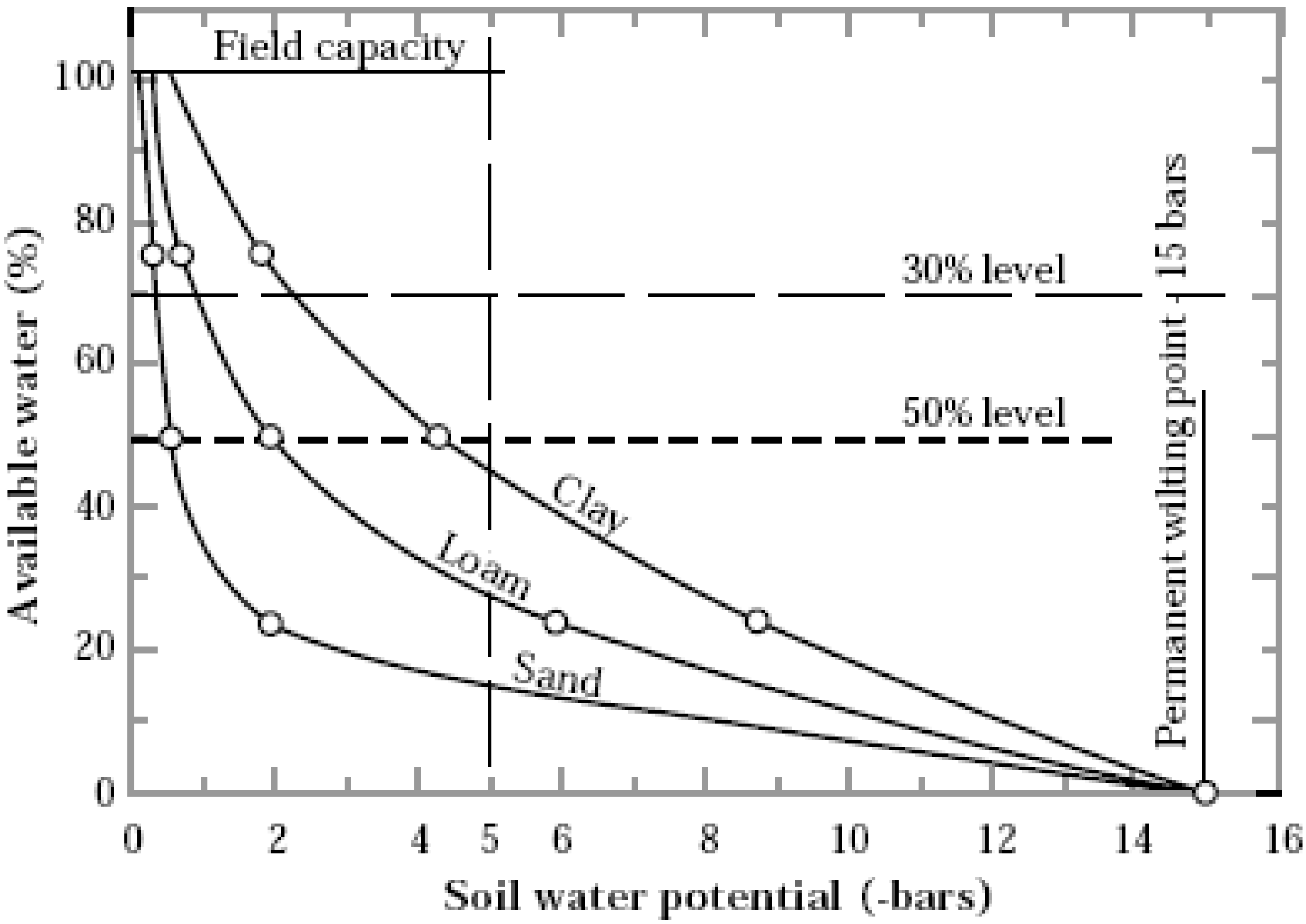

Figure NC2-2 Representative Soil moisture release curves for three soil groups

2c - Permeability

Soils can be viewed as a permeable medium in which air and water can move within and through the medium. Permeability is the quality of the soil that enables it to transmit gases and liquids within and through the medium. Generally, there is a concern for the rate at which water can move into or out of the soil. It should be noted that other liquids, such as oil or gasoline, may also move through a permeable medium such as soil. Often, saturated hydraulic conductivity will be confused with or used interchangeably with permeability. They are similar, but different terms. Permeability is a characteristic of a permeable medium that is based on mean grain diameter of the particle, grain shape, packing order, and other factors. Permeability affects the rate of movement of all gasses and liquids in that porous medium and is generally given as a length squared term, such as ft^2 or cm^2. (Warren Wessman Jr., John W. Knapp, Gary L. Lewis, and Terence E. Harbaugh, Introduction to Hydrology, 1977, pg 300)

Hydraulic conductivity is generally used in reference to the movement of water in a porous medium such as soil. It is the rate at which water will move through a soil under a driving head. Hydraulic conductivity is related to soil permeability, but also considers the properties of the liquid being transmitted through the soil or porous medium, and the state of saturation.

Generally, the saturated hydraulic conductivity, of water in a soil at a specific depth, is the property most often measured during the investigation of a specific field site or location. This term, saturated hydraulic conductivity, is a specific state within the soil where it is saturated and the hydraulic conductivity is determined for that state. Hydraulic conductivity is a term that applies to both saturated and unsaturated water movements within the soil. For example, there will be unsaturated movement of water from a subsurface water table upward into the drier soil above. This movement upward can supply plant available water to a plant root system above the water table and is therefore important in sub-irrigation systems.

The saturated hydraulic conductivity of a soil, shown in NRCS soils reports, is based on the most restrictive layer in the soil. The saturated hydraulic conductivity of soils may be separated into water movement rate classes as described by the terms listed in Table NC2-1.

Table NC2-1: Relative Water Movement Rate Class for Soils

Rate Term	Saturated Hydraulic Conductivity (in/hr)	Saturated Hydraulic Conductivity (µm/sec)
Very slow	<0.06	<0.42
Slow	0.06 - 0.2	0.42 – 1.41
Moderately slow	0.2 - 0.6	1.41 – 4.23
Moderate	0.6 - 2.0	4.23 – 14.1
Moderately rapid	2.0 - 6.0	14.1 – 42.3
Rapid	6.0 - 20.0	42.3 – 141.1
Very rapid	>20	>141.1

The saturated hydraulic conductivity, K_{sat} (µm/sec) for North Carolina soils are shown in the Physical Soil Properties report at the NRCS Soil Data Mart. These values can be converted to in./hr. if desired. The conversion equation would be 1 in/hr = 25400 µm/3600 sec = 7.0555 µm/sec.

2d - Intake Rate

Intake rate is a measure of soil's capacity to absorb irrigation water (or rainfall) from the surface, and move it into and through the soil profile. It is an expression of several factors, including infiltration and percolation. The term, “basic intake rate” is the rate at which water moves into soil after infiltration has decreased to a low and nearly constant value.

Infiltration is the downward flow of water from the surface through the soil. Water enters the soil through pores, cracks, worm and decayed root holes, and cavities introduced by tillage. Surface sealing and crusting can restrict or reduce infiltration. This surface sealing effect can be reduced by vegetative or mechanical (usually mulch) covers which protect the soil surface from raindrop impact energy.

Percolation is the movement of water through the soil profile. In order for irrigation water to be effective in replenishing the soils water supply, it must be able to move through the profile, or percolate, to a predetermined irrigation depth. The crop rooting zone generally sets the irrigation depth that is targeted for moisture replenishment. The percolation rate is governed by the permeability of the soil or its hydraulic conductivity. Both terms (see previous section on permeability) are used to indicate the ease with which water can move within a soil medium.

The amount of moisture already in the soil greatly influences the rate at which water enters the soil. The soil takes in and absorbs irrigation water or rainfall rapidly when water is first applied to the field surface and the soil is at less than saturation. As the irrigation application or rainfall continues, the rooting zone gradually becomes saturated and the intake rate decreases until it reaches a nearly constant value.

The intake of any soil is limited by any restriction to the flow of water into or through the soil profile. The soil layer with the lowest transmission rate, either at the surface or in the rooting zone below it, usually determines intake rate. The most important general factors that influence intake rate are the physical properties of the soil and, in sprinkler irrigation, the plant cover. But for any given soil, other factors may affect the intake rate, such as surface sealing, hard pans, frosting, very hot temperatures, salts, organic matter, dispersiveness, worm activity, and so on.

Since so many factors affect the water intake, it is not surprising that it varies so much among soils. Furthermore, the intake characteristics of a given field vary from place to place within the field, from irrigation to irrigation, and from season to season. The intake characteristics that must be considered in sprinkler irrigation design differ from those for other surface irrigation methods.

Actual measured intake rates are unavailable for North Carolina soils. Intake rates are estimates based on the characteristics of the top two feet of the soil. If the soil has a water table within two feet of the surface, the intake rate is assigned as if the soil is drained. Typically, for a well-drained soil with good cover and no clayey or restrictive subsoil, the intake rate is estimated at 2.0 in./hr (14 µm/sec). Note that this soil intake rate is not the same as the irrigation application rate, which is discussed in the following section. For other soil types, consult with a soil scientist to determine an intake rate value.

2e - Irrigation Water Application Rates

The Irrigation Water Application Rate (IAR) is the rate at which water is applied to a field by an irrigation system in inches per hour (in/hr) or micro meters per second (µm/sec). The IAR will be less than the soil intake rate and should not cause runoff to occur at any time during the irrigation cycle. Generally a dry soil will begin the irrigation cycle with a high surface infiltration rate and can easily adsorb irrigation water, but later when a soil is at or near field capacity, surface infiltration rates will decline and runoff may occur. The IAR is an average rate with areas that are above it and a portion of the field below this average. Slope also increases the likelihood of runoff from a field for a given soil intake rate under irrigation.

The rate at which irrigation water can be applied to a field soil depends on many factors, including, but not limited to the following:

a. The time required for the soil to absorb the calculated depth of application without runoff for the given conditions of soil, slope, and cover. The depth of application divided by this required time is the maximum application rate. The depth of application varies with crop type and associated soil rooting zone with consideration given to the soil and any restrictions therein.

b. The minimum application rate that will result in reasonably uniform distribution and satisfactory efficiency under prevalent climatic conditions.

c. The desirable time for applying the required depth of water considering efficient use of available labor and the other operations on the farm.

d. The application rate adjusted to the number of operating sprinklers using the most practical layout of lateral and main lines.

In general, the selected irrigation water application rate should fall somewhere between a minimum value of 0.2 in./hr (1.4 μm/sec) and a maximum of 1.0 in./hr (7 μm/sec). Irrigation application rates less than 0.2 in./hr (1.4 μm/sec) may have distribution uniformity issues. Irrigation application rates greater than 1.0 in./hr (7 μm/sec) may have excessive runoff issues. Maximum irrigation water application rates are given for most North Carolina soil/crop combinations in Tables NC6-1 through NC6-4 and additional discussion can be found accompanying these tables in Chapter 6.

2f - Slope

Slope refers to the incline of the surface of the soil area. A simple, or single slope is defined by its gradient, shape, and length. Slopes may also be defined as single or complex depending on the nature of the area. Soil slope is expressed in terms of a percentage. It is the difference in elevation in feet for each 100-feet horizontal. A soil inclined at 45 degrees has a slope of 100 percent since the difference in elevation of two points 100 feet apart horizontally is 100 feet.

Soil slope and intake rate are important factors in determining runoff rates. However, runoff should not be allowed during an irrigation event. Adjustments should be made to the irrigation equipment or management strategy so that there is little to no runoff. Extreme slopes should not be irrigated since there is such a high potential for substantial runoff losses. If a tractor cannot safely maneuver on a slope, it probably should not be irrigated. Any slope greater than 3% (3 feet of drop in 100 feet of run) may require special measures to address the increased runoff potential, sprinkler pressure drops, and any other negative effects. If irrigation is necessary on steeper slopes (>5%), great care should be exercised by the designer to control runoff and other negative impacts to the irrigation system.

2g - Wetness

Wetness problems are generally found to cause equipment passage issues for a farmer and/or poor crop growth. Wetness is expressed as a function of soil drainage and depth to water table. Internal soil drainage is a natural condition of the soil that refers to the frequency and duration of periods when the soil is free of saturation. For example, in well drained soils the water is removed readily but not rapidly; in poorly drained soils the root zone is waterlogged for long periods unless artificially drained. In excessively drained soils, water is removed so completely that most plants suffer from lack of water.

Table NC2-2. Drainage Classes of Soils

Drainage Class	Abbreviation
Very poorly drained	VP
Poorly drained	P
Somewhat poorly drained	SP
Moderately well drained	MW
Well drained	W
Somewhat excessively drained	SE
Excessively drained	E

Except for very young soils, the natural soil drainage conditions are reflected in soil morphology. The drainage class shown for the various soils is the drainage that existed during the development of the soil as opposed to altered drainage as the result of artificial drainage. Table NC2-2 lists classes (with their abbreviations) to define natural soil drainage in broad terms.

High water table is defined as the top of the zone of saturation at the highest average depth elevation during the wettest season. It persists in the soil for more than a few days. The depth to water table is given for each soil in the Water Features report in the NRCS Soil Data Mart. Refer to a soil scientist or engineer, who can usually determine the seasonal high water table for a given farm field or location.

The presence of a saturated zone (water table) is a prime factor in determining soils adaptability for irrigation. If a saturated zone is at a shallow depth, a hazard always exists that heavy rains can raise the saturated zone to depths shallow enough to slow or inhibit plant growth. Thus, soils with wetness limitations are given different considerations than other similar soils that do not have a wetness limitation.

2h - Surface Texture, Drainage, and Restrictive Feature

Table NC2-3: Soil Texture Abbreviations

Soil Texture	Abbreviation
Sand	S
Coarse sand	COS
Fine sand	FS
Loamy coarse sand	LCOS
Loamy sand	LS
Loamy fine sand	LFS
Coarse sandy loam	COSL
Sandy loam	SL
Fine sandy loam	FSL
Very fine sandy loam	VFSL
Loam	L
Silt loam	SIL
Clay loam	CL
Sandy clay loam	SCL
Silty clay loam	SICL
Silty clay	SIC
Sandy clay	SC
Clay	C
Muck or peat	MK or PT
Additional Textural Modifiers	
Channery	CN
Gravelly	GR
Shaley	SH

<u>Surface Texture</u>

Surface texture is displayed in the Engineering Properties report in the NRCS Soil Data Mart, for all soil series. The abbreviations in Table NC2-3 are used to describe soil texture.

<u>Drainage</u>

Land to be irrigated should be well drained. If the land is not naturally well drained, adequate surface and subsurface drainage should be provided. Otherwise, a large rainfall event following an irrigation cycle may cause crop damage.

<u>Restrictive Features</u>

Certain soil features affect design, layout, construction, management or performance of an irrigation system. Those features important in design and management of most irrigation systems are wetness or ponding and the need for drainage, flooding, available water capacity, intake rate, permeability, susceptibility to wind or water erosion, and slope. Soil features that influence construction are large stones and depth to bedrock or cemented pan. The features that affect performance of the system are rooting depth, amount of salts or sodium, and soil acidity. These properties, limits, and restrictive features are shown in Table NC2-4. Particular soils with restrictive features are displayed in the Engineering Properties, Physical Properties, and Irrigation reports in the NRCS Soil Data Mart or the NRCS Web Soil Survey (both are discussed in a previous section on internet access to Soil Surveys).

Table NC2-4. Irrigation Restrictive Features

Property	Limits	Restrictive Factors
Fraction >3 in. (wt. %)[1/]	>25	Large Stones
Depth to High Water Table (ft)	<3	Wetness Ponding
Available Water Capacity (in./in.)[1/]	<0.10	Droughty
USDA Texture (Surface Layer)	S, FS, VFS, LS, LFS, VFSL	Fast Intake
USDA Texture (Surface Layer)	SIC, C, SC	Slow Intake
Wind Erodibility Group	1, 2, 3	Soil Blowing
Permeability (in./hr.) - (0-60")	<0.2	Percs Slowly
Depth to Bedrock (in.)	<40	Depth to Rock
Depth to Cemented Pan (in.)	<40	Cemented Pan
Fragipan (Great Group)	All Fragi	Rooting Depth
Bulk Density (g/cc) - (0-40")	>1.7	Rooting Depth
Slope (%)	>3	Slope
Erosion Factor (K) - (Surface Layer)	>0.35	Erodes Easily
Flooding	Occasional or Frequent	Floods
Sodium Absorption Ratio (Great Group)	>12 (Natric, Halic)	Excess Sodium
Salinity (mmho/cm)	>8	Excess Salt
Soil Reaction (pH)	<5	Too Acidic
-------------	None of Above	Favorable

1/ Weighted average to 40 inches (101.6 cm).

Chapter 3 (NEH 652.0308) North Carolina NRCS Irrigation Guide Supplement - Crops (in North Carolina)

The primary crops irrigated in North Carolina are horticulture crops, corn, cotton, pastures, peanuts, small grains, sorghum, soybeans, strawberries, tobacco, turfgrasses, and vegetables. Low fertility, low or high pH, and/or an imbalance of nutrients are often the limiting production factors on irrigated land. A well-fed plant uses water more efficiently than a plant deprived of nutrients. The irrigator should monitor soil moisture, control weeds and pests, plant high quality seed of adapted varieties, and use timely operations. Weeds, insects, and diseases can be a greater problem for irrigated land than for non-irrigated farm land.

Small grains are best suited to medium texture soils. Peanuts and most pasture plants are best suited to moderately coarse texture soils. Most vegetables do well on coarse textured soils. Alfalfa, tobacco, corn, cotton and soybeans will perform well on most deep, well drained, medium, and coarse textured soils when irrigated and fertilized properly.

Computer modeling with irrigation management software has shown that a winter cover crop should be used with a waste water irrigation system in order to increase crop utilization of fall, winter, and spring irrigation applications. Irrigated waste water is often applied in the fall/winter/spring periods which generally last four to five months in North Carolina, and sometimes longer in the mountain regions. This fall/winter/spring period is outside of the normal growing season of most harvested crops. A cover or winter crop can grow later into the fall and starts growing earlier in the spring. Irrigation applied waste water must be consumed by growing plants and is not allowed to be lost in runoff or deep percolation below the rooting zone. Soils are often at maximum plant available water in the spring, which limits the irrigation potential. Use of Irrigation Scheduling accounting methods (computer models or spreadsheets) is needed to properly schedule waste water irrigation applications during the spring time.

Crop residue or vegetative cover should be maintained on the surface to keep soil loss within the allowable limits for irrigated soils. At the outer portions of some center pivot irrigation systems, the application rate may exceed the soil water intake rate. Leaving crop residue on the surface can minimize this condition. Also minimum tillage will improve or maintain soil water intake rates. Cover crops (usually small grains) are essential to control wind and water erosion on many soils, especially in the southeastern Coastal Plains and Sandhills regions of North Carolina.

3a - Critical Crop Growth Periods

For optimum production and the most efficient use of water, plants must have ample moisture throughout the growing season. For most crops there are critical periods in the growing season when a high moisture level must be maintained for high yields. The critical period can best be defined as that time when soil moisture stress can most reduce yield in an otherwise healthy crop. This is not to say that it is the only time in the life of the crop that moisture stress reduces yield. It is the time when moisture stress has the greatest effect. If there is enough moisture for germination and for the development of an adequate stand, the critical moisture period is almost always in the latter part of the growing season during the reproductive growth stage. Although plants indicate moisture stress by various symptoms, yields will usually be reduced by the time the plant shows stress. Time and duration of irrigation should be determined by an accurate estimation of the soil moisture content and the remaining plant available water in the rooting zone. Critical moisture periods for North Carolina crops are shown in Table NC3-1.

3b - Crop Rooting Depth and Moisture Extraction

The effective root zone depth is the depth of soil used by the main body of the plant roots to obtain most of the stored moisture and plant food under proper irrigation. It is not the same as the maximum root zone depth. Application of irrigation water should be limited to an amount that will penetrate only the effective root zone depth. Applications in excess of this amount will result in waste of water and added pumping cost. Also, in the lighter textured soils, heavy applications may cause leaching of plant food beyond reach of the plant feeder roots.

It should be noted that some irrigators in North Carolina define the effective root zone as being the surface 12 to 18 inches of a soil for most crops. The NRCS uses a more national approach in the determination of the effective root zone, and thus may have larger values for crops as shown in Table NC3-1. It is recognized that managing the surface 12 to 18 inches will be very effective at scheduling and applying the proper amounts of irrigation water. However, using less effective root depth may cause a reduction in the irrigation application amount and an increase in the irrigation frequency. Therefore it is left to the irrigation designer and grower/user to determine the effective root zone that will be managed with a specific field and crop that are to be irrigated.

In uniform soils with ample available moisture, plants use water rapidly from the upper part of the root zone and slowly from the lower part. Most plants have similar moisture extraction patterns. The usual crop moisture extraction pattern for soils with a uniform texture is as follows: about 40% from the upper quarter of the root zone, 30% from the second quarter of the root zone, 20% from the third quarter, and 10% from the bottom quarter. Therefore, it follows that most crops will meet 70 percent of their moisture needs from the upper half of the effective root zone. Because of this pattern of water extraction, if 50% of the available water capacity (AWC) has been used, the upper portion of the root zone is most affected by the lack of moisture. This will make the upper 12 to 18 inches the most critical zone for a given crop and soil combination from an irrigation management view point.

The effective rooting depth of the crop determines the volume of the soil moisture reservoir to be managed by the irrigator. The effective rooting depth depends on the crop being grown and soil conditions. Table NC3-1 gives the normal effective rooting depth of common crops grown in deep soils. Shallow soils can limit the rooting depth of crops. This rooting depth restriction can be due to shallow depths to bedrock, gravel, acidity, soil with a hardpan, high water table, or any other restriction to root development. A minimum effective rooting depth as shown in Table NC3-1 should be available to support the crop. There may be occasions where field conditions indicate that effective root zone depth other than those listed may be more appropriate. The proper effective root zone depth can be determined in the field by observation and measurement. If moisture conditions and growth period have been sufficient to develop normal rooting characteristics, the effective root zone depth may be determined by digging a hole alongside the plant and carefully tunneling back underneath the plant to expose the hair like moisture feeder roots. The depth to which two or more rootlets are noted per six square inches of exposure indicates effective moisture utilization. Determination of the moisture content of each layer encountered can also indicate the moisture extraction pattern.

3c - Plant Moisture Stress and Limited Irrigation

Many factors contribute to the need to limit irrigation. These factors include declining ground water supplies, salt-water intrusion, increases in pumping cost and disease control. For any crop, there is a point where further application of irrigation water cannot be justified economically. Profit may be maximized by limiting irrigations to the particular crop's critical moisture characteristics in lieu of trying for maximum yields by maintaining a high soil-moisture level throughout the growing season.

Plant growth is a very complex process that can be impacted by many external factors such as pests, disease, soil alkalinity or acidity, plant available water, plant nutrient availability, and soil toxicity levels (salts, heavy metals, etc.). However, some generalities can be made in regards to plant response to water related stresses. It should be noted that this does not hold true for every year due to the complex interactions that govern plant growth. Plant moisture stress is any period during the plant’s growing season when its water needs are not met. Plants are generally most sensitive to soil plant-available moisture deficits during the flowering and fruiting or grain filling stages of its growth cycle. Critical plant moisture stress periods for some of the major crops of North Carolina are discussed in the following list and are shown in Table NC3-1.

Alfalfa

Alfalfa needs adequate soil moisture for high production. The most critical need for moisture is at the start of flowering and after cutting. Irrigations should be scheduled 3 to 5 days after each cutting, if possible. The soil should be brought to field capacity 2 to 3 feet deep depending upon soil type. The spring, before cutting, and in the fall are the most critical periods of growth in the maintenance of a highly productive stand. Fall growth should be sufficient to permit the production and storage of large quantities of reserve food in the crown and roots to reduce winter kill of plants. Irrigation scheduling computer programs or spreadsheet scheduling type methods is recommended for irrigated alfalfa crops since water stress results in reduced ET and usually reduced yields. Irrigation scheduling should also reduce over-application of water, which increase costs and will not increase yields or make up for a previous stress period.

Blueberries

Irrigation water should be applied according to the water needs of the blueberry. The root system on a blueberry plant will begin to grow before the top. Therefore, if the winter has been dry, it is important to irrigate thoroughly 3 to 4 weeks before the top starts to grow. From bloom until harvest is a critical moisture period for blueberries. After harvest the blueberry continues to make new growth to support the next season's crop. Water and adequate fertility are critical during this stage of growth.

Corn

The use of irrigation for growing corn in North Carolina has increased steadily over the past 30 years. The major advantages of irrigation in corn production come from an increase in yield potential and more consistent yields over time. Comparisons of commercial fields over a seven year period found that irrigated corn fields yielded over 215 bushels per acre on average; while non-irrigated fields on the same farm over the same period averaged only 140 bushels per acre. Furthermore, the irrigated yields during the seven years ranged from 194 to 245 bushels per acre; while non-irrigated yields ranged from 13 to 204 bushels per acre. (R. W. Heiniger, NC Corn Production Guide-Ch 4-Irrigation and Drought Management, NC State Crop Science Department, 7/26/00)

Corn is a shallow rooted plant until it nears tasseling. Water requirements for corn, whether from rain or irrigation are as follows:

(1) about 1 inch of water every 12 days for the first 40 days of growth,
(2) about 1 inch every 5 to 7 days between 40 days and tasseling, and
(3) 1 inch every 3 to 4 days from tasseling to maturity.

Total irrigation and/or rainfall requirement for corn during the first 60 days is about 7.7 inches. Demand for water from 60 days to maturity is high, totaling about 13.0 inches, and is especially high and important during the tasseling and grain filling period. The grain filling period is the 3 weeks following tasseling.

Corn should never be allowed to wilt since yield losses will probably have already occurred once the wilting is evident. A drought period of a few days can significantly reduce yields, especially if occurring during critical growth stages. Under limited irrigation the critical period for irrigation is from the tassel stage through grain filling.

Cotton

Cotton is a drought tolerant plant. However, timely irrigation increases yields considerably. Quite often, preplant irrigation will supply adequate moisture up to the blooming period. The next irrigation should be at the early bloom stage. The first bloom through boll maturing stage is the most critical period for cotton. Adequate moisture is needed at this time to maintain high yields. An additional irrigation may be needed during the boll forming stage. High moisture levels after the boll forming stage will delay the crop and increase the amount of immature fibers.

Grapes

Adequate soil moisture is critical for grapes during the first year after planting. Many first-year plants die from moisture stress when there is no irrigation system. The most critical moisture period is during the sizing of the fruit. Applications of 1 inch of water every week during late April, May and early June should be sufficient for both old and young vines when rains do not occur. Extended periods of drought are common in North Carolina during the summer and will also benefit from irrigation. Competition with weeds may also stress grapes and must be controlled.

Pasture Grasses

Irrigation of pastures in eastern North Carolina is often associated with the disposal of animal wastes. Animal waste irrigation is not addressed specifically in this guide. There are nutrient concerns, state permits, and other waste-specific issues that must be addressed with a waste irrigation system design in North Carolina.

In droughty locations and during dry years inadequate soil moisture may limit production of warm season grasses during the late spring and early summer. Where economically feasible apply 0.6 to 1 inch of irrigation water per week during this period to improve forage production.

Cool season grass in the coastal plains may fail to establish in some years due to poor soil moisture conditions in November and December. Where economically feasible, apply 0.6 inches of water per week, when rains do not occur. Cool season forages are generally not recommended in eastern North Carolina, especially without supplemental irrigation during the establishment period.

To reduce opportunity of soil compaction on irrigated pastures, livestock should be excluded during and after irrigation until adequate soil surface dry-out occurs.

Peaches

The fruit growth pattern of peaches is referred to as a double sigmoid growth curve that brings fruit to maturity in 70 to 120 days. Depending upon the variety, there is an initial period of rather rapid fruit enlargement followed by a pit hardening period during which fruit enlargement is slight. Finally the flesh of the fruit thickens and total enlargement is very rapid immediately prior to maturity. It is during this final swell that moisture stress can reduce yield the most. During the last 30 days before harvest, about two-thirds of the final volume is attained.

Researchers have not agreed on the proper Management Allowable soil-water Depletion (MAD) to maintain for peaches, but data on cling peaches show that the growth rate is reduced when the MAD in the upper two feet root depth was less than 50%, especially during final swell. See chapter 4 for a discussion of MAD and its use in irrigation system management.

Several agricultural water-related precautions should be considered. Practically all peach production locations require irrigation. Water may be applied through micro-sprinklers under the tree, or by overhead systems. Drip irrigation is generally not used with peaches. Compared to any other form of irrigation, overhead irrigation is more likely to spread pathogens into the tree canopy. Water used as a means of frost protection must be potable (safe for drinking).

The quality of source water is a key concern. Surface waters, such as lakes, ponds, streams, etc., should be tested. The presence of the bacterium Escherichia coli (*E. coli)* is an indicator of fecal contamination. Do not irrigate from a pond or lake if animals were grazing nearby or had access to the water.

Underground (well) water is less likely to have fecal contamination, although such situations have been documented. Pesticide residues and heavy metals are generally of more concern in underground sources of water.

Peanuts

Only a small percentage (less than 20 percent) of North Carolina peanuts is grown under irrigation. The majority of the peanuts grown in North Carolina is the Virginia-type and is targeted primarily for the in-shell market. (Rick L. Brandenburg, David L. Jordan, Barbara B. Shew, John W. Wilcut, and Stephen J. Toth, Jr. (ed.), Crop Profile for Peanuts in North Carolina, North Carolina State Univ., 2005)

Peanuts respond well to irrigation with the greatest increases in yields on light textured sandy soils. During the growing season, peanuts will require from four to eight inches of supplemental irrigation. Usually, irrigation commenced at no more than 50 percent MAD during the peak growing season will result in maximum yields. This will require an application every 4 to 5 days on light sandy soils and every 6 to 8 days on heavier soils. Do not exceed 1 inch per application for light sandy soils whereas 1.5 inches may be necessary for heavy soils.

If water supplies are limited or restricted, probably the most important irrigation is preplant if moisture is not adequate at planting time. One-half to three-fourths inch of water applied just before planting has proven to be very effective in producing good plant population. Growers should also irrigate during the main fruiting period.

Pecans

Irrigation is strongly encouraged to maximize pecan production in North Carolina. Low-volume irrigation systems, such as drip or micro-sprinkler systems have been very effective at maintaining tree growth and productivity. (Micael L. Parker and Kenneth A. Sorensen, Growing Pecans in North Carolina, AG-81, NC Cooperative Extension Service)

Irrigation is very important on newly planted pecan trees. A water ring should be maintained around the tree for at least a year and water applied every 7-10 days during the growing season in the absence of suitable rainfall. Microsprinklers work well for this application. Under no circumstance, should the young trees be allowed to wilt. Critical moisture periods for older trees are during nut forming and nut filling.

Small Grains

Moderate to high small grain yields can be obtained with limited quantities of irrigation water. One method of achieving this goal is to delete the preplant irrigation when a good stand can be obtained without it. Spring irrigation can be delayed until the boot stage unless the small grains begin to show moderate soil moisture stress. Usually the most economical irrigations are at preplant and boot stage.

Sorghum

Grain sorghum is a drought tolerant plant that responds well to limited irrigation. Probably the most important irrigation is preplant if soil moisture is not adequate. In addition to preplant irrigation, be sure to irrigate at boot to early heading stage of growth.

Soybeans

Inadequate moisture during germination and early seedling growth can prevent establishment of a uniform stand. If there is not sufficient moisture in the surface layer to stimulate the germination of the seeds, it is desirable to apply a preplant or pre-emergence irrigation. Once a good stand is established soybeans can tolerate short droughts up until bloom with minimum adverse effects. The soybean uses water most in the reproductive phase. Particularly during pod growth and seed fill, lack of water will significantly reduce final soybean yields. Water stress in the early reproductive stage (flowering) may result in higher than normal levels of flower abortion, leading to reduced numbers of pods per plant. Moisture deficiencies during the seed filling stage will result in smaller than normal seeds, tending to lower overall yields. If irrigation is limited, then supplemental water at mid to late flowering will help produce the greatest increase in yield per unit of water applied.

Strawberries

The strawberry plant is shallow-rooted with 80 to 90 percent of its roots in the top 12 inches of soil. In the plastic mulch cultural system, adequate moisture is necessary in the surface soil to permit transplants to set and make maximum growth. Irrigation is needed at transplanting, during fruit bud formation and fruit enlargement. Usually, irrigation commenced at no more than 50 percent MAD or less appears to be adequate.

Tobacco

Irrigation of tobacco at transplanting will improve plant survival and early growth and enable weaker plants to initiate growth similar to the stronger plants. An analysis of moisture uptake by tobacco during the first three weeks after transplanting has shown the main moisture supply to be in the top 6 inches of soil and during the next two weeks it is in the top 12 inches. The top 18 inches of soil supplies most of the water for the plants for the remainder of the growing period. This being so, it is suggested that the soil be irrigated to a depth of 6 inches during the first three weeks, 12 inches during the next two weeks, and 18 inches during the remaining period of growth. Under limited irrigation, the critical time other than at transplanting is when the tobacco is from the knee-high stage until the top leaves are filled out.

Turfgrass

Many turfgrass species can be grown in North Carolina. Determining which one is best for a particular situation is based on several factors. Many soils in eastern North Carolina are sandy in nature which makes a deep-rooted grass desirable. If properly maintained, bahia grass and St. Augustine grass provide deep rooting and therefore increased drought resistance. Bahia grass can survive on natural rainfall whereas St. Augustine requires supplemental irrigation even during the winter months.

If the purchaser is willing to allot more time, energy and economic resources to turf maintenance, a finer-texture species is suggested such as one of the Bermuda grass or zoysia grass cultivars. In addition, centipede grass is available for those regions with heavier, acidic soils, such as the piedmont area of North Carolina, and for those with less resources and time available for upkeep.

Supplemental irrigation is necessary to maintain a desirable turfgrass. For North Carolina's sandy soils, in the absence of rain, irrigation will be necessary a minimum of one to two times weekly during summer to prevent stress on the turf. In most North Carolina areas, 0.75 inch of water should be applied per irrigation. Irrigation with 0.75 inch will wet the entire root zone without leaching nutrients from the soil profile. Do not irrigate frequently (i.e. daily) with light rates of water as this encourages shallow turf rooting as well as increased pest activity. Irrigation with 0.75 inch should be applied when the turf shows signs of drought stress (i.e. wilting or bluish-grey color). Once applied, wait until drought symptoms reappear before watering again.

Irrigate in early spring when day temperatures are warm but night temperatures are still cool. Turfgrass crowns coming out of winter dormancy are especially susceptible to dehydration at time of 'green-up'. Higher mowing heights and adequate soil potassium will increase the drought tolerance of turfgrasses.

Irrigation is required for turfgrass to produce quality sod for resell. Ample water of good quality should be a priority during the planting stage.

Vegetables

Vegetables are 80-95 percent water. Since they contain so much water, their yield and quality suffer very quickly from drought. Thus for good yields and high quality, irrigation is essential to the production of most vegetables. If water shortages occur early in the crop's development, maturity may be delayed and yields are often reduced. If a moisture shortage occurs later in the growing season, quality is often reduced even though total yield is not affected. Most vegetables are rather shallow rooted and even short periods of two to three days of stress can hurt marketable yield.

Most vegetables have small seeds which are planted 0.75 inches deep or less. When seeds are planted shallow, the upper layer of soil can dry rapidly leaving the seed without sufficient moisture to complete germination. When this happens, no stand or at best a poor stand will result. An irrigation of 0.5 inch immediately after planting should be applied to settle the soil and to start germinating seeds. For larger seeded crops, irrigation a few days prior to seeding is desired. If seed is slow to emerge, then irrigations of 0.50 inch should be applied as needed. This should keep the area around the seed moist until seedlings emerge. Irrigation is a valuable tool in getting good, uniform stands which ensure high yields. Good uniform stands also mean uniform harvest dates and more efficient production.

Vegetable transplants also require irrigation and adequate water cannot be applied to dry soil with a transplanter. A light irrigation of 0.5 to 0.75 inch will help transplants get firmly set in the soil and will provide a ready supply of water to young broken roots in the small root system of the transplants.

Irrigation at planting time can hasten seedling emergence. If 0.5 inch of irrigation is slowly applied, either with low rates or by turning the irrigation system off long enough to allow the water to soak in, crusting can be reduced and the stand improved.

Most vegetables that are fruits, such as tomatoes and peppers, are injured by wide fluctuations in soil moisture. These contain large amounts of water and depend on this water for expansion and growth. When soil moisture is allowed to drop below the proper level, the fruit does not expand to produce maximum size before it ripens, thus reducing yield. If moisture is allowed to fluctuate too much, blossom end rot can occur and fruit is no longer useable.

If moisture fluctuation occurs during the fruit expansion stage, fruit cracking will occur. Fruit cracking usually occurs when inadequate water has been applied and then heavy rains bring too much water. The best way to prevent fruit cracking is a steady moisture supply. Second growth or knobs in potatoes are also caused by soil moisture fluctuations.

Additional information for crops, including some specialty crops, may be found on the internet at the website for North Carolina Cooperative Extension "http://www.ces.ncsu.edu/depts/".

Table NC3-1: Critical crop moisture periods and effective rooting depths

Crop	Critical Cropping Period	Normal Effective Rooting Depth Unrestricted-Inches	Min Effective Rooting Depth restricted-Inches
Apples	During final swell prior to harvest	Tree - variable	
Alfalfa	Early spring and immediately after cuttings	36	24
Blueberries	Transplanting and from bloom until harvest	24	18
Corn, grain	15 days prior to and 15 days after silking	36	24
Corn, silage	15 days prior to and 15 days after silking	36	24
Corn, sweet	From silking through ear formation	30	18
Cotton	During and immediately after bloom stage	36	24
Flowers, annual	Throughout growing season	6	6
Grain, small	Planting and 2 weeks before pollination through head formation	24	18
Grapes	Transplanting, and during fruit enlargement	60	36
Hay	Planting and just prior to harvest and for perennials, immediately after harvest		
Lespedeza Seed	Planting and during seed formation		
Pasture Grass	At planting and throughout summer	36	30
Peaches	During final swell prior to harvest	60	36
Peanuts	Nut enlargement stage	24	18
Pears	During final swell prior to harvest	tree	
Pecans	During nut set (Apr-May) and nut fill (Aug-Sept)	60	48
Sorghum, grain	From boot to flowering stage	36	24
Soybeans	Pod filling stage	30	24
Strawberries	Transplanting, prior to and during harvest and during fruit bud formation	12	10
Tobacco	Transplanting, knee high to bloom, during harvest	18	18
Turfgrass	Planting and throughout growing season	6	6

Table NC3-1: Critical crop moisture periods and effective rooting depths (continued)

Vegetables			
Asparagus	Crown set and transplanting	24	18
Beans, Dry-Snap	During and Immediately following bloom	24	18
Beans, Lima	During and Immediately following bloom	30	24
Beans, Pole-Green	During and Immediately following bloom	24	18
Beans, Soy	During and Immediately following bloom	24	18
Beets	During rapid root expansion	24	18
Beets, Sugar	During early growth and Root expansion	36	24
Brussels Sprout	Sprout formation	18	12
Cabbage	Last 3-4 weeks prior to harvest	18	12
Cabbage, Chinese	Throughout growing season	18	12
Carrot	Seed germination, root expansion	18	12
Cantaloupe	Flowering & fruit development	18	12
Cauliflower	Throughout growing season	18	12
Celery	Throughout growing season	18	12
Collards	Throughout growing season	18	12
Cucumber, Pickling-Slicing	Flowering & fruiting	18	12
Eggplant	Flowering & fruiting	18	12
Endive	Throughout growing season	6	6
Greens	From just prior to maturation and during harvest	18	12
Leeks	Throughout growing season	18	12
Lettuce	Throughout growing season	24	18
Melons, Water-others	At pollination and 2-3 weeks afterwards	36	24
Nursery Stock	Throughout growing season	varies	
Okra	From bloom through harvest	24	18
Onion	Throughout growing season to just prior to harvest	18	12
Parsnip	Root Expansion	24	18
Peas, Green-Southern	From bloom through harvest season	18	12
Peppers	1-2 weeks prior to bloom to 2-3 weeks prior to end of harvest	18	12
Potato, Irish	4 weeks prior to harvest	18	12
Potato, Sweet	During rapid root expansion	24	18
Pumpkin	During Fruiting	24	18
Radish	Continuous	12	6
Rhubarb	Leaf emergence	24	18
Rutabagas	Root expansion	18	12
Spinach	From just prior to maturation through harvest	24	18
Squash, Summer	From bloom through harvest season	24	18
Squash, Winter	From bloom through harvest season	24	18
Tomatoes	1-2 weeks prior to bloom to 2-3 weeks prior to end of harvest	24	18

3d - Salinity Tolerance

Salts originate from mineral weathering, inorganic fertilizers, soil amendments (e.g., gypsum, composts and manures), and irrigation waters. An additional source of salts in many landscape soils comes from ice melters used on roads and sidewalks. It is only when salts are present in relatively high amounts that plant growth is adversely affected.

North Carolina has a humid climate with coastal yearly rainfalls of 40 to 60 inches. The rainfall is somewhat evenly distributed with October through December receiving the smallest amounts. The fall to early winter is the period where limited rainfall availability may be an issue. Spring and summer often have drenching rains which can offset or reduce the impacts of salinity in irrigation water. Salinity is generally not an issue for North Carolina irrigators, but should be a consideration in some situations.

High levels of salt accumulation in the root zone of the soil may affect plant growth in several ways.

First, it decreases the availability of nutrients and water for easy and rapid uptake by plant roots. This could lead to the need for more frequent irrigation on "salty" soils even though less than 50 percent of the normally available water has been used in the root zone. Such plants are usually stunted and have a bluish-green color.

Second, plants may be affected by a direct toxicity of one or more of the constituents of the salt in the irrigation water. This is more likely to affect tree fruit than field or vegetable crops.

Third, after a certain amount of sodium has been absorbed on the clay particles, the soil tends to puddle very easily, becomes less permeable to air and water, and forms into hard lumps and crusts when dry. When and if this happens, the grower should consult Rutgers Cooperative Extension for powdered gypsum application rates, to counteract the excess sodium in the soil.

In Table NC3-2, vegetable, fruit, and field crops are grouped according to their salt tolerances. Table NC3-3 shows the number of permissible irrigations with salt (brackish) water between leaching rains for crops of different salt tolerances. The number of irrigations permitted should be decreased on heavier soils (silt and clay loams). If there is any evidence of severe leaf burning after one or two irrigations owing to excessive salt accumulation on the plant leaves, no more irrigations should be applied unless the failure to irrigate would result in greater loss than that due to burning of the crop.

TABLE NC3-2 SALT TOLERANCE OF PLANTS 1/		
Plants that can tolerate 2/		
Up to 8-16 Millimhos 3/, 5120 to 10,240 ppm (Good Resistance)	Only up to 4-8 millimhos 3/, 2560 to 5120 ppm (Moderate Resistance)	No more than 1-4 millimhos 3/, 640 to 2560 ppm (Poor Resistance)
FIELD CROPS		
Barley and rape	Rye, wheat, oats, sorghum, corn, soybeans, and sorghum (grain)	Field beans
FORAGE CROPS		
Bermudagrass and barley hay	Sweet clover, sorghum, sudangrass, alfalfa, tall fescue, wheat and oat hays, orchardgrass perennial ryegrass, vetch, smooth brome, soybeans, Proso millet, pearl millet, and Alsike clover	White clover, Ladino clover, and red clover
VEGETABLE CROPS		
Garden beets, kale, asparagus, and spinach	Tomatoes, broccoli, cabbage, peppers, cauliflower, lettuce, sweet corn, potatoes, carrots, onions, peas, squash, cucumbers, collards, radishes, and rhubarb	Radishes, celery, and green beans
FRUIT CROPS		
	Grapes, cantaloupe	Pears, apples, plums, peaches
OTHER CROPS		
Bermudagrass, Zoysia, creeping bentgrass American beachgrass (production of)		Red fescue, Ky. bluegrass, colonial bentgrass

1/ The information in this table were obtained from USDA Agricultural Research Service Publication ARS41-29, "Brackish Water for Irrigation in Humid Regions" 1960.
2/ Crops, plants, or trees are listed in order of increasing sensitivity.
3/ These figures represent the electrical conductivity (ECe) of the soil saturation extract, where 1 millimho equals approx. 640 ppm of salts.

TABLE NC3-3 PERMISSIBLE NUMBER OF IRRIGATIONS WITH BRACKISH WATER BETWEEN LEACHING RAINS FOR CROPS OF DIFFERENT SALT TOLERANCES 1/

Irrigation Water		Irrigations allowed between Leaching (heavy) Rainfalls		
Total Salts (ppm)	**Electrical Conductivity (millimhos per cm at 25° C)**	**Good Salt Tolerance**	**Moderate Salt Tolerance**	**Poor Salt Tolerance**
640	1		15	7
1280	2	11	7	4
1920	3	7	5	2
2560	4	5	3	2
3200	5	4	2-3	1
3840	6	3	2	1
4480	7	2-3	1-2	
5120	8	2	1	

1/ The information in this table was obtained from USDA Agriculture Information Bulletins Nos. 213 and 283.

Chapter 4 (NEH 652.0408) North Carolina NRCS Irrigation Guide Supplement - Water Requirements (for North Carolina)

General Issues for Water Supply Requirements

The first requirement for irrigation is an adequate supply of good quality water during those periods when the need for irrigation water is greatest. The number of acres which can be properly irrigated at such times is dependent on the available water supply. The water supply should be adequate to irrigate the intended area of crops during a prolonged dry period before serious crop damage occurs. When water supply capacity is limited, it is often better to irrigate fewer acres well than to irrigate more acres poorly.

In North Carolina the following recommendations (shown in Table NC4-1) are made with respect to the minimum water supply that should be available for each acre to be irrigated.

Table NC4-1: Recommended minimum irrigation water supply

Crop to be Irrigated	Wells or Streams	Ponds
Improved Pasture and Mixed Hay	5 – 7 GPM / ac	1.0 ac-ft / ac
Most Vegetable Crops and Tobacco	6 – 10 GPM / ac	1.0 ac-ft / ac
Most Field Crops and Clean Tilled Orchards	7 – 13 GPM / ac	1.3 ac-ft / ac
Orchards with Cover	9 – 16 GPM / ac	1.6 ac-ft / ac
Note: GPM is gallons-per-minute flow rate, and ac-ft is the storage volume in acre-feet of water		

In Table NC4-1 above, for the "Wells or Streams" column, the value of GPM has a range that is related to the number of hours per day that the irrigation system is operated. The lower GPM flow rate is for a system that is operated daily for 18 hours. Whereas, the larger GPM flow rate is for an irrigation system that is operated daily for 10 hours. Container grown nursery plants are not covered in the Table NC4-1 above. They require the greatest amount of water, up to 0.5 inches per day, and therefore would require a larger water supply.

The capacity, Q, of a system may be computed by the formula:

$$Q = \frac{(453 * A * d)}{FH}$$

Where: Q = discharge capacity in GPM
A = size of the irrigated area in acres
d = gross depth of application in inches
F = the days allowed for completion of one irrigation cycle
H = the actual hours of operation per day

Note that gross application depth, d, must take irrigation efficiencies into account by the following formula:

$$d = \frac{d_n}{E_a}$$

Where: d_n = net application in inches
Ea = application efficiency of the system in decimal form

In some areas of North Carolina deep wells are the most dependable source of irrigation water. Information concerning such wells can be obtained from local well drillers or the state geologist.

Ponds and reservoirs, used as sources of irrigation water, can have losses as high as 50 percent of the total capacity. Losses are generally in the form of seepage and evaporation. The pond or reservoir must be large enough to meet the irrigation demands and overcome the storage losses. It can be helpful to run a reservoir water balance model for a period of about 10 years of recent weather data to evaluate the storage capacity. Computer models such as the NRCS Technical Release 19 (TR19), Reservoir Operation (RESOP) computer program are suited for this type of analysis. A water supply should be able to meet maximum crop irrigation demands for at least 8 out of 10 years.

Upward flow of water from a water table can be used to meet part of or the entire seasonal crop water requirement. Reasonable estimates need to be made of the water supplied by a water table. Methods to predict upward soil-water flow rates (upflux) from a water table are given in the water table management software program DRAINMOD. Soil parameters required for this procedure may require field data to evaluate specific sites.

Determination of irrigation water needs requires a measurement or estimate for the rate of crop water use. Daily and weekly crop water use estimates are needed to schedule irrigation applications and determine minimum system capacities. Seasonal or annual water use estimates can be used to size irrigation reservoirs and to determine consumptive use permits. Therefore, a procedure to determine both short- and long-term rates of water use may be necessary. NRCS NEH, Chapter 2, Irrigation Water Requirements, describes the processes needed to determine crop evapotranspiration and irrigation water requirements for a crop, field, farm, and project.

Crops grown in North Carolina generally need about 6 to 10 inches of irrigation per year to supplement the natural rainfall during a growing season (NC Cooperative Extension Service, Pub. No. AG 452-4, Irrigation Scheduling to Improve Water- and Energy-Use Efficiencies, June 1996; NC State University, Tobacco Irrigation Costs for the Piedmont and Coastal Plains of NC, updated 2007; NC Cooperative Extension Service, Animal Waste Management Systems, Chapter 5: Proper Application of Liquid Animal Waste-Type A, Draft Copy, 1997). The amount of irrigation needed will vary with the crop, management goals, weather conditions, soil and location within the state. There will be wet years when little to no irrigation is needed. There will also be drought years when lower than normal rainfalls occur and more irrigation is needed.

Crop evapotranspiration (ET_c), sometimes called crop consumptive use, is the amount of water that plants use in transpiration and building cell tissue plus water evaporated from the adjacent soil surface. Crop evapotranspiration is influenced by several major factors: plant temperature, ambient air temperature, solar radiation (sunshine duration/intensity), wind speed/movement, relative humidity/vapor pressure, plant growth stage, canopy coverage, and soil-water availability. Daily, weekly, monthly, and seasonal local crop water use requirements may need to be determined. These data can be used for planning, designing, and operating irrigation systems and for making irrigation management decisions, such as determining when and how much to irrigate. Irrigation operating expenses can be very large and are generally associated with the amount of irrigation water that is applied. Irrigation scheduling will generally reduce the amount of over-applications and insure soil moisture is available when and where it is needed. The irrigator can easily recoup the small amount of time/cost needed to input data into an irrigation scheduling program or method by the increased water-use efficiencies and associated cost savings.

Seasonal water requirements, in addition to crop water needs, may also include water used for preplant irrigation, agricultural waste application, leaching for salt control, temperature control (for frost protection, bud delay, and cooling for product quality), chemigation, facilitation of crop harvest, seed germination, and dust control.

The NC Agriculture Cost Share Program and the federal USDA Environmental Quality Incentives Program (EQIP) offer financial assistance for water conservation and for water saving technology. These programs offer over forty approved best management practices for producers that contribute to water use reduction and efficiency. Improved water management often results in improved water quality as well as water savings. State and federal agricultural cost share and technical assistance programs recognize this connection and are giving more attention to water use efficiency and conservation.

4a - Direct Measurement of Crop Evapotranspiration

Direct measurement of crop evapotranspiration is generally used by research or regional weather stations, and is not often used by a single farm entity. Direct measurement methods generally use a lot of costly equipment to directly measure or determine crop evapotranspiration (ET_c). Direct measurement methods for ET_c include:

Aerodynamic method
Detailed soil moisture monitoring
Lysimetry
Plant porometers
Regional inflow-outflow measurements

All these methods require localized and detailed measurements of plant water use. Detailed soil moisture monitoring in controlled and self contained devices (lysimeters) is probably the most commonly used. Little long term historical data outside of a few ARS and university research stations are available. Use of lysimetry is discussed in more detail in NRCS NEH, Chapter 2, Irrigation Water Requirements. The use of soil moisture monitoring devices to monitor ET_c is described in NRCS NEH Section 15, Chapter 1, Plant-Soil-Water Relationships.

4b - Methods for Estimating Crop Evapotranspiration

More than 20 methods have been developed to estimate the rate of ET_c based on local climate factors. The simplest methods are equations that generally use only mean air temperature. The more complex methods are described as energy equations. They require real time measurements of solar radiation, ambient air temperature, wind speed/movement, relative humidity/vapor pressure, and crop parameters. The concept of a reference crop/surface was introduced to obviate the need to define unique evaporation parameters for each crop and stage of growth. These ET equations have been adjusted for reference crop ET with lysimeter data. Selection of the method used for determining local ET_c depends on:

Location, type, reliability, timeliness, and duration of climatic data;
Natural pattern of evapotranspiration during the year; and
Intended use of crop evapotranspiration estimates.

In the past, an open water surface has been proposed as a reference surface. However, the differences in aerodynamic, vegetation control and radiation characteristics present a strong challenge in relating ET_c to measurements of free water evaporation. Relating reference evapotranspiration (ET_0) to a specific crop has the advantage of incorporating the biological and physical processes involved in the evapotranspiration (ET) from a cropped surface.

Grass, together with alfalfa, is a well-studied crop regarding its aerodynamic and surface characteristics and is accepted worldwide as a reference surface. Because the resistance to diffusion of vapor strongly depends on crop height, ground cover, leaf area index (LAI) and soil moisture conditions, the characteristics of the reference crop should be well defined and fixed. To avoid problems of local calibration which would require demanding and expensive studies, a hypothetical grass reference can be selected. Difficulties with a living grass reference result from the fact that the grass variety and morphology can significantly affect the evapotranspiration rate, especially during peak water use. Large differences may exist between warm-season and cool-season grass types. Cool-season grasses have a lower degree of stomatal control and hence higher rates of evapotranspiration. It also may be difficult to grow cool-season grasses in some arid, hot, or tropical climates.

The NC State Climate Office (a source of climate data in North Carolina) and others have accepted the following definition for the reference crop surface: "A hypothetical reference crop with an assumed crop height of 0.12 m (4.7”), a fixed surface resistance of 70 s m-1 and an albedo of 0.23 (from Food and Agriculture Organization of the United Nations [FAO], Irrigation and Drainage Paper No. 56, Crop Evapotranspiration, by Richard G Allen, Luis S Pereira, Dirk Raes, Martin Smith)”. This reference surface closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. The requirements that the grass surface should be extensive and uniform result from the assumption that all fluxes are one-dimensional upwards.

With grass reference crop ET_0 known, ET estimates for any crop at any stage of growth can be calculated by multiplying ET_0 by the appropriate crop growth stage coefficient (K_c), usually displayed as a curve or table. The resulting value is called crop evapotranspiration (ET_c). The following methods and equations can be used to estimate reference crop evapotranspiration, ET_0. The methods are described in detail in NRCS NEH, Section 15, Chapter 2, Irrigation Water Requirements (1990). The crop coefficients should be based on local or regional growth characteristics. The following methods are recommended by the Natural Resources Conservation Service (NRCS).

(1) Temperature method:
- Food and Agricultural Organization of the United Nations (FAO) Modified Blaney-Criddle (FAO Paper 24)
- Modified Blaney-Criddle (SCS TR 21). See NRCS NEH, Section 15, Chapter 2, “Irrigation Water Requirements”, for more information on this method.

(2) Energy method:
- Penman-Monteith method (used by the NC State Climate Office)

(3) Radiation method:
- FAO Radiation method (FAO Paper 24)

(4) Evaporation pan method

The FAO Modified Blaney-Criddle, Penman-Monteith, and FAO Radiation equations represent the most accurate equations for these specific methods. They are the most accurately transferable over a wide range of climate conditions. These methods and equations are also