for adding color and natural beauty to any area. Unlike the straight lines, square corners, and manicured edges of formal European gardens, wildflower gardens have the appeal of low maintenance by requiring little water and reduced mowing frequency once they are established.

A recent investigation conducted by NCSU's Dr. Seth-Carley, Horticultural Science Department shows that compared to adjacent, non-mown rights of way, wildflower beds have:

- 6 times more pollinator bees,
- 2.5 times more pollinator flies,
- 5 times more pollinator butterflies, and
- 37 times more pollinator wasps.

The value of wildflowers supporting pollinator species is undeniable.

Wildflowers cannot be grown successfully by simply scattering the seed on the soil and expecting good results. Most wildflowers require specific soil and temperature conditions and a certain amount of personal attention to make them a success. For the best wildflower results, follow the same planting dates recommended for small grain seeding in your area.

Supplemental Seeding

Supplemental seeding is performed to reestablish annuals in perennial beds, and to renovate older perennial beds in order to maintain a visually pleasing bed (Chapter 5).

NCDOT Applications

This section describes the programs used by the NCDOT to maintain the vegetation along North Carolina's roadsides and NCDOT facilities. The NCDOT's Roadside Environmental Unit applies the same principles discussed in the previous section but there are differences in the amount of maintenance required and the time it is performed.

Turfgrass

Mowing

The Department implemented a reduced mowing program in the early 1970's to conserve fuel. This led to the mowing pattern concept that is still in use today. The mowing patterns (**Figure 6.1**) identify areas covered per cycle. These patterns have proven useful to encourage wildflowers and preserve or establish nesting cover for wildlife. The mowing operations of the NCDOT are divided into two turf categories: Utility turf and residential-quality turf. Utility turf is located along the roadsides and it is the majority of the turf the NCDOT maintains. Residential-quality turf is located at facilities that are maintained by the NCDOT, namely rest areas, welcome centers, NCDOT office buildings, and maintenance complexes. These areas are mown often enough that less that 50 percent of the vegetative growth is removed with each mowing.

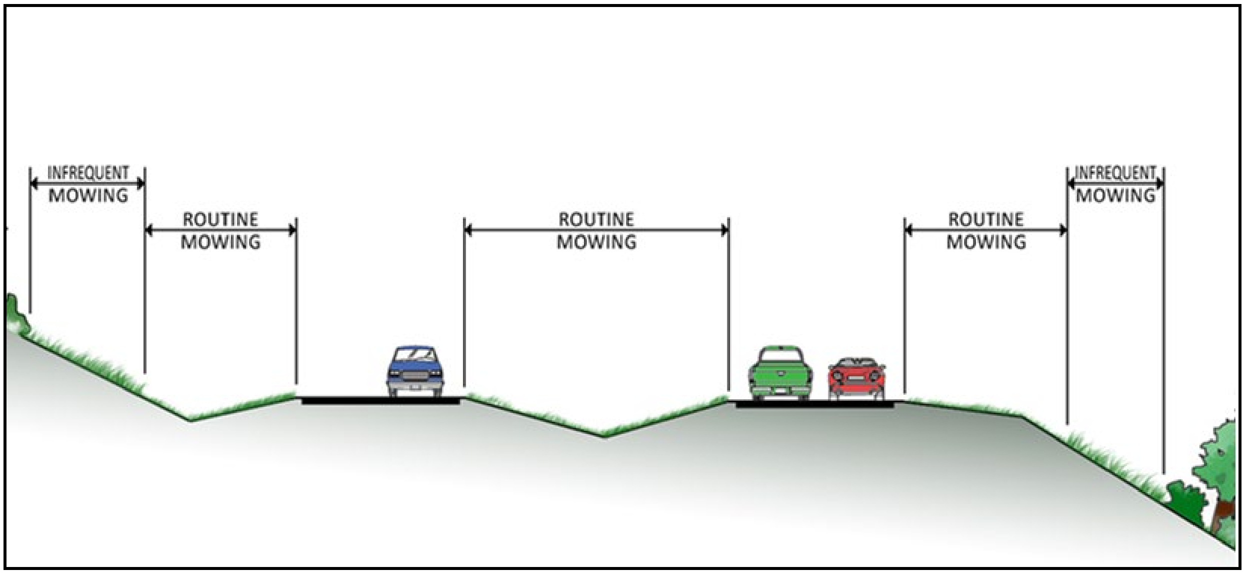


Figure 6.1: Typical Mowing Pattern

The mowing operations for the utility turfgrasses will vary across the state due to the type of turf and seasonable conditions that are present. The mowing cycle should begin before the grass reaches ten inches in height. The first mowing is the most important one since it will dictate the appearance of the turf throughout the balance of the year.

Cleanup mowing operations are conducted on roadsides on the first or second mowing cycle as directed by the Division Engineer and on the last mowing cycle of the year. Mowing operations are conducted within the limits set by the NCDOT Mowing Guidelines.

The height of roadside utility turfgrass located in established mowing zones is maintained between 4 and 18 inches. Four-inch cutting heights are maintained in the Divisions where bahiagrass, centipedegrass, and bermuda or other low-growing warm-season turf are grown. All other areas of the State containing cool-season turf (e.g., tall fescue, hard fescue, and bluegrass) are maintained at a six-inch minimum mowing height.

Considering average growth rates in North Carolina, this level of service can be maintained on all interstate, primary, and major secondary routes with an average of five annual mowing cycles. At least three of these cycles should be conducted as routine mowing and up to two cycles should be conducted as cleanup mowing as outlined in the NCDOT mowing guidelines.

The height of residential-quality turf located at the NCDOT facilities is maintained between 1 to 3 inches in height. The number of mowing cycles varies across the state and depends on the growth rate of the turfgrass. In most instances, weekly to bi-weekly mowing accomplishes the desired effect.

Liming

Lime should be applied before planting or before active plant growth starts. This will allow the lime to have enough time to react with the soil, which may take several months depending on the soil condition. Most liming occurs in the winter months when warm-season turf is dormant.

Fertilization

Fertilizer topdressing on turf depends on the geographical location, climate, and grass species. The window for applying fertilizer on warm-season grasses such as bahiagrass, centipedegrass, and bermuda is from June to October. The window for applying fertilizer on cool-season grasses such as fescue and bluegrass is from September to mid-March (**Table 6.4**).

Table 6.4: NCDOT Maintenance Fertilization for Turfgrasses

Monthly Application Rate – pounds of N per 1000 sq. ft.												
Turf	J	F	M	A	M	J	J	A	S	O	N	D
Bahia						1.0						
Bermuda						1.0						
Kentucky Bluegrass									1.0			
Centipede						0.5						
Tall Fescue									1.0			

Supplemental Seeding

Sometimes it is necessary to add seed to an area that is poorly established. Supplemental seeding of warm-season grasses is performed from March to July.

The warm-season grasses need to be established before cool weather begins so that the turf will not suffer any winter injury.

Supplemental seeding of cool-season grasses is performed between mid-August and mid-October, depending on the location. Seeding after these dates will increase the chance for winter injury. Supplemental seeding of cool season grasses in the spring does not always result in satisfactory establishment. If spring supplemental seeding must be performed, it should be done before the end of March to avoid injury from summer heat and dryness.

Ornamental Plants

Fertilization

Fertilizer application to ornamental plants depends on several factors that influence the time and rate of application. Fertilization is done most often in the fall and spring months of the year, or after flowering species of ornamental plants have flowered. The rate of fertilizer will depend on soil conditions at the site and the plants that are being fertilized (**Table 6.5**).

Table 6.5: NCDOT Maintenance Fertilization for Ornamental Plants

Actual Application Rates		
	Fertilizer Ratio (N:P:K)	**#N/1000 sq. ft./year**
All Woody Ornamental Plants	1 : 1 : 1 (e.g., 10-10-10) or	0.75
	1 : 3 : 0 (e.g., 16-48-0)	0.75
Daylilies	(e.g., 32-3-8 with 30% slow N and 8.6 % sulfur in February) and	2.2 (typical soils) or 3.0 (sandy soils)
	34-0-0 following bloom	0.8

Pruning

Pruning is performed on four categories of plants: broadleaf and narrow-leaf evergreens; spring-flowering trees and shrubs; summer-flowering shrubs; and berry-producing shrubs.

Pruning is performed on broadleaf and narrow-leaf evergreens during their dormant season, typically from mid-November to mid-March. It should be noted that evergreens cannot tolerate severe pruning.

Spring-flowering trees and shrubs should be pruned immediately after the flowering period. Pruning these plants later will result in fewer future flower buds which will diminish the appearance of the plant the following year.

Summer-flowering shrubs should be pruned during their dormant period from mid-November to February. These plants will develop their flower buds in the current growing season.

Berry-producing shrubs should be pruned lightly after berry production. This will have a slight affect on the flower production on the plant the following year.

Mulching

The mulching of plants and plant beds is performed throughout the year and it depends on labor and mulch availability.

Wildflowers

Fertilization

Fertilization helps wildflowers grow large enough to compete with weeds. Wildflowers have much larger blooms with fertilization, and this creates a more solid appearing stand for travelers to view at high speeds. Fertilization also extends the blooming period. February 15 is an optimum application date for fertilization of wildflower beds. If a current soil test is not available, 300 to 400 pounds per acre of a 32-3-8 fertilizer with 30% slow N and 8.6 % sulfur is recommended to assure extended bed life, vigor, and color.

Supplemental Seeding

Supplemental seeding is performed in the spring and fall months on older wildflower beds to rejuvenate them. The Tye, series (V) Pasture Pleaser I Seeder (7 foot) has a fertilizer box, grain box, legume box, and native grass box. The native grass box is used most often with cosmos and bidens wildflower seeds due to their tendency to be fluffy and cling together. Supplemental seeding is performed in the fall and spring as needed.

Hydroseeders are used in conjunction with a straight blade disk. The seed is applied to the bed and then allowed to dry. Then the straight blade disk will help to assure good seed-to-soil contact without destroying the existing perennials.

Equipment

Maintenance equipment is selected for use by the NCDOT based on equipment specifications and how easily the equipment can be transported from site to site. The equipment selected to perform a specific job will vary among the Divisions. Eastern Divisions work mainly with sandy soils while the western Divisions work mainly with clayey soils. The size of the equipment depends on the Division's ability to transport it and how well the equipment functions with other equipment. For each Division there are separate equipment needs that are site specific and must be addressed by the Division Roadside Environmental Engineer.

Summary

The NCDOT allocates funds each year to maintain the landscaping and wildflower plantings on NCDOT rights of way. Federal funds and license plate funds are used in this allocation to support the various programs that maintain and establish vegetation along the roadsides and around building complexes of the NCDOT. These funds are limited and, with the continuous development of the North Carolina highway system, there are constant efforts to search for better ways to reduce the cost of maintaining the roadsides. Landscape designers and engineers continually look for innovative and creative ways to address maintenance responsibilities.

The REU of the NCDOT works with universities and other related agencies to find ways to control the weeds in wildflower beds and ornamental plantings. Controlling weeds allows for wildflower and ornamental plant beds to sustain themselves for longer periods, and it reduces the labor needed to maintain their appearance. There are also efforts to reduce the cost of mowing by using growth regulators and grass species that require less mowing (Chapter 5). The increased use of alternative mulch materials is being used to lower mulching cost. Plant materials such as daylilies are being utilized to reduce the need for maintenance. Finally, the NCDOT is increasing its maintenance agreements with cities and towns to maintain landscaped areas. This has proven to be mutually beneficial.

North Carolina has a roadway system that receives minimal landscape maintenance while displaying superior vegetation management, a long-standing tradition of the NCDOT.

Introduction

In This Chapter . . .

- *Integrated Pest Management*
- *NCDOT Applications*
  - *Plant Selection and Management*
  - *Monitoring Plants and Pests*
  - *Cultural Practices*
  - *Pest Biology and Ecology*
  - *Determining When Pests Need to be Controlled*
  - *Using Pesticides as Needed*
  - *Evaluating an IRVM Program*
  - *Educating the Pest Manager*
  - *Pest Identification*
  - *Pesticide Safety and Training*

Roadside vegetation management can be divided into two categories: (1) n*atural areas* where the vegetation is allowed to grow as nature dictates; and, (2) *managed areas* where the vegetation is designed, planned, and maintained for specific goals and objectives. The highest priority for the vegetation manager is supplying safe transportation corridors with hazard-free safety clear zones, low growing vegetation in the operational zone and open sight distances (**Figure 7.1**). Actively managing vegetation in these zones contributes greatly to biological diversity in North Carolina, provides attractive roadsides, preserves biological heritage, and reflects local landscape character.

Control of noxious weeds and undesirable plants is also a requirement for managing roadside vegetation. Noxious weeds, as identified by federal and state agencies, threaten thousands of acres of public lands annually. These aggressive plants invade and create masses of unwanted vegetation and greatly reduce biodiversity.

North Carolina roadside vegetation managers have endorsed and will continue to implement an *Integrated Pest Management (IPM)* program for the roadside acreage in North Carolina. The broad IPM principles have been refined and directed into Integrated Roadside Vegetation Management (IRVM). IRVM guidelines, developed by the National Vegetation Roadside Management Association (NRVMA), are used as a process to manage vegetation in the various zones and to control noxious weeds. This chapter will explore integrated pest management philosophies and key elements for managing roadside vegetation in North Carolina.

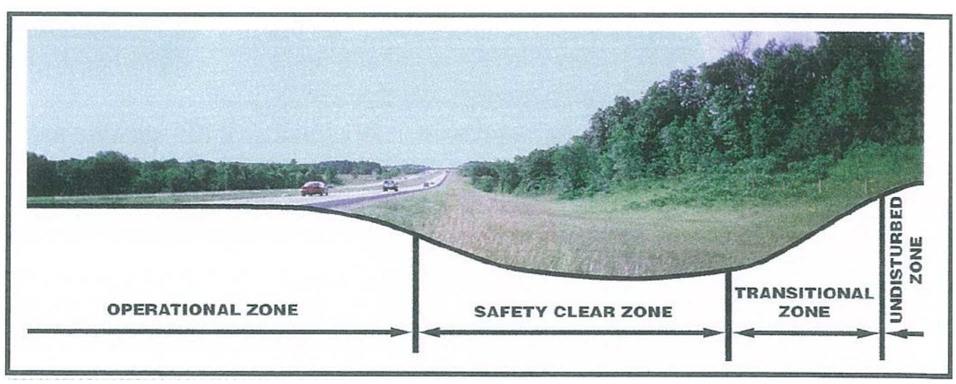


Figure 7.1: Zone Concept for Roadside Vegetation Management (NRVMA)

Integrated Pest Management

IPM is a term used to describe a system of managing pests whereby all possible methods of controlling pests are considered in reducing populations to levels that are economically acceptable. IPM employs proven, practical and least costly methods in a plan designed to exclude pests from the management unit.

The term “pest” is used to describe any unwanted plant or animal species in a landscape. However, this term has no ecological meaning. It is simply a word that broadly characterizes a competitor for resources. Pests are part of a natural system at work. As such they have a role in nature that has been operative for many centuries. Managing unwanted species is most successful when the biological characteristics of organisms are understood and used to advantage. An IPM program has several major components as described below.

Plant Selection and Management

Landscape designs should incorporate species and cultivars that are well adapted to the landscape sites and exhibit genetic resistance to insects and diseases common to the area. Plants genetically predisposed to pests or known to be high maintenance problems are excluded under an effective IPM program. Physical aspects of landscaping such as the geographical layout should be considered an integral part of the landscape design process. Physical aspects may depend on factors such as slope, accessibility, adjacent structures, waterways, traffic, and microclimatic conditions.

Redtip Photinia is avoided
in plant selection due to disease problems.

Plant pest in the pavement area.

Roadside vegetation is designed to fulfill specific needs. Public safety, cost, and aesthetic appeal all play a role in plant selection, placement and maintenance. Potential pest problems are often low on the priority list. Roadside vegetation areas are artificial habitats that will begin to revert to a natural state as soon as planting is completed unless management is introduced and continued. Pest problems will be lessened to a degree that a roadside landscape is designed and maintained to restrict competition from pests.

Healthy, vigorous plants are good competitors and less likely to have pest problems. Poor variety selection, improper placement for the needs of the plant, and poor maintenance will often be the cause of pest problems. Weeds can be indicators of soil conditions such as compaction, pH imbalance, or low fertility. Before any pest management action is taken, these soil problems must be resolved. In numerous situations, correcting other problems will eliminate pest problems.

Landscape redesign begins with a complete survey that obtains information on species, varieties, location, pest history, past pest control activities, costs, and success of pest control programs. This information should be used to develop a priority list so the most important problems can be addressed first. It is important to ask the question “Why is this pest here?”; or stated another way, “What conditions are allowing this pest to successfully compete in this arena?” The answers to this question will aid the development of permanent pest solutions.

Monitoring Vegetation and Pests

An effective IPM program depends upon regular surveys of managed areas to determine which pests are present and to monitor their population(s). Observations are evaluated in order to make decisions about the necessity for action. Roadside managers can use this information to judge whether the pest population is or will become large enough to cause unacceptable damage or a negative aesthetic impact.

Pesticides must be employed frequently because pest problems occur “overnight” requiring immediate control. Such pest occurrences may take weeks to develop but they seem to appear suddenly because the initial signs were not noticed. This situation can be avoided by utilizing a regular and systematic check for pests.

The complexity of the monitoring program should be proportional to plant value, time available, resources, life cycle of the pest, and skill level of the observer. Monitoring programs may be as simple as doing a visual inspection or as complex as conducting a detailed investigation. For example, a median strip of grass and a cultivated area of flowers will not require the same effort. Monitoring involves both plant and animal pests. The condition of plants will influence the activity of herbivores. Any variance from acceptable norms of appearance or growth should be carefully evaluated for problem causes such as soil fertility and improper soil pH in order to prevent future pest problems.

Recordkeeping is a part of the monitoring effort. It may appear easy to remember what pests occurred when and where, but daily activities are often distracting and observations are soon forgotten. Making a drawing of the management area to identify locations will help track pests through time. Recordkeeping can be as simple as writing general observations or as detailed as tracking counts of specific pests.

Cultural Techniques

Proper cultural methods are an important part of pest management. Vigorous plants and turf are much more pest-tolerant, and even pest-resistant. Emphasis should be placed on maintenance programs for turf and ornamental plantings to insure the correct performance of mowing, fertilization, iirrigation, pruning and other cultural practices.

Plant maintenance plans should allow for individual species' needs. Close mowing of some grass species will guarantee weed problems. Infrequent mowing for some grasses will result in unhealthy plants not able to compete. The changing needs of plants should be considered also. Newly planted grass in a well prepared area will face new stresses after 1-2 years. A small landscape plant, after several years of growth, may become crowded leading to stress or shading of other plants. Change must be considered in pest management planning. Keeping plants healthy requires a maintenance plan that changes according to the needs of the plants.

Pest Biology and Ecology

Learning the biology, ecology, and behavior of pests is a critical part of developing an IPM plan. Understanding the life history of pests and their interaction with the environment will yield the keys to management. The objective is to deny the pest part or all of its life support system. This will provide an initial reduction in numbers which, in some cases, may be all that is necessary for adequate control. For example, mulching plants denies weeds both the soil temperatures for germination and sunlight required for growth. Plants in full sun in an exposed area dry quickly denying foliar diseases the moisture required to infect leaves. Acquiring this knowledge will allow an IPM manager to rearrange the landscape to discourage pests.

Even after the landscape has been rearranged, other measures may be needed to further reduce pest populations. Again, the key to success is in the life system of the pest. There may be effective natural enemies that can be employed either by encouraging their establishment in an area or by releasing them directly to an inhabitable site. For native pests, there are many beneficial species that can provide at least partial control. Soil pathogens may be resisted by increasing organic matter or inoculating the roots before planting.

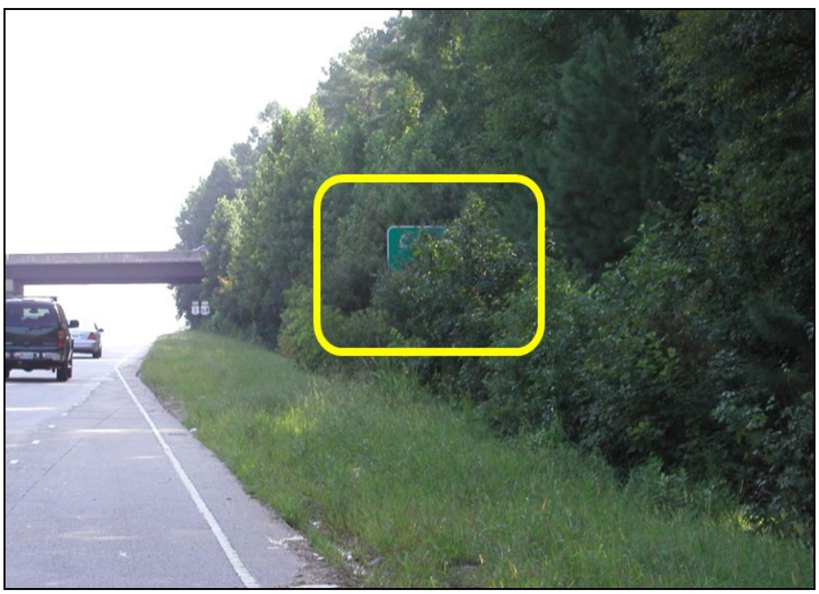
The selection and use of biological control agents is not a casual effort. This is a knowledge-based activity and careful study is required for success. Where products are purchased, where and how they are utilized, the target species, and other factors must be considered before any release is considered.

Determining When Pests Need To Be Controlled

Monitoring of turf and plantings is extremely important to determine when pests reach intolerable levels. IPM does not mean that pesticides are never used. In some situations there are no effective alternatives. Simply sighting a pest is not enough to justify using a pesticide. No action is necessary unless the potential pest damage exceeds acceptable damage levels. The point at which action is necessary is called an aesthetic threshold. Using aesthetic thresholds helps in several ways. First, it assures that a pesticide is not used until and unless necessary. Additionally, by waiting until a threshold is reached, natural control agents (which give free control) can increase and possibly control pests without using a pesticide. Waiting also allows plants more time to grow, possibly outgrowing pest problems, or growing into a less susceptible stage.

Setting thresholds is a two step process. First, the level of acceptable damage must be determined. Second, the number of pests required to reach that level of injury must be ascertained. Thresholds can be determined by monitoring, recording pest counts, and comparing the numbers to what is considered to be unacceptable.

Aesthetic thresholds can only be determined on a site-specific basis. Defoliation of landscape plants may not threaten the health of the plant but is unacceptably unsightly. The appearance of specific plantings may not accurately reflect the actual health of the plants. Thus, thresholds vary with the situation. A foundation plant that lines the entrance to an important building will likely have a threshold that differs from a foundation plant that is distant from the road and cannot be easily observed. Some plants do not lend themselves to thresholds. Tea roses, for example, are highly susceptible to several serious pests and are highly valued for their appearance. It would be difficult to set thresholds for these plants. But the majority of plants on a roadside landscape will tolerate some damage.



Vegetative sight-distance obstruction.

Using a threshold to make pest control decisions supports the idea that a (healthy roadside ecosystem is occupied by a diversity of species. A diverse species community is more likely to stabilize at a desirable level and less likely to suffer outbreaks.

Using Pesticides As Needed

The agricultural chemicals industry has made great strides in improving the selectivity of pesticides. For more than 40 years it has been possible to remove unwanted broadleaf weeds from grasses without harming the grasses. Pesticide products are now available that remove grasses from broadleaf plants without harming the broadleaf plants. Startling new discoveries in chemistry have even resulted in products that can safely remove one class of broadleaf plants (such as legumes) from others. These advances mean that herbicides can be selected to remove only certain weeds while retaining plants which are desirable or have negligible impact. An effective IPM program utilizes this information to insure that pesticide usage is highly target-specific. Where possible, effective biological controls should be used in lieu of chemical pesticides for added environmental protection.

Any time a pesticide is needed, the pesticide, rate, timing and method of application is "customized" to the specific pest. The old "shotgun" approach is too expensive and is no longer acceptable. By selecting pesticides and rates according to the pest found, using proper application techniques, and applying them at the most susceptible pest stage, effective control can be obtained for less cost.

Selecting a pesticide, rate, and timing of use should be a careful process. Too often the same pesticide is used over and over with little awareness of negative side effects or that more effective materials may be available. When evaluating pesticides consider:

1) Effect on natural enemies. Certain commonly available pesticides can have a devastating effect on beneficial insects or soil microorganisms. This leads to the need for more pesticides to manage pests that can no longer be controlled naturally.

2) Hazard to human applicators. Most pesticides cleared for roadside use are among the safest pesticides available. But pesticides should be considered with respect to:

   - risk to non-target organisms (e.g., wildlife).
   - risk to environment (Is it likely to move offsite? If it does, what is the potential impact?).
   - risk of voiding a pennanent solution to pest control.

Re-evaluating a Pest Management Program

Once implemented, an IPM program must be carefully re-analyzed after an appropriate amount of time has passed (this may be months or years). Initial plans are based on expected outcomes but biological systems sometimes behave in unexpected ways. Thus, the effectiveness of decisions must be evaluated and changes instituted if needed. As landscape plants mature, new situations arise that must be considered (e.g., roots occupy more area and shading increases) with respect to the effectiveness of the IPM program. Questions such as "Is my plan achieving the desired results?" must be asked. If the answer is negative, then steps must be taken to identify what is not working and make corrections. This step may seem self evident but, too often, plans are made and never reviewed.

Educating the Pest Manager

An IPM plan is likely to be hard to implement, slow to show results, and may initially cost more. In many cases pest managers may not have an appreciation for the complex interaction of events occurring on the Landscape. It may be critical for them to learn more about biological and ecological processes. IPM managers should continually upgrade their knowledge of pests, pesticides, monitoring systems, plants, and many other subjects. Knowledge of relevant subjects will strengthen the manager’s ability to anticipate and correct pest problems.

NCDOT Applications

Application of Integrated Pest Management Principles for Integrated Roadside Vegetation Management.

"Integrated Roadside Vegetation Management (IRVM) is a decision-making and quality management process for maintaining roadside vegetation that integrates the following:

- *needs of local communities and highway users*
- *knowledge of plant ecology (and natural processes)*
- *design, construction, and maintenance considerations*
- *monitoring and evaluation procedures*
- *government statutes and regulations*
- *technology*

... with cultural, biological, mechanical, and chemical pest control methods to economically manage roadsides for safety plus environmental and visual quality.

“IRVM is a spinoff of the integrated pest management (IPM) concept used in agriculture, horticulture, and forestry. IPM is a coordinated decision-making and action process that uses the most appropriate pest control methods and strategies in an environmentally and economically sound manner to meet pest management objectives.” (National Roadside Vegetation Management Association)

Notice the signs in this photo

Results of not maintaining a roadside

Safety for NCDOT employees and the traveling public is the number one priority for the Division of Highways. Vegetation management is a major function in providing safe transportation facilities free of vegetative obstructions with clear and open sight distances.

Interstate and primary highway corridors in North Carolina have become linear forested strips with tremendous biological tendency to grow into and over the manmade structures. This natural biological succession has created a safety challenge to controlling unwanted vegetation in the operational zone and promoting low maintenance plants in the transitional zone.

NCDOT has adopted Integrated Roadside Vegetation Management (IRVM) philosophies developed by the National Roadside Vegetation Management Association. The implementation of IRVM principles by NCDOT is described next.

Plant Selection and Management

The Aesthetics / Landscape Design and Development Section of the Roadside Environmental Unit plays an important role in pest management through plant selection. Plants are rejected for rights of way use for reasons such as being highly susceptible to disease (e.g., photinia) or tendency to be invasive (e.g., miscanthus).

In addition, *allelopathic* plants, those which have the ability to inhibit weed growth through the secretion of toxins, are selected wherever possible. Daylilies and centipedegrass are examples of allelopathic plants and the Roadside Environmental Unit is rapidly expanding the use of these plants in ornamental plantings and turfgrass areas, respectively.

Centipedegrass on Interstate Median

Daylilies Used for Aesthetics and Erosion

Monitoring Plants and Pests

NCDOT has a monitoring network through its statewide roadside environmental engineers (**Figure 7.2**). A problem can be identified in a region of the state and quickly reported to the REU, which immediately communicates this information statewide by distributing "alert" notices and/or electronic messages describing the problem and recommending solutions. This early warning system has proven to be very beneficial in pest management.

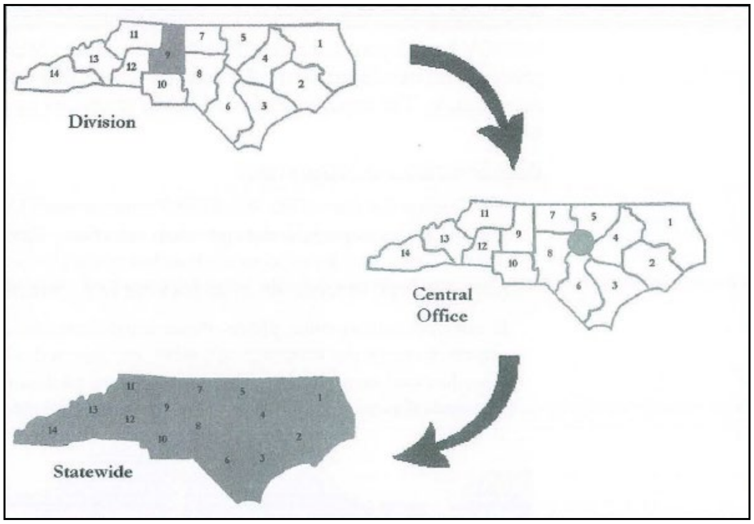


Figure 7.2: NCDOT Statewide Monitoring Network

Cultural Practices (Mowing, Fertilization, and Pruning)

Turf Mowing

NCDOT places a high priority on cultural methods of vegetation control. Mowing is the single most widely used cultural method of vegetation control on North Carolina highway rights-of-way. The three (3) major categories of mowing - *routine, safety sight distance, and cleanup* - determine the turf mowing programs in the various zones.

The state varies widely in climate and topography ranging from the coastal region with the warm temperatures and relatively flat terrain to the Mountain region with its cooler temperatures and steep terrain. This accounts for the adaptation of warm-season grasses to the Coastal Plain and cool-season grasses to the mountains, with the Piedmont region being a transition area utilizing both warm- and cool-season grasses (Chapter 4). The state also varies from densely populated urban areas to rural agricultural areas. This diversity greatly influences the frequency and coverage of roadside mowing.

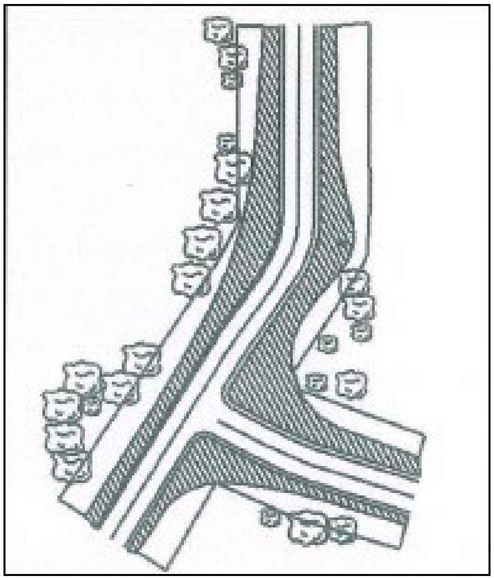


Figure 7.3: Hatched Areas Identify Sight Distance Requiring Frequent Mowing

The Department's mowing policy places the safety of the traveling public as the primary consideration. *"Sight distances are considered critical areas and should be maintained on every mowing cycle on interstate, primary and secondary routes. All routes should be scheduled in accordance with normal priorities, i.e., interstate and major primary routes, minor primary and secondary collector routes, other paved secondary routes and finally unpaved secondary routes."* (North Carolina Department of Transportation Mowing Policy). See **Figure 7.3.**

Sight distance restriced by overgrown brush

Interstate and primary routes, in or near metropolitan areas, generally receive more frequent full-width mowings than secondary roads. In these areas, the rights-of-way are managed to blend with adjacent property. Regionally, mowing requirements vary greatly and the Divisions are encouraged to minimize mowing cycles and area covered whenever possible.

Brush Control with Mowing

Mechanical cutting is the most widely used method to control brush on highway rights-of-way in North Carolina. Tree saplings and fast growing vines and brambles can quickly reduce distance visibility and pose immediate safety hazards. Drainage ditches and channels must be cleared periodically to facilitate water movement away from road surfaces and structures. Canals that are not maintained become overgrown with vegetation, increasing the potential for flooding. Also prolonged subsurface saturation can cause pavement failure. Mechanical cutting quickly removes the hazards, improving drainage and enhancing public safety.

Mechanical cutting has certain disadvantages such as operator and public safety risk during the cutting operation, large capital investment, unattractive landscape appearance and rapid regrowth potential. The Department recognizes these disadvantages and thus limits the size of trees and saplings that can be removed with heavy rotary equipment. Creating extensive vertical cuts or aggressive side trimming is strongly discouraged due to safety and aesthetics. Large trees that interfere with public safety are generally removed individually by ground crews.

Mechanical cutting, brush control

Fertilization

Roadside Vegetation Managers also topdress vegetation with fertilizers at levels to sustain low maintenance vegetation and not at levels to stimulate rapid growth. The turf fertility program is usually sporadic and repeated 3 to 6 years as needed. Supplemental fertilizer topdressing for ornamental plantings may be required for establishment and generally the requirement decreases over time. Healthy turf and ornamental plantings can prevent erosion, filter runoff, and provide attractive and safe transportation corridors.

Pruning

Pruning of trees and shrubs is one of the primary means of controlling growth. Pruning becomes necessary when one of the following purposes is to be accomplished: restoration, sanitation, shaping or hazard control. Uncontrolled growth can cause problems for the traveling public such as obstructed sight distance, and vehicle or personal injury. Most shrubs are chosen and utilized in a planting bed so that minimal pruning is required.

Pest Biology and Ecology

Methods of pest control are often developed through understanding how a pest interacts with its environment, then creating ways to deny the pest what it needs to survive. The following methods of biological and ecological pest control are employed by NCDOT Roadside Vegetation Managers.

- Guardrail matting - Weed control under guardrails is achieved by using a fabric barrier to deny weeds the sunlight and air that they require for survival. This matting is installed underneath and directly adjacent to guardrails where mowers normally do not reach. This durable barrier has been shown to provide years of weed control under guardrails without the need for mowing or applying herbicides.

Guardrail before installation of weed barrier matting.

Guardrail after installation of weed barrier matting.

- Musk thistle control through release - Musk thistle is a European weed which was accidentally introduced into the eastern United States in the mid to late 1800s. It has become a weed of considerable economic importance, and is especially damaging in pastures and rangeland. It was declared a noxious weed in North Carolina in 1991. Musk thistle is found most commonly along roadsides, railroad rights-of-way, fence borders, wastelands and in pastures (see below). It reproduces entirely by seed which is dispersed by wind. If musk thistle can be prevented from producing viable seed it can be eradicated over time. Each plant lives a maximum of two (2) years.

Musk thistle growing along a NCDOT guardrail
with vulnerable pasture land in background.

A natural enemy of musk thistle is the flowerhead weevil *(Rhinocyllus conicus).* The adult of this weevil lays its eggs on the developing flowerheads of musk thistle. When the eggs hatch, the larvae feed on the flower receptacle and disrupt seed formation.

Adult weevil on musk thistle flower.

The seed on the right is from a musk thistle flower which was not infested with the flowerhead weevil. The seed on the left is not viable due to weevil infestation.

Newly emerged flowerhead weevil adult on damaged musk thistle flowerhead.

After feeding for 25 to 30 days the larvae begin a two-week pupation period after which they emerge as adults.

In cooperation with the NCDA&CS, the NCDOT has participated in a weevil release program for musk thistle control on NCDOT rights-of-way. This is a purely biological control program which has the following advantages over more traditional methods of control: (1) It is very cost effective; (2) It is not a threat to non-target organisms; (3) Once established, the weevils move into adjoining infested areas; (4) Little additional effort is necessary once the weevils are established, while other controls must be applied periodically.

NCDOT and NCDA&CS employees releasing flowerhead weevils on musk thistle.

Close up of weevils being released.

It has been shown that releasing weevils can result in a 95% reduction in musk thistle over a 5 to 10 year period.

Determining When Pests Need To Be Controlled

The two most important factors which roadside vegetation managers consider in determining when pests need to be controlled are: **SAFETY,** then **aesthetics.**

Safety in roadside vegetation management primarily involves sight distance concerns and the potential for plant debris on road surfaces. Whenever the growth of vegetation inhibits the view of drivers so as to increase the risk of an accident, the situation must be corrected at once. This immediate response also applies to situations where a highway sign may be obstructed, preventing the driver from receiving important information or instructions. In addition, action must be taken quickly if debris from a plant (fallen branches or other plant material) represents a risk to driving safety.

Aesthetics are a secondary concern when determining the need for pest control. While the majority of plants on a roadside landscape will tolerate some damage, the damage may be so unsightly as to be unacceptable. There also comes a point at which pest damage may result in economic loss to state property. In these cases action must certainly be taken to protect the interests of the state and the desires of its citizens. However, the need for an immediate response is still less critical than where safety is an issue.

Using Pesticides as Needed

An effective IRVM program requires the vegetation manager to be knowledgeable about turfgrass, ornamental plantings, brush control and noxious and invasive weeds. During the pest control evaluation phase, herbicides may be the only realistic and cost effective control method available. Herbicide application is not an automatic response when a pest is seen. Rather, herbicide use is the result of a “step down” procedure of evaluating all methods of control to maintain public safety and aesthetics. When herbicides are the chosen method of control, products are general use materials selected on the basis of least environmental impact. Herbicides are then applied in a safe manner according to label directions when the pest is in a controllable stage.

Decisions to utilize herbicides are made after cultural or biological control methods have been evaluated. Short-term and long-term pest impacts are considered as well as the cost of application and economic benefits. With proper planning, herbicides can be used to reduce the frequency of mowing cycles and ultimately reduce the annual maintenance cost for interstate and primary routes.

The following sections describe how herbicides can be important and necessary tools in an IRVM Program.

Turf Management

The Warm Season Release Program controls undesirable grass and weed species while releasing or maintaining warm-season turf grasses such as bahiagrass, bermuda and centipedegrass. Preemergence and postemergence herbicide treatments may be utilized in late winter or early spring to prevent growth of weeds and reduce early season sight distance problems and mowing cycles.

The Annual Grass Control Program may utilize herbicide treatments during the summer to control annual and perennial grasses such as crabgrass, dallisgrass, broomsedge, goosegrass, and others. Annual grass control is crucial in any vegetation management program because undesirable annual and perennial grasses compete for plant nutrients during the summer months, resulting in thin stands of desirable turf.

The Broadleaf Weed Control Program consists of controlling weed species along the roadsides while they are small and actively growing. Broadleaf weeds can present a major sight distance problem if not addressed properly. The Department may utilize preemergence or postemergence herbicides which effectively control broadleaf weeds.

All of the turf treatments reduce the frequency of mowing and mowing costs. However, the Plant Growth Regulator Program can reduce one to two mowing cycles per year. The growth regulator program may be utilized to control the growth of cool-season and warm-season grasses, such as fescue and bahiagrass, respectively. A growth retardant typically interferes with cell division and thus, prevents seedhead development. A plant growth regulator program can be an alternative to mechanical mowing but it is currently not widely used on highway rights-of-way.

Ornamental Plant Management

Good cultural practices such as mulching can significantly reduce unwanted weed growth and conserve moisture in formal roadside ornamental plantings. Experience has shown that weed management in these plantings is not practical without the use of herbicides. Preemergence herbicides may be applied in the fall for control of winter weeds and grasses, and also during the spring to control summer weeds and grasses. Postemergence herbicides may be applied throughout the year to control undesirable vegetation that has emerged during the growing season.

Brush Control

Mechanical mowing continues as the most frequently used method to control brush on rights-of-way. Mowing with a sequential herbicide application has proven the most efficient and cost-effective approach for controlling brush. The preferred process consists of mowing smaller brush late in the growing season or winter followed by herbicide treatment the following year after the plants resprout and begin to "sucker" at the cut location. This process will control the root system and generally reduce the mowing requirements for several years. This sequence should be closely followed to avoid the need to cut or spray large brush.

For several years the Department has utilized dormant stem treatments during the winter months. This has allowed the Department to expand the window of opportunity to control brush, without causing "brown out" to the treated vegetation. In addition, it is a preferred practice to apply a 'cut stump' application immediately following the process of cutting brush back to the stump or ground level. A systemic herbicide applied to stumps prevents them from resprouting.

Vegetation Control for Stationary Objects and Pavement

Stationary objects such as guardrails and sign posts must remain clear of unsightly vegetation for them to be useful and effective. Preemergence and postemergence herbicide treatments may be utilized to prevent weeds and brush from growing around these structures. The Department is currently encouraging the establishment of low growing turf (e.g., centipede and zoysia) under guardrails, to reduce erosion and weed growth. The allelopathic effect of centipede should reduce the need for future herbicide applications.

Asphalt and concrete roadway surfaces often have weed growth which can deteriorate pavement rapidly. Herbicide treatments may be applied prior to asphalt resurfacing or widening to prevent growth of weeds and grasses, especially bermuda.

Noxious Weed and Aquatic Treatments

Johnsongrass, kudzu, purple loosestrife, and vaseygrass are some of the noxious weeds controlled by a variety of selective postemergence herbicides. Generally, these are very invasive weeds that not only affect highway vegetation but also the properties of adjacent landowners. The Department participates in a cooperative eradication program in which each party is required to control the undesirable vegetation on its respective property. This program has proven to be successful in reducing the competition of problem species.

Aquatic weeds, such as alligator weed and purple loosestrife, occur along canals and wet ditches mainly in the coastal counties of North Carolina. They may be controlled to facilitate drainage. The NCDOT selects only herbicides which are labeled for aquatic use and are environmentally safe.

Evaluating an IRVM Program

The NCDOT reevaluates its IRVM program continually rather than periodically. The most important objectives of the program are to ensure safety and to provide aesthetically pleasing roadsides. The degree to which the NCDOT efficiently achieves these objectives largely determines the success of the program. The highly visible and public nature of roadside vegetation management assures constant evaluation of the program by the citizens of the state and other highway users. Feedback from the traveling public is helpful in determining positive aspects of the program as well as those that need improvement.

Educating the Pest Manager

New IRVM techniques are being developed nationwide and it is imperative that vegetation managers participate in training programs to understand current practices as well as explore new methods. The roadside vegetation manager expends much of the resources available to control unwanted vegetation. Proper pest identification and proper use of pesticides should be reviewed periodically to maximize efficiency and safety.

Pest Identification

Accurate pest identification is necessary for any IRVM program to be successful. Knowing what the specific pest is, i.e., type of insect, disease or weed, allows one to select the best management tools.

For weed identification NCDOT has compiled the booklet Weeds of North Carolinal Roadsides. This booklet contains color photographs with key identification characteristics of the most common and troublesome weeds found on North Carolina roadsides. Also available at all Division offices are the Southern Weed Science Society Weed Identification Guides which contain color photographs of 300 different weeds. Other weed identification sources include: Common Weed Seedlings of the United States and Canada, University of Georgia Extension Service; Weeds of the Southern United States, University of Georgia Extension Service; Grass Weeds in World Agriculture, BASF; Some Grasses of the Northeast, University of Delaware Agricultural Experiment Station; and Weeds of Arkansas Lawns, Turf, Roadsides, Recreation Areas: A Guide to Identification. In situations where positive weed identification cannot be made, samples are sent to REU personnel who then contact NCSU botanists and/or other scientists for weed identification and control recommendations.

Some of our most troublesome weeds are pictured below.

Purple Loosestrife

Kudzu

Vaseygrass

Japanese Knotweed

Currently there are very few insect and disease problems that occur in roadside situations. When they do occur they are generally in ornamental landscape projects or wildflower beds. Those insects and diseases that are likely to occur are addressed in the Vegetation Pest Management Manual.

Pesticide Safety and Training

Safety is considered an extremely important part of pest management when utilizing pesticides. The two primary safety considerations are:

- Protection of employees and other humans from exposure to pesticides.
- Protection of the environment and non-target organisms.

Properly trained and competent personnel are essential for an effective safety program. All employees involved in pesticide application or in planning pesticide programs for the Department are licensed by the NCDA&CS Pesticide Board in accordance with the North Carolina Pesticide Law. To obtain this license, the North Carolina Pesticide Law states, “Each applicant must demonstrate upon written or written and oral examination his knowledge of pesticides, their usefulness and their hazards; his competence as a pesticide applicator; and his knowledge of the laws and regulations governing the use and application of pesticides in the classification for which he has applied." In addition to the training required to obtain a license initially, a specified number of credit hours of training is required to maintain the pesticide license. Employees are encouraged to attend field days, seminars and other training provided by North Carolina State University, Institute for Transportation Research and Education, North Carolina Vegetation Management Association, North Carolina Landscape Contractors Association, and the Roadside Environmental Unit. Through this continual training, personnel involved with pest management are kept up to date on new programs, innovations, and techniques for the effective and safe application of pesticides.

Mixing and Loading

Mixing and loading pesticides is the occasion when exposure to pesticides is potentially the greatest. It is also the time when the possibility of environmental contamination is the greatest. This is because the concentrated pesticides are being handled during mixing and loading. To avoid exposure at this critical time, waterproof gloves and other protective clothing as instructed by the pesticide label and/or Material Safety Data Sheet (MSDS) are required. To avoid contaminating the environment, mixing and loading are not conducted in close proximity to ponds, streams, or drainage ditches. To further reduce the possibility of point source contamination or pesticide buildup, mixing and loading points are varied throughout the season. Absorbent material is also available on site and in the application trucks to contain possible spills. REU employees periodically inspect mixing and loading sites/operations to ensure they are being managed correctly.

Other important considerations in mixing and loading are tank mixes and adjuvants. Tank mixes (combination of two or more pesticides in the application tank at time of application) are often used to reduce the number of application trips. Tank mixes are considered consistent with the pesticide label if:

- The products in the mix are applied at a dosage rate that does not exceed label rates when used singly for the same pests on the same crop.
- The label on any one of the products does not explicitly instruct against such a mixture.

Compatibility is another consideration when tank mixing. Physical incompatibility may occur because different formulations are added in the improper sequence or because the formulations are inherently not compatible. Although pesticides may mix physically, chemical or biological incompatibility may occur causing reduced efficacy or increased crop injury.

Adjuvants are inert ingredients that are added to pesticide formulations or tank mixes to increase the effectiveness of the pesticide's active ingredients. Examples of adjuvants are: wetting agents, emulsifiers, spreaders, stickers, penetrants, drift reduction agents, thickeners, buffers, and compatibility agents. Adjuvants should not be used unless they are needed. Some pesticides require specific adjuvants for optimal performance. The pesticide label should be followed when selecting and using adjuvants.

Pesticide Storage

The NCDOT adheres to the North Carolina Pesticide Storage Regulations which became effective January 1, 1984. General requirements of these regulations are:

- Pesticides shall be stored to prevent leaking.
- Formulated pesticide products must be stored in properly labeled containers with the common name, percentage active ingredient, EPA registration number, signal word and classification of uses.
- Pesticides shall not be stored in a manner that could cause the contamination of foods, feeds, or other materials.
- Pesticides must be stored to prevent unauthorized access.
- Pesticides must be stored in a dry ventilated area.
- Pesticides must be stored away from combustible materials.

In addition to the requirements of the North Carolina Pesticide Storage Regulations, each Division is equipped to minimize hazards to human health and the environment from fires, explosions, spills or any other unplanned release of pesticides to air, soil or surface water. Personnel within each Division keep accurate records of pesticide inventory and pesticide needs in order to keep a minimal quantity of pesticides in storage at any one time. The pesticide storage facilities are periodically inspected by Roadside Environmental Unit personnel. Empty pesticide containers are triple rinsed or pressure rinsed with the rinsate going into the spray tank. Plastic pesticide containers are retained for recycling. To this date analysis of containers submitted for recycling by NCDOT has not revealed the presence of pesticide residue. The recycled containers are processed into plastic drain pipe only and are approved for NCDOT use.

Summary

Integrated Pest Management (IPM) and, more specifically, Integrated Roadside Vegetation Management (IRVM), are used to manage vegetation by applying information, communication, technology, planning and research. An effective IRVM program improves safety for the public and employees, satisfies long range economic goals, maintains or improves environmental quality, provides aesthetically pleasing facilities, and improves public relations.

The zone management concept is used to communicate prescribed levels of maintenance and to prioritize resources. The number one priority for the vegetation manager is providing SAFE transportation corridors for the traveling public by utilizing cost-effective methods.

Use of Bermuda Grass repealed by Session Law 1999-29.

[LS-9] USE OF BERMUDA GRASS

The Division of Highways is prohibited from using Bermuda grass in seeding operations except under conditions described in G.S. 136-18.1, as follows:

§ 136-18.1. Use of Bermuda grass.

The use of Bermuda grass shall be restricted to sections of the highway where the abutting property is not in cultivation, except where the Department of Transportation has written consent of the abutting landowner. In long sections of woodland or wasteland sufficiently distant from cultivated areas, Bermuda grass may be used. The Department of Transportation and its employees shall use every reasonable effort to eliminate Bermuda grass heretofore planted on the shoulders of the highways through cultivated farm areas. (1945, c. 992; 1957, c. 65, s. 11; 1973, c. 507, s. 5; 1977, c. 464, s. 7.1.)

GENERAL ASSEMBLY OF NORTH CAROLINA
SESSION 1999

SESSION LAW 1999-29
SENATE BILL 27

AN ACT TO REPEAL THE PROHIBITION AGAINST THE DEPARTMENT OF TRANSPORTATION USING BERMUDA GRASS ALONG CERTAIN ROADS.
The General Assembly of North Carolina enacts:

Section 1. G.S. 136-18.1 is repealed.

Section 2. This act is effective when it becomes law.

In the General Assembly read three times and ratified this the 12th day of April, 1999.

s/	Marc Basnight President Pro Tempore of the Senate
s/	James B. Black Speaker of the House of Representatives
s/	James B. Hunt, Jr. Governor

Approved 2:17 p.m. this 22nd day of April, 1999