PROSPECTS FOR MONITORING COTTON CROP MATURITY WITH NDVI

C. Owen Gwathmey[1*], Donald D. Tyler[1], and Xinhua Yin[1]
[1]University of Tennessee, West TN Research & Education Center, Jackson, TN 38305
[*]**cogwathmey@utk.edu**

ABSTRACT

Cotton (*Gossypium hirsutum* L.) producers monitor crop maturity during the season to determine when to terminate crop inputs and to defoliate. We conducted a 4-year study in Tennessee to evaluate the suitability of the Normalized Difference Vegetation Index (NDVI) for monitoring cotton crop maturity. Maturity was varied by treatments that included nitrogen fertilization rates of 0 and 90 lb N/ac, and cover crops of winter wheat (*Triticum aestivum* L.) and hairy vetch (*Vicia villosa* L.). Crop maturity was estimated by heat-units accumulated from planting to open boll. Relative to zero N, boll opening was delayed by 90 lb N/ac in 3 yr. Cover crop effects on maturity were inconsistent. Canopy NDVI data were collected after mid-bloom with a hand-held GreenSeeker sensor. Significant date-by-treatment interactions indicated potential to detect maturity differences, but NDVI time courses obtained in different years were dissimilar. Late-season NDVI was positively correlated with degree-days to open boll in 3 yr. Relationships between changes in NDVI and maturity did not provide a simple basis for predicting maturity and readiness for defoliation. Improved NDVI sensors are needed for this purpose.

INTRODUCTION

Cotton producers monitor the maturity of their crops as the season progresses, in order to plan late-season defoliation and harvest operations. Prediction of crop readiness for defoliation and harvest facilitates the scheduling of operations in different fields. One management tool that monitors earliness and predicts crop readiness for defoliation is the COTMAN system (Oosterhuis et al., 1996). Data collection for COTMAN is relatively laborious and time consuming, however, and more efficient methods of crop monitoring are needed.

The advent of precision agriculture has increased interest in remote methods of crop monitoring. A common type of remote sensing data is the Normalized Difference Vegetation Index (NDVI), which indicates crop biomass and condition from the relative amounts of near-infrared (NIR) and visible light reflected from the canopy (Plant et al., 2001). It is calculated as the difference between NIR and visible light reflectance, divided by the sum of the two reflectances. Plant et al. (2001) concluded that remote NDVI sensing was useful for detecting spatial patterns in a field, but not as useful in measuring changes over time, due to changes in solar radiation and other environmental factors with time. This constraint was thought to be alleviated with the introduction of "active" sensors deployed in relatively close proximity (<4 ft) to the canopy. Because active sensors emitted pulses of NIR and visible light and detected their reflection from the canopy, they were considered to be insensitive to changes in background solar radiation (Schepers, 2008; NTech Industries, 2009).

Most research on use of active NDVI sensors in row crops has been directed towards site-specific detection and remediation of N deficiency early in the growing season (Samborski et al., 2009). Lower NDVI values of N-deficient cotton are associated with lower plant biomass and leaf area, relative to cotton with sufficient N (Li et al., 2001). Earlier studies had shown that flowering of N-deficient cotton cut out earlier than cotton with sufficient N, while higher N rates delayed maturity (McConnell et al., 1995). Hutchinson et al. (1995) reported that N rates that optimized yield resulted in slightly later maturity than lower N rates, but excessive N resulted in significant maturity delay with no additional yield.

Residue from a winter cover crop can modify cotton response to fertilizer N. Hutchinson et al. (1995) observed that N-deficient plants showed visible chlorosis by the first week of bloom, especially following wheat cover with no fertilizer N. Cotton with sufficient N following native vegetation or wheat, and cotton with zero N following vetch, began to show visible leaf chlorosis about 40-45 days after first bloom. Excessively fertilized plants remained dark green until defoliation. Larson et al. (2001) showed that cotton yield after vetch and no fertilizer N was as high as cotton after no cover and 74 lb N/ac, or cotton after wheat and 87 lb N/ac, with no tillage. However, Larson et al. (2001) did not investigate N or cover effects on crop maturity.

Temporal patterns of NDVI reflectance were studied over a cotton growing season with a passive sensor (Li et al., 2001). Maximum leaf area and NDVI occurred about 15 August and declined thereafter. As the crop matured in September, red reflectance increased but NIR reflectance decreased, reducing NDVI. Late-season leaf senescence also reduces leaf chlorophyll content, revealing accessory leaf pigments such as carotenes and xanthophylls (Pinter et al., 2003). The net effect is to decrease NDVI of leaves during senescence.

If changes in plant biomass and leaf senescence due to N status can be detected by proximal sensing of canopy NDVI, then crop progress towards maturity may be monitored by analyzing changes in NDVI with time. Objectives of this field study were to determine the effects of N fertilization and cover crop residue on crop maturation, and to evaluate the suitability of NDVI for monitoring crop maturity as influenced by N and cover crop residue.

MATERIALS AND METHODS

The suitability of NDVI for monitoring crop maturity was evaluated in a long-term field study of tillage regime, N fertilization, and cover crop effects on cotton at the West Tennessee Research & Education Center, Jackson TN. The underlying experiment was described by Larson et al. (2001). The soil was a non-irrigated Memphis silt loam (Typic Hapludalf). The field was planted to ‘DP451BR’ on 18 May 2005, to ‘DP455BG/RR’ on 17 May 2006, to ‘ST4554B2RF’ on 10 May 2007 and 21 May 2008 in 38-inch rows. Cotton was managed by following UT Extension guidelines. Treatments reported here were combinations of winter cover crop (wheat or hairy vetch) and N fertilization (0 or 90 lb/ac), applied annually to designated no-tillage plots. Nitrogen rates were main plot treatments and covers were subplot treatments in a RCB split-plot design with four replications. Nitrogen was broadcast to designated plots as ammonium nitrate between 12 and 28 days after planting (DAP) each year. Winter cover crops and native vegetation were killed prior to cotton planting, and re-seeded after cotton harvest each year.

Canopy NDVI data were collected from the center rows of each plot using a GreenSeeker hand-held red/NIR sensor (Model 505, NTech Industries, Ukiah CA). The sensor head was suspended by telescoping boom over the center of each row, oriented vertically at 30 to 36 in. above the top of the canopy. Light emitting diodes in the sensor generated red (656 nm) and NIR (774 nm) light (NTech Industries, 2009). The light generated was reflected from the crop and measured by a photodiode in the sensor head. NDVI data were collected weekly from mid-bloom (69 to 78 DAP) until early boll opening (112 to 118 DAP) each year. Additional details about NDVI data collection in this study were reported by Gwathmey et al. (in press).

About 20 white flowers blooming at a reference fruiting site (five nodes above white flower; NAWF=5) were flagged in each plot. Dates of boll opening at the flagged fruiting sites were recorded. Accumulation of ambient heat-units were measured as degree-days, base 60°F, calculated from daily maximum and minimum air temperature data from a nearby NOAA weather station. The number of heat-units accumulated between planting and boll opening estimated the total crop maturation period in each plot.

After defoliation each year, the two center rows of each plot were harvested with a JD9930 cotton picker. Seedcotton harvested from each plot was weighed at picking. Gin turnout was determined for each treatment sample using a 20-saw gin assembly. Lint yields were calculated from seedcotton weights, gin turnouts, and plot areas harvested.

The NDVI data collected each year were analyzed with the Mixed procedure of SAS 9.2, with observation date as a repeated measure on subplots of N fertilization and cover crops. Other data were analyzed with the GLM procedure of SAS with fixed effects for each year of the study. Where F-tests indicated significant differences, least square means were separated at $p=0.05$ by independent pairwise comparisons (pdiff).

RESULTS AND DISCUSSION

Heat-unit accumulation was fairly similar in the four years of the study, but rainfall accumulation differed markedly between years. Several large storms in 2005 contributed to higher seasonal rainfall accumulation than in other years. Two drought episodes occurred between 65 and 115 DAP in 2007, accompanied by relatively high average air temperatures.

Year-to-year differences in cultivar, rainfall, and plant growth regulation resulted in differences between years in cotton plant height. Effects of N fertilizer and cover crop residue on plant height were fairly consistent (Table 1). Across cover crops, 90 lb N/ac increased plant height by 17 to 33%, relative to zero N ($p<0.06$). Across N rates, vetch residue increased plant height by 8 to 19%, relative to wheat (Table 1). Lint yields responded to treatment in most years, but not in 2007 because of heat and drought effects. Across cover crops, 90 lb N/ac increased yields by 22 to 31%, relative to zero N in 2005, 2006, and 2008 ($p<0.08$). Across N rates, vetch residue increased lint yields by 15 to 38% in those three years, relative to wheat ($p<0.07$) (Table 1).

Heat-unit accumulation from planting to open boll at the NAWF=5 fruiting site showed N and cover effects on crop maturity (Table 1). In three of four years, N fertilization delayed cotton maturity by 12 to 102 DD60, relative to zero N ($p<0.05$). Cover crop had relatively small influence on earliness of maturity. Nitrogen and cover effects on crop maturity were generally consistent with Hutchinson et al. (1995) and McConnell et al. (1995).

Date of observation was the predominant source of variance for NDVI in each year (data not shown). Main effects of N were significant in all except 2006, but cover effects were significant in all years. There were significant date-by-N interactions in three years, and date-by-cover interactions two years. Date-by-treatment interactions indicate that treatments differed in NDVI change with time, which may be useful in detecting treatment effects on maturity.

In a general sense, time courses of NDVI in 2005 and 2006 showed similar patterns consisting of a mid-season plateau followed by a late-season decline as the crop matured (Fig. 1). The late-season decline started ~180 DD later in 2006 than 2005, but once started, NDVI continued to decline until ~2000 to 2050 degree-days after planting (DDAP) each year. Time courses of NDVI in 2007 and 2008 (Fig. 1) showed different patterns than in 2005 and 2006. The main dissimilarity was an unexpected rise in NDVI values in late season. In 2007, NDVI values rose significantly at 2128 DDAP, before decreasing to the lowest levels observed in 2007, at 2284 DDAP. The peak at 2029 DDAP in 2008 represented the highest NDVI values observed for each treatment in that year. By the following week, however, NDVI values decreased for all treatments to levels similar to those observed 1810 and 1928 DDAP (Fig. 1). Mean separation of data points shown in Figure 1 were reported by Gwathmey et al. (in press).

The late-season NDVI peaks recorded in 2007 and 2008 occurred in all treatments, and they did not persist. Thus it seems less likely that they were caused by changes in crop condition or biomass than by variation in NDVI sensor performance or environmental conditions, relative to other dates of observation. Regarding stability of sensor performance, the manufacturer estimated NDVI variation to be ±0.02 for >500 h of sensor operation at optimal height (28 to 44 in) above canopy (NTech Industries, 2009). Differences between the late-season peaks observed in 2007 and 2008, and NDVI data collected one week before and after these peaks, were two to six times larger than this specification. There was no indication of instrument malfunction on these dates. Regarding environmental influence, Oliveira (2008) found that the GreenSeeker sensor was sensitive to solar time, air temperature, and solar irradiance. Allen et al. (2009) also reported strong negative linear relationship between GreenSeeker NDVI and ambient radiation intensity. Variation in NDVI observed in the present study is consistent with Oliveira (2008) and Allen et al. (2009).

Significant linear correlations were found between mean of NDVI values collected >1800 DDAP in each plot, and heat-units accumulated between planting and boll opening (Fig. 2). In these years, maturity was delayed by about 60 to 120 DD60 for each 0.1 unit increase in mean NDVI. The exception occurred in 2006, when the relatively short stature of the crop resulted in early cutout of flowering and relatively small differences in crop maturity (Table 1). In 2007, delayed flowering at NAWF=5, along with high temperatures in late season, elevated cumulative DD60 to boll opening. Despite these relationships between NDVI and crop maturity, the NDVI data do not provide a simple basis for predicting maturity and readiness for defoliation. For practical value, maturity prediction should occur sufficiently early in the season to influence defoliation and harvest management. Treatment differences in NDVI corresponding to maturity differences appeared between 99 and 112 DAP in 2005-07, just 3 to 32 d before bolls opened at the NAWF=5 fruiting site, and 15 to 39 d before harvest aids were applied each year.

These results also underscore the need for a new generation of multispectral sensors specifically designed for monitoring row crops. Ideally, sensors designed for monitoring of crop maturity would estimate the plant senescence reflectance index, based on difference in reflectance at 678 and 500 nm (Merzlyak et al., 1999). A sensor system that measures reflectance from lower leaves, from an oblique angle would be more likely to detect leaf senescence earlier than a nadir-oriented sensor over the row, and thus monitor crop maturity more effectively.

ACKNOWLEDGMENTS

This study was supported in part by a Cotton Incorporated Core Project. Technical assistance was provided by Randi Dunagan, Janet Gibson, Ernest Merriweather, and Carl Michaud at the University of Tennessee.

REFERENCES

Allen, P.B., J.B. Wilkerson, and M.B. Ramirez. 2009. Evaluating temporal variation in active-light plant sensors. p. 367-373. *In* Proc 2009 Beltwide Cotton Conf., San Antonio TX, 5-8 Jan 2009. Natl. Cotton Council Am., Memphis TN.

Gwathmey, C.O., D.D. Tyler, and X. Yin. Monitoring cotton crop maturity with NDVI and COTMAN. Agron. J. (in press)

Hutchinson, R.L., G.A. Breitenbeck, R.A. Brown, and W.J. Thomas. 1995. Winter cover crop effects on nitrogen fertilization requirements of no-till and conventional-tillage cotton. p. 73–76. *In* M.R. McClelland et al. (ed.) Conservation-tillage systems for cotton: A review of research and demonstration results from across the cotton belt. Ark. Agric. Exp. Sta., Fayetteville, AR.

Larson, J.A., R.K. Roberts, E.C. Jaenicke, and D.D. Tyler. 2001. Profit-maximizing nitrogen fertilization rates for alternative tillage and winter cover systems. J. Cotton Sci. 5: 156-168.

Li, H., R.J. Lascano, E.M. Barnes, J. Booker, L.T. Wilson, K.F. Bronson, and E. Segarra. 2001. Multispectral reflectance of cotton related to plant growth, soil water and texture, and site elevation. Agron. J. 93:1327–1337.

McConnell, J.S., R.E. Glover, E.D. Vories, W.H. Baker, B.S. Frizzell, and F.M. Bourland. 1995. Nitrogen fertilization and plant development of cotton as determined by nodes above white flower. J. Plant Nutr. 18:1027–1036.

Merzlyak, M.N., A.A. Gitelson, O.B. Chivkunova, and V.Y. Rakitin. 1999. Non-destructive optical detection of pigment changes during leaf senescence and fruit ripening. Physiol. Plant. 106:135–141.

NTech Industries. 2009. Model 500 Series GreenSeeker® Sensor. NTech Industries, Inc., Ukiah, CA. Available at: http://www.ntechindustries.com/lit/gs/DataSheet_Model_500_GS_Sensor.pdf (verified 11 June 2010)

Oliveira, L.F. 2008. Reflectance sensors to predict mid-season nitrogen need of cotton. M.S. Thesis, University of Missouri-Columbia. Available at: http://edt.missouri.edu/Fall2008/Thesis/OliveiraL-010708-T15791/research.pdf (verified 11 June 2010)

Oosterhuis, D.M., F.M. Bourland, N.P. Tugwell, and M.J. Cochran. 1996. Terminology and concepts related to the COTMAN crop monitoring system. Ark. Agric. Exp. Sta. Spec. Rep. 174. Fayetteville, AR.

Pinter, P.J., Jr., J.L. Hatfield, J.S. Schepers, E.M. Barnes, M.S. Moran, C.S.T. Daughtry, and D.R. Upchurch. 2003. Remote sensing for crop management. Photogrammetric Engineering & Remote Sensing 69(6):647–664.

Plant, R.E., D.S. Munk, B.R. Roberts, R.N. Vargas, R.L. Travis, D.W. Rains, and R.B. Hutmacher. 2001. Application of remote sensing to strategic questions in cotton management and research. J. Cotton Sci. 5:30-41.

Samborski, S.M., N. Tremblay, and E. Fallon. 2009. Strategies to make use of plant sensors-based diagnostic information for nitrogen recommendations. Agron. J. 101:800–816.

Schepers, J.S. 2008. Active Sensor Tidbits. Iowa Soybean Association. Available at: http://www.isafarmnet.com/08OFNConfPresent/Nitrogen/Nitrogen_Sensors_Handout.pdf (verified 11 June 2010)

Table 1. Cotton plant height, lint yield, and cumulative degree-days (DD60) from planting to open boll at the NAWF=5 fruiting site, as affected by N fertilizer and cover crop residue at Jackson, TN, 2005-2008, and *p*-values of F-tests.

Year	N rate	Cover crop	Plant height†		Lint yield		Degree-Days, planting to open boll	
	lb/ac		in.		lb/ac		DD60	
2005	0	Wheat	29	c‡	670	b	2211	b
	0	Vetch	36	b	1024	a	2216	b
	90	Wheat	42	a	1035	a	2296	a
	90	Vetch	44	a	1028	a	2335	a
	p (N-rate)		0.009		0.075		0.003	
	p (Cover)		0.013		0.006		0.337	
	p (N-by-cover)		0.119		0.005		0.448	
2006	0	Wheat	20	c	672	b	2042	b
	0	Vetch	25	b	1226	a	2039	b
	90	Wheat	27	b	1165	a	2049	ab
	90	Vetch	30	a	1316	a	2055	a
	p (N-rate)		0.057		0.059		0.019	
	p (Cover)		0.003		0.001		0.670	
	p (N-by-cover)		0.255		0.008		0.180	
2007	0	Wheat	28	c	513	a	2354	c
	0	Vetch	34	b	524	a	2378	bc
	90	Wheat	34	b	460	a	2460	a
	90	Vetch	37	a	484	a	2420	ab
	p (N-rate)		0.059		0.565		0.008	
	p (Cover)		<0.001		0.595		0.562	
	p (N-by-cover)		0.016		0.842		0.049	
2008	0	Wheat	32	c	892	b	2219	a
	0	Vetch	36	b	1178	a	2243	a
	90	Wheat	42	a	1262	a	2274	a
	90	Vetch	44	a	1303	a	2286	a
	p (N-rate)		0.003		0.049		0.119	
	p (Cover)		0.021		0.012		0.067	
	p (N-by-cover)		0.443		0.037		0.504	

† Measured at 97 DAP in 2005, 76 DAP in 2006, 92 DAP in 2007, and 77 DAP in 2008.

‡ Letters separate means within groups at *p*=0.05 by independent, paired comparisons (pdiff) in SAS Proc GLM.

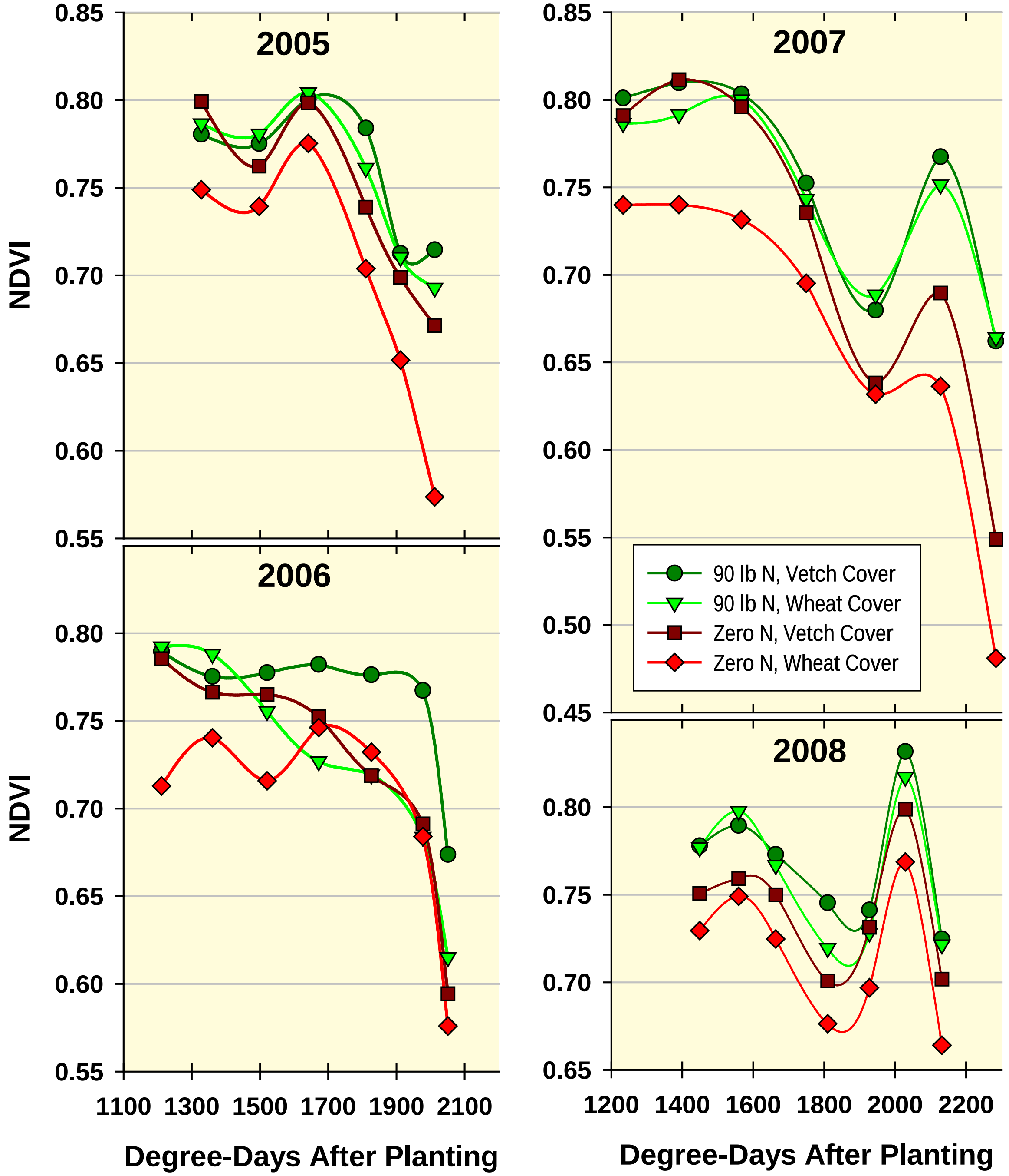

Figure 1. Changes in Normalized Difference Vegetation Index (NDVI) of the cotton canopy with heat-unit (DD60) accumulation, as influenced by two levels of N fertilization and two cover crop residues, Jackson, TN, 2005-2008.

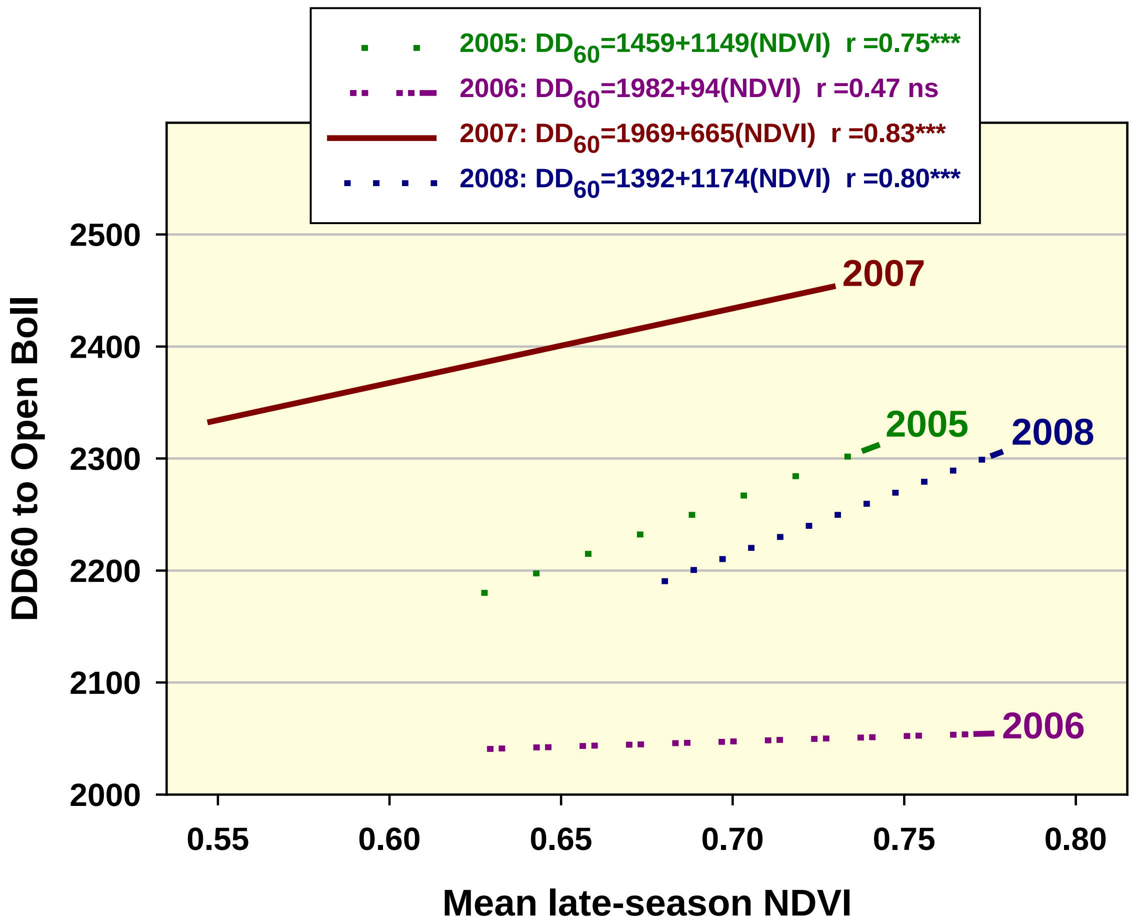

Figure 2. Linear relationships between late-season Normalized Difference Vegetation Index (NDVI) and degree-days (DD60) from planting to open boll at the NAWF=5 fruiting site, Jackson, TN, 2005-2008. NDVI data were collected >1800 DD60 after planting. For each regression, n=16.