Science Societies

Considerations for stand establishment and early seedling growth in cotton

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Setting the planting equipment for cotton correctly for your soils and climate is important for germination and growth. Photo by Jodie Reisner.

Obtaining an adequate plant stand is an important first step towards realizing the yield potential of cotton. The stand establishment phase of crop development involves a number of different processes and can be influenced by multiple factors, some that are within the grower's control and some that are not. The current article starts with an overview of the germination and emergence phase of cotton development with an emphasis on key developmental events. Thereafter, it focuses on recent research conducted in Georgia that addresses the effects of seed characteristics, temperature conditions, and planter settings on stand establishment.

This time of year, growers in the southeastern United States are preparing to plant cotton as soon as the opportunity presents itself. In some areas with a broad planting window, planting may begin as early as late March and continue into June. As one might imagine, planting season comes with a tremendous amount of anticipation and sometimes anxiety as growers must decide what, when, where, and how to plant. In addition to the standard challenges associated with answering these questions, producers must also navigate weather conditions that can wreak havoc on even the best laid plans.

Having a uniform stand and a vigorously growing cotton crop in the early season is an important first step toward realizing cotton's yield potential. Vigorous seedling growth is desirable because it increases crop competitiveness with weeds, lessens the

negative impacts of early-season pathogens and insects, and minimizes the risks of stand loss (Snider et al., **2021a**). Additionally, rapid crop growth and leaf area development in the early season maximizes light interception by the cotton canopy at a time during the year when incoming solar radiation is at its highest (Snider & Oosterhuis, **2015**). This is particularly important in cotton, a crop known to have poor seedling vigor compared with other, larger-seeded row crops such as corn, peanuts, and soybeans.

Seedling growth can be influenced by cultivar, management, and environmental conditions. While the current article will be primarily focused on these three factors, it is first necessary to have a general understanding of the key events that occur during the germination and emergence phases of crop development (Also described in Snider & Virk, **2020a**; Snider et al., **2021b**).

Soon after the seed is placed in a moist, well-aerated seedbed with adequate seed-to-soil contact, the seed begins to take up water through a process called imbibition. Depending on temperature conditions (higher temperatures accelerate imbibition while low temperatures slow the process), the quiescent cotton embryo inside the seed coat will be completely hydrated within four to six hours after planting. Soon after imbibition, the embryo starts rapidly consuming energy reserves in the seed to drive growth, which requires oxygen uptake. Finally, the radicle will protrude beyond the seed coat within one or two days after planting (depending on temperature). Nutrient reserves such as oil and protein that were stored in the cotyledons will then be mobilized to actively growing parts of the seedling to fuel growth before the plant is photosynthetically self-sufficient.

The protrusion of the radicle marks the end of the seed germination phase and the beginning of the seedling stage of plant development. The primary root will continue to

grow downward into the soil profile, and the hypocotyl, which is the region below the cotyledons, will produce a hook-like appearance and begin to elongate upward. The end result is that the cotyledons, still covered by the seed coat, are pulled up through the soil by the expanding hypocotyl. Scratching just below the soil surface a few days after planting but just prior to emergence will reveal the hypocotyl, which is the closest part of the plant to the soil surface during this phase of development (Figure 1, left panel). Once the cotyledons have completely cleared the soil surface, emergence is complete (Figure 1, right panel).



Figure 1, *The expanding hypocotyl just below the soil surface (left) and newly emerged seedlings (right). Source: Snider & Virk,* ***2020a****. Photos by Gurpreet Virk.*

A number of factors can influence the cotton crop during stand establishment. Dry soil conditions at planting or soon thereafter can negatively affect seed germination by desiccating embryos that have already started the germination process. Additionally, once germination is complete, drought stress can limit cell expansion and growth in pre- and post-emergent seedlings. Conversely, waterlogging conditions deprive the growing embryo of oxygen, resulting in death of young seedlings. The formation of compacted soil at the soil surface is known as crusting and mechanically impedes

emergence. In some instances, the hypocotyl will snap as it attempts to pull the cotyledons through the crust. In situations where soil crusting is a problem, it may be necessary use a rotary hoe to alleviate soil surface tension and facilitate emergence.

At the opposite extreme, poor seed-to-soil contact and a lack of mechanical pressure against the seed coat and developing seedling may not provide enough resistance to remove the seed coat as the seedling moves through the soil profile. When this happens, the seed coat may prevent the unfolding of the cotyledons (tight seed cap), thereby preventing post-emergence seedling development. The need for adequate seed-to-soil contact also illustrates the importance of adjusting planter settings for specific field conditions. Thus, this article will primarily focus on the importance of the seed, the environment (temperature specifically), and finally, the planter in determining stand establishment and early-season growth in cotton.

The Seed

Well before planting, growers have usually already decided what cultivar to plant for their particular farm. While cultivar selection decisions can be made with a number of considerations in mind, it is useful to first identify cultivars that yield well in on-farm variety trials conducted in production environments that most closely resemble their own. The results of the 2021 University of Georgia on-farm cotton variety trials are available at **https://bit.ly/3rhkIF4** and can serve as a useful guide for Georgia cotton producers. Other than yield, growers should also consider seed vigor as this parameter can have a pronounced effect on germination and emergence. Seed lots with high vigor are defined as ones that exhibit high germinability and emergence over a range of environmental conditions (Bourland et al., 2019).

While there are many different tests that could be used to estimate seed vigor in cotton, the most common approach is to evaluate germination percentage at a specific incubation period and temperature. Warm germination percent provides an indication of seed performance under optimal temperature conditions and is published on the label of any given bag of cotton seed. The cool germination test quantifies percent germination under sub-optimal conditions and can be requested from the seed provider. An index that sums the germination percentage for these two tests combined is likely a better indicator of seed performance under a broad range of conditions than either test alone (Bourland, **2019**; Pilon et al., **2016**).

Other than germinability, chemical and physical characteristics of planting seed can be strongly indicative of seedling vigor. Seedling vigor is typically estimated using some measure of seedling size or growth rates (Bourland, **2019**; Liu et al., **2015**; Pilon et al., **2016**). Recent work conducted in Georgia has evaluated the effect of seed characteristics on seedling vigor under field conditions. For example, an on-farm variety trial documented planting seed characteristics (seed mass and oil and protein content) and seedling fresh weight for 11 cotton cultivars at five locations across southern Georgia (Snider et al., **2014**). When seedling fresh weight was averaged for all locations for each cultivar and plotted versus seed characteristics, it was found that seed mass and seed oil content were most strongly and positively associated with seedling vigor. A follow-up report (Snider et al., **2016**) showed that the total calorie content of oil + protein in the cotton seed was a strong predictor of seedling dry weight. There are two possible explanations for these observations. The first is that seed mass influences the quantity of energy reserves available to fuel early growth. The second possibility is that large seeds have the ability to house larger cotyledons, which would provide more photosynthetic surface area to drive early growth (Liu et al., **2015**).

Small-plot studies conducted in Georgia also showed that larger-seeded cultivars tended to have greater seedling vigor, especially when planted early in the season under sub-optimal temperature conditions (Virk et al., **2019, 2020b**). Other than cultivar, seed physical and chemical traits are also governed by environmental conditions (temperature, humidity) during seed development and storage. Furthermore, the importance of seedling vigor to an individual grower will depend heavily on weather and field conditions at planting. Thus, in situations where vigorous seedling growth is especially important, one of the best and most easily obtained predictors of seedling vigor is average seed mass (Figure **2**). This information can usually be calculated from information given on the seed bag label (i.e., seeds per pound) and should be considered on a bag-by-bag and case-by-case basis.

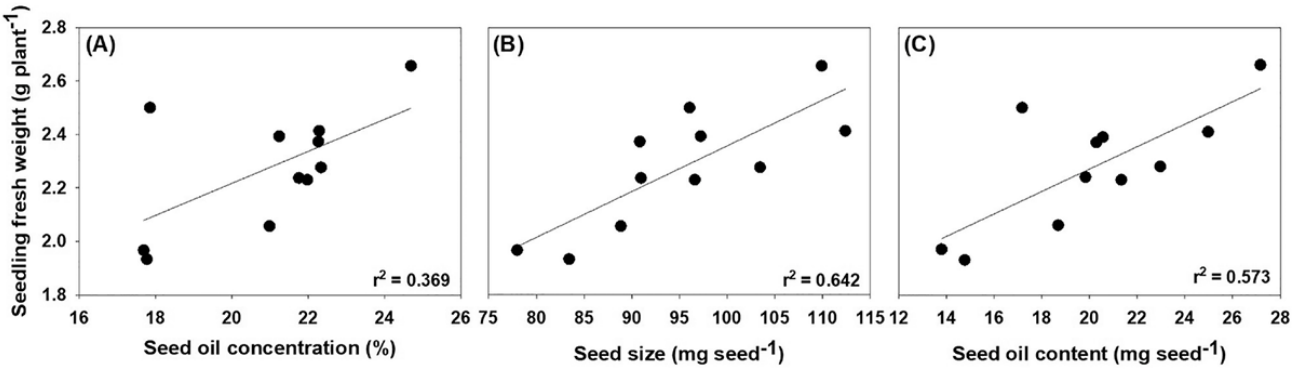


Figure 2, *Linear regression of seedling fresh weight at the two- to three-leaf stage vs. percent oil (A), seed size (B), and total seed oil content (C) for 11 commercially available cotton cultivars. Fresh- weight data were averaged from five locations, four replicate plots at each location, and 20 plants per plot (each data point represents the average weight of 400 seedlings). Adapted from Snider et al. (**2014**).*

Temperature

Though not specifically addressed above, temperature is a key factor governing germination and emergence. Cotton is an indeterminate plant with tropical origins, which makes it an inherently cold-sensitive plant and limits production to areas with

long, warm growing seasons (Snider et al., **2021a**). To better understand the effect of low temperature on seedling growth and development, it is first useful to distinguish between chilling temperatures and suboptimal, non-chilling temperatures.

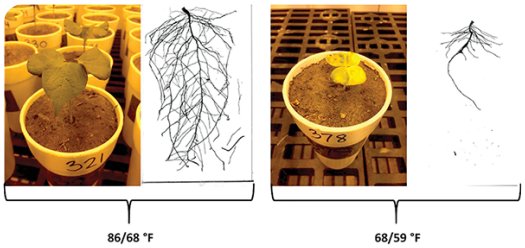


Figure 3,*Representative images of seedling shoots and roots for two-week-old cotton seedlings grown under optimal (86/68 °F) and suboptimal (68/59 °F) temperature conditions.*

Chilling temperatures are above freezing but less than 50 °F, and if these temperatures are experienced soon after planting, it will cause the primary root tip to die, leading to root growth abnormalities such as the absence of a well-defined taproot or the development of a primary root that curls upwards instead of down into the soil profile. Seedlings exhibiting chilling injury also exhibit a swollen hypocotyl or other injury symptoms that may eventually lead to the death of the developing seedling and reduce final plant stand. Importantly for producers, chilling temperatures during the imbibition phase of development (four to six hours after planting) have the greatest potential to cause stand-limiting injury.

Suboptimal, non-chilling temperatures are temperatures greater than 50 °F and less than 77 °F. While these temperatures do not cause irreversible injury to plant tissues, they substantially limit root and shoot growth rates relative to optimal temperature conditions and can delay the arrival of key growth stages. Multiple experiments conducted in controlled-environment facilities at the University of Georgia have documented the negative impacts of suboptimal temperature on seedling growth. When a suboptimal growth temperature regime (68/59 °F) was compared with an optimal day/night growth temperature regime (86/68 °F), reductions in shoot growth ranged from 33 to 70%, depending on which growth parameter was being evaluated

(Snider et al., **2018**; Virk et al., **2021b**). Root growth is also negatively impacted by low temperature as can be seen in Figure **3**. When low temperature-induced reductions in growth are combined with other common biotic stressors such as thrips and nematodes, the level of pest injury to the plant can also become amplified.

The timing of specific growth stages in cotton is directly associated with growing degree day (DD60) accumulation. Daily DD60 accumulation is calculated as the daily average temperature [$(T_{max} + T_{min})/2$] minus a standard base temperature, which is 60 °F for cotton. The cotton plant requires approximately 50 DD60s from planting to emergence and another 50 after emergence to produce its first true leaf. Current University of Georgia recommendations for planting cotton include a soil temperature of 65 °F and 50 DD60s forecasted to accumulate within the first five days after planting (Hand et al., **2021**). A relatively new online tool developed by North Carolina State University called the Cotton Planting Conditions Calculator (**https://products.climate.ncsu.edu/ag/cotton-planting/**) utilizes the five-day temperature forecast to characterize planting conditions as poor, fair, good, or excellent; it is a user-friendly resource for growers throughout the U.S. Cotton Belt. Increased daily average temperatures cause more rapid accumulation of DD60s, which can hasten the addition of new leaf nodes, further increasing plant growth rates.

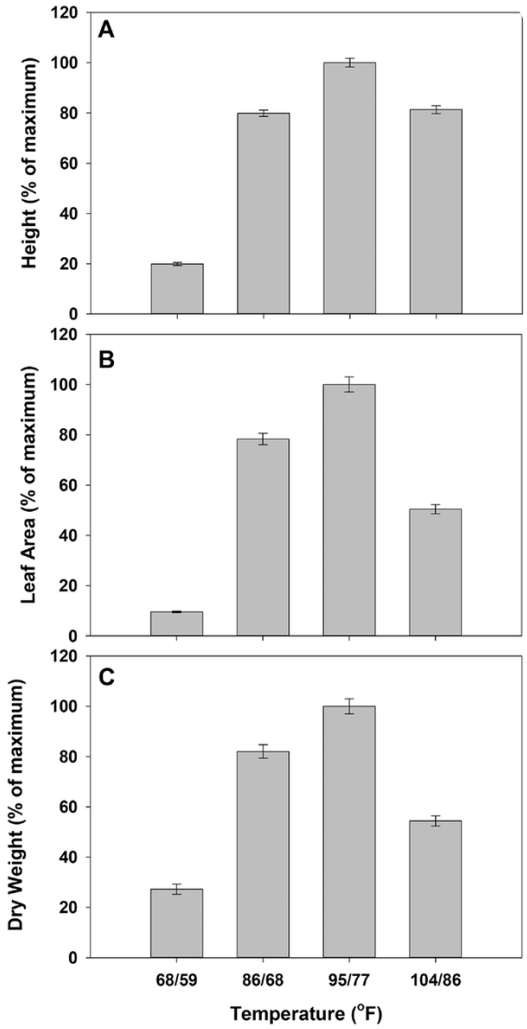


Figure 4, *Growth of cotton seedlings in response to different day/night growth temperature treatments. Parameters measured include plant height (A), leaf area (B), and dry weight (C). Source: Snider et al. (**2021c**).*

It should be understood, however that even though cotton is widely regarded as a heat-tolerant plant, there is a point above which higher temperatures will not necessarily increase growth and can even decrease growth due to negative impacts on final leaf area and photosynthetic efficiency (Virk et al., **2021b**). Figure **4** shows the results of a recently conducted experiment at the University of Georgia. All shoot growth parameters are expressed as a percent of the maximum growth observed at two weeks after planting for cotton sown under four different growth temperature regimes. The temperature treatments ranged from 68/59 °F to 104/86 °F, and two observations are notable within the context of early-season growth in cotton. This first is that cotton seedlings responded positively to increases in growth temperature up to 95/77 °F. This supports the widely held assertion that cotton performs well under high-temperature conditions, at least in the very early seedling stage represented by Figure **4**. The second notable observation is that as temperatures increased from 95/77 °F to 104/86 °F, plant growth decreased by as much as 40%. These high-temperature-induced reductions in growth are likely the result of reductions in photosynthesis

combined with increases in respiratory carbon loss (Salvucci & Crafts-Brandner, **2004**).

How does the information above factor in to on-farm decision making? (1) Cotton is a tropical plant that needs warm temperatures for growth and development. Follow extension recommendations and plant when the weather forecast calls for sufficiently warm temperatures to ensure stand establishment (minimum soil temperatures above 65 °F and 50 DD60s predicted to accumulate in the first five days after planting). (2) Be cognizant of the fact that high temperature may limit seedling growth in some instances. Specifically, it is important to understand that prolonged exposure to maximum daily temperatures in the low 100s and nighttime temperatures in the 80s may be a contributor to reduced seedling vigor in growing seasons where high temperatures are experienced early in development.

Planter Settings

Planting constitutes one of the most critical field operations within a growing season as any mistakes during planting can have an adverse effect over the entire season. For cotton, timely and uniform emergence is important to attain adequate stand establishment and to maximize yield potential early in the season. In the southeastern U.S., it is recommended that growers target a seeding rate of 2.5 seeds per linear foot of row and plant seed at 0.5- to 1-inch depths with the goal of achieving a final plant stand of 1.2 to 1.9 plants per foot to maximize lint yields (Hand et al., **2021**). Because the number of seeds planted per linear foot and seed placement (seed depth and seed-to-soil contact) in the soil affects emergence, it is crucial to ensure a proper planter setup and high in-field planter performance during planting. While the proper setup and operation of a seed-metering unit is recommended, and relatively easy to attain, verifying that the correct population and seed placement have actually been achieved

is more complicated, as it is influenced by both planter settings and field conditions at planting.



Figure 5, *Planter depth (A) and downforce (B) settings need to be adjusted for the prevalent field conditions to ensure timely and uniform emergence. Photo by Simerjeet Virk.*

Several small-plot and large-scale planter studies in cotton were conducted at the University of Georgia from 2017 to 2019 to better understand the influence of planter settings, specifically depth and downforce, on crop emergence with different soil moisture levels and in fields with varying soil textures (Figure 5; Virk et al., **2020a, 2021a**). Results from these studies suggested that planter depth and downforce need to be optimized for the soil type/texture and prevalent field conditions at planting. In regards to soil moisture, it was noticed that when planting conditions were favorable, the most timely and uniform emergence was observed at a seeding depth of 1 inch, which is also the typical seeding depth recommended for cotton in the southeastern U.S. Similarly, emergence was improved when seed was placed deeper at 1.5 inches in dry field conditions and shallower at 0.5 inches in wet field conditions.

The importance of utilizing the correct planter downforce was illustrated by these studies, especially in unfavorable conditions as a higher planter downforce in wet field conditions can cause excessive compaction around the seed bed, hindering seed germination and emergence while less-than-adequate downforce results in seeds being placed shallower than the desired seeding depth. In some cases, the emergence penalties were as high as 50% due to the combined effect of both inadequate depth

and downforce.

As cotton seed size can influence seedling vigor, and larger seeds tend to produce more vigorously growing seedlings, the effects of seed size, depth, and downforce were also evaluated in one of the studies. The results indicated that although the larger-seeded cultivar exhibited higher overall emergence than the small-seeded cultivar, the trend was more pronounced when seeds were placed at seeding depths of 3.8 cm or when a planter downforce equal or greater than 445 N (100 lb) was utilized. In some field conditions, especially where emergence was considerably reduced (40–50%) (Figure **6**), the adverse effects of inadequate depth and downforce on emergence also translated into lower lint yields.



Figure 6, *Illustration of a reduced and non-uniform emergence (left) vs. uniform emergence (right) for cotton planted in two different soil moisture conditions using the same planter settings. Photo by Simerjeet Virk.*

Beside the effect of improper planter settings, one of the other primary challenges in achieving uniform seed placement in the southeastern U.S. is large inherent spatial variability, especially due to soil type and texture, within grower fields. Therefore, one of the on-farm planter studies also investigated the influence of different (constant) planter downforces on cotton emergence in fields with varying soil textures. An

interaction between planter downforce and soil texture, characterized by soil electrical conductivity (EC), in these studies suggested that heavy-textured soils require a higher downforce (≥890 N) to achieve the desired seeding depth and crop emergence than downforce requirements (0-445 N) in a light-textured soil within the same field. Varying downforce requirements to ensure uniform seeding depth and crop emergence across the field also showed that row-crop planters with traditional downforce systems (single or manually adjusted springs) are limited in achieving different downforces within the same field during planting and that active downforce systems (hydraulic) available commercially through different planter manufacturers and technology companies today will prove beneficial for better control and downforce management in fields with high soil variability. In summary, optimization of planter settings and careful selection of cultivar based on prevalent field conditions at planting are important and can help in maximizing emergence across the field.

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