INTENSIVE SPATIAL DATA CHARACTERIZATION: SPATIAL DATA RELATIONSHIPS IN COTTON PRODUCTION

Kendall R. Kirk
Brennan E. Teddy
Michael T. Plumblee
John D. Mueller
Jeremy K. Greene
Benjamin B. Fogle
Clemson University, Edisto REC
Blackville, SC

Abstract

This study took an intensive approach to seek to identify and quantify factors critical to cotton yield limitation. The premise for the study was that for a given lot of seed, each seed generally has the same potential to make yield and quality lint. However, due to in-field variability, each seed does not perform equally in producing cotton. In this study models were developed too seek to identify and quantify the effects of the factors that cause spatial variability in cotton yield. Two years of data were collected at fifty positions of a field and these data were subjected to stepwise regression analyses to identify the factors most significant in prediction of yield deficit.

Introduction

In-field variability can result from a number of different factors including, but not limited to water holding capacity of the soil, pest pressure, nutrient availability, soil moisture content, and weed competition. Traditional studies investigate these factors individually, taking care to reduce the effects of the factors not being tested. This study takes a different approach; the collective, naturally occurring in-field variability was measured and modeled in an effort to characterize each factor's effect on cotton production.

The objectives of this study were to:

1. Quantify spatial factors related to cotton yield deficit
2. Quantify economic value of spatial variability on cotton production.
3. Identify factors that may warrant further investigation through replicated trials.

Materials and Methods

A field in Barnwell County, S.C. with a relatively high potential for spatial yield variability was divided into fifty, 0.4 ha (1 ac) grids (Figure 1) and the naturally occurring in-field variability across a number of measured variables in two consecutive production years of Deltapine 1646 was used to seek to explain observed differences in cotton yield and other factors. Lint yield deficit was defined as the 97.5 percentile yield minus the observed yield at a given position; i.e. lower yields result in larger deficits. Put simply, yield deficit is the shortfall at a position as compared yield potential for the crop year, variety, and field.

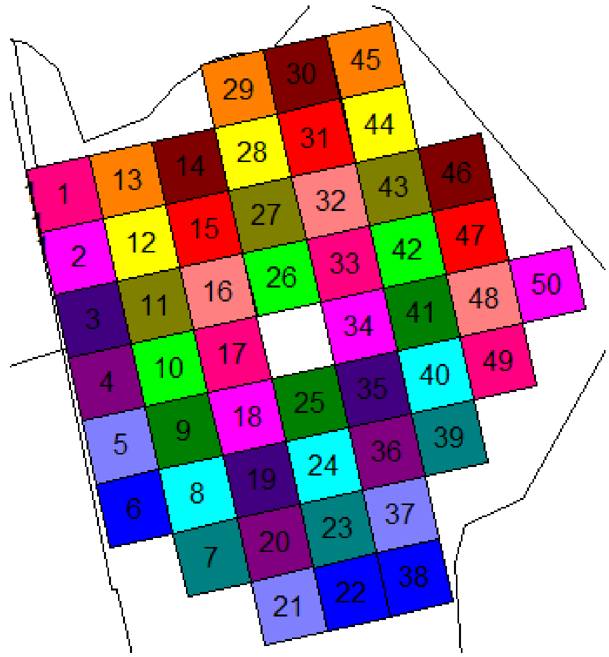


Figure 1. Grid definition and sample positions for data collection and modelling.

Data were collected from the center of each grid position. Data collected one or two times included the following: soil texture, soil organic matter, pre-plant shallow and deep soil fertility, penetrometer measurements for detection of hardpan, thrips counts, thrips damage ratings, maturity measurements, mid-season soil nematode counts, deer damage ratings, square retention ratings, sweep net samples and insect counts, leaf and petiole tissue fertility analysis, mid-season shallow soil fertility, stink bug damage ratings, plant heights, on-plant picker losses, on-ground lint losses, lint fiber quality, gin turnout, and yield. Data collected about every two to four weeks included the following: 0.08 ha (0.2 ac) aerial imagery for NDVI, canopy closure, and weed coverage estimates, soil moisture, soil surface temperature, soil temperature at four inch depth, and canopy temperature.

The collected data were used to construct multiple linear regression models using stepwise regression methods. Model outputs from the stepwise regressions were further refined to reduce likelihood of multiple collinearity and to reduce models to using only terms that were significant at the α=0.05 level. Variance inflation factor (VIF) was used as an indicator of multiple collinearity and terms were reduced until all VIF values were less than 5.0. After model reduction, regression outliers or influential observations were identified using Cook's distance; for a given model, observations were removed if Cook's distance was ever greater than 1.0. If observations were identified for a given model, the stepwise regression model development was restarted with that observation removed.

Results and Discussion

Stepwise linear regression seeks to isolate the variables most important in predicting the modelled variable, in this case yield deficit, or the 97.5 percentile yield for all positions minus the yield for a given position in the field. Put simply, yield deficit is the shortfall at a position as compared yield potential for the crop year, variety, and field. Several models can and will be constructed from the datasets collected. Within the scope of this paper, model results shown here were for factors considered to be independent of cotton growth and production. Independent variables were defined as those that were generally thought to be independent from (i.e., unaffected by) cotton plant growth. When dependent variables are included, causal relationships are thought to be less clear. It must be emphasized that the models are suggestive of relationships between terms and yield but do not directly indicate causality. In other words, we can say that yield deficit was associated with the factors defined, and it may have been caused by the factors defined, but we cannot say with any certainty that it was caused by the factors defined.

Table 1 shows model results for predicting cotton yield deficit as a function of the independent factors measured in the 2018 crop year for the Market Back field and Figure 2 characterizes model prediction accuracy for Market Back in the 2018 crop year. Key observations of the models presented in Table 1 and Figure 2 include:

- Average absolute error of lint yield deficit prediction from the combined model across all field positions was 78.8 kg ha^{-1} (70.3 lb ac^{-1}) with model R^2=0.8265. Residuals were normally distributed, satisfying the assumptions for analysis.
- Volunteer peanut was associated with the greatest yield deficit, possibly due to harboring or direct competition (Dillard, 2012), being associated with 577 kg ha^{-1} (515 lb ac^{-1}) of lint yield differences in the field. A follow-up, replicated trial in 2019 showed significant yield effects of volunteer peanut termination timing.
- Normally we would suspect that increases in soil moisture would result in decreases in yield; increases in 41 DAP soil moisture were likely associated with decreases in yield because it was a particularly wet time period (Bange et al., 2003), with 6.4 and 3.0 cm (2.5 and 1.2 in.) rainfall events at 29 DAP and 33 DAP.
- Deer damage was indicated as a factor relating to yield deficit in all three models, suggesting lint yield reduction of 9.3 kg ha^{-1} (8.3 lb ac^{-1}) for each one percent deer damage observed to have occurred prior to 8 WAP and being associated with 281 kg ha^{-1} (251 lb ac^{-1}) of observed differences in lint yield in the field. The models suggest that if deer damage had been reduced by 50%, the lint yield benefit would be \$37 ha^{-1} (\$15 ac^{-1}).
- Micronutrients suggesting possible toxicity effects and relating to yield deficit were zinc and manganese, being associated with 28 kg ha^{-1} and 2.4 kg ha^{-1} of lint yield deficit, respectively, per kilogram per hectare observed in the soil fertility samples (28 lb ac^{-1} and 2.3 lb ac^{-1} per pound per acre observed). More modeling work needs to be done to include the interactive effects of pH on nutrient availability.
- Ring nematode was associated with observed lint yield differences across the field of 183 kg ha^{-1} (163 lb ac^{-1}), having a negative relationship with yield, although ring nematode is not generally thought to be a major cotton pest (Mueller, 2011).
- Harvest speed was a significant factor in two out of the three models, being associated with observed differences in lint yield of 172 kg ha^{-1} (153 lb ac^{-1}) across the field, and showing decreases in lint yield with increases in harvester speed. This factor is a good example of why the model results do not show causality: was the yield lower because the harvester was travelling faster, or was the operator travelling faster because he observed the lint yield and plant size to be smaller?
- Soil phosphorous concentration shows up as a factor related to yield decrease and yield increase, the net effect being associated with yield increase, suggesting 2.0 kg ha^{-1} (1.8 lb ac^{-1}) of increased lint yield production per each pound per acre of phosphorous observed in the soil fertility samples.
- Southern root knot (SRK) nematode was only a significant factor in one of the three models, being associated with a net overall reduction in lint yield of 1.7 kg ha^{-1} (1.5 lb ac^{-1}) per SRK nematode per 100 cc of soil at 45 DAP and an overall observed range differences in lint yield of 64 kg ha^{-1} (57 lb ac^{-1}). It must be noted that the 2018 crop year followed peanut in 2017, so SRK nematode populations were relatively low.
- Increasing soil moisture content at 8 WAP, showing increases in lint yield of 16.0 kg ha^{-1} (14.3 lb ac^{-1}) for each one percent increase in volumetric soil moisture content and being responsible for 115 kg ha^{-1} (103 lb ac^{-1}) of observed differences in lint yield. This generally corresponds to the timing of first bloom, which has been well-documented to relate to the maximum rate of increase in crop evapotranspiration.
- Increases in soil boron and soil sodium concentrations were both associated with increases in cotton yields, suggesting possible deficiencies in areas of the field, accounting for 111 and 74 kg ha^{-1} (99 and 66 lb ac^{-1}) of observed lint yield differences across the field.

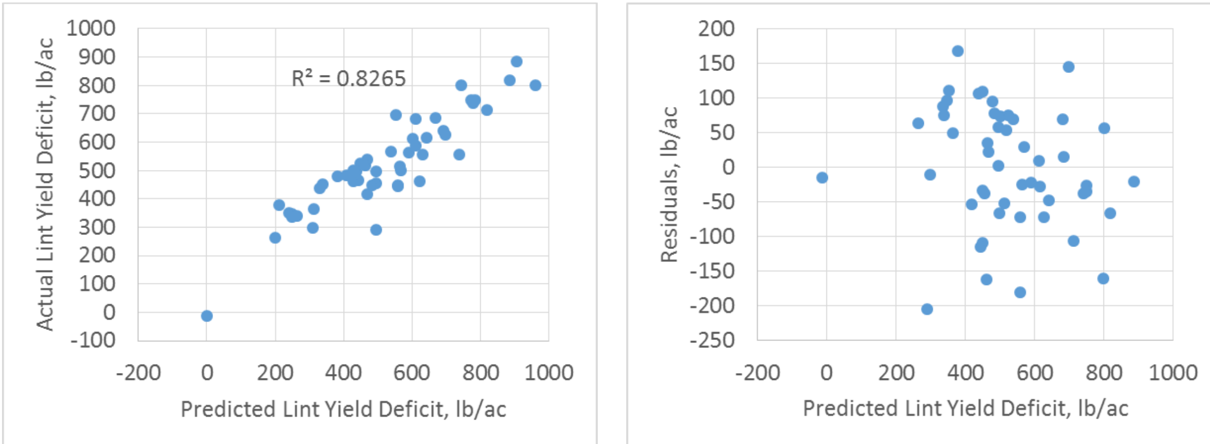
Table 1. Summary of models predicting lint yield deficit for Market Back in the 2018 crop year.

Term	HD7[a] Estimate	HD8[a] Estimate	HD9[a] Estimate	Combined Estimate[b]	Range of Effect on Lint Yield[c], lb/ac
13 DAP Volunteer Peanut, %	29.78	27.21	53.40	36.80	-515
41 DAP Soil Moisture, %vmc	29.53	24.12	21.37	25.01	-350
58 DAP Deer Damage, %	6.029	11.72	7.057	8.267	-251
Pre-Plant Deep Soil Zn, lb/ac	23.66	26.78	33.78	28.07	-165
45 DAP Ring Nematode, #/100cc	0.7832	1.006	0.7312	0.8401	-163
159 DAP Harvest Speed, mph	1974	1856	-	1277	-153
Pre-Plant Deep Soil P, lb/ac	3.079	-	1.949	1.676	-126
Pre-Plant Shallow Soil Mn, lb/ac	7.097	-	-	2.366	-90
45 DAP So. Root Knot Nematode, #/100cc	-	-	4.615	1.538	-57
58 DAP Square Retention, %	-	-	6.811	2.270	-44
45 DAP Lesion Nematode, #/100cc	-	-	9.787	3.262	-37
Intercept	-7723	-7771	-45.23	-5180	
45 DAP Dagger Nematode, #/100cc	-34.47	-	-	-11.49	64
93 DAP Shallow Soil Na, lb/ac	-16.54	-	-	-5.514	66
115 DAP Soil Moisture, %vmc	-13.37	-	-16.67	-10.01	84
Pre-Plant Deep Soil B, lb/ac	-	-932.7	-	-310.9	99
56 DAP Soil Moisture, %vmc	-27.62	-	-15.36	-14.33	103
29 DAP Immature Thrips, #/10 plants	-4.878	-2.668	-	-2.515	111
164 DAP Lesion Nematode, #/100cc	-4.099	-4.746	-3.573	-4.139	114
Pre-Plant Deep Soil K, lb/ac	-	-	-2.688	-0.8959	118
15 DAP Depth to 300 psi BtwRow, in	-6.668	-	-10.86	-5.844	122
93 DAP Shallow Soil P, lb/ac	-3.586	-2.587	-4.220	3.464	489

[a] HD7, HD8, and HD9 represent three models using three different stepwise regression stopping rules. Estimates are slope coefficients for that term; e.g. the HD7 model estimate for 13 DAP Volunteer Peanut suggests 29.78 lb/ac increase in lint yield deficit (reduction in lint yield) for each one percent increase in volunteer peanut canopy at 13 DAP.

[b] Combined Estimate represents the average slope coefficient estimate across the three models.

[c] Range of Effect on Lint Yield was calculated as Combined Estimate multiplied by the range of values observed for each term, which was calculated as four standard deviations. Terms are sorted by Range of Effect on Lint Yield, where negative values indicate that increases in the term relate to decreases in yield and positive values indicate that increases in the term relate to increases in yield.



(a) (b)

Figure 2. Actual versus predicted lint yield deficit for the combined models (HD7, HD8, and HD9) in the 2018 crop year (a) and model prediction residuals vs. predicted lint yield deficit for the combined models (HD7, HD8, and HD9) in the 2018 crop year (b).

Table 2 shows model results for predicting cotton yield deficit as a function of the independent factors measured in the 2019 crop year for the Market Back field and Figure 3 characterizes model prediction accuracy for Market Back in the 2019 crop year. Key observations of the models presented in Table 2 and Figure 3 include:

- Average absolute error of lint yield deficit prediction from the combined model across all field positions was 56.7 kg ha^{-1} (50.6 lb ac^{-1}), with model R^2=0.9281. Residuals were normally distributed, satisfying the assumptions for analysis.
- Increases in square retention at 9 WAP were associated with decreases in yield. Hake et al. (1992) discusses how desirable plant responses to early square shed can result in greater total square and bloom production from promotion of vegetative growth. The data showed positive, although weak relationships between square retention and final plant height (R^2=0.220), final plant height divided by node count (R^2=0.230), and 84 DAP cotton canopy coverage (R^2=0.324).
- Increases in average stand gap were related to decreases in lint yield. Average stand gap was a measure of emergence, with larger gaps relating to lower emergence and decreased yields. In an emergence delay test, Wanjura (1982) showed reduction in yield from 10 to 56%, which he attributed to lower plant populations.
- Thrips appear as factors related to increased and decreased yields; the net thrips effect considering averages of all terms was +53 kg ha^{-1} (+47 lb ac^{-1}). In the 2018 models (Table 2), similar relationships were shown. More work needs to be done to understand why thrips populations were associated with net increases in lint yields in both crop years.
- Increases in lesion nematode at harvest in the prior crop year related to decreases in lint yield, but increases in lesion nematode at 7 WAP related to increases in lint yield. The net effect showed a reduction in lint yield as a function of increased lesion nematode populations, explaining a range in observed lint yield differences across the field of 180 kg ha^{-1} (161 lb ac^{-1}).
- Soil manganese, sodium, and copper were associated with decreases in lint yield, suggesting possible toxicity effects and explaining 359, 332, and 57 kg ha^{-1} (320, 296, and 51 lb ac^{-1}) of observed lint yield differences across the field. As stated previously, interactions between pH and nutrients should be evaluated in future models to reflect effect of nutrient availability. The models here only reflect effect of nutrient and micronutrient presence, ignorant of plant availability.
- Weed canopy coverage at 4 WAP was associated with 466 kg ha^{-1} (416 lb ac^{-1}) of reduced lint yield per one percent increase in coverage of weed canopy. Weed canopy coverage was measured to range from 0 to 1.09% at 4 WAP in this test.
- Ring nematode showed up once again as a significant factor related to reduced yields, with at-harvest populations from the previous crop year explaining 307 kg ha^{-1} (274 lb ac^{-1}) of observed differences in lint yield and 7 WAP populations explaining 256 kg ha^{-1} (228 lb ac^{-1}) of observed differences in lint yield. There was a weak positive relationship between these two factors (R2=0.156).

- Increases in early season soil potassium were associated with decreases in lint yield, although literature has well established the opposite relationship: increases in potassium relate to increases in yield. It is thought that the relationship between cotton and yield deficit exhibited in Table 2 may be suggest a secondary relationship, i.e., increases in soil potassium were strongly related to some other factor that resulted in yield reduction.
- At-harvest SRK nematode population from the prior crop year was a significant factor in predicting cotton yield deficit, showing reduced yield with increased populations, but the other measures (populations at 7 WAP and at-harvest in current crop year) of SRK nematode were not significant. This supports many nematode sampling recommendations for basing control on prior year harvest populations. SRK nematode populations conducted at harvest of the prior production year explained 307 kg ha^{-1} (274 lb ac^{-1}) of observed lint yield differences across the field.
- Stink bug damage at 16 WAP was associated with decreases in yield, explaining 276 kg ha^{-1} (246 lb ac^{-1}) of observed lint yield differences and 9.0 kg ha^{-1} (8.0 lb ac^{-1}) of lint yield reduction per one percent increase in observed stink bug damage.
- Deer damage was once again associated with reductions in yield, although the yield reduction per percent damaged plants being less than that predicted for the 2018 crop year, at 2.0 kg ha^{-1} (1.8 lb ac^{-1}) of yield reduction per one percent damaged plants.
- Lesion nematode population showed up in both years as a significant factor, being associated with increases in cotton yield. It is thought that lesion nematodes do not directly provide benefit for the cotton, although they may be associated with soil properties that do provide benefit.
- Soil moisture content at 22 DAP and 29 DAP related to increases in lint yield, explaining 233 and 348 kg ha^{-1} (208 and 310 lb ac^{-1}) of observed differences across the field.

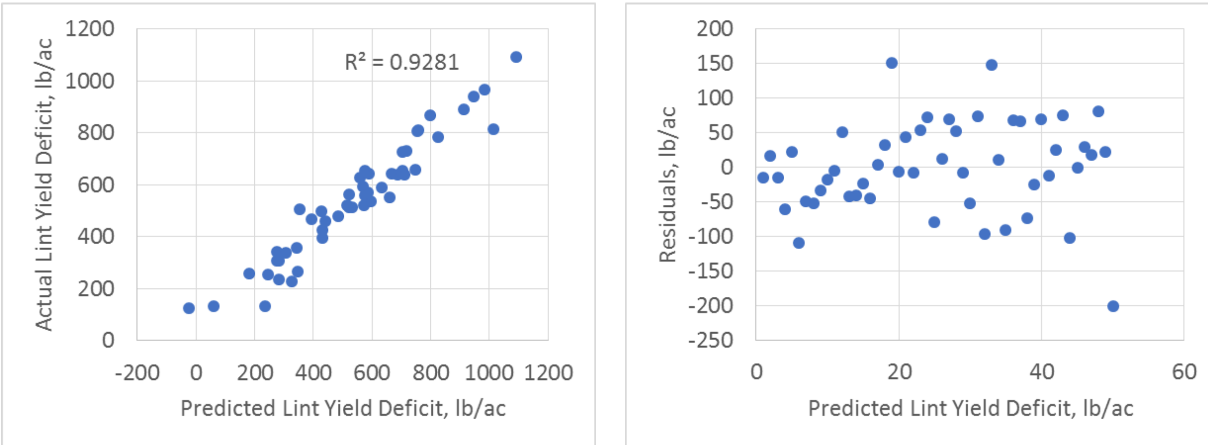
Table 2. Summary of models predicting lint yield deficit for Market Back in the 2019 crop year.

Term	HD7[a] Estimate	HD8[a] Estimate	HD9[a] Estimate	Combined Estimate[b]	Range of Effect on Lint Yield[c], lb/ac
64 DAP Square Retention, %	14.31	8.386	14.40	12.37	-603
45 DAP Avg. Stand Gap, ft	749.8	362.5	804.2	638.8	-382
2018 Harvest Lesion Nematode, #/100cc	16.28	6.236	16.63	13.05	-361
36 DAP Shallow Soil Mn, lb/ac	20.42	20.98	20.61	20.67	-320
22 DAP Immature Thrips, #/10 plants	51.53	93.92	102.4	82.63	-312
36 DAP Shallow Soil Na, lb/ac	13.39	7.702	13.02	11.37	-296
29 DAP Weed Canopy, %	527.9	259.0	461.5	416.1	-281
14 DAP Adult Thrips, #/10 plants	127.5	-	104.0	77.14	-277
2018 Harvest Ring Nematode, #/100cc	1.689	-	2.644	1.445	-274
112 DAP Stink Bug Damage, %	12.72	-	11.22	7.980	-246
50 DAP Ring Nematode #/100cc	1.361	1.138	1.240	1.246	-228
36 DAP Shallow Soil K, lb/ac	1.580	-	1.558	1.046	-143
2018 Harvest SRK Nematode, #/100cc	0.1885	-	0.1847	0.1244	-140
29 DAP Adult Thrips, #/10 plants	22.67	-	18.12	13.60	-122
64 DAP Total Pest Insects, #/10 sweeps	5.729	-	3.463	3.064	-114
64 DAP Deer Damage, %	-	5.510	-	1.837	-112
36 DAP Deep Soil Cu, lb/ac	-	-	302.5	100.8	-51
Intercept	-641.7	1026	-888.2	-167.9	
36 DAP Shallow Soil pH	-	-165.0	-	-55.01	59
Harvest Col. Lance Nematode, #/100cc	-	-2.920	-	-0.9732	74
50 DAP Lesion Nematode, #/100cc	-15.36	-	-12.16	-9.176	200
29 DAP Soil MC, %	-118.2	-	-71.63	-63.26	208
50 DAP Stubby Root Nematode, #/100cc	-9.636	-7.568	-11.25	-9.485	225
29 DAP Thrips Damage, 0-5	-109.2	-114.1	-105.9	-109.7	231
22 DAP Thrips Damage, 0-5	-191.7	-	-194.7	-128.8	267
22 DAP Adult Thrips, #/10 plants	-	-71.91	-51.61	-41.17	271
22 DAP Soil MC, %	-58.40	-77.28	-78.54	-71.41	310

[a] HD7, HD8, and HD9 represent three models using three different stepwise regression stopping rules. Estimates are slope coefficients for that term; e.g. the HD7 model estimate for 64 DAP Square Retention suggests 14.31 lb/ac increase in lint yield deficit (reduction in lint yield) for each one percent increase in square retention at 64 DAP..

[b] Combined Estimate represents the average slope coefficient estimate across the three models.

[c] Range of Effect on Lint Yield was calculated as Combined Estimate multiplied by the range of values observed for each term, which was calculated as four standard deviations. Terms are sorted by Range of Effect on Lint Yield, where negative values indicate that increases in the term relate to decreases in yield and positive values indicate that increases in the term relate to increases in yield.



(a) (b)

Figure 3. Actual versus predicted lint yield deficit for the combined models (HD7, HD8, and HD9) in the 2019 crop year (a), and model prediction residuals vs. predicted lint yield deficit for the combined models (HD7, HD8, and HD9) in the 2019 crop year (b).

Conclusion

- Models were developed suggesting the factors that were most strongly related to two years of cotton yield in a field in Barnwell County, S.C.
- The datasets collected as a part of this project were large and complex, but they hold a great deal of value in the relationships that can be drawn from them. The models demonstrated in this paper only represent a subset of what can be done with these datasets.
- Yield reduction was associated with deer damage in both years at 9.3 kg ha^{-1} (8.3 lb ac^{-1}) and 2.6 kg ha^{-1} (2.3 lb ac^{-1}) per percent deer damage at 8-9 WAP.
- Yield reduction was associated with ring nematode populations in both years, being associated with over 168 kg ha^{-1} (150 lb ac^{-1}) of observed lint yield differences across the field each year. More yield loss was associated with ring nematode in the year following cotton than in the year following peanut.
- Yield reduction was associated in both years with increases in soil manganese concentration, being associated with 101 and 359 kg ha^{-1} (90 and 320 lb/ac^{-1}) of differences in lint yield losses across the field.
- Differences in soil moisture content were significant factors relating to lint yield deficit in both years; in the wetter, 2018 year, later soil moisture contents (56 and 115 DAP) were significant and in the drier, 2019 year, earlier soil moisture contents (22 and 29 DAP) were significant.
- Increases in southern root knot nematode were associated with decreases in yield in both years; the effect being greater in 2019 (cotton behind cotton) than in 2018 (cotton behind peanut).

Acknowledgments

Thank you to the South Carolina Cotton Board for providing the funding to support this project. Thank you also to the individuals who assisted in data collection: Travis Avent, Bill Bonnette, Wendy Buchanan, Kayla Carroll, Julianna Corbin, Perry Loftis, and Alex Samenko.

References

Bange, M. P., S. P. Millroy, and P. Thongbai. 2004. Growth and yield of cotton in response to waterlogging. Field Crops Res. 88:129-142.

Dillard, B. A. 2012. Volunteer peanut (Arachis hypogaea L.) control in glyphosate/glufosinate resistant cotton (Gossypium hirsutum L.). MS thesis. Auburn, Alab.: Auburn University, Agronomy and Soils.

Hake, K., F. Carter, J. Mauney, N. Namken, J. Heitholt, T. Kerby, and B. Pettigrew. 1992. Square retention. Cotton Physiology Today 3(6).

Mueller, J. D. 2011. The use of Temik 15G on cotton and soybean in the Southeast. 2011 Beltwide Cotton Conferences, Atlanta, Ga., January 4-7, 2011.

Plumblee, M. T., D. M. Dodds, L. J. Krutz, T. B. Raper, A. S. Jones, A. L. Catchot Jr., J. T. Irby, and J. N. Jenkins. 2019. Effect of physical damage to early- and late-maturing cotton cultivars. Agronomy J. (in-press). https://doi.org/10.1002/agj2.20104

Wanjura, D. F. 1982. Reduced cotton productivity from delayed emergence. Trans. of the ASAE 25(6):1536-1539.