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Vigor Indices for Cotton Management

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Among crop plants, cotton is unique in many aspects of its growth, development, and management. Adjusting its balance between vegetative and reproductive growth is one of the biggest challenges of cotton farmers throughout the world. Although profit comes from reproductive growth (bolls with lint), vegetative growth (leaf and stem tissue) is needed to support boll development.

Due in part to the fact that cotton is a perennial plant that we produce as an annual, it is very responsive to environmental conditions. Changes in its surroundings such as fluctuations in temperature, humidity, soil moisture or salinity may result in redirection (allocation) of its energy (photosynthate). For instance, a period of drought may result in photosynthate moving into roots with no vegetative shoot growth or reproductive boll loading occurring.

If a cotton plant can think, as some people suggest, it very likely concludes that if things are not right in a given year for setting bolls, it must take care of itself first and delay starting a family until next year. However, this is not an option that a cotton farmer or crop manager wants to offer to the plant. Yield potential can be lost if a cotton crop takes off into a period of rank, vegetative growth. This is about the last thing that a cotton grower wants to see. So the challenge becomes identifying the initial conditions or trends that can lead to excessive vegetative growth, and trying to respond with proper management as soon as possible.

What we do know is that we like high lint yields. The basic question is "how much plant do we need to achieve high yields?" First, it is important to recognize that a certain amount of stem, leaf, and root development is necessary to provide the framework and physiological machinery needed to support the reproductive portion of the plant. However, what constitutes a proper balance between the vegetative and reproductive parts of the plant is a point of discussion.

We might ask "what is normal?"; "how do you measure it?"; or very importantly, "what do you do about it?" These questions have provided incentive for developing a vigor index for cotton.

Over the last 10 years, a number of vigor indices have been proposed. Cotton growers and consultants have used various means, such as the width of 3 to 4 fingers, to measure internode length (and crop vigor) quickly in the field. Having a standard vigor index may be in the best interest of cotton researchers, educators, and managers across the Cotton Belt. In this article, we outline several indices that have been developed for field evaluation of cotton plants. The three vigor indices or techniques that we address are the height to node ratio (**HNR**), the growth rate (**GR**), and the average length of the top five internodes (**ALT5**).

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General Requirements

A vigor estimate represents the amount of "horsepower" that is available for further plant development. The general requirements associated with a good vigor index should include that it: 1) is easy to conduct, 2) reflects the balance between vegetative and reproductive growth 3) is sensitive enough to serve as a warning device helpful in guiding management decisions and not simply to verify rank growth after the fact, and 4) includes a reference base for use in determining crop condition at various stages of growth.

Although a given vigor index may have broad potential for application, extensive data collection is required to develop baselines for specific regions. There are three basic approaches that have been evaluated as measures of crop vigor. The most widely documented, the HNR, expresses the crop's season-long vigor by calculating the distance between all the nodes produced to date. A second approach that recognizes that rainfed cotton may encounter abrupt shifts in conditions, focuses on recent changes by measuring growth rates. The inherent limitation in these two approaches has stimulated interest in a series of related methods that concentrate on the active growth of internodes that are still elongating (ALT5). The discussions that follow have been developed from large databases collected in several distinct environments. What may represent "normal" growth in one area may not apply directly to another area.

Height to Node Ratio (HNR)

HNRs are based upon having 1) a linear relationship between plant height and main stem node number, and 2) a computable relationship between heat unit accumulation after planting (HUAP) and node production. Heat units used in this paper are calculated with 86°F and 55°F upper and lower thresholds, respectively, a practice common to Arizona. In most states, degree day 60s (DD 60s) are used. The 86/55°F threshold heat unit results in more early season heat units, but fewer heat units during the hottest part of the Arizona summer when temperatures soar far above 86°F. To help readers outside of Arizona, we have put a second axis on the graphs to indicate the number of nodes corresponding to Arizona HUAP.

HNRs, probably the most widely accepted and tested technique for estimating cotton vigor, require:

- measuring the height of the plant, in inches, from the base of the plant (cotyledons) to the terminal;
- counting the total number of main stem nodes, starting from the cotyledonary nodes at the base of the plant (as node 0), and continuing up the stem to the youngest node with a subtending leaf that is at least one inch in diameter (approximately the diameter of a quarter);
- calculating the HNR by dividing the plant height (inches) by the total number of main stem nodes;
- referencing the HNR to an established baseline as a function of stage of growth, node number, or HUAP.

HNRs change with stages of growth as evident in Figure 1 where HNRs are graphed against Arizona HUAP and number of main stem nodes. The baseline (center line) represents an average plant response, over many site-years, to optimum, non-stressed growing conditions. This baseline is bounded by both upper and lower thresholds which represent the variability associated with optimum conditions. An HNR falling between the thresholds is within the realm of “normal” growth under fully irrigated conditions in Arizona. Generally, the closer an HNR is to the baseline, the better the balance between vegetative and reproductive growth in a particular field.

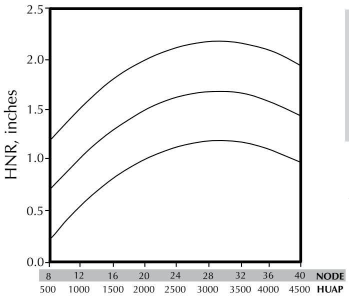


Figure 1. Height to node ratios plotted against number of main stem nodes and heat units accumulated since planting, 86/55 threshold (Source: J.C. Silvertooth)

The intense, dry heat of Arizona produces HNRs that are lower than those in many other areas of the Cotton Belt. HNRs based on 40 site-years of data for the San Joaquin Valley of California can be used to judge crop performance (Figure 2). Optimum yield has generally occurred when HNRs are 10-15% less than these “non-stressed” values.

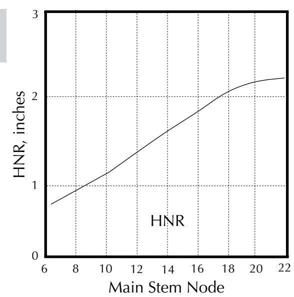


Figure 2. HNRs plotted against plant age as number of main stem nodes (Source: T.A. Kerby)

Growth Rate (GR)

Recent changes in the elongation rate of main stem internodes are accounted for by growth rate (GR) measurements. GRs warn of potential tendencies toward vegetative growth. To calculate a GR, divide the change in plant height by the change in number of nodes. Follow the same procedure as for HNRs, but visit the field more than once in order to measure change. Very recent changes in vigor can be detected with GRs, giving the method potentially greater sensitivity than that obtained through HNRs. However, this greater sensitivity also renders GRs more susceptible to slight sampling errors. GRs require reliable, regional, reference baselines.

Because growth rate patterns have not been studied extensively across the Cotton Belt, reference baselines are not abundant. GR is plotted against number of main stem nodes for the Arizona and California databases (Figure 3). Comparing GRs for the San Joaquin with Arizona values illustrates that less nodes are formed and GRs are higher outside of Arizona. Arizona and California’s Imperial Valley are unique environments. Even under well-irrigated conditions, plants enduring the intense, dry heat typical of these areas become water-stressed. Plants cannot move water through themselves fast enough to meet the evaporative demand from the surfaces of their leaves. Consequently, HNRs and GRs are lower than in other areas of the Cotton Belt.

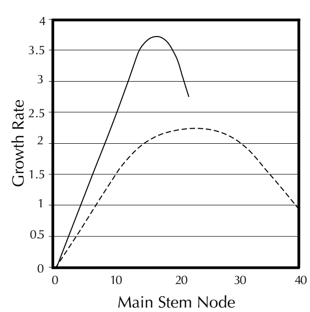


Figure 3. GRs plotted against main stem node number for Arizona (———) and for San Joaquin Valley (———) data sets (Source: J.C. Silvertooth, T.A. Kerby)

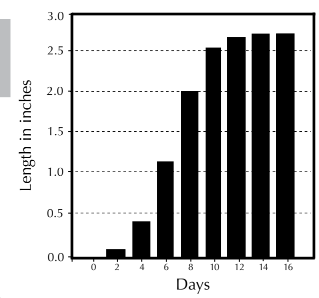
Average Length of the Top Five Internodes (ALT5)

Because the zone of active stem growth is near the growing terminal of a cotton plant, some researchers have focused on developing a vigor index utilizing this region. Specifically, the upper five nodes are commonly those still undergoing rapid elongation. The average length of the top five internodes (ALT5) has been proposed as an indicator of the actual main stem elongation rate, or vigor. An ALT5 is basically an HNR of the top five nodes. The technique assumes: 1) main stems attain their maximum height in a period of 12 to 15 days, and 2) plant growth follows an S-shaped pattern (Figure 2).

An ALT5 is very similar to an HNR when plants are small. As plants grow, HNRs continue to take into account all main stem nodes, but ALT5s focus only on the zone of active growth. The very simplicity of an ALT5 is also its biggest liability. Because the ALT5 uses only five nodes, miscounting even a single node will cause an error in the final measurement and any reference to a standard baseline. Care must be taken to standardize the way measurements are made in the field.

Data for a single early-maturing variety grown one season in Corpus Christi show that internode 14 (between main stem nodes 13 and 14) develops rapidly for 5 to 6 days (Figure 4). The rate of internode elongation then slows and becomes negligible in 12 to 14 days. All internodes of the plant were found to display this pattern of development. Because elongation rate and duration are influenced by environmental factors such as temperature, growth patterns are plotted frequently as a function of heat units instead of days. Assuming that water is not limiting, under cooler temperatures with fewer HUAP, internodes may elongate for up to 15 days. With warmer temperatures, this same period of internode elongation may be reduced to 12 days.

Figure 4. Elongation pattern for internode #14 of an early-maturing variety (Source: J.A. Landivar)



ALT5s are useful when the daily increase in plant height is constant and not slowing down or speeding up. This period of ‘linear’ growth occurs between approximately 50 and 80 days after emergence. Over this period, ALT5s are more sensitive indicators of plant response to a Pix® (mepiquat chloride) application than HNRs (Figure 5). It is important to note that this method works best from 1 week before flowering to about 2 weeks after flowering, when vegetative growth becomes depressed as a result of boll loading. This timing corresponds to plants having between 13 and 19 total nodes.

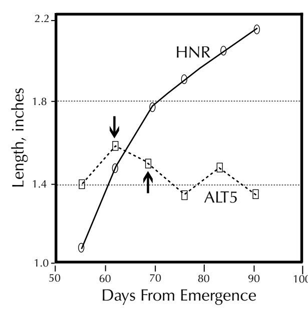


Figure 5. Effect of Pix® applications (arrows) on average internode length of all main stem nodes (HNR) and of the top five nodes (ALT5) of an early-maturing variety at Corpus Christi (Source: J.A. Landivar)

Because of the consistency of ALT5 measurements, researchers have been able to develop a simple, color-coded ruler to use to quickly take ALT5s in the field (Figure 6). Contact your local extension agent for a copy. When using one of these color-coded rulers, start measuring from the uppermost internode. (This internode needs to be 0.5 inches or more in length to be included in the measurement.) Closely examine the terminal to identify the top internode, and then count down the main stem four additional internodes. Place the color-coded ruler at the base of this fifth internode, and measure the distance to the top of the first internode. This distance divided by five is the ALT5.

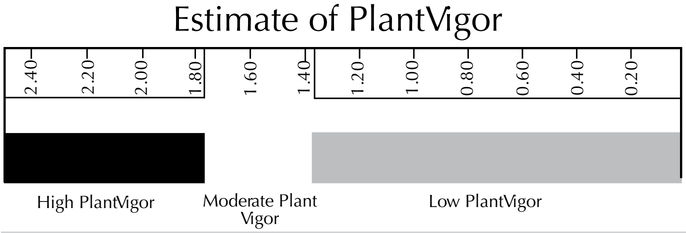


Figure 6. Generic example of color-coded ruler for measuring ALT5s (Source: J.A. Landivar)

Initial evaluation and validation of this technique has been done in Corpus Christi. Data collected there have shown that if the ALT5 is less than 1.4 inches, the plant is growing at a rate to produce a maximum plant height at cut-out of 30 inches or less. No Pix® is needed. If the ALT5 is in the range of 1.4 to 1.8 inches, plant height at cut-out may be from 30 to 40 inches. Any decision to apply Pix® needs to take into account fruit retention and field history. If the ALT5 is between 1.8 and 2.4 inches or greater, the plant height at cut-out is estimated to be 40 to 52 inches or greater. The top five internodes are elongating rapidly and Pix® may be needed.

Regional Perspectives

At this point, you may be wondering how these methods are applied across the Cotton Belt. Here we discuss, region by region, how these techniques measure up. Some are clearly more useful in one region than in others.

West (AZ, CA)

Timely and adequate application of water, combined with bountiful heat units, assures more consistent growth. Consequently, growth is probably most predictable in this region, primarily because plants are irrigated and water should not be limiting. In non-irrigated regions, growers often must contend with too much or too little rainfall and variable amounts of solar radiation in addition to the plethora of other problems, such as pests, that afflict crops Beltwide. In those regions, HNRs may not accurately assess plant vigor.

HNRs are valuable in the West, particularly when used in conjunction with fruit retention data. For example, in Arizona when fruit retention dropped near 1500 HUAP, HNR increased (Figure 7). Similarly, when fruit retention improved around 2000 HUAP, HNR decreased. The fact that HNR and fruit retention are so closely linked is important. In developing any vigor index on a regional level, the sensitivity and relationship of HNRs and fruit retention must be addressed.

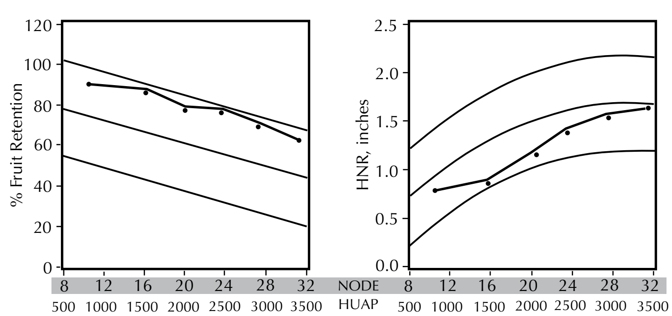


Figure 7. Comparison of height to node ratios and fruit retention levels for ‘95 Arizona Upland cotton plotted against number of main stem nodes and HUAP, 86/55 thresholds (Source: J.C. Silvertooth)

Southwest (NM, OK, TX)

Total heat units and rainfall vary considerably over this region of the Cotton Belt. Anywhere from 1800 to 4000 heat units and from 15 to 40 inches of rain can be received in a growing season. Cotton can sometimes be planted in West Texas even after fields have been harvested in South Texas. Many of the plant vigor indices used elsewhere work well in southern areas of the Southwest. For instance, ALT5s from early-squaring to mid-bloom have been successfully used in the Coastal Bend Region of Texas to determine potential plant height at cutout.

The uniqueness of the High Plains creates special challenges. There, cotton is affected by wind which can shorten the stalk. Vigor measurements that incorporate total plant height are less useful predictors of potential growth. Average HNRs for top, medium, and low yielding fields are plotted in Figure 8. Differences in HNRs for fields yielding 390 versus 1087 pounds of lint per acre were not apparent until late in the year, after critical management decisions had been made. At this time, ALT5s may offer the sensitivity needed in this region.

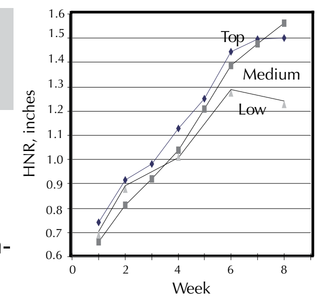


Figure 8. Average HNRs for 35 fields grouped according to yield - top, medium, and low, or 1087, 833 and 390 lbs of lint per acre, respectively (Source: K. Hake)

Mid-South (AR, LA, MO, MS, TN)

Vigor in Mid-South crops typically can be influenced more by in-season rainfall than any other factor. Often adequate to excessive early in the season, rainfall can decrease so that drought is not uncommon later in the season. Vigor indices must adequately reflect the influence of these fluctuating environmental conditions.

HNRs are commonly used, but suffer from a lack of sensitivity to recent environmental changes as the season progresses. GRs are being more widely adopted as a good measure of vigor. If the GR is more than 3 inches per node, an application of Pix® may be needed. Decisions should take into account patterns of fruit retention. As in the other regions, these methods will be more useful as regional data bases are developed for reference purposes.

Southeast (AL, FL, GA, NC, SC, VA)

Environmental conditions can fluctuate rapidly in this region. Characteristically light-textured soils quickly can be depleted of moisture following rainstorms that saturate the soil profile. Moisture availability rarely exceeds 1 to 1.5 inches in the active rooting zone. Consequently, growth rates may range from less than 1 to over 3 inches in adjacent internodes. HNR alone may not adequately describe current, or predict future, growth tendencies.

HNRs have gained acceptance as a general indicator of crop health at early bloom. Along the northern margins of this region (where the season’s length is limited), HNRs have proven reliable predictors of yield response to early bloom applications of Pix®. In more southern latitudes, efforts to associate final field performance with HNR at early bloom have not been successful. This result may be expected - given the potential for rapid onset of drought stress and subsequent premature cutout in a longer season production system.

Crop managers have turned to more sensitive measures of recent growth conditions. Whereas growth rates and ALT5s are more sensitive than HNRs and can heighten the grower’s capabilities, the full utility of these methods awaits the development and validation of a southeastern data base for these indices of crop vigor.

Conclusions

Several vigor indices are useful in evaluating a cotton crop's balance between vegetative and reproductive growth, and in guiding management decisions. All methods discussed here require a reference baseline to use to gauge what is typical or abnormal for a crop. Because baselines developed for one particular region will not necessarily apply to other regions of the Cotton Belt, substantial regional databases are needed in order to develop useful baselines for each region. Beltwide comparisons would be made easier if all reference baselines referred to stage of plant growth (i.e. number of nodes developed). Since each node requires a specific number of heat units to develop, using nodes as an indication of time would serve to normalize plant development Beltwide.

Various techniques to assess plant vigor have been developed in different parts of the country. Goals and objectives have often been similar, cotton growth conditions have been varied, and the ideas and approaches (people) have been different. Here we review the techniques for assessing plant vigor, discuss their strengths and weaknesses, and offer direction for development of a standardized technique. Regional adaptation and refinement will certainly be required for the various states and regions involved.

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