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Inter-relationships of cotton plant height, canopy width, ground cover and plant nitrogen status indicators

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ABSTRACT

Petiole-NO_3, leaf N and chlorophyll (SPAD) meter readings are good in-season indicators of the N status of the uppermost part of cotton (*Gossypium hirsutum* L.) plants. Petiole-NO_3, particularly is widely used in the USA as an in-season plant N test that guides N fertilizer recommendations in cotton. However, these N status indicators do not take account of plant biomass, canopy width or percent cover. The objectives of this study were to assess the effect of N fertilizer rates on the commonly used indicators of plant N status; leaf N, petiole sap NO_3 and chlorophyll meter (SPAD) readings and the plant growth measurements; plant height, canopy width, and percent ground cover, and determine to inter-correlations among the them. Irrigated field studies were conducted at Lubbock, TX USA in 2010 and 2011, New Deal, TX in 2010, and at Halfway, TX in 2011. Zero-N and a full N fertilizer rate of 134, 101, and 112 kg N ha^{-1} were used at Lubbock, New Deal, and Halfway, respectively. The 2010 cotton growing season in West Texas was much wetter than average, and the 2011 season was much drier than normal. As a result, plant height, canopy width, and ground cover were greater in the 2010 sites than in 2011. The effects of N fertilizer were greatest for the two cultivars in subsurface drip irrigation (SDI) at New Deal in 2010 for all three N status indicators, and for the three plant growth measures compared to the other site-years. Correlation analysis indicated that among the three plant N indicators, leaf N was the most sensitive to plant parameters. These effects were positive in 2010 and negative in the 2011 dry year. Petiole NO_3 was the plant N indicator that was the most insensitive to plant growth, but the marked seasonal decline pattern reduces its usefulness for late-season N management.

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1. Introduction

Nitrogen is the most important nutrient required in cotton. However, cotton is an indeterminate plant, so balancing vegetative and reproductive growth is crucial for crop production. Excess N application can promote excessive vegetative growth (Gerik et al., 1998), which in turn delays boll maturity (Jackson and Gerik, 1990) and increases susceptibility to disease and boll rot (Oosterhuis, 2001). Insufficient N, on the other hand, limits boll production and yield (Stewart, 1986; Ramey, 1986).

Nitrogen fertilizer has been shown to increase leaf number and leaf area (Bondada et al., 1996), plant height (Gardner and Tucker, 1967), number of nodes (Jackson and Gerik, 1990), number of bolls (Jackson and Gerik, 1990; Boquet et al., 1994), and individual boll weight (Bondada et al., 1996). On the other hand, symptoms of N deficiency are readily identifiable. Nitrogen deficit decreases production of chlorophyll (Radin and Mauney, 1986; Hay and Porter, 2006), causing chlorosis (Stewart et al., 2010) and limiting the photosynthetic capacity of the plant. Leaf expansion is also affected by N deficiency (Radin and Mauney, 1986), the size of the youngest leaves remains small (Stewart et al., 2010), and the leaf area index remains low (Jackson and Gerik, 1990; Fernandez et al., 1996). Nitrogen-deficit plants characteristically have stunted height, shortened petioles, and thin stalks (Grundon, 1987).

The conventional methods of assessing plant available N for cotton in the Western US are pre-plant soil NO_3 testing, and in-season plant tissue N and petiole sap NO_3 analysis (Silvertooth et al., 2011; Sabbe and Hodges, 2010; Sabbe and Zelinski, 1990). Although these methods are reliable, they are also time-consuming and expensive. The advantages of testing for leaf N compared to petiole sap for N concentration analysis in cotton has been reported by several researchers (Read et al., 2002; Buscaglia and Varco, 2002 and

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Bronson et al., 2003). Zhao et al. (2010) found that the seasonal pattern of N concentrations derived from the entire plant canopy was consistent to the analysis obtained from uppermost, fully expanded leaves. Many researchers have explored the potential of the chlorophyll (SPAD) meter as an alternative method to assess plant N, with varying results (Wood et al., 1992; Bronson et al., 2001). Since chlorophyll contains the majority of N in leaves (Takebe et al., 1990; Yoder and Pettigrew-Crosby, 1995), leaf N content can be estimated from leaf chlorophyll concentration. Bronson et al. (2001) reported that SPAD readings were less variable than petiole NO_3 meter readings for assessing N status in cotton at blooming. However, Wiedenfeld et al. (2009) found petiole sap readings to be more closely related to N rate than leaf N or SPAD measurements. On the other hand, factors such as crop age, plant species, leaf–soil water status, time of measurement and irradiance level can affect how well SPAD readings do in distinguishing exhibiting N treatment effects (Wood et al., 1992; Bronson et al., 2001; Wiedenfeld et al., 2009; Martinez and Guiamet, 2004).

Bronson et al. (2003) reported that both leaf N and SPAD readings could be used to guide N fertilization rates as early as at squaring. Rosolem and Van Meliss (2010), and Malavolta et al. (2004) found that the efficiency of SPAD in distinguishing N contents was viable well into flowering. However, the use of SPAD meter still requires the contact with the leaves. The practical application of SPAD meter is limited by time and labor factors when it was used in a large field with high N variability (Osborne et al., 2002; Peterson et al., 1993).

Plant growth indicators such as plant height has been used to provide estimates of crop yield and N status, in combination with spectral reflectance of the respective crops. Thenkabail et al. (2000) found that the accuracy in estimating plant height could be improved by using reflectance in narrow spectral wavebands in the red and NIR regions (R^2 = 0.64). Freeman et al. (2007) developed a 3-dimensional index based on the multiplication of NDVI and plant height to estimate corn biomass at early and later stages (R^2 = 0.66 and 0.45), yield (R^2 = 0.62 and 0.64), and N uptake (R^2 = 0.77 and 0.46). Liu and Wiatrak (2011) proposed the use of plant height, NDVI and LAI in estimating corn grain yield. Sui and Thomasson (2006) found that plant height in combination with reflectance in visible spectral bands represented the best estimator for cotton N status (R^2 = 0.50 to 0.51). Jones et al. (2007) utilized plant height and ground cover measurements to estimate plant biomass for spinach (R^2 = 0.91).Shaver et al. (2011) reported that the inclusion of plant-related data such as leaf N content and plant height did not markedly increase the ability of NDVI to estimate corn N status or grain yield (R^2 from 0.88 to 0.95). This may be related to the long-standing problem of "saturation" of NDVI at maximum biomass or plant height.

Ground cover or vegetation fraction is defined as the fraction of an area covered with plant canopy (Maas, 1998). Since different N application rates can induce differences in physiological parameters as such chlorophyll concentration, leaf are index (LAI) and biomass (Milroy et al., 2001; Bronson et al., 2005; Zhao et al., 2007), percent ground cover can also provide information regarding crop growth and health independent of chlorosis. Therefore, ground cover can be a valuable measure of crop growth and N status. This parameter has been found to be highly correlated with spectral reflectance in multiple crops (Colwell, 1974; Verstraete and Pinty, 1991), including cotton (Huete et al., 1985; Maas, 1997; Ritchie et al., 2010). Jackson et al. (1979) used ground cover and ratio of plant height to width to model the components of spectral reflectance for incomplete canopy covers. In a study to model cotton canopy reflectance by using physiological parameters, Maas (1997) found that canopy width was consistently related to the ratio of leaf area per plant per plant spacing. Maas (1998) also developed and tested a method to estimate cotton ground cover from scene reflectance by accounting for three main reflectance components which were plant, bare soil and shadow. However, there are few studies that explores the effects of ground cover or canopy width on plant N status.

The objectives of this study were to:

(1) assess the effect of N fertilizer rate on leaf N, petiole NO_3, chlorophyll meter readings plant height, plant width, and ground cover, and to determine inter-correlations among these plant N indicators and plant growth parameters.
(2) Compare leaf N, petiole NO_3, and chlorophyll meter readings as in-season indicators of plant N status, especially as affected by the plant height, plant width, and ground cover.

2. Materials and methods

2.1. Experimental sites and designs

In 2010, N fertilizer experiments were conducted at the Texas Tech University Quaker Avenue Research Farm (33.598°N, 101.906°W) and the Texas AgriLife Research and Extension Center (33.690°N and 101.827°W), in Lubbock County, Texas. Henceforth, these experimental sites will be referred to as Lubbock and New Deal. In 2011, a study site at the Texas AgriLife and Extension Center in Halfway (34.147°N, 101.948°W), in Hale County, Texas was used. The soil types at Lubbock, New Deal and Halfway are Acuff sandy clay loam, Lubbock sandy clay, and Pullman clay loam, respectively (USDA-NCRS, 2011). Lubbock was furrow-irrigated, while other experimental sites were irrigated using sub-surface drip irrigation (SDI). At Halfway, the SDI system had drip tape spaced at 2 m in the middle of alternate furrows at 30-cm depth with emitters spaced at 60 cm. Irrigation for was 1 L min^{-1} at 0.08 MPa. Target in-season irrigation, accounting for rain was 90% evapotranspiration (ET) replacement. Reference ET was calculated with weather data and, and ET was calculated by multiplying cotton crop coefficients by reference ET, which was calculated with a modified Penman Monteith equation (Lascano and Salisbury, 1993).

The experimental design at Lubbock was a randomized block design (RBD) with three levels of N fertilizer and four replications. At this station, FiberMax 9170 and PHY 375 WRF (PhytoGen 375 WideStrike and Genuity Roundup Ready Flex) were planted on 20 May 2010 and 23 May 2011, respectively, in 16, 1-m rows that were 52 m long. In 2010 and at 2011, N fertilizer rates were 0, 67 and 134 kg ha^{-1} representing zero, intermediate and full N rates as determined using soil-based tests for recommended yields. The N was applied as urea ammonium nitrate (UAN) (320 g N kg^{-1}) split in two equal applications on 25 and 60 days after planting (DAP) 2010. The fertilization was followed immediately by irrigation.

The experiment at New Deal was conducted as a factorial Randomized Incomplete Block Design (RIBD) with three blocks (replicates), where the zero treatment had only two replications. The site was planted on 20 May 2010 with Stoneville 5458 (ST 5458) and FiberMax 9180 (FM 9180) in 8, 1-m row plots that were 180 m long. There were 3 levels of N fertilizer in New Deal, a zero-N, intermediate N (50 kg ha^{-1}) and full N rates (101 kg ha^{-1}) determined as the first reflectance-based N strategy described in Bronson et al. (2011). Each block consisted of 8 rows that were supplied by an individual irrigation and fertilizer injection station. Nitrogen as urea ammonium nitrate (UAN) (320 g N kg^{-1}) was injected through the SDI for five weeks starting from 33 to 64 DAP for five days per week in twenty five equal doses until the total rates were achieved. To ensure optimum pH level of the irrigation water and to avoid precipitation of calcium carbonate, sulfuric acid (250 g kg^{-1} H_2SO_4) was injected continuously into the irrigation water.