International Journal of Plant Production 5 (4), October 2011
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

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Corn production and plant characteristics response to N fertilization management in dry-land conventional tillage system

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Received 16 March 2011; Accepted after revision 23 May 2011; Published online 15 September 2011

Abstract

Nitrogen (N) application management needs to be refined for low yielding environments under dryland conditions. This 3-yr study examined nitrogen fertilization management effects on corn (*Zea mays* L.) plant characteristics and grain yield in rain fed environment under conventional tillage system. Nitrogen fertilization management consisted of two timing methods of N application [all N at planting and as split with 35 kg N ha^{-1} applied at planting and remaining N applied at vegetative (V) 6 growth stage] and five N rates (0, 45, 90, 135, and 180 kg N ha^{-1}). Insufficient rainfall at reproductive stage in 2008 and 2009 likely resulted in significant reduction of grain yield compared with grain yield in 2007, average 2.9 vs. 5.9 Mg ha^{-1}. Grain yield increased with N application up to 45 kg ha^{-1}; however, no further increase in N application resulted in increased yields. Plant height, ear height, relative chlorophyll (SPAD) content, and normalized difference vegetation index (NDVI) at reproductive (R_1) stage increased with increasing N rate up to 90, 90, 135, and 90 kg N ha^{-1}, respectively. Corn grain yield significantly correlated with plant height at R_1, SPAD at V_8, NDVI and LAI at V_8 and R_1 stage. The combination of plant height, NDVI, and LAI of R_1 stage explained most of the variability of grain yield (r-square = 0.71). The fertilization timing had no effect on corn grain yield and plant characteristics. These observations showed that applying more than 45 kg N ha^{-1} to corn under dryland conditions with insufficient rainfall, especially during corn pollination, may not significantly increase grain yields.

Keywords: N fertilizer; Corn grain yield; Plant characteristics; Correlation.

Abbreviations: CT, conventional tillage system; V_6, 6th fully expanded leaf with the leaf collar; V_8, 8th fully expanded leaf with the leaf collar; R_1, the first reproductive stage, silk stage; SPAD, Soil Plant Analysis Development; NDVI, normalized difference vegetation index; LAI, leaf area index.

Introduction

Conservation tillage has been widely adopted as an effective management for water conservation and environment protection. Some growers, however, still use conventional tillage (CT) for corn production due to some risks of applying conservation tillage which include excess residue accumulation, higher fertilizer input, and cooler and wetter seedbeds (Vyn and Raimbault, 1993; Vetsch and Randall, 2004; Al-Kaisi and Kwaw-Mensah, 2007; Meyer-Aurich et al., 2009). Archer et al. (2008) reported that reduced tillage required 16 to 55 kg ha^{-1} more N than CT to obtain similar optimal corn grain yield. Randall and Bandel (1991) observed that up to 25% more N fertilizer was required to prevent yield limitations from short-term N immobilization under conservation tillage system. Karlen and Sojka (1985) observed slower and non-uniform plant emergence and early season growth with conservation tillage than conventional tillage under dryland conditions. These adverse factors of conservation tillage contributed to corn grain yield reductions as compared to conventional tillage systems (Vyn and Raimbault, 1992; Busscher et al., 2006; Archer et al., 2008).

Nitrogen is the most limiting factor in corn production (Sims et al., 1998; Ma et al., 2005; Uribelarrea et al., 2009). Numerous studies have reported that different water and soil conditions may affect N utilization and corn production (Martin et al., 1982; Pandey et al., 2000; Lapen et al., 2001; Torbert et al., 2001). In general, increasing N fertilization increases corn grain yield (Mullins et al., 1998; Halvorson et al., 2006) and increasing soil moisture enhances corn yield response to N fertilization, especially when high N rates are applied (Eck, 1984; Al-Kaisi and Yin, 2003). However, Almaraz et al. (2009) observed that the corn response to N fertilizer was low under drought conditions during growing season. Corn nitrogen fertilizer requirements varied temporally among and within seasons (Devienne-Barret et al., 2000). Fertilizer N management that does not accommodate this temporal and spatial variability may lead to lower yields and economic returns, poor N use efficiency, and detrimental environmental effect due to excessive N inputs. Recent research has highlighted the adverse impact of excessive N fertilizer use in crop production (Robertson et al., 2000; Russell et al., 2006). Therefore, development of more efficient fertilizer N application strategies is important to enhance N use efficiency and producer profitability.

A number of optical spectral indices and canopy characteristics have been widely applied to assist with nutrient management. For example, the Minolta Soil Plant Analysis Development (SPAD-502) chlorophyll meter is used to measure relative chlorophyll (SPAD) content. Nitrogen is part of the enzymes associated with chlorophyll synthesis (Chapman and Barreto, 1997); hence, chlorophyll concentration predicts the relative N status of the crop (Blackmer et al., 1994; Blackmer and Schepers, 1995). Numerous researchers have correlated SPAD values with corn N status and various growth stages with grain yield (Varvel et al., 1997; Bullock and Anderson, 1998; Vetsch and Randall, 2004; Ma et al., 2005; Ma et al., 2007). Crop reflectance is defined as the ratio of the amount of radiation reflected by an individual leaf or canopy to the amount of incident radiation (Schröder et al., 2000). Normalized difference vegetative index (NDVI), widely used to estimate crop growth, has shown a good relationship with corn N status (Shapiro, 1999; Gitelson et al., 2005; Rambo et al., 2010) and grain yield (Ma et al., 1996; Inman et al., 2008; Martin et al., 2007).

Under dryland conditions, with often insufficient rainfall in southeastern Coastal Plain, N fertilization management needs to be further evaluated to determine best management practices to optimize corn production. In Kansas, Norwood (2000) reported that a combination of irrigation and appropriate nutrient management could be a viable economic alternative to dryland production. Therefore, our objective was to characterize corn plant characteristics at specific growth stages and grain yield response to N fertilization management in order to improve N management recommendations under dryland conventional tillage system.

Materials and Methods

Experimental site

The field research was conducted at Clemson University's Edisto Research and Education Center near Blackville, SC (33° 21′ N, 81° 19′ W) on corn from 2007 to 2009. Soil was classified as Dothan loamy sand (fine loamy, kaolinitic, thermic Plinthic Kandiudult) with average soil pH of 6.2. Mehlich I extractable P, K, Mg, and Ca concentrations in 0-15 cm soil layer at the beginning of the study were 29, 59, 88, and 325 mg kg^{-1}, respectively. Organic matter content in this layer was 16 mg kg^{-1}. The study was conducted under dry-land rain fed environment. Monthly precipitation and average air temperature during this study are shown in Table 1.

Table 1. Average monthly air temperature and total precipitation during corn growing season at Edisto REC, Blackville, SC, 2007-2009.

Year	Month					
	March	April	May	June	July	August
	Temperature, °C					
2007	14.7	16.5	20.9	24.6	25.1	27.2
2008	13.0	16.5	21.0	26.4	25.6	25.2
2009	12.8	16.8	21.4	25.9	25.3	25.7
20-yr. Average	16.4	17.6	21.7	25.2	26.7	25.9
	Precipitation, mm					
2007	49	99	14	151	113	70
2008	72	63	76	44	146	161
2009	85	137	284	54	147	24
20-yr. Average	106	80	88	129	130	123

Treatments design and management

The study was arranged as a split-plot design with four replications. Two N application timing methods (single and split N applications) were main plots and five N rates (0, 45, 90, 135, and 180 kg N ha^{-1}) were subplots. All treatments were arranged in a randomized complete block design. With single N application, all N was applied at planting. Split N application consisted of 35 kg N ha^{-1} applied at planting (excluding plots without N application) with the remaining N applied to corn at V_6 growth stage. The N source was urea-ammonium sulfate (25-0-0-3.5 of N-P_2O_5-K_2O-S), which was applied to corn using a Reddick 4-row fertilizer applicator (Reddick Equip. Co., Inc., Williamson, NC). Each plot was 3.9 m wide by 6.1 m long.

Cover crop, winter wheat (*Triticum aestivum* L.), was planted on 8 December 2006, 21 November 2007, and 26 November 2008, and killed by spraying glyphosate at a rate of 1.1 kg a.i. ha^{-1} on 26 February 2007, 6 March in 2008 and 2009. Disk and worksaver (Worksaver, Inc., Litchfield, IL) were used in the experimental area prior to planting corn. Pioneer 31G65 corn (Pioneer Hi-Bred International Inc., Johnston, IA) was planted at 69, 200 seeds ha^{-1} and 0.97 m row spacing using a John Deere 7300 Max Emerge II vacuum planter (John Deere Co., Moline, IL) on 13, 18, and 23 March in 2007, 2008, and 2009, respectively. During corn growing season, weed control program was based on the South Carolina Extension recommendations.

Plant measurements

The measurements included plant height, ear height, nitrate-nitrogen (NO_3-N) concentration in corn ear leaves, leaf relative chlorophyll (SPAD) content, normalized difference vegetation index (NDVI), leaf area index (LAI), and corn grain yield. Corn growth, between V_6 and R_1 stages, was reported as an important period due to a strong relationship between canopy characteristics and corn grain yield (Vestch and Randall, 2004; Raun et al., 2005). In our study, V_8 and R_1 stages were selected to evaluate corn plant characteristics. Plant height and ear height were determined based on at least ten plants per plot at R_1 growth stage. Plant height and ear height were measured from the ground to the tip of the tassel and base of the corn ear, respectively. Corn ear leaf samples were collected from about 25 plants per treatment at R_1 stage for nitrate-nitrogen (NO_3-N) analyses. Relative chlorophyll (SPAD) content, NDVI, and LAI measurements were recorded at V_8 and R_1 corn stages. Relative chlorophyll (SPAD) content was measured in corn leaves with Minolta SPAD-520 meter (Konica Minolta Sensing, Inc., Japan). At least ten chlorophyll (SPAD) meter readings were recorded in the top leaf with collar at V_8 stage and corn ear leaf at R_1 stage and averaged for each treatment. Plant NDVI was measured in two adjacent rows of each plot at V_8 and R_1 stages using the GreenSeeker^{TM} hand held optical sensing instrument (NTech Industries, Inc. Ukiah, CA). Plant NDVI was recorded and calculated based on the NIR and red reflectance (Tucker, 1979). Leaf area index (LAI) was measured between two adjacent center rows (3.0 m long) using LAI-2000 (Li-Cor, Lincoln, NE). Corn grain was harvested from the entire length of two center rows by hand on 29 and 30 August in 2007 and using an Almaco plot combine (Almaco, Nevada, IA) on 22 and 18 August in 2008 and 2009, respectively. Grain moisture was measured using the Burrows Model MC750 Digital Moisture Computer (Seedburo Equip. Co., Chicago, IL) and grain yield was adjusted to 155 g kg^{-1} moisture content.

Statistical analysis

The effects of N fertilization timing and rate on corn plant height, ear height, NDVI, SPAD, LAI, and grain yield were analyzed using the PROC MIXED procedure of SAS (Littell et al., 2006). Year, fertilization timing, N rate, and their interactions were considered fixed effects. Replication (block) and its interactions with treatments were considered random effects. Data were analyzed by year when interaction with year was significant. Single degree-of-freedom contrasts were used to compare years and fertilization timing methods. Means were separated using the least square means test when treatments were significant. The correlations among corn grain yield and plant variables were accessed using Pearson's correlation coefficients generated by the PROC CORR statement of SAS (SAS institute, Inc., 2000). The correlation coefficients between grain yield and plant variables provided a basis for deciding which variables to consider. The suitable variables and their combinations were evaluated to explain final grain yield. To assess the proportion of variability in corn yield that could be explained by each of plant variables, single linear regressions were performed using the PROC REG of SAS (Freund and Littell, 2000). To establish a predicted yield equation which included several suitable plant variables, a multiple linear regression approach was used. Treatment effects and interactions were considered significant if $P \leq 0.05$.

Results and Discussion

Plant characteristics

The N fertilization timing × N rate interaction and N timing fertilization were not significant for plant and ear height. However, plant and ear height were affected by N rate applications (Figure 1). Significantly taller plants and greater ear height was recorded from treatments with 135 kg N ha^{-1} than treatments with 0 or 45 kg N ha^{-1}. Increasing N rate from 0 to 180 kg ha^{-1} increased corn ear height from 60 to 70 cm and was most likely associated with the increase of plant height (Figure 1). In this study, we observed a positive correlation between plant height and ear height (Table 2). Boomsma et al. (2009) also observed shorter plants with low N application rate. Rates above 90 and 135 kg N ha^{-1} did not significantly increase plant and ear height, respectively.

Table 2. Correlation coefficients between plant and ear height, plant NO_3-N concentration, relative chlorophyll (SPAD) content and plant normalized difference vegetation index (NDVI) and leaf area index (LAI) at V_8 and R_1 growth stages, and grain yield during 2007-2009.

	Plant height	Ear height	Plant NO_3-N	SPAD-V_8	SPAD-R_1	NDVI-V_8	NDVI-R_1	LAI-V_8	LAI-R_1
Ear height	0.88*								
Plant NO_3-N	0.45*	0.32*							
SPAD-V_8	0.53*	0.20	0.25*						
SPAD-R_1	0.69*	0.67*	0.42*	0.02					
NDVI-V_8	0.64*	0.67*	0.26*	0.44*	0.41*				
NDVI-R_1	0.67*	0.78*	0.26*	-0.11	0.71*	0.55*			
LAI-V_8	0.34*	0.45*	0.22*	-0.12	0.32*	0.43*	0.39*		
LAI-R_1	-0.06	0.45*	-0.37*	-0.17	0.20	0.23	0.62*	0.16	
Yield	-0.19*	0.14	-0.15	-0.43*	0.04	0.46*	0.36*	0.18*	0.59*

$P \leq 0.05$ (two-tailed test).

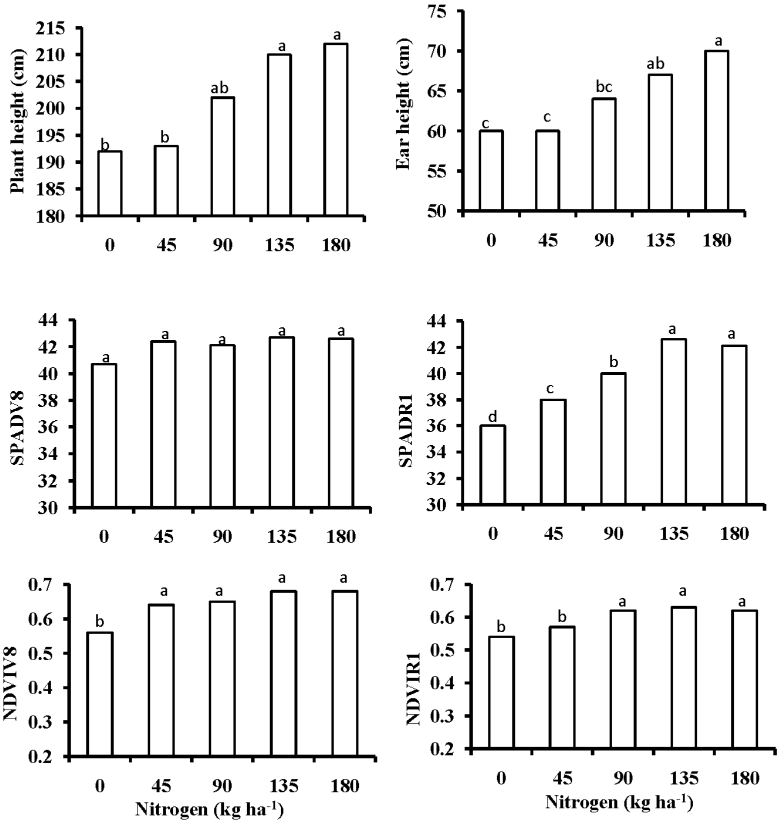

Figure 1. The influence of N rate on plant and ear height at R_1 growth stage, relative chlorophyll (SPAD) content at V_8 and R_1 stages, and normalized difference vegetation index (NDVI) at V_8 and R_1 stages during 2007-2009. The bars followed by different letters indicate significant difference ($P \leq 0.05$).

Chlorophyll (SPAD) content was not influenced by N fertilization timing × N rate and timing of N application at V_8 and R_1 stages. The N rate did not affect chlorophyll (SPAD) content at V_8 stage (Figure 1). It ranged from 40.7 to 42.6 as N rate increased from 0 to 180 kg ha^{-1}. However, chlorophyll (SPAD) content at R_1 growth stage significantly increased with N application rate up to 135 kg ha^{-1} (Figure 1). This was in agreement with Boomsma et al. (2009). Bullock and Anderson (1998) also reported a relationship between chlorophyll (SPAD) and N fertilizer rate. It indicates that chlorophyll (SPAD) content at R_1 stage may be a good predictor to estimate N status in plant for N rates below 135 kg ha^{-1}. Rates above 135 kg N ha^{-1} decreased chlorophyll (SPAD) content predicting ability for N status in plants, because not all N is converted into chlorophyll with high N availability (Varvel et al., 1997).

Plant NDVI at V_8 corn growth stage was greater with N application than without N input (Figure 1). At R_1 stage, plant NDVI increased with increasing N rates up to 90 kg N ha^{-1}. The N fertilization timing and N rate and their interaction had no significant effect on LAI at V_8 and R_1 growth stage. Plant LAI ranged from 1.44 to 1.65 at V_8 stage and from 1.69 to 1.98 at R_1 stage.

Plant NO_3-N concentration in corn ear leaf at R_1 stage increased from 399 to 480 mg kg^{-1} as N rate increased from 0 to 180 kg ha^{-1} (Figure 2), but N fertilization timing had no significant effect on this concentration. Observations on increasing nitrate-N with N application were similar to reports by Al-Kaisi and Kwaw-Mensah (2007). Binford et al. (1990) reported a positive relationship between the availability of soil mineral nitrogen and the nitrate concentration of corn. They noted that the nitrate concentration of maize at the end of the season is a reliable indicator of the N status of that crop during its growth. Greater NO_3-N accumulation in plants, as N rate increases, may indicate inefficient N untilization and luxury N accumulation in stalks from excess N application. Several studies have shown that the N concentration in shoots can be greater than the minimum plant requirements for maximum growth. Studies conducted by Plenet and Lemaire (1999) showed that the N concentration in shoot dry matter (DM) could be up to 65% higher than the minimum requirements for maximum growth in irrigated corn.

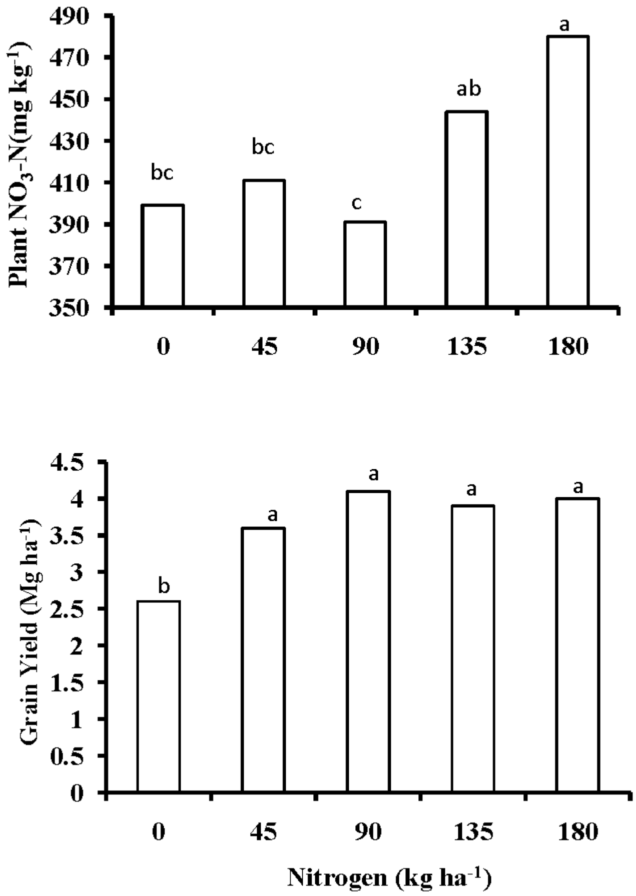

Figure 2. The influence of N fertilization on plant NO_3-N concentration and corn grain yield. The bars followed by different letters indicate significant difference (P≤0.05) during 2007-2009.

Corn grain yield

There was no effect of the year × N fertilization timing × N rate interaction on corn grain yield; however, yield was mainly affected by year and N application rate. Corn grain yield ranged from 5.9 Mg ha^{-1} in 2007 to 2.7 Mg ha^{-1} in 2008 and to 3.0 Mg ha^{-1} in 2009. Insufficient rainfall in June, during corn pollination, in 2008 and 2009 compared with 2007 (44 and 54 mm vs. 151 mm, respectively) most likely contributed to low grain yields (Table 1). Payero et al. (2009) reported a strong positive correlation between the yield and water availability during 12-14 weeks from corn emergence, 'milk' and 'dough' growth stages. Water deficit during the reproductive period shortens the grain filling period (Westgate, 1994), and reduces the grain yield (Bennett et al., 1989). Viswakumar et al. (2008) reported low corn grain yield due to reduced response of corn to N application under dry conditions. Osborne et al. (2002) observed that water stress occurring prior to silking, decreased yields by 22.1% for the dry-land compared with the full irrigation treatment in Nebraska. Claasen and Shaw (1970) noted that water stress at 75% silking resulted in great reduction in corn grain yield, compared with stress during vegetative periods or 3 wks after silking. In a limited-irrigation study in Kansas, Norwood (2000) reported both linear and quadratic yield responses to increasing irrigation. In our study, water stress during reproductive stage resulted in reduction of corn grain yield.

Corn grain yield significantly increased with increasing N application rate up to 45 kg ha^{-1}, but N fertilization timing had no effect on grain yield. Mullins et al. (1998) reported a linear response between corn grain yield and N rate on a Dothan sandy loam under conventional tillage in Alabama. In our study, N application exceeding 45 kg ha^{-1} was not efficiently utilized and did not increase corn yields under low yield environment. Insufficient rainfall and its uneven distribution during corn growth stage, especially during corn pollination, probably contributed to low N use efficiency. In contrast, increase in water availability enhances corn yield response to N fertilization, especially when high N rates are applied (Eck, 1984). In Texas, Torbert et al. (2001) reported that grain yields increased with N fertilizer up to 168 kg N ha^{-1} in wet years, but N application had a limited effect on corn yields in years with insufficient rainfall. Other researchers also observed different critical levels of N application under CT system. In Iowa, Al-Kaisi and Kwaw-Mensah (2007) reported that increasing N rate above 85 kg ha^{-1} had no significant effect on increasing corn grain yield. In Ontario, Canada, Ma et al. (2005) observed yield increase with up to 120 kg N ha^{-1}. However, the total required N was 276 kg ha^{-1} to maximize corn grain yield in CT system under irrigation in Colorado (Halvorson et al., 2006). These reports indicate that the selection of N application program depends on location and environmental conditions, especially precipitation.

Variables correlation

Significant correlations were observed between measured corn parameters (Table 2). Plant height at R_1 stage was positively correlated with plant NO_3-N concentration, ear height at R_1, chlorophyll (SPAD) content and NDVI at V_8 and R_1 growth stages, and LAI at V_8 stage. Ear height was significantly correlated with chlorophyll (SPAD) content at R_1 and NDVI at V_8 and R_1 stages. Also, positive correlations were observed between chlorophyll (SPAD) content and NDVI at V_8 and R_1 stages. Ma et al. (1996) also reported that plant NDVI was strongly correlated with the chlorophyll (SPAD) measurements at almost all growth stages.

Corn grain yield had a significant correlation with corn plant height at R_1 stage, chlorophyll (SPAD) content at V_8 stage, and NDVI and LAI at V_8 and R_1 stages (Table 2). It indicates that plant height, chlorophyll (SPAD) content, NDVI, and LAI have the potential to predict corn grain yield. Previous research has shown the potential for using plant parameters to explain grain variability. Machado et al. (2002) observed that plant height explained 61% of the variation in corn grain yield. Girma et al. (2006) reported that mid-season NDVI, chlorophyll content, plant height, and total N uptake were good predictors of final winter wheat grain yield. Ma et al. (1996) also observed that both plant NDVI and relative chlorophyll (SPAD) measurements recorded pre-anthesis were closely correlated with corn grain yield. Vetsch and Randall (2004) reported that chlorophyll (SPAD) content began to show great relationship with corn grain yield from V_6 growth stage (r-square > 0.77). Inman et al. (2008) found that plant NDVI divided by the number of days from planting to sensing had a strong relationship with corn grain yield (r-square = 0.65).

In our study, grain yields could be explained at higher rate when some variables were used in a multiple regression analysis. For instance, combining LAI at V_8 and R_1 stages or combining NDVI at V_8 and R_1 stages explained 35% and 36% of the variability in grain yield, respectively (Table 3). The best fit equation in this study was as follows:

$$\text{Corn grain yield} = 3.07 - 0.04\ \text{Plant height} + 13.8\ \text{NDVIR}_1 + 0.54\ \text{LAIR}_1$$

Table 3. Regression equations for predicting corn grain yield based on plant height, relative chlorophyll (SPAD) content at V_8, normalized difference vegetation index (NDVI) and leaf area index (LAI) at V_8 and R_1 growth stage during 2007-2009.

Regression equation	r-square
Yield= 5.77 - 0.01 Plant height	0.03
Yield= 12.64 - 0.20 $SPADV_8$	0.19
Yield= -0.52 + 4.74 $NDVIV_8$	0.21
Yield = 0.78 + 4.85 $NDVIR_1$	0.13
Yield = 2.47 + 0.77 $LAIV_8$	0.03
Yield = 0.075 + 2.15 $LAIR_1$	0.34
Yield = -0.38 + 0.38 $LAIV_8$ + 2.10 $LAIR_1$	0.35
Yield = -0.82 + 2.09 $NDVIV_8$ + 3.33 $NDVIR_1$	0.36
Yield = 0.005 + 0.03 $SPADV_8$ + 1.49 $NDVIV_8$ - 0.14 $LAIV_8$	0.07
Yield = 3.07 - 0.04 Plant height + 0.54 $LAIR_1$ + 13.8 $NDVIR_1$	0.71

The combination of these three variables explained 71% of variability in corn grain yield. It indicates that corn grain yield, to some extent, could be more accurately predicted by combining appropriate variables than using one variable alone. Some researchers also reported similar findings. Inman et al. (2008) observed that combination of soil color-based management zones and NDVI in the yield regression model explained among 25 to 82% of the variability in relative corn grain yield compared with explaining only 10 to 47% by NDVI itself. Freeman et al. (2007) reported that the NDVI × plant height index provided higher correlation with by-plant corn forage yield than NDVI and plant height separately, r-square = 0.62 vs. 0.52 and 0.59, respectively. In our study, the equation containing plant height, NDVI, and LAI at R_1 stage may help to predict corn grain yield in dry-land low yield environment.

Summary and Conclusions

In low yield and rain fed environment, N fertilization timing had no significant effect on corn plant characteristics and grain yield under CT system. However, N application rate affected plant characteristics and corn yields. Plant height, ear height, chlorophyll (SPAD) content, NDVI, and nitrate-N concentration in plant generally increased with increasing N rates up to 90, 90, 135 and 90 kg N ha^{-1} for plant height, ear height, SPAD, and NDVI at R_1 stage, respectively. Insufficient rainfall at corn reproductive stage significantly reduced corn grain yields. Our results indicate that the application of N above 45 kg ha^{-1} did not significantly increase grain yields.

Significant correlations existed among plant height, ear height, SPAD, and NDVI at R_1 stage. Also, plant height, chlorophyll (SPAD) content at V_8, NDVI and LAI at V_8 and R_1 stages were significantly correlated with corn grain yield. The combination of plant height, NDVI, and LAI at R_1 growth stage in the regression equation may be a potential tool to predict corn grain yield under dry-land low yield environment.

Acknowledgement

We appreciate a partial support from International Plant Nutrition Institute (IPNI). This material is also based upon work supported by NIFA/USDA, under project number SC-1700328. Technical Contribution No. 5919 of the Clemson University Experiment Station.

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