Proper Seedbed Preparation[1]

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THE BASIC requirements for cotton seed germination and seedling emergence are discussed including the cultural and planter design implications.

Introduction

A good seedbed for cotton is somewhat like a good meal; if you are satisfied with the results it must have been good. A good meal in one area of the world may not be considered as good in another area. Likewise, a good seedbed used by a farmer in the black lands of Texas may not be considered good or even possible in southern Arizona. A planter can be evaluated in the same way. Planters that are still sold must be judged to be good, but each in its own area with specified farm management. Cotton planting is a compromise involving the correct assessment of the impossible requiring precision equipment and perfect management all within a few days. If a cotton farmer is still in business after 4 years, he must have developed a good if not optimum planting system. Within the widely differing methods developed for different soil type and environment there must be some common principles. My goal is to review some of these principles and their implications upon the development of proper or optimum planting systems rather than to discuss 'good' practices.

Bowen (1966) identified four soil environment factors that are necessary and sufficient for cotton germination and emergence. These factors are: 1) air permeability for oxygen diffusion and respiration, 2) moisture for metabolic processes, 3) temperature for metabolic processes and 4) soil strength lower than seedling capacity. In reports he referred to these variables as 'edaphic factors' which describes the variables relating to the soil. (Use of exact terminology may be the reason the work is not well known and used; a simple library search of titles using common seedbed terminology may overlook the citations). Soil chemistry and plant pathology contributions to poor emergence were not ignored but considered special emergence problems rather than basic variables. He presented data and theory arguing that cotton response to these fundamental variables was not continuous but that within a range of values no detrimental effect could be observed. Beyond the 'optimum' range the degradation in response may follow some relation or be a step function which at some point would cause catastrophic results. He used the limiting factor concept presented by Blackman (1905) to develop the basis for modeling emergence. Blackman wrote 'Plant growth is limited by that necessary factor that is in least relative abundance'. The responses observed by Bowen and others led to the development of a figure of merit for each factor that divides the range of no response and the range of the detrimental relationship.

Although the information developed by this approach could be used in different ways for modeling, perhaps the most useful would be a knowledge base system or expert system. Following is my interpretation of how this approach can be used for determining proper seed bed and planter design.

Moisture

Mechanisms: Germination and emergence obviously require moisture transfer from the soil to the seed and root. Both cases require moisture movement across a membrane as a liquid rather than as a gas. Recognition of this fact is usually not important for root uptake since root soil contact is assured. However, for germination the planting system must assure an intimate seedcoat to soil contact. This has been traditionally accomplished by puddling or by pressing either the seed or soil to assure contact. Unfortunately there is a delicate balance between time to germinate and loss of soil moisture through evaporation or transpiration. Once the radical has found a suitable downward path the root generally can extend about 6 times faster than soil drying with depth. Bowen determined for one soil that the root extended 1.5 inches per day and the permanent wilting point interface proceeded at .25 inches per day. However, if insufficient moisture is transferred across the seed coat to complete germination during the first wetting cycle, the seed may die.

Measurement: The farmer has traditionally estimated planting moisture by color and feel and this indeed may be adequate for most situations. Commonly, researchers use moisture blocks for these shallow measurements. I have suggested (1970) location of the moisture front using the abrupt change in electrical resistance associated with the moisture front which will be discussed later.

Figure of Merit: Bowen determined, for the conditions studied and assuming the other three factors are not limiting, that the moisture of the soil in contact with the seed must remain greater than −15 bars for three days to allow germination and radical entry into sustaining moisture.

Cultural and Planter Implications: Unless post plant rain or irrigation is planned, soil moisture in the planting zone must increse with depth. The source of water, either irrigation or rain, is not important, however, as I will discuss later, the rate of application and method have implications on the other three factors. The soil to seed contact should be controlled with a seed firming device such as a seed firming wheel rather than by firming the covering soil around the seed. The surface press wheel common on the majority of cotton planters indeed provides soil-seed contact but with confounding effects on the other three factors while providing a continuous media which increases soil water evaporation. If the planter does not disturb the soil below the seed, if the seed is pressed into that soil and if the covering soil has less moisture and lower density or greater pore space, a soil textural discontinuity exists at seed midline or slightly above. This discontinuity retards water loss from below while the loose soil above dries quickly, allowing higher temperatures and increased air permeability. Without post-plant rain or irrigation, the planter must accurately remove dry soil and control the seed covering. This approach has been described using a moisture seeking control (Carter, 1970) that if combined with the seed firming wheel and automatic controls for depth of soil covering the seed and degree of soil compaction would eliminate most of the uncertainty in meeting the figure of merit for seed zone moisture content.

Air Permeability

Mechanisms: Oxygen is required to initiate the metabolic processes for germination and sustain growth during emergence. (Menaei, 1989) Cotton seed is higher in oil content compared to legumes, corn and grains and therefore requires a higher oxygen diffusion threshold (Hake, 1989; Menaei, 1989) Bowen and Coble showed that cotton seeds cannot obtain sufficient oxygen for normal growth from air-saturated water or soil solutions at temperatures above 65 F. Aerobic soil conditions have been reported to be desirable for other reasons that are important but not part of this discussion.

Measurement: Oxygen diffusion is difficult to measure and simple instrumentation suitable for field use does not exist. Although there are many valid criticismns of air permeability as a method of estimated oxygen diffusion, the relative abrupt change in the shape of the germination vs/permeability curve at levels corresponding to diffusion limits suggest use of simple air permeameter instruments patterned after Grover (1955).

Figure of Merit: Bowen determined that, if the absolute permeability was greater than .05 square microns, the oxygen diffusion rate would not be limiting. However, his work did not include high organic residues which may increase the oxygen demand. Values below .05 were catastrophic allowing no latitude with reduced germination.

Cultural and Planter Implications: Preplant tillage, soil type, irrigation methods and organic material management affect air permeability at planting time. Macro pores are destroyed by tillage and plugged when water saturated. Air space is also reduced by

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compaction and puddling. The initial oxygen diffusion conditions are set by these preplant operations but the planter methodology is critical to maintaining these conditions particularly in fine textured soils. The use of a seed firming wheel or device is an important control. With a seed firming wheel the lower ½ to ⅔ of the seed coat can be in close contact with the soil for water transfer leaving the upper surface un-impeded for oxygen diffusion. Second in importance, the covering soil should be at a moisture content no greater than that removed and compaction limited to the unavoidable related to the covering tool action. A rough soil surface with organic material from pervious crop residues will minimize temporary sealing after rainfall. The moisture seeking planter control has equal application for control of air permeability as for moisture control. Current methods requiring surface compaction or capping for moisture preservation are a potential problem for oxygen diffusion and can be replaced if a functioning seed firm wheel and a moisture seeking control are used.

Soil Impedance

Mechanisms: During germination the seed swells slightly requiring deformation of the surrounding soil and under extreme conditions germination might fail. However, of much greater concern are radical and hypocotyl extension. For radical success pores or cracks must be sufficiently large and the soil strength sufficiently low to allow vertical extension and lateral deformation. Otherwise the radical will travel laterally (or even upward) and in the extreme limit emergence. A secondary problem observed at least 50 years ago occurs when the new tap root cannot expand laterally resulting in a weak hair-like tap root that cannot supply transpiration needs. Hypocotyl extension has three modes of failure associated with soil impedance. A uniform high strength zone extending from surface to seed depth or below (thick crust) will impede or inhibit the upward thrust. A thin crust over a loose soil presents a different problem with early extension followed by serpentine growth and/or 'broken necks'. The third problem is seldom observed, but if the covering soil is extremely loose or shallow the seed coat will not be shed.

Measurement: Bowen devised a method that measured a strength character of the soil in approximately the same way the seed experiences soil impedance: a seed size balloon expanded with air or water until the soil was fractured. The balloon pressure at fracture was used to define impedance. A small penetrometer can be used but care must be used in interpretation of results between thick and thin crusts and because of extreme variability. Bowen and Coble (1967) have proposed an instrumented reverse pick wheel as an instrument suitable for survey and as input for a control. Another possibility would be a small instrumented wedge something like a miniature subsoiler.

Figure of Merit: Using Bowen's methodology, plant emergence is inhibited when the impedance is greater than 12 psi and drops linearly to zero at 30 psi.

Cultural and Planter Implications: In preparation for planting, tillage compacting forces and method of irrigation can initiate conditions for high impedance. Bedding operations that include modified listers with shaping compact the soil. Of historic interest, compacted soil plus water plus drying produce adobe bricks. Cultural controls then include replacing pushing tools with lifting tools, avoiding puddling and encouraging organic material in the seed bed. In my experience, the planter and methodology must be held responsible for most failures due to high soil impedance above the seed. Without moisture seeking control, soil is removed for the worst or driest condition in the field, therefore, the moisture level is higher than desired for most of the field. Part of the weight of the planter is supported by a press wheel which compresses the covering soil and the planter is often followed by drags or chains. Often the full weight of the planter is supported over the drill compacting not only the covering soil but to some depth below the seed. These operations are custom made for soil crust formation. Elements of a cotton planter for impedance control are: 1) a successful seed firming wheel for emergence moisture and aeration control, 2) moisture sensitive surface soil removal, 3) depth control responsive to soil type, 4) planter support other than over the drill and 5) minimal, but controllable, compression on covering soil.

Temperature

Mechanisms: Once triggered by moisture and provided that moisture is not limiting, the rate of germination and emergence is related to temperature with the rate of chemical reactions doubling for each 10 degrees celsius. Bowen, (1955), Kerby, (1989), and many others have determined a minimum value of heat units (defined in different ways) for emergence with the time to emerge related to heat unit accumulation. It is important to recognize that 'heat units' are a record of temperature above an experimentally determined threshold and not heat flow or units of heat. Temperature is also a driving force for moisture evaporation from soil and for crust formation. Since oxygen diffusion must increase as the growth rate increases, high temperature requires greater soil air permeability.

Measurement: Temperature is the easiest of the four factors to measure: simple thermometers to complex models. Bowen used thermocouples to develop the figure of merit and Kerby has developed emergence criteria based upon a 5-day weather forecast.

Figure of Merit: Bowen determined that a figure of merit for temperature in terms of degree-hours above 55 F was 2600. A rule based approach by Kerby applicable to knowledge base modeling specifies that planting should not be attempted if heat-units (degree-days) above 65 is less than 10 or the average of the cold and warm germination is less than 60 percent. Both Kerby and Bowen suspect that a high temperature figure of merit may be identified with further investigation.

Cultural and Planter Implications: Cultural controls that affect seed bed temperature include bed shape, soil surface, residues, compaction and irrigation method. The seed zone within a high triangular bed will warm faster than a low wide compact bed or, in the extreme, flat residue covered soil. Applied water cools the bed. The surface texture can vary from a near black body (day heating, night cooling) to a greenhouse effect (day heating, night conserving). After soil preparation the only controls left are awaiting a minimum soil temperature and checking the weather forecast. Planter design and use offer at least three modes of affecting temperature: depth of planting, covering soil state and com-

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paction. To enhance temperature at seed depths planting should be shallow but consistent with moisture, aeration and impedance figure of merits. Dry soil warms faster than wet, therefore a drier soil for seed covering promotes a higher temperature at seed depth sooner. Without a functioning seed firming wheel, dry covering over shallow planting would be risky.

Conclusions

Where do we go from here? From the discussion above, it is obvious to me that modifications to planter design, management and predictive modeling are needed to facilitate a shift from a 'good' seed bed to a proper seed bed. I would suggest the following. 1) We encourage developement of rule-based or expert systems as planting models that incorporate all of Bowen's edaphic factors and the limiting factor concept. At least one effort, CALEX COTTON, is using this approach. The resulting model should run on low-end home computers and should contain independent modules rather than all-or-nothing operation. 2) We encourage design and development of planters that: a) do not require wheels for support directly over the drill, b) move soil with minimum or no compression, c) measure and control covering soil within the figures of merit, d) allow use of an electronic moisture seeking control as an option, e) perfect the seed firming wheel for operation in all soil condition and f) direct seed into stubble or cover crops. 3) We should encourage basic as well as applied research for: a) preservation or enhancement of soil organic content, b) direct seeding without tillage, c) macropore establishment and preservation, and d) extension of the edaphic factors to include soil chemistry and the extension of limiting factors to include pest management.

Success in germination and emergence can be improved. I have attempted to discuss some of the possibilities with emphasis on edaphic factors, limiting factor concepts, the ubiquitous seed firming wheel, moisture seeking control, modeling, and need for research.

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