CHAPTER 5

SOIL CLIMATIC AND EDAPHIC EFFECTS ON COTTON GERMINATION AND THE FINAL STAND

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INTRODUCTION

Germination, emergence, and seedling survival are critical aspects of obtaining a profitable cotton (*Gossypium hirsutum* L.) crop, and this period of growth represents an extremely stressful time for the grower. Historically, a grower principally only had to fear the embarrassment of a skippy or failed stand and having to replant, and possibly ending up with a crop later than desired as well as a crop with mixed maturity. Currently, the cost of replanting genetically modified cultivars containing multiple stacked technologies on a large scale is becoming cost prohibitive. Nonetheless, growers in an attempt to plant extensive acres in a timely manner as well as try to avoid stresses due to water and insects, continue to take the risk of planting when the probability of unfavorable weather conditions is high. Various rules exist for obtaining a successful stand including, do not plant until the soil temperature is at least 20ºC at a 5-cm depth for three days in a row followed by a five-day favorable weather forecast or 50 Degree Day 60's (MSU Cares, 2014). Implied in such rules and recommendations are the known detrimental effects that cool soil temperatures have on a tropical perennial oilseed. Less than optimal soil temperatures during the rapid phase of water imbibition by a cotton seed planted in moist soil prevents efficient re-organization of cellular membranes and initiation of biochemical processes and results in the leakage of essential electrolytes such as sugars and proteins. The loss of electrolytes not only can hamper germination, but it can also lead to the growth of pathogenic organisms.

Other soil factors to consider when trying to optimize germination, emergence and seedling survival of cotton includes soil texture, tilth, aggregation, soil potential for crusting, moisture, aeration, compaction, organic matter, surface residues, surface smoothness, and overall planting conditions. Silt to silt loam textured soils are somewhat optimal for cotton growth and provide ideal conditions for emergence as long as rainfall following planting does not result in soil crusting. Sandy textured soils are prone to rapid drying after the disturbance caused by planting and may form a crust following rainfall, while clayey soils present obstacles such as excessive moisture, less than optimal O_2, poor seed-to-soil contact due to large aggregate size, and excessive soil strength. The placement of cotton seed at a proper depth of 2.0-cm to no more than 3.2-cm is critical for rapid germination and emergence. Seed-to-soil contact is important to allow for adequate moisture delivery to the seed and the emerging radical. Soil friability and tilth are extremely important for unimpeded emergence of the epicotyl and cotyledons so that the seedling can get off to a rapid start.

CLIMATIC AND EDAPHIC EFFECTS

Soil temperature is a primary factor influencing cotton seed germination and emergence. Generally, a minimum temperature of 15°C has been recommended for germination under controlled conditions as cooler temperatures can reduce germination (Christiansen and Rowland, 1986). The maximum temperature at which cottonseed germinate has been defined as 42°C (Nabi, 1998). Thus, soil temperatures in the zone of seed placement should be greater than 15°C and less than 42°C for a long enough period to allow for germination. The optimal temperature for cotton seed germination itself has not been well-defined and studies have focused mainly on the effects of chilling temperatures on radicle growth and metabolic activity (Krieg and Carroll, 1978). Christiansen (1967) noted that as little as 4 h of chilling temperatures during imbibition can cause aborted root tips. Pre-hydrating to 12-13% of the weight of the seed prevented chilling injury. Chilling temperatures following 24 h of imbibition at 31°C can have season-long effects on growth. Plant height at maturity was reduced up to 36 cm with 6 d of chilling at 10°C, 14 cm with 4 d, and 5 cm with 2 d (Christiansen and Thomas, 1969). Ultimately lint yield was not affected, but micronaire readings were reduced with the length of chilling from 3.89 to 3.38, presumably due to a delay in flowering and maturity. Although conditions may be favorable for a cotton seed to germinate and grow a radicle 2- to 3-cm in length, chilling temperatures following germination can have a negative impact on vascular tissue sloughing, electrolyte leakage, slowing of growth and development, and increase susceptibility to fungal diseases (Christiansen, 1963, 1967; Christiansen et al., 1970).

The rapid growth of both the radicle and hypocotyl is important for seedling emergence. The role of the radical is to anchor the plant and seek out water and nutrients essential for growth, while the hypocotyl, located between the radicle and cotyledons, facilitates the pulling of cotyledons through to the soil surface and then straightens to expose the cotyledons to sunlight. Increasing soil temperature from 15.6°C to 32.2°C has been shown to increase the rate of growth as well as total growth of cotton radicles and hypocotyls, while a temperature of 37°C caused a decline in growth of radicles and hypocotyls (Wanjura and Buxton, 1972). Krieg and Carroll (1978) demonstrated at a temperature of 15°C that radicle growth rate was initially related to lipid metabolism, but by 6 d it became dependent on the metabolism of the non-lipid fraction with protein being the most important. Cultivars were also studied and the differences between them were mostly found in the utilization of N compounds. More recent research by Mills et al. (2012) examining seedling root growth response of several cotton cultivars to cool temperatures noted no significant trends on root dry matter production after germination, but substantial variation from differing varieties. The overall effects of colder temperatures were to reduce metabolism in the radicle. Under field conditions, the time to reach 45% of the final stand decreased with an increase in temperature from 10 to 21°C for the cotton seed planted 5-cm deep (Wanjura et al., 1969b). The effects of temperature on hypocotyl elongation rate of cotton were modeled and studied by Wanjura et al. (1970). A near linear response in hypocotyl elongation was noted for a temperature range of 14.44°C up to 32.5°C and a decrease with temperatures above 35°C.

Optimal soil moisture supply is critical for rapid cotton seed germination and emergence. Cotton seeds generally reach full hydration in 4 to 6 h (Dewez, 1964; Wanjura and Minton, 1974). Maximum hydration of cotton seeds occurred at 80% of the initial seed weight as compared to corn which hydrated up to 155% of initial seed weight (Stiles, 1948). Phillips (1968) noted species differences in the imbibition rate of water with soybean (*Glycine max* L.) seed hydrating faster than corn (*Zea mays* L.), and corn faster than cotton. Germination times varied accordingly with soybean germinating in 20 h, corn in 54 h, and cotton in 62 h. Murungu et al. (2003) observed 94 % emergence at a soil moisture content of -10 kPa, 35 % at - 50 kPa, and 2 % at -100 kPa. No emergence was found at a soil moisture content of -200 to -1500 kPa. A decline in the ratio of hypocotyl elongation to radicle elongation with an increase in soil moisture stress suggests that the plant preferentially develops a deeper taproot seeking out soil water (Wanjura and Buxton, 1972). Some evidence exists that suggests water vapor transport may play an important role in germination and emergence, which implies that soil porosity is important (Wuest et al., 1999; Wuest, 2002). Soil porosity is dependent on aggregation of individual sand, silt, and clay particles. Murungu et al., (2003) in a study on whether seed priming with water for 24 h is beneficial for cotton seed germination, suggested that priming helped as soil aggregate size increased and seed to soil contact decreased. Seed priming was not effective with soil having small aggregates. These results suggest that water uptake was optimal in finer aggregated soil, but as aggregates became larger that water diffusivity to the cotton seed became restricted.

In areas where a high probability of rainfall can occur between the time of planting and seedling emergence, soil crusting can occur which can slow or impede emergence. Efforts to overcome a crusted soil include using a rotary hoe to disturb the surface crust, switching to a hill drop planting configuration, or reducing tillage to increase crop residue protection of the soil surface. Susceptibility to surface crusting is dependent on soil aggregate stability and decreases with increasing clay and organic matter contents. Soil crusting increases bulk density, decreases porosity, and proportionally decreases macropore space (aeration and drainage) relative to micropore space (capillarity or water holding capacity and conductivity). Bulk density and air porosity are inversely related to each other, although the ratio of aeration pores to capillary pores is dependent on soil texture and degree of aggregation or structure. Nabi et al. (2001) studied the effects of planting depth and irrigation on cotton germination to simulate the effects of hot conditions and soil crusting following planting and irrigation. They determined that germination itself was relatively unaffected and was completed by day three after planting. Slight differences were found in cotton seedling emergence with planting depths of 23 and 46 mm, while no seedlings emerged when planted at a depth of 92 mm. Simulated rainfall prevented seedling emergence due to the formation of a hard crust which produced a strong mechanical impedance. Since cracks in the soil crust formed, the prevention of emergence was not believed to be related to poor soil aeration, but rather to soil strength. Increasing soil bulk density and increasing aggregate size has been shown to delay and reduce total seedling emergence in wheat (*Triticum aestivum* L.) but for opposing reasons (Nasr and Selles, 1995). Increased aggregate size caused an increase in tortuosity for the emerging coleoptile while increasing bulk density increased interfacial stress. Montemayor (1995) demonstrated a reduction in cotton emergence from 66.5% to 32.1 % with an increase in soil sheer strength from 5.5 kPa to 8.2 kPa from mechanically induced soil compaction from press wheels.

On an Amarillo fine sandy loam, Wanjura and Minton (1981) tested the effects of delaying the time of emergence by 50 and 100% of the control to simulate the physiological effects of a crusted soil with high penetration resistance. Hypocotyl diameter was measured and the greatest increase occurred with the first 50% delay in emergence. Taylor and Gardner (1963) investigated the effects of soil moisture, bulk density, and soil strength on cotton root growth under controlled conditions. Root penetration decreased with increasing bulk density across soil moisture contents of -1/3 to -2/3 bars but was preferentially decreased with increasing soil moisture tension. Soil strength increased with increasing bulk density across all soil moisture tensions and increased with increasing soil moisture tension from -1/3 to -2/3 bars. Soil strength appeared to be the critical impedance factor rather than bulk density for this sandy soil as the strongest linear correlation found was declining soil root penetration with increasing soil strength. Taylor and Ratliff (1969) confirmed the primary effect of decreasing cotton root elongation with increasing penetration resistance and minimal effects of soil moisture tension at a given penetrometer resistance. Wanjura and Buxton (1972) noted that cotton hypocotyl elongation was reduced preferentially more than radicles with increasing soil impedance. Emergence can also be delayed due to excessive depth of planting. Wanjura et al. (1969a) noted a decrease in seedling survival with increasing planting depth and time to emergence negatively correlated with lint yield. Also, seed of known poorer quality had lower survival rates with increasing planting depth and when seedling days to emergence increased.

PRODUCTION MANAGEMENT EFFECTS

With an increase in adoption of conservation tillage systems for cotton, questions have arisen with regards to whether soil conditions or the inclusion of cover crops would be detrimental or beneficial to cotton germination and emergence. An early survey of no-till cotton studies found that obtaining a stand could be problematic (McWhorter and Jordan, 1985). Bauer and Bradow (1993) noted from the literature increases in seedling disease due to legume cover crops, NH_3 toxicity due to soil incorporation of legumes, emittance of volatile compounds during cover crop decomposition, and potential for soil moisture depletion by cover crops prior their termination and cotton planting. Megie et al. (1967) using conventional tillage showed that soil incorporation of crop residues can be detrimental to cotton germination when high protein residues such as alfalfa (*Medicago sativa* L.) or peanut (*Arachis hypogaea* L.) were used. It was believed that elevated NH_3 levels were damaging to germinating cottonseed. Hicks et al. (1989) found reduced emergence of cotton planted into wheat stubble and identified intolerant and tolerant cotton cultivars to wheat extracts during germination. Allelopathic type compounds can be leached from crop residues or produced during the initial decomposition of certain crop residues. Straw incorporation reduced germination 26% and dry matter 14% as compared to when wheat straw was applied to the soil surface in a greenhouse study. Similar results were found in a field study where standing wheat stubble improved emergence relative to wheat stubbled removed or tilled into the soil. Triplett et al. (1996) found a reduced stand of cotton with no-till and a wheat cover crop versus conventional till the first year of a 4-year study, a greater stand the 3rdyear and no difference either the 2nd or 4th year with essentially no difference when averaged across the 4 years of the study. No-till planting into cover crops by Touchton et al. (1984) did show a 20 to 30% seedling mortality with a crimson clover (*Trifolium incarnatum* L.) cover crop. Stevens et al. (1992) noted a 3-y average reduction in plants/ha for cotton planted no-till into a hairy vetch (*Vicia villosa* Roth) cover crop, but not wheat or no cover crop. Average maximum soil temperature was 5.0°C cooler when planted into wheat and 1.7°C to 2.8°C cooler when planted into hairy vetch for the first 5-d following planting. Varco et al. (1999) did not monitor cotton stand in a no-till cover crop experiment, but found the greatest profitability across a 3-yr period with a hairy vetch cover crop, followed by the use of a rye (*Secale cereale* L.) cover as compared to winter fallow. Stand loss due to cutworm spp. has been shown to increase with the adoption of no-till and favors where legume cover crops are used relative to grass cover crops (Gaylor, 1989; Leonard et al., 1993). Terminating the cover crops at least four weeks before planting minimizes the detrimental effects of cutworms (Leonard et al., 1993). Chambers (1995) noted an increased incidence of seedling disease severity with no-till versus conventional till and the severity increased with earlier planting dates and an increase in stress caused by poor weather conditions.

Nyakatawa and Reddy (2000) studied specifically the effects of tillage, cover cropping, and poultry litter addition on cotton germination and seedling growth. Seedling emergence was more rapid with no-till than with conventional till, but no differences in stands were noted on day four after planting the first year and a 14% advantage the second year when a rye cover crop was included. The more rapid emergence with no-till was attributed to the greater soil volumetric water content. No-till resulted in greater volumetric water content from day 1 through seedling emergence (day 4), while the greatest soil water content was found with no-till and a rye cover crop. Both were compared to conventional tillage. Poultry litter addition which supplied an N equivalent of 200 kg ha^{-1} also increased soil water content and enhanced emergence up to 4 days from planting, but only increased the final stand the second year. Soil temperature in the surface 7 cm of soil was 2°C cooler with no-till than conventional till up through day 4 both years of the study. When a rye cover crop was included, soil temperature one year was 4°C cooler on day 4 only but averaged 3.5°C cooler up through day 4 the second year than without a rye cover crop. Poultry litter also had a tendency to reduce soil temperature 2.4°C. No-till alone tended to the average 2°C cooler in the top 7 cm of soil than for conventional till. Overall, seedling emergence was enhanced with no-till, rye cover crop, and poultry litter addition due to great soil water availability, and although cooler temperatures were observed, they were not cold enough to be detrimental. These results support an altered root: shoot ratio in favor of the growth of the hypocotyl compared to the radicle with increasing soil water availability (Wanjura and Buxton, 1972; Xiao-tang et al., 2009).

Potential problems with increased soil strength when tillage is reduced or eliminated has been explored. Bauer and Busscher (1996) did not find an increase in soil strength for a conservation tillage system when compared to a conventional till system, especially in areas where normal row traffic occurred. When a tillage pan does exist, subsoiling has been shown to be beneficial in increasing cotton rooting depth (Salih et al., 1998). Grant and Lafond (1993) noted increased soil penetration resistance in the top 10 cm depth only when tillage was eliminated on a clay soil. Burmester et al. (1995) noted an increase in soil penetration resistance in conservation tillage systems down to a depth of 30 cm with the greatest difference occurring within the top 10 cm. A wheat cover crop in a conservation tillage system resulted in lower penetration resistance than with cotton stalks only. More recently, Raper et al. (2000) examined the response of soil compaction and cotton lint yields in a silt loam to a combination of conventional, conservation, and no-till practices both with and without cover crops. Results suggested that soil compaction beneath the row could be reduced by shallow, in-row tillage or cover crops and that these treatments resulted in comparable seedcotton yields to the conventional tillage treatment. Further research by Raper et al. (2007) examined the response of seed-cotton yields in a fine sandy loam to a combination of no-tillage, variable depth sub-soiling (15-45 cm, based on depth to hardpan), and deep sub-soiling (45 cm) both with and without cover crops. No overall effect of cover crop on seed cotton yield was noted, but both subsoiling treatments yielded greater than no-tillage systems. These studies highlight the need to address soil compaction in the root zone, with either cover crops or a hardpan-disrupting subsoil tillage event, in order to reach full cotton yield potentials.

Consideration should be given to the effects of fertilizer application near cotton seed on the soil osmotic potential as well as the production of NH_3/rise in pH. Hood and Ensminger (1964) concluded that the detrimental effect of diammonium phosphate (DAP), when placed with the seed, was not an osmotic or NH_3 effect alone. They suggested that magnesium utilization may be adversely affected. In contrast, Bremner and Krogmeier (1989) studied the effects of urea placement with four different seed species and concluded that production of NH_3 with resulting toxicity was the cause of reduced germination. Bennett and Adams (1970) demonstrated the toxic effects of aqueous NH_3 on cotton root growth of seedlings in solution culture and soil. In nutrient solution culture, increasing pH increased the deleterious effects of NH_3 on root growth. The critical concentration for both solution culture and soil for incipient toxicity was between 0.17 mM and 0.22 mM. Excessive salinity from either salt buildup in the soil or from too close of contact with fertilizer is detrimental to cotton seed germination as it increases the soil osmotic potential which restricts imbibition of soil water by seed. Little to no effect on cotton seed germination was found at a soil salinity level of 1.9 dS m^{-1}, 16 to 43% reduction at 10.0 dS m^{-1}, and 46 to 83 % reduction at 20 dS m^{-1} (Qadir and Shams, 1997). There was also clear genotype tolerances/susceptibility to salinity.

SUMMARY

Given the sensitivity of the cotton seed to adverse weather and soil conditions, seed costs, and availability of seed of desired cultivars, planting the seed of the highest quality and vigor under the most optimal conditions should be a priority. This includes waiting until the soil temperature is 20°C or above at a depth of 5-cm, soil moisture is slightly less than field capacity, and the weather forecast is favorable. Soil should be conditioned or prepared to provide the greatest seed to soil contact in both conventional and no-till planting systems. For soils prone to crusting, consideration should be given to switching to a minimum till or no-till system as well as including a cover crop to provide residues for soil protection. Organic matter additions such as poultry litter or gin trash compost can also provide aggregate stabilizing benefits and improve moisture relations. Plowing under cover crop residues, especially legumes, should be done at least two weeks prior to planting to allow enough time for decomposition processes to reach their peak and then taper off to minimize NH_3 levels as well as other decomposition products which may have allelopathic effects. In no-till conditions, cover crops should be terminated at least 30 days prior to intended planting to minimize cutworm populations and potential stand damage. Cover crops with known strong allelopathic effects on cotton should be avoided. Planting under more ideal weather conditions will also reduce the likelihood of disease pressure and the need for fungicides. In-furrow fertilizer application at the time of planting should be kept to low rates and sources with low salt effect as well as low NH_3 production potential. In order to maximize profitability, planting under the most ideal conditions will increase stand vigor and minimize the risk of stand loss or failure, increase the growth rate and yield potential, and minimize the stress level of all those involved in the production of the crop.

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