



Mapping Cotton Boll Opening at Field-Scale (%Open Bolls) Using UAV Imagery

Authored by Arunachalam Manimozhian, Postdoctoral Research Associate; Pius Jjagwe, Graduate Research Assistant; and Abhilash Chandel, Assistant Professor, Biological Systems Engineering, Tidewater Agricultural Research and Extension Center, Virginia Tech

Introduction

Cotton growth is indeterminate; therefore, it is critical to terminate after the bolls reach a certain level of maturity and the fiber reaches a certain level of quality—failure to meet these criteria results in discounted prices at sales points offered to producers. Producers typically scout their cotton fields to identify the number of cotton boll openings and maturity levels from a few random locations within the entire field. A general rule for initiating defoliation sprays is when cotton bolls are 60% open, or, for some varieties, 40–60% open. Other methods include counting the number of “nodes above cracked bolls (NACB)” and the “sharp knife technique”. Importantly, these estimates are based on a few locations within the field and therefore may inaccurately represent boll open or maturity status across the entire field, particularly when microclimate and soil conditions vary significantly and affect physiological parameters. In addition, manual scouting and visualization can be tedious and subjective. Inaccurate spatial assessments can delay or advance defoliation and harvest operations. Previous studies have reported that premature defoliation (when 60% of bolls were not open) can result in yield and economic losses up to 15% (National Cotton Council). The advent of remote sensing technology and data science can be useful for autonomously assessing spatial variations in cotton boll status to minimize losses from untimed defoliation and harvest.

This article describes a UAV-based method for mapping visible lint exposure (% open bolls) using multispectral imagery. The method provides: (1) field-scale maps at 33ft x 33ft resolution with aggregated % open bolls and (2) boll opening trends over time to aid operational decision-making.

Methods

Study site and UAV imagery

A cotton field at the Tidewater Agricultural Research and Extension Center in Suffolk, Virginia, was selected for this study. A total of 16 UAV imaging campaigns were conducted between late August and early November 2025 to capture the progression of boll opening through the late season. Figure 1 shows a representative map of the study area captured by the UAV.

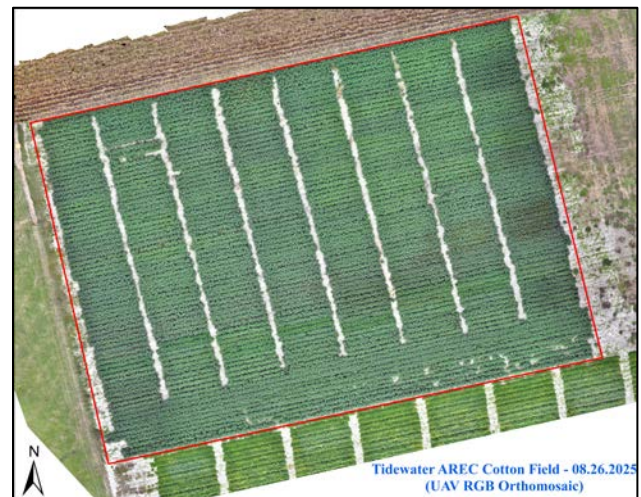


Figure 1. Representative map of a cotton Field at Tidewater Agricultural Research and Extension Center captured using the UAV on August 26, 2025. The map shows full canopy growth with negligible open cotton bolls. The imaging was conducted at a resolution of 1 cm/pixel.

Data processing

The analysis used a rule-based approach with campaign-wise processing of multispectral images, specifically the red-band reflectance thresholds.

Multispectral imagery was used instead of RGB imagery because RGB is more broadband and highly sensitive to object exposure variations across imaging campaigns. As a result, several non-lint objects (soil, residue, stems, glare) may appear bright, increasing false positives. In contrast, multispectral red-band reflectance is narrower and more physically stable, enabling more reliable lint-vegetation separation across imaging campaigns.

Key data processing steps include:

1. **Campaign alignment:** All imaging campaigns were aligned with the maps from 8/26/2025 (baseline).
2. **Canopy masking:** Crop canopy and other background (e.g., soil) were segmented using Normalized Difference Vegetation Index (NDVI) maps to extract lint only (cotton bolls) maps.
3. **Thresholding:** Using the red-band reflectance thresholds, a visible lint map was generated with lint pixels classified as 1 and non-lint pixels classified as 0. The red-band thresholding was used because cotton lint appears bright in the red band due to strong reflectance; healthy leaves appear dark because chlorophyll absorbs red light; and soil and other residues show intermediate reflectance, allowing lint to be isolated reliably using rule-based thresholding.
4. **Field-scale aggregation:** Lint-only maps were aggregated to 33ft x 33ft grid resolution, and percent open bolls were computed for each grid in the map to generate the final map product.

% open bolls were computed as:

$$\% \text{ Open bolls} = \left(\frac{N_{\text{lint}}}{N_{\text{canopy}}} \right) \times 100$$

Where N_{lint} is the number of visible lint pixels in a 33ft x 33ft grid for a given UAV-based map, and N_{canopy} is the total number of canopy pixels in the same grid. It must be noted that percent open bolls serves as a proxy for visible lint exposure and is not a direct replacement for manual boll counting. Figure 2 illustrates the processing workflow for % open boll mapping.

5. **Temporal boll open tracking:** In addition to percent boll opening mapping, the temporal progression of boll opening and the rate of boll opening visible per day were also tracked at the field scale to highlight the capabilities of UAV imagery.

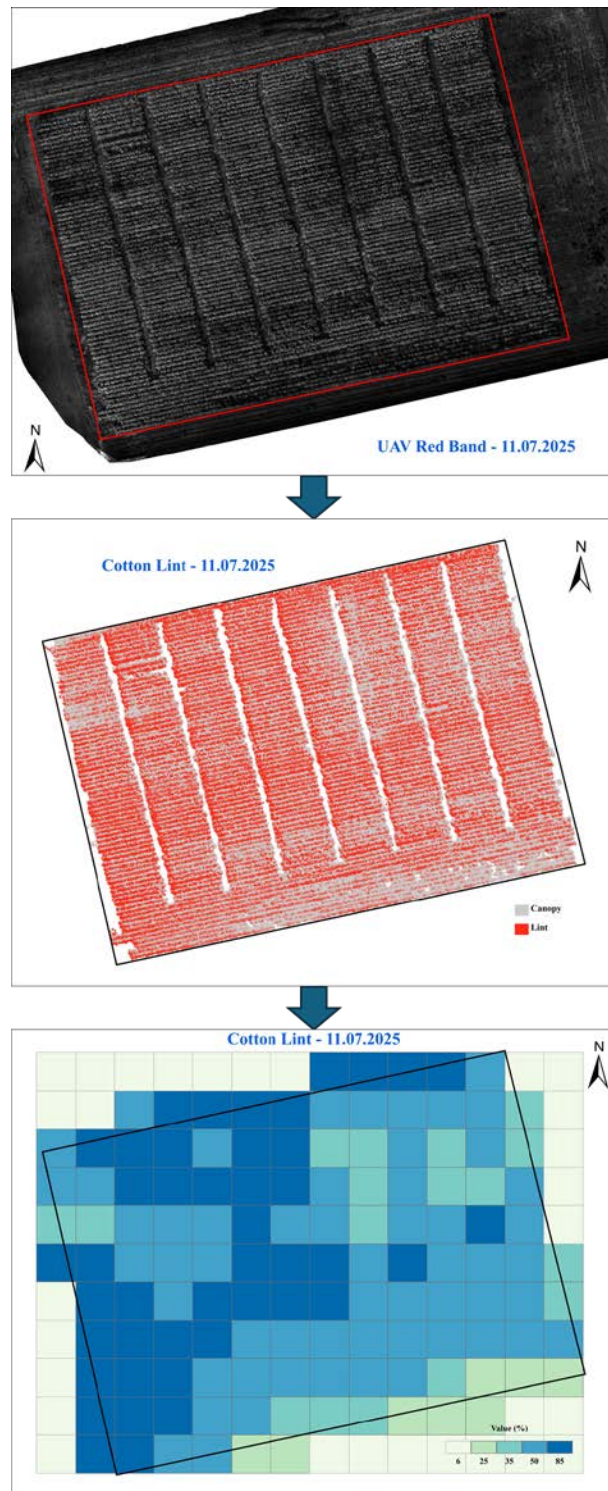


Figure 2. This figure illustrates the processing of UAV multispectral imagery to generate aggregated percent open boll maps at the field scale for November 7, 2025. The topmost image represents a raw image obtained after stitching the UAV multispectral imagery. The middle image represents the segmentation of open cotton bolls from the canopy and soil background. In comparison, the bottommost image shows the scaling of percent cotton bolls at the field scale, with a spatial resolution of 33 ft x 33 ft.

Results

Boll opening mapping

Through campaigns, the red-band rule-based method consistently isolates cotton lint exposure patterns in the canopy. Lint masks captured spatially coherent patches and showed increasing lint density toward later-season dates. Some localized segmentation ambiguity was observed under canopy shadows or in bright background zones (e.g., dry residues or exposed soil). To improve robustness across varying illumination conditions and reduce threshold sensitivity across campaigns, we adopted a percentile-based adaptive thresholding approach to manage image-to-image brightness variation. Mapped cotton boll opening was aggregated to a 33 ft x 33 ft resolution to create spatially interpretable field maps shown in figure 3. High % open boll values indicate a higher fraction of visible cotton lint relative to the canopy in that grid location. The spatial variations in percent boll opening are most likely due to spatial differences in plant growth and health, soil, and/or micro-climate.

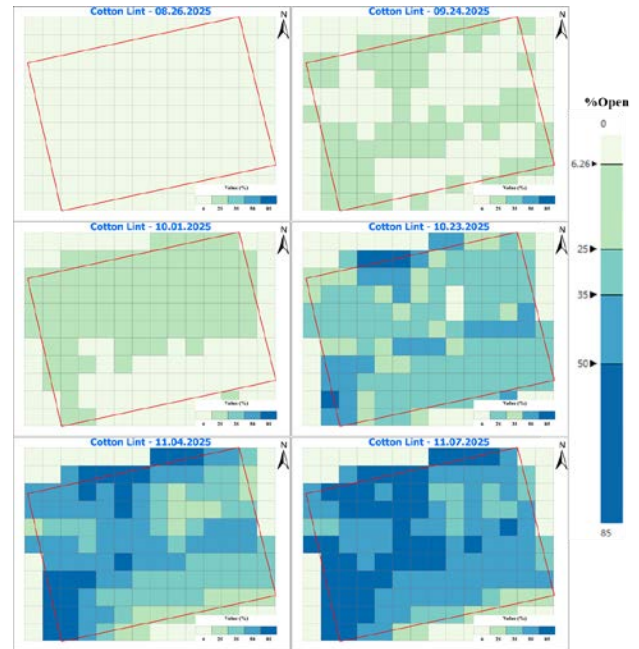


Figure 3. This figure displays the percentage of open cotton bolls at the field scale at different imaging dates, including August 26, September 24, October 1, October 23, November 4, and November 7, 2025. These field-scale maps show how the % open bolls increased over time between different days, as well as in-field variability in opening within every imaging campaign. Lighter green color codes show lower boll opening while deeper blue color indicates higher boll opening within the field.

Boll opening overtime

Figure 4 presents the temporal progression of cotton boll opening during the growing season for the entire field derived from UAV multispectral imagery. The mean and median values show a clear increasing trend from late August through early November, consistent with progressive boll opening and expanding lint visibility across the growing season. The shaded P10-P90 envelope highlights substantial within-field variability, indicating that lint exposure develops heterogeneously, with some field zones opening bolls earlier and reaching higher % open bolls than others. Minor campaign-to-campaign fluctuations (zigzag pattern) are expected due to differences in illumination, canopy shadows, and thresholding across imaging flights; however, the overall seasonal trajectory remains consistent and provides a robust numerical representation of lint exposure progression.

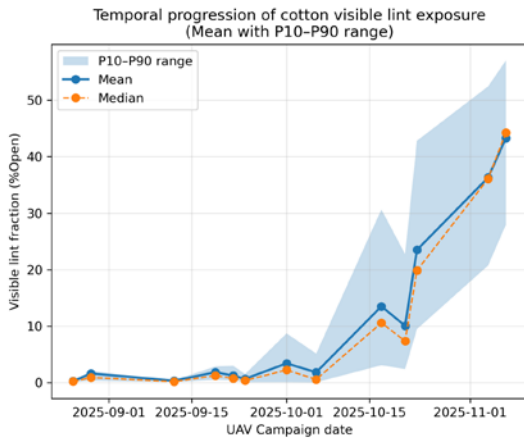


Figure 4. This graph shows the increasing percentage of cotton bolls mapped from UAV imagery, averaged across the entire field, for the period from August 26 to November 7, 2025. The observations highlight increasing boll opening over time, as well as increasing in-field variability, as shown by the P10-90 range curve.

Figure 5 presents the daily boll opening rate computed as the change in field-scale boll opening between successive UAV campaigns divided by the number of days between campaigns. The results show that boll opening rate is temporally variable, with relatively low rates early in the season, increasing during the period of rapid opening, and declining thereafter as the remaining unopened boll fraction decreases. Peaks in the rate curve indicate periods of accelerated lint exposure. Because percent open boll is a remote-sensing proxy derived from segmented imagery of visible lint, short-term variability may occur due to campaign-to-campaign differences in illumination and shadow fraction, which affect segmentation response. The apparent late-season increase following a brief dip does not imply any physiological “reversal” of boll opening; rather, a defoliation spray was applied on 10/23/2025 (REI ending 10/30), which likely reduced canopy occlusion and increased lint visibility, leading to renewed increases in % open bolls and thus a higher opening rate in the final campaigns.

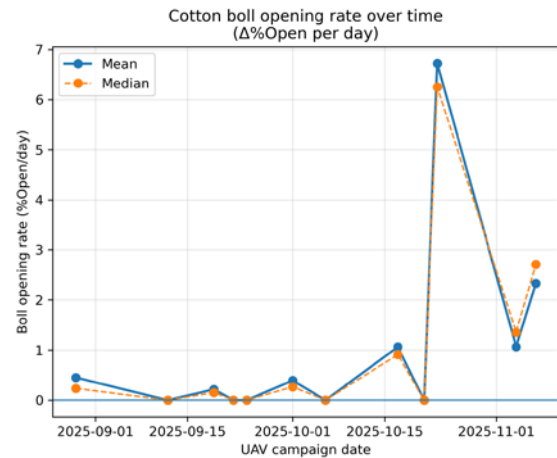


Figure 5. This graph shows the mean and median rates of cotton boll opening, normalized to a daily interval, mapped from UAV imagery. The boll opening rate remained lower and fairly consistent until early October and increased in a zigzag pattern until November 7, 2025 (Last flight campaign).

Key takeaways

- UAV multispectral red-band reflectance provides a robust signal for cotton boll opening quantification.
- Aggregating results to 33ft grids produces interpretable maps for within-field comparison.
- The boll opening progression enables tracking over time that can aid operational decision-making and scalable monitoring.

Boll opening maps for decision support

The 33 ft grid maps provide a numerical representation of boll opening across the field and its progression over time, well suited for integration into digital advisory and decision-support tools. Such maps can serve as guidance for planning and initiating defoliation and harvest operations. For example, when % boll open increases steadily and reaches a threshold (e.g., operational boll-opening readiness), alerts can be generated to support scouting and application planning.

Limitations and practical considerations

Even though red-band lint isolation is physically robust, field conditions can influence output quality. Canopy shadow pixels may reduce lint visibility from an aerial view. Similarly, bright residues or exposed soil may create false positives if masking is

not appropriate. There could also be hotspot effects where strong sun-angle reflectance can mimic cotton lint. To minimize such noise, acquiring aerial imagery under consistent solar conditions between 10 a.m. and 2 p.m. with correct canopy masking can yield the best results and comparability across time. Furthermore, the use and evaluation of satellite imagery can serve as a practical and autonomous solution for decision support, free of cost.

Virginia Cooperative Extension is a partnership of Virginia Tech, Virginia State University, the U.S. Department of Agriculture (USDA), and local governments, and is an equal opportunity employer. For the full non-discrimination statement, please visit ext.vt.edu/accessibility.

2026

BSE-385NP

References

- Faircloth, J.C., Sanders, J., and Wilson, H.P. 2009. Cotton Harvest Aid Selection and Application Timing. Virginia Cooperative Extension Publication 424-201.
- Chen, P., Xu, W., Zhan, Y., Yang, W., Wang, J., and Lan, Y. 2022. Evaluation of cotton defoliation rate and establishment of spray prescription map using remote sensing imagery. *Remote Sensing*, 14(17), p.4206.
- Shrestha, A., Swaminathan, V., Thomasson, J.A., Rajan, N., Poudyal, C., Miyanaka, N., and Siegfried, J.A. 2023, June. A modular artificial neural network technique for early estimation of cotton yield using an unmanned aerial system. In *Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping VIII* (Vol. 12539, pp. 25-33). SPIE.
- Sanders, J.C. 2003. Determining optimal cotton harvest-aid application timing based upon remotely sensed crop data. Mississippi State University.
- Wrona, A.F., Banks, J.C., Hake, K., Lege, K., Patterson, M., Roberts, B., Snipes, C.E., Supak, J., 1996. Achieving a Clean Finish. *Cotton Physiology Today- Newsletter of the Cotton Physiology Education Program* — National Cotton Council, 7(6), 1-32.

Acknowledgments

This work was supported by the Cotton Incorporated grant # 24-956. We acknowledge Prof. David Langston and Tidewater Agricultural Research and Extension Center, Virginia Tech, for providing facilities in support of this work.