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Root Physiology and Management

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Several years ago I was in Rankin County, Mississippi looking at cotton fields with a group of local growers. I asked them for a shovel to dig up a plant and examine the roots. Not one had a shovel in his truck, though many did have umbrellas, so I had to wait until a shovel was retrieved from a nearby shop. After a half hour of standing on that shovel and being reminded why Mississippi growers don't routinely dig up cotton plants, I extracted a scrawny, bent up root system that reflected the adverse spring and helped explain the poor uptake of fertilizer that summer. Despite the difficulty of examining roots, proper application of fertilizers and irrigation requires knowledge of root growth in the soil profile. This issue of Cotton Physiology Today will discuss root physiology and management of root limitations. — Kater Hake

Root Structure

Cotton roots have a simple structure. The root tip is preformed in the seed and only needs warmth and moisture to emerge from the seed coat, just like the cotyledons and shank. The root tip grows by adding new cells and enlarging at the tip, forming the tap root. This growth pattern allows the root to wind around dense clods, growing in cracks or older root channels, constantly turning downward due to the influence of gravity on the direction of tap root growth.

The root tip produces a tap root of 5 to 8 inches by the time cotyledons emerge from the soil. For all practical purposes, if soil has sufficient moisture for the cotyledons to emerge the root tip is already well anchored at the bottom of the plow layer.

The first 2 - 3 " behind the root tip is the most active site of water and nutrient uptake because it is always exploring fresh soil. The older tissue directly behind the root tip absorbs water and nutrients by extending root hairs and lateral roots into the surrounding unexplored soil. Root hairs are similar to lint, in that each one grows from a single surface cell. Further behind the root tip in even older tissue, lateral roots develop. Lateral roots initiate inside the tap root tissue and grow horizontal into fresh soil for nutrient and water uptake. Because these young lateral roots proliferate near the surface in warm, nutrient rich soil, they are critical for seedling vigor.

Tap roots and lateral roots, like stems, have the ability to thicken by adding new cells from the inside. Once roots start to thicken, their ability to absorb water and nutrients decreases. The term "feeder roots" is often used to describe young roots most active in absorption.

Because each root has the potential to grow both at its tip and by pushing out new lateral roots, the plant retains flexibility to regrow after cultivation or severe drought. Cotton roots loose this flexibility to adjust or regrow as the plant puts on bolls. Thus, root damage in July and August, from late cultivations or water stress, should be avoided to maintain an active root system for boll filling.

Cotton Root Growth versus Other Crops

Compared with cereal crops, such as barley, corn or wheat, cotton root growth is slowed to a greater extent by soil drying. Both cotton and cereal root growth is stimulated slightly in the early stages of soil drying as the plant partitions extra dry weight to roots. Additionally, cotton roots are less opportunistic than cereals and do not compensate in favorable soil zones when compaction or infertility limit root growth elsewhere in the soil profile. The following table characterizes the root growth of cotton versus cereal crops.

	Cotton	Barley, Wheat, Corn
Root Density under Favorable Conditions	5" per cubic inch of soil	15-25" per cubic inch of soil
Growth in Drying Soil	Poor	Good
Growth Response to Frequent Irrigation	Slight Increase in Surface Roots	Dramatic Increase in Surface Roots
Response to Subsoil Compaction	Little Increase in Surface Roots	Large Increase in Surface Roots
Response to Nutrient Rich Surface Soil	Slight Increase in Root Density	Large Increase in Root Density

Moisture and Nutrient Uptake

Roots take in moisture by providing an unbroken column where soil water is in contact with leaf water. When water in the leaves evaporates it tugs on this water column, pulling soil water into the roots. Nutrients that are dissolved in the soil water also will be carried along passively into the root. This is the uptake method for nitrate, a highly water soluble nutrient. That is why conditions such as severe drought or humid/overcast weather that limit leaf evaporation also limit soil nitrate uptake.

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Nutrients that are less soluble such as phosphate, potassium and micronutrients require roots to grow nearby so they can diffuse from the soil particles to the root surface. Once these less soluble nutrients approach the root surface, they are actively pumped inside via metabolic processes. Because of this energy requiring uptake mechanism, uptake of phosphate and potassium is more sensitive to cold soils and restricted root growth.

Where Do Roots Grow

Cotton roots only grow in soil with moisture, oxygen and warmth. Absence of any one will halt root growth. This observation is best illustrated by several examples. Most producers are aware of the shallow root phenomena when young cotton is over-irrigated or spring rain is excessive. Under these conditions roots proliferate in the surface because this is the warmest zone <u>and</u> has sufficient oxygen for root growth. Likewise, producers observe deeper root growth if moisture is withheld until bloom. Under these conditions the surface soil dries to a point that upper root growth halts, and the best zone for root growth is now deeper into moist soil. Because the surface soil is dry, ground pores are open for oxygen to diffuse to deeper depths. Warmth also is enhanced, because lack of rainfall has allowed the sun to heat the soil rather than just evaporate water. Understanding the root growth requirements for moisture, oxygen and warmth allows us to predict where roots will be located in the soil profile.

Root Limitations — Cool Soils.

Of these three requirements for root growth, temperature is the most limiting early in the season. Cotton roots do not grow if the soil temperature is less than 60°F. Growth is half of maximum at 70 to 75°F, and reaches a maximum at 90°F. Since soil has a high heat capacity, it warms up slowly in the spring. A few hours of high temperatures do little for root growth if the nights are cool. A few hours of high temperature may only warm the surface inch.

Cool soils cause problems for seedling growth. First, nutrient uptake is limited. Phosphate uptake is reduced because cool soil limits not only root elongation and branching but also the processes for P uptake. Secondly, roots in cool soils are more susceptible to seedling disease. As part of the plant's defense mechanism against disease, new roots continue to grow while older roots are lost to the disease. When new root growth is curtailed, an increasing percent of the root mass becomes diseased and unable to absorb water or nutrients. This further weakens seedling-diseased plants due to nutrient deficiencies and moisture loss if the weather suddenly turns hot.

Managing Cotton in Cool Soils

Managing cotton planted in cool soils is difficult. In most parts of the Cotton Belt, producers prefer to wait until the soil warms prior to planting, but often the variable spring weather replays a winter storm.

- Phosphate starter fertilizers are beneficial under conditions that restrict early root growth. For example, the early root zone of no-till cotton is not only colder but also more dense and therefore often respond to starter phosphate fertilizer.
- Cultivating cool soils may be of benefit <u>if</u> the surface soil is moist. When the surface is moist, a cultivation will speed soil drying and allow sunlight to heat the soil instead of evaporating water. But if the surface is already dry, cultivation will damage roots and create a thermal blanket over the moist cold soil below. Under these conditions, the loose surface soil will warm but like foam insulation will keep the heat from moving to the root zone below.
- Cultivation can be of benefit <u>if</u> it leaves the surface rough to minimize wind damage or is necessary to break crusts for emerging seedlings. In general, cultivating seedling cotton under cool conditions will do more harm than good.
- Definitely do not irrigate seedling cotton in cool weather, as this will further retard growth and increase the potential for disease.

Root Limitations — Oxygen Supply

Cotton roots rely on a steady supply of oxygen from the atmosphere above because roots consume oxygen and release CO_2. The root zone requirement for oxygen flow depends on temperature. In warm soils, the active roots and microorganisms respire heavily, thereby increasing the demand for oxygen. High organic residue will aggravate root problems under waterlogged conditions, because the microorganisms feeding on the residue will consume most of the oxygen supply.

The supply of oxygen to the roots is limited by soil water content and porosity. Since oxygen must diffuse from the surface through open soil pores, closing these pores with water or compaction will dramatically reduce the flow of oxygen from the surface.

Under moderate oxygen deficit, root growth is reduced. But as the deficiency increases, plants lose the ability to absorb nutrients and water. Cotton can wilt and die from lack of water even though the root system is waterlogged.

Managing Oxygen Supply

Water management is one tool used by producers to maintain oxygen supply.

- Avoid furrow or flood irrigations longer than 48 hours during the summer. For some growers this requires large on-flow rates or re-leveled fields to push the water rapidly down the furrows.
- Alternate row irrigation allows air to enter the soil in the non-irrigated row, and also allows lower irrigation amounts.
- Match the applied water to the soil water deficit, thus avoiding a 8-inch irrigation when the soil only needs 4. Measurements of soil water content or estimates from computer models such as CALEX/Cotton or Gossym provide guidance for optimum irrigation amounts.

Cultivation is one of the few tools available for rain-belt producers to increase oxygen flow. Surface cultivation will enhance porosity and dry the surface soil, increasing oxygen diffusion. Producers often observe a recovery in previously water-logged fields after cultivation. For this cultivation, it would be ideal to use light weight tractors to minimize compaction and delay after irrigation or rain. Cultivation of fields that are not water-logged destroys surface roots, putting the plant into a stress that may be short lived or more severe depending on the ability to regenerate surface roots.

Nutrient Stratification

For maximum uptake to occur, roots must proliferate in nutrient rich soil zones. It should be clear from the previous discussions that roots are not evenly distributed throughout the soil. Nutrients also are not evenly distributed. This poses a challenge to cotton producers to identify not only the overall nutrient status of their soil but also where in the soil profile nutrients are located. For example, prior to fertilization, nitrates tend to be concentrated at the bottom of the root zone, due to their high solubility. After the crop cuts-out, this deep nitrate can interfere with crop termination when the tap root starts to regrow, pulling moisture and nitrate from deeper layers.

Nutrients other than nitrate tend to accumulate in the surface soil. These nutrients have limited mobility and, when applied to the surface either as fertilizer or crop residue, will remain in the soil zone that is plowed or disced. After many years of nutrient extraction from throughout the soil profile, and replenishment only on the surface, some nutrients become stratified or concentrated in the surface soil. This nutrient stratification has recently been identified as a cause of potassium deficiency in high yielding fields throughout the Cotton Belt. Cotton has its highest demand for potassium during boll growth. When many bolls are set over a short period, the daily boll demand for potassium can exceed 3 lbs of potash per day. If the root system is not able to meet this demand, potassium is scavenged from nearby leaves, which turn bronze and prematurely senesce if petiole K drops below 1.5%.

The stratification of potassium, whereby the surface soil is nutrient rich while the subsoil is deficient, limits the ability of the root system to adequately supply developing bolls. Under these conditions the cotton plant may respond to added K in the bottom of the soil profile. Moreover, since the vigor and health of surface roots is critical in stratified soils, nutrient uptake problems are exacerbated by surface drying, verticillium wilt, root pruning, nematodes or wheel track compaction.

Management of Nutrient Stratification

Nutrient stratification problems are corrected by either placing the nutrients where roots will remain active or employing cultural practices to maintain root health in nutrient rich zones.

- A ripper that places potash or lime in a vertical slot throughout the field has been designed by Gordon Tupper of Mississippi State University.
- Use cotton varieties that are more efficient in K uptake. These varieties are being identified only now, such as GC-510 for California.
- Changes in tillage, away from plowing and towards reduced tillage, as necessitated for erosion control, have aggravated nutrient stratification by allowing nutrients to accumulate in the surface soil.
- Maintaining healthy disease-free roots through crop rotation and planting varieties that are more tolerant of disease may decrease the yield loss from nutrient stratification.
- Shorten the irrigation cycle, because surface roots decline with the surface drying and recover by sprouting new roots after an irrigation.

Soil Compaction

Soil compaction is an inescapable result when ground is worked wet in the spring. For many Mid-South and Southeast cotton growers, the continued rains have left them no option but to pull beds and plant into soil that is simply too wet. These fields will pose specific management problems later in the year, especially in a drought.

Cotton roots grow rapidly when the soil can be easily pushed aside by the expanding root tip, such as through a moist clay or loam soil. These soils allow root growth even when compacted because moisture enables the small soil particle to give way to the developing root tip. Compacted sandy soils on the other hand retain their impedence even when wet and thus compaction is more detrimental. Compacted soils will have lower root densities and be inefficient absorbers of water and nutrients.

Managing Compacted Soils

Management practices that increase water and nutrient availability, along with promoting root health, will offset soil compaction at planting.

- Reduce the number of trips across the field if at all possible. Fields do not need to be table-top smooth just to pull rows. Make sure that every trip across the field is really necessary.
- Consider alternate weed control strategies that minimize cultivation when soils are moist, to reduce compaction and root pruning.
- Use split applications of nitrogen to avoid losses from denitrification or leaching below the shallow root zone.
- Anticipate that cotton planted into compacted soil will be droughty. Use frequent, shallow irrigations if possible.
- Be alert for unexpected nutrient deficiencies that may show up due to restricted rooting. Nematode problems also are aggravated in compacted soil due to the shallow restricted root system.
- Be careful when using a plant growth regulator on cotton planted into compacted soils, because the restricted root system often stunts the plant and increases it's susceptibility to drought.

Root Limitations to Maximum Yield

One of the physiological concepts gaining acceptance Beltwide is that avoiding stress and maintaining healthy vigorous growth is conducive to maximum yield. This same concept also applies to cotton roots. A major limitation to yield is the ability of roots to maitain activity during the boll filling period when the plant has it's highest requirement for water and nutrients. During boll filling, root exploration fails to keep pace with the boll growth. This imbalance between root and shoot activity affects the ability of the plant to fill late set bolls and ward off root diseases.

The avoidance of water stress is a management tool to minimize root decline during boll filling. Water stress during bloom greatly accelerates root system decline. If the field is not approaching cut-out, the root system will recover after an irrigation or rain, by developing new roots. When water stress occurs at cutout, few nutrients are available for root growth. Thus, after a late stress, the plant only slowly recovers the ability to absorb moisture and nutrients from the soil.

Frequent irrigations such as with drip systems avoid the surface root stress and decline that generally occurs during the irrigation cycle. Thus, the plant maintains its ability to absorb water and nutrients and continue setting bolls later into the season.

New Publication and Video on Cotton Growth

In addition to newsletters and seminars, the Cotton Physiology Education Program develops publications that cover a management topic in depth. Copies of the first of these publications the "Beginning Plant Map Program" are still available. The second publication "Cotton Growth and Development for Production Agriculture" is now available from the Memphis office of the National Cotton Council. This illustrated publication provides producers with a background in cotton growth by identifying and explaining field problems. In addition to this 20-page publication, a short video describing the various plant parts is also available from this office at no cost. This video was developed by Stephanie Johnson Hake, former Cotton Farm Advisor from Tulare County, California.

About the Authors

Ken Cassman is on the Agronomy Faculty at the University of California at Davis. Ken recently reviewed his work on the effect of potassium deficiency on cotton growth and quality at the 1990 Beltwide Cotton Conferences. Dan Upchurch, USDA Soil Physicist at Lubbock has focused his research on root dynamics and water flow, including the effect of cold soil temperatures, a severe problem in the Texas High Plains. Frank Whisler is a Professor of Soil Physics at Mississippi State, and associated with the Crop Simulation Team. He has worked with producers throughout the Cotton Belt to develop accurate soil and root sub-routines for the Gossym computer model.