



Yield Response of Overhead Irrigated Snap Bean to Nitrogen Rates[†]

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Adequate nitrogen (N) and irrigation management are critical to optimize the yield of a shallow-rooted vegetable crop like snap bean (*Phaseolus vulgaris* L.). The goals of this project were to establish snap bean responses to N rates with overhead irrigation and to develop preliminary petiole sap and SPAD interpretative thresholds. The study was conducted on a Blanton–Foxworth–Alpin complex sandy soil in fall 2007 and spring 2008. ‘Bronco’ bush snap beans were fertilized with a total of 0, 40, 80, 120, 160, or 200 lb/acre (0, 45, 90, 134, 179, 224 kg/ha) N rates with three identical applications at planting, first trifoliate leaf, and first flower bud. Plots consisted of four, 40-ft (12.2-m) long rows with the two middle rows harvested. In both years, the marketable pod yield response to N rate was quadratic and maximum pod yield for both fall 2007 and spring 2008 occurred near the current recommended N rate. Preliminary data for petiole sap interpretative NO₃-N thresholds were also proposed. A significant positive linear relationship between SPAD and marketable yield was observed for all growth stages in 2007, but not in 2008, thereby limiting the practicality of this measurement as an in-season monitoring tool.

Snap beans, which are also referred to as green beans or string beans, are marketed as fresh, canned, or frozen products. The United States is the largest snap bean producer in the world with approximately 60% of total production (Abate, 2006). Florida’s snap bean production ranks first in the nation and constitutes 43% of the nation’s total production and 51% of the market value (USDA, 2002). Total USA market value was \$113 million in 32,800 planted acres in 2009 (FDACS, 2009). In North Florida, snap beans are grown on deep sands, in the spring and fall with center pivot irrigation systems. Most Florida bean acreage is mechanically harvested. The Florida snap bean industry operates on thin profit margins, therefore, snap bean producers need to minimize input cost such as fertilization. Important attributes for snap beans are marketable yield, pod length, pod straightness, and pod color. Also, plants should remain upright for proper mechanical harvest. Snap bean plants may become large and heavy when excessive N is used and may lodge near maturity (Mengel et al., 2001). Excessive N application may also negatively impact biological N fixation of legumes (Vankosky et al., 2011).

Current UF/IFAS recommendations for nutrient and water management for snap bean are an N rate of 100 lb/acre (112 kg/ha)

and 95% of plant water use as evapotranspiration (ET_o) during the rapid growth and development period and 85% of ET_o during the last period of crop growth (Olson et al., 2011). In-season nutrient applications may be adjusted based on plant nutritional status of snap bean when real-time measurements using chlorophyll meters such as SPAD meters or ion-selective electrodes such as Cardy meters are available (Davenport and Jabro, 2001; Westerveld et al., 2003; Wetscott et al., 1993;). Cardy meter readings can be compared with established thresholds in order to diagnose plant nutritional status for N as “low,” “sufficient,” or “high” (Folegatti et al., 2005; Ito, 2010; Rodrigo et al., 2007; Shrestha et al., 2010). While these thresholds are available for most vegetable crops grown in Florida, they are not currently available for snap bean (Olson et al., 2011). In addition, no calibration or reference data linking SPAD readings to ion-specific measurements are available, thereby currently limiting its use as a best management practice (BMP) tool.

Because snap bean growers are encouraged to adopt nutrient BMPs, the goal of this study was to determine snap bean responses to N rates with overhead irrigation. The objectives were to: 1) determine the N rate that maximized yield and snap bean quality; 2) develop preliminary interpretative data for NO₃-N sap petiole concentration; and 3) determine if SPAD chlorophyll meters could be used as another crop nutrient monitoring tool.

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Materials and Methods

Weather data were downloaded from the Live Oak Weather Station at <http://fawn.ifas.ufl.edu/> (Table 1) located approximately 300 ft (90 m) from the trial field. The irrigation requirement in the table was based on ETo and a 70% irrigation efficiency. Total water usage was calculated by adding the water quantity of both irrigation and precipitation during either of the growth seasons. Soil moisture level was vertically assessed in the top 8 inches (20 cm) of the soil profile with a portable Hydrosense Time Domain Reflectometer (TDR) probe (Model #CS-620 Spectrum Technologies, Plainsfield, IL). The overhead irrigation system was controlled by the TDR probe to maintain soil moisture level in the recommended range of 8% to 12%. Plots were 40 ft long and 10 ft wide (400 ft², 37.2 m²) and established on a Blanton-Foxworth-Alpine complex sandy soil at the Suwannee Valley Agriculture Extension Center, near Live Oak, FL. The results of a Mehlich I soil-test conducted in Aug. 2007 were: phosphorus (P), 60 ppm (high); potassium (K), 30 ppm (low); magnesium (Mg), 19 ppm (medium); calcium (Ca), 317 ppm (high); and pH 5.8 (medium). On 27 Aug. 2007 and 9 Apr. 2008, 100 lb/acre (112 kg/ha) of 0-0-60 were broadcasted, and 3 pints/acre of Eptam herbicide (3.5 L/ha) and a micronutrient mix with 2.8% sulfur (S), 1.0% copper (Cu), 1.0% manganese (Mn), 4.5% zinc (Zn) at 3 quarts/acre (8.2 L/ha) were sprayed uniformly on the experimental area. The ground was then rototilled and irrigated with 0.5 inch (13 mm) of water using a center pivot irrigation system. 'Bronco' snap bean was hand-seeded on 27 Aug. 2007 and on 11 Apr. 2008 at a depth of 0.75 inch (19 mm) at a seeding rate of 6 seeds/linear foot row (20 seeds/linear meter row).

Nitrogen as ammonium nitrate was manually applied to one side of the row and 2 inches (5 cm) apart from the center of the row on 29 Aug. 2007 (2 d after seeding, DAS) and on 14 Apr. 2008 (3 DAS), on 19 Sept. 2007 (23 DAS) and on 7 May 2008 (26 DAS), and on 3 Oct. 2007 (37 DAS) and on 27 May 2008 (46 DAS). All N applications were followed with an overhead irrigation of 0.33 inch (8 mm). Total N rates ranged from 0 to 200 lb/acre (0 to 224 kg/ha) in 40-lb (18.2 kg) increments. Each plot consisted of four, 40-ft (12.2 m) long rows, 30 inches (76 cm) apart. All treatments were replicated four times in a randomized, complete-block design. The fungicide, Ridomil (Syngenta, Greensboro, NC) was applied to the soil surface at 1 pint/acre (1.35 l/ha), and was immediately irrigated into the soil with 0.33 inch (8 mm) of water on 29 Aug. 2007 (2 DAS) and 11 Apr. 2008 (0 DAS). Plants were treated weekly with labeled fungicide and insecticide applications as needed according to UF/IFAS recommendations (Olson et al., 2011).

Twenty of the most recently matured tri-foliolate leaves and petioles were randomly collected from each plot on 18 Sept. (22 DAS), 26 Sept. (30 DAS), 3 Oct. (37 DAS), and 11 Oct. (45 DAS), 2007, and 14 May (33 DAS), 21 May (40 DAS), 28 May (47 DAS), and 4 June (54 DAS), 2008 for the measurement of NO₃-N sap concentrations using a Cardy NO₃-N meter (Spectrum Technologies). A portable SPAD-502 leaf chlorophyll meter (Minolta, Japan) was also used on those dates to measure the chlorophyll contents of the leaves.

One of the inside two rows selected randomly within each plot was hand-harvested on 19 Oct. 2007 (53 DAS) and on 9 June 2008 (58 DAS) and pods were hand graded into marketable and unmarketable (broken and small) categories based on USDA standards (USDA, 1990). Only marketable yields were used for the comparison and regression calculations in this article.

Nutrient sap concentrations were statistically analyzed by sampling date using analysis of variance (ANOVA). Marketable yield responses to N rates were analyzed using regression techniques (SAS Institute, Cary, NC, 2013). The regression equations and corresponding coefficients of determination were generated by Microsoft Excel 2007. The three types of regression relationships were: 1) between SPAD and Cardy meter readings; 2) between marketable yields and SPAD readings; and 3) between SPAD readings and N rates.

Results and Discussion

WEATHER CONDITIONS. Fall 2007 and spring 2008 were typical weather and growing seasons for snap bean in North Florida. Harvests were conducted 53 DAS in the spring and 59 DAS in the fall. Rainfall amount was greater in the fall than in the spring (Table 1). Based on the UF/IFAS recommendations and BMP criteria, "leaching rain" events are defined as rainfalls of 3 inches (76 mm) in 3 days or 4 inches (102 mm) in 7 d. No leaching rain events occurred during either growing season. However, a 0.9-inch (23 mm) rainfall event occurred 6 DAS in fall 2007. Since seeds were planted 0.75 inch (19 mm) deep, and assuming that roots expand at a rate of 0.5 inch/day (13 mm/day) (Portas, 1968), the estimated root depth 6 DAS was approximately 3.75 inches

Table 1. Weather summary for the fall 2007 and spring 2008 growing seasons from the Florida Automated Weather Network (FAWN) station at the Suwannee Valley Agricultural Extension Center, near Live Oak, FL.

Weather parameter	2007	2008
	27 Aug.–19 Oct.	11 Apr.–9 June
Total rainfall (inches)	5.7 (145 mm)	2.4 (61 mm)
Average temp (°F)	76.0 (24 °C)	72.0 (22 °C)
Total radiation (w/m ²)	9813.0	15149.0
Total ET (inches)	6.6 (168 mm)	8.3 (211 mm)
Irrigation (inches)	4.4 (112 mm)	8.0 (203 mm)
Water usage (inches) ^a	10.1 (257 mm)	10.3 (262 mm)

^aThe usage was calculated based on the water quantity of both irrigation and precipitation in the growth season of either fall 2007 or spring 2008.

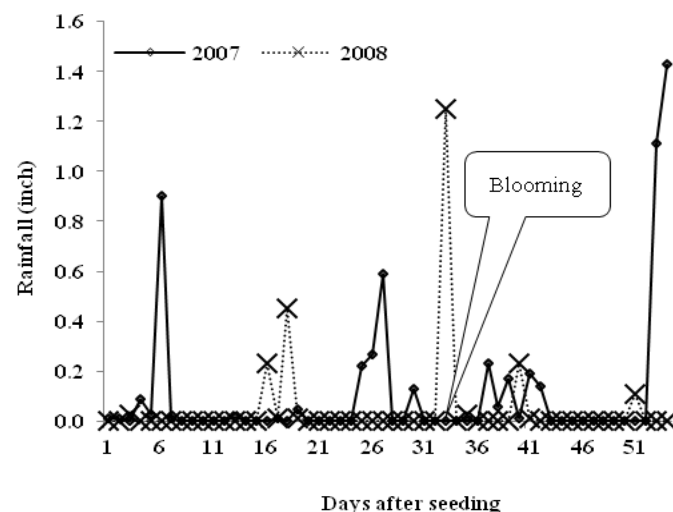


Fig. 1. Rain events during snap bean crop seasons at the Suwannee Valley Agricultural Extension Center, near Live Oak, FL. in fall of 2007 and spring 2008. 1 inch = 25.4 mm.

[0.75 + (6 × 0.5)] (95 mm). In soils with 10% water holding capacity, as in this study, a 1-inch (25 mm) application of water may move the water front down to approximately 10 inches (254 mm). Since 6 DAS, the estimated wetted depth (9 inches or 229 mm) was greater than the estimated root depth (3.75 inches, 95 mm). Therefore, some soluble nutrients may have moved below the root zone on that day. However, using the same approach, the 1.25-inch (32 mm) rainfall 33 DAS in the fall of 2008 coincided with full bloom and was unlikely to have resulted in nutrients moving below the root zone (Fig. 1). On that day, the estimated water front depth of 12.5 inches (32 cm) was close to the maximum rooting depth of 12 inches (30 cm) reached when roots reach the bottom of the plow zone (Portas, 1968).

SNAP BEAN MARKETABLE POD YIELDS. The responses of marketable yield to N rate in 2007 (MKY07) and 2008 (MKY08) are best described by quadratic relationships:

$$MKY07 = 2813 + 53.5N - 0.18N^2 \quad (1)$$

$$R^2 = 0.87^{**}$$

$$MKY08 = 4030 + 22.8N - 0.11N^2 \quad (2)$$

$$R^2 = 0.56$$

The above equations show that the two constants (53.5 and -0.18) in Eq. 1 are both markedly greater than those (22.8 and -0.11) in Eq. 2. This means that the yield response to N rate in 2007 was significantly greater than that in 2008 (Fig. 2). The first derivative of a yield response equation such as Eq. 1 or 2 represents the yield increment per additional unit N input at a given N rate. The first derivative of the above equations is as below:

$$MKY07' = 53.5 - 0.36N \quad (3)$$

$$MKY08' = 22.8 - 0.22N \quad (4)$$

Obviously, the MKY increment decreased as N increased (Eqs. 3 and 4) as the coefficients for N rates are negative. This is common between fertilizer input and crop yield or profitability. Therefore, to maximize the profitability in snap bean production optimizing nutrient management is imperative. Particularly, the crop should not be over-fertilized because N fertilize inhibits root nodule development and fertilized plants may have fewer nodules (Vankosky et al., 2011). In fact, the second derivative of the yield response equation (Eqs. 1 or 2) describes the rate of change in the yield increment and can give further information:

$$MKY07'' = -0.36 \quad (5)$$

$$MKY08'' = -0.22 \quad (6)$$

The negative constant coefficients in Eqs. 5 and 6 means the MKY increment decreased incrementally with additional increases of N. The absolute value of the coefficient in Eq. 5 is 64% greater than that in Eq. 6. This indicates that the yield response of snap bean to N rate in 2007 was 64% greater than in 2008.

The greater yield response to applied N in 2007 may be attributed to the more favorable weather in 2007 (Fig. 1 and Table 1) and the different growing season (spring vs fall). The rainfall was 141% greater in 2007 than in 2008 but the crop evapotranspiration (ETc) was the opposite: ETc in 2008 was 25.8% greater than in 2007 (Table 1). Additionally, the distribution of precipitation in 2008 may have negatively impacted crop growth and

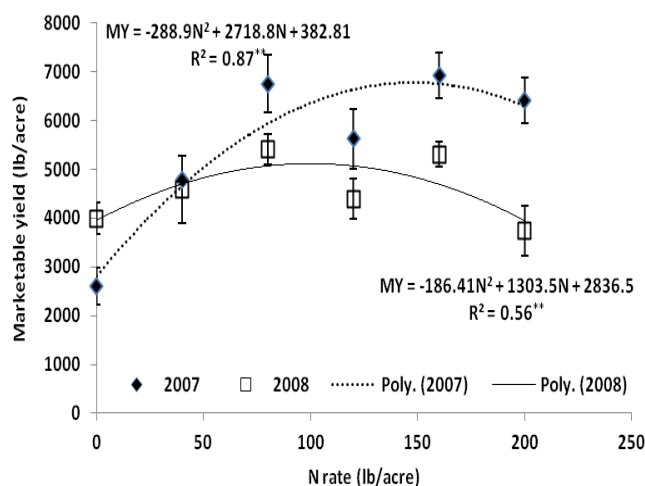


Fig. 2. Nitrogen rate effect on the yield of 'Bronco' snap bean grown at the Suwannee Valley Agricultural Extension Center, near Live Oak, FL in fall 2007 and spring 2008. 1 lb/acre = 1.12 kg/ha.

development. The full bloom stage of the crop coincided with a 1.25-inch rain event in 2008 (Fig. 1), which likely harmfully impacted the pollination and fertilization of the crop and hence MKY. This may explain why the snap bean MKY in 2008 was lower than in 2007 (Fig. 2).

The MKY of the control in 2008 was 53.1% greater than that of the control in 2007 (Fig. 2). This yield difference may be attributed to the effect of N deficiency on the progress of snap bean plant development because the plants suffering from N deficiency shorten the vegetative growth stage and mature earlier. This early maturity may be closely associated with the effect of the shortage of the N supply on biosynthesis and ratio of different plant hormones (Mengel et al., 2001). However, because of the early maturity, plants were able to accomplish their normal pollination and fertilization prior to significant rain events in 2008 and hence the yield was not impacted by heavy rain events. The weather in 2008 was not only moderate, but also favored the yield of the control because solar radiation was more plentiful than that in 2007 (Table 1). The abundant radiation energy in 2008 was probably able to increase the crop's photosynthesis and hence the yield of the control without N fertilization. This may be a possible explanation for the difference in the bean yields of the controls in 2007 and 2008.

The determination of the N rates producing the highest yields has been shown to depend on the method used. When means comparisons are used, the MKY with the 80 lb/acre (90 kg/ha) N rate was either second maximum [slightly less than the treatment receiving 160 lb/acre (179 kg/ha) N rate in 2007] or maximum (2008) across the five N rates, while the lowest MKY was in those treatments receiving 0 lb/acre (224 kg/ha) N for 2007 and any N rate in 2008 (Fig. 2). When the calculated maxima from the regression equation is used (N rate that produces a MKY = 0 in Eqs. 3 and 4), highest marketable snap bean yields were obtained with 149 and 104 lb/acre (167 and 117 kg/ha) N rate for 2007 and 2008, respectively. Hence, this study supports the current UF/IFAS recommended total N rate for snap beans of 100 lb/acre (112 kg/ha). When an irrigation schedule based on crop evapotranspiration and daily soil moisture measurement is used, leaching risk when the plants are small is reduced. Hence,

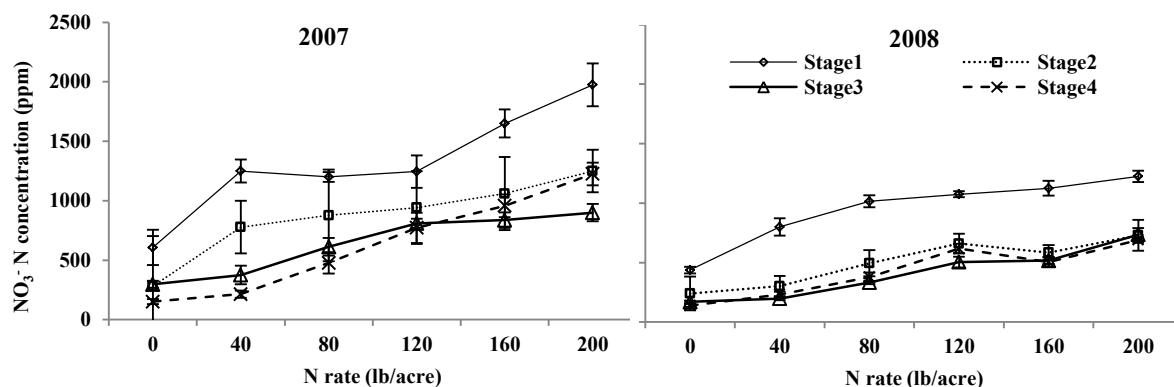


Fig. 3. Changes in nitrate-nitrogen concentration in petiole sap during the 1-to-2 trifoliate leaves (stage 1); plants branching (stage 2); 1-inch long pods (stage 3) and 1 week before harvest (stage 4) in 'Bronco' snap beans grown at the Suwannee Valley Agricultural Extension Center, near Live Oak, FL in fall 2007 and spring 2008. 1 ppm = 1 mg/L; 1 lb/acre = 1.12 kg/ha.

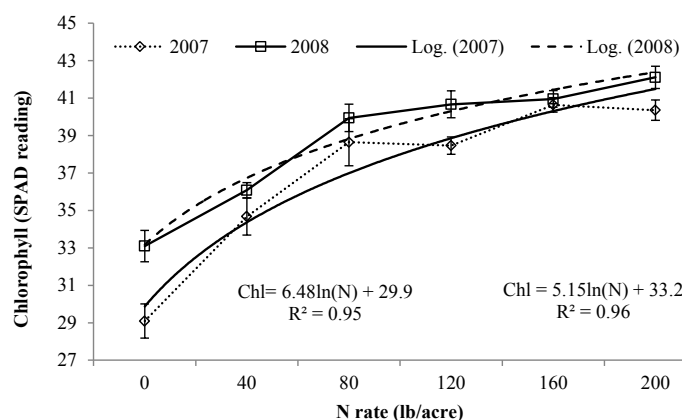


Fig. 4. Changes in chlorophyll concentration as a response to N rates in leaves of 'Bronco' snap bean grown in the fall 2007 and spring 2008 at the Suwannee Valley Agricultural Extension Center, near Live Oak, FL. The measurements were taken on 18 and 26 Sept., 3 and 10 Oct. 2007 and on 14, 21, 28 May, and 4 June 2008. 1 lb/acre = 1.12 kg/ha.

it may be possible to reduce the amount of N applied during the first sidedress

Inter-annual changes in $\text{NO}_3\text{-N}$ petiole sap concentration with N rates. Nitrate-N concentration in plant petiole sap is indicative of N status of mature plants. Fig. 3 shows that: 1) $\text{NO}_3\text{-N}$ concentrations were greater in 2007 than in 2008 no matter the growth stage and N rate; 2) $\text{NO}_3\text{-N}$ concentrations were always significantly greater in stage 1 than in stage 2 through stage 4; 3) $\text{NO}_3\text{-N}$ concentrations were not significantly different in any two stages among stage 2 through stage 4, except for one point at N rate of 40 lb/acre (45 kg/ha) for which stage 2 $\text{NO}_3\text{-N}$ concentration was significantly greater than either stage 3 or stage 4; and 4) $\text{NO}_3\text{-N}$ concentration was positively proportional to N rate.

Using 90–150 and 90–100 lb/acre (101–168 and 101–112 kg/ha) N as the N rate that produced the highest snap bean MKY, these results suggest that $\text{NO}_3\text{-N}$ ranges of 1,000–1,500 ppm for stage 1, 500–1,000 ppm for stage 2, and 300–700 ppm for stages 3 and 4 in 2007 and 800–1,000 ppm for stage 1 and 300–500 ppm for stages 2, 3, and 4, for 2008 could be used to interpret in-season snap bean petiole sap results. Since this experiment did not use K as a variable, it is not possible to propose interpretative ranges for K from these data.

Table 2. Mean value of four chlorophyll measurements in snap bean plants with a SPAD meter in fall 2007 and spring 2008.

N rate (lb/acre)	2007	2008	2008/2007 (%)
0	29.1 D ^a	33.1 D	113.7
40	34.7 C	36.1 C	104.0
80	38.5 B	40.0 B	103.8
120	38.7 B	40.7 B	105.2
160	40.4 AB	41.0 B	101.5
200	40.7 A	42.1 A	103.4
LSD _{0.05}	1.9	1.1	105.3
P	<0.01	<0.01	

^aThe SPAD readings with different letters in the same column are significantly different at $P < 0.05$ with LSD_{0.05} is 1.9 and 1.1 for 2007 and 2008, respectively. 1 lb/acre = 1.12 kg/ha.

The N source used in this particular research was ammonium nitrate, which provides 50% each of elemental N sources from ammonium and nitrate. Due to ammonia-oxidizing bacteria in soil, the ammonium component in the fertilizer is converted into nitrate. Cavagnaro et al. (2008) reported that only 36 h after application all of the applied ammonia had oxidized into nitrate. This suggests that the actual N source for the snap bean plants was likely nitrate 36 h after N fertilization even though 50% of the N was applied as ammonium. This nitrate is biochemically reduced into organic nitride compounds and metabolized primarily in leaves. The reducing power needed for the reduction of nitrate is primarily exported from the chloroplasts (Mengel et al., 2001). This suggests that photosynthetically active radiation plays a key role in the conversion from nitrate to ammonium in crop plants. The total radiation in 2008 was 54.4% greater than that in 2007 (Table 1). Accordingly, the photosynthetically active radiation in 2008 was significantly greater than in 2007 and likely explains the inter-annual difference in nitrate concentration in petiole sap. Similarly, the leaf area in stage 1 was smallest and hence the nitrate concentration was the greatest in that growth stage in the crop's lifetime. Likewise, nitrate concentration was positively associated with N rate because the greater the N rate the more the soil provides nitrate (Nelson and Anderson, 1977). Because nitrate is readily leached downward through sandy soils, split N applications are much more efficient than a single application (Havlin et al., 1999). Fertigation may be preferred over the split application method for efficient use of N in crop production because fertigation is instant and dynamic, can provide N to the

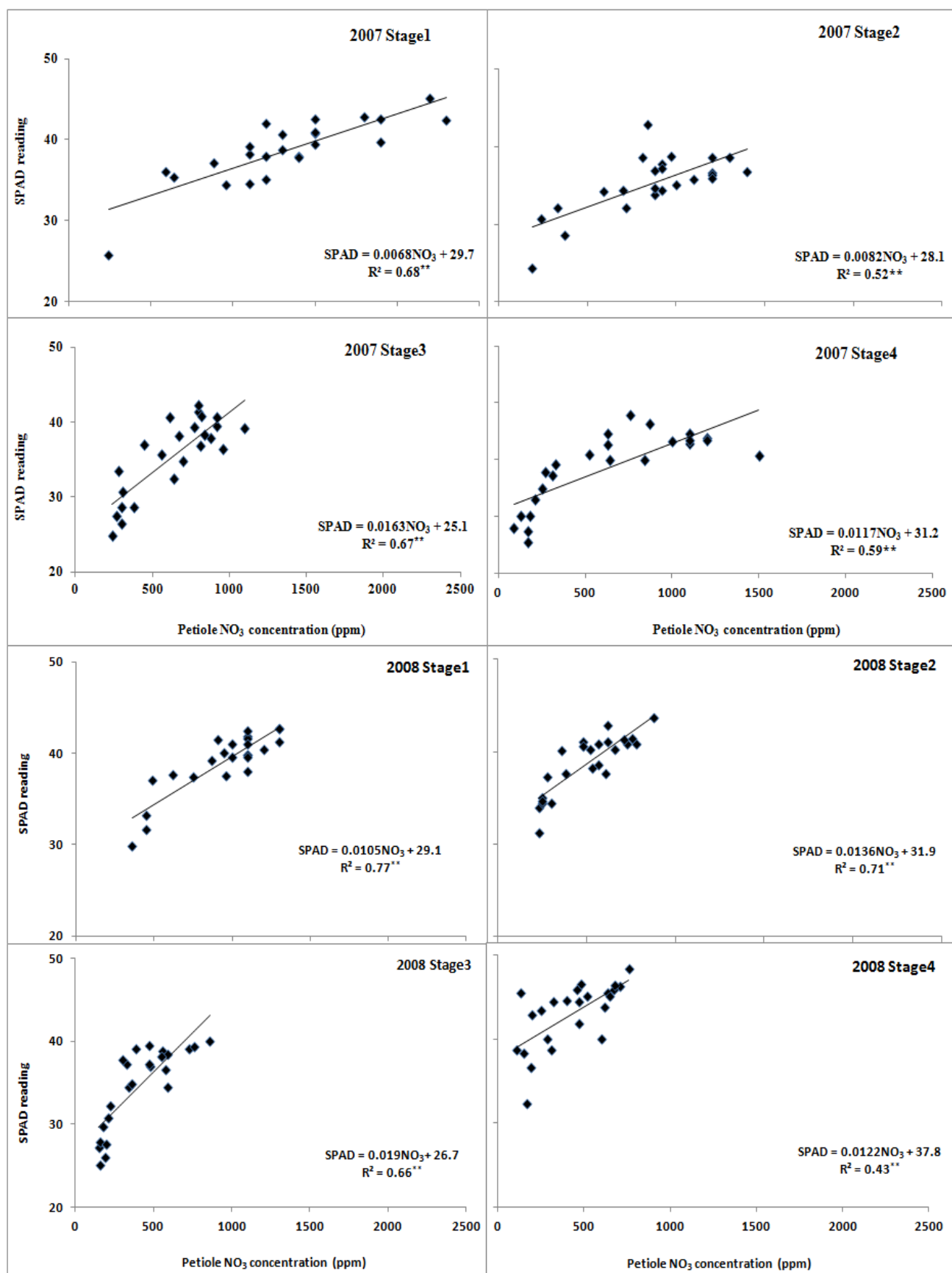


Fig. 5. The linear relationship between chlorophyll content and nitrate concentration in petiole sap of snap bean in 2007 and 2008. 1 ppm = 1 mg/L.

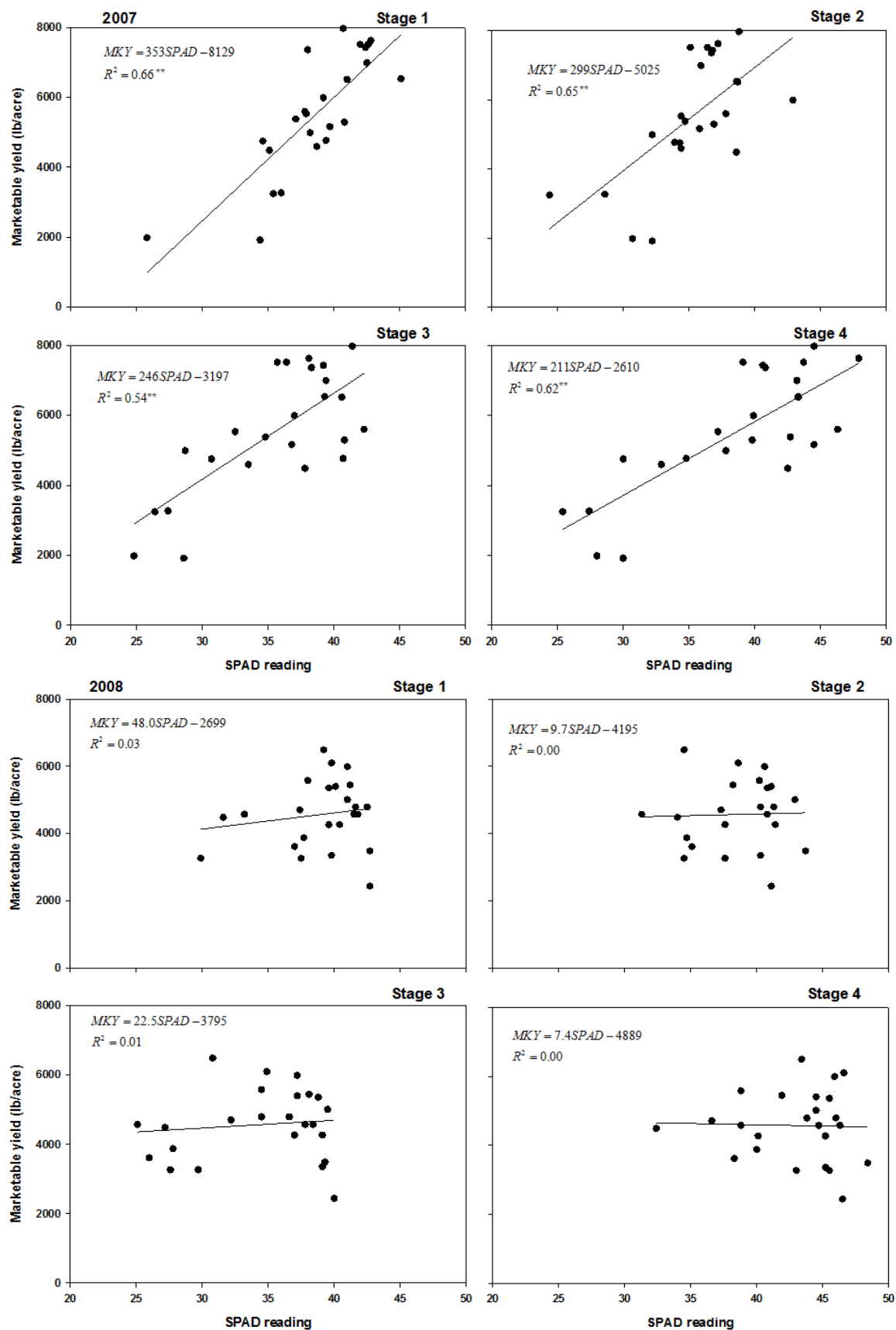


Fig. 6. The relationship between marketable yield and SPAD readings in different growth stages of snap bean grown in 2007 and 2008. 1 lb/acre = 1.12 kg/ha.

crop continuously, and can split the N application as many times as the number of irrigations.

CHLOROPHYLL CONTENT DIFFERENCE. Solar radiation and chlorophyll play a core role in the conversion of energy from the sun into active chemical energy currency, adenosine triphosphate (ATP). Chlorophyll is a nitride biochemical compound containing more than 6% N. In snap bean physiology, only metabolized N can be a part of chlorophyll; nitrate N cannot be metabolized into chlorophyll. Table 2 shows the difference in the mean value of the four chlorophyll measurements (stage 1 to stage 4) of the snap beans in 2007 and 2008. The chlorophyll contents always increased with N rates. In 2007, the chlorophyll content of plants in the 200 lb/acre N treatment compared to the control was almost 40% greater in 2007 and 27.2% greater in 2008. The overall mean SPAD values were 37.9 and 38.8 for 2007 and 2008, respectively. The difference between these two years was significant at $P < 0.01$ with $LSD_{0.05} = 0.74$. Fig. 4 directly illustrates that snap beans grown in 2008 always had greater chlorophyll content than in 2007. The two equations show the regressive relationship between N rate and chlorophyll content. The regression analysis indicates that the plants grown in 2008 had greater chlorophyll content than those grown in 2007 (Fig. 4). Again, this was closely associated with annual differences in photosynthetically active radiation. Plants in 2008 were better supplied with reducing power than those in 2007 due to the total radiation difference. This implies that the 2008 snap beans should have had a better chance to achieve higher yields than the 2007 plants. However, the yield was, in fact, just the opposite. This is indicative of the importance of crop management from the very first day to the last day. Some of the factors are not controllable, for instance heavy rains, but some are controllable and manageable. Fertilization and irrigation belong to the latter. Maximum profitable production of snap bean requires careful and integrated management.

CHLOROPHYLL CONTENT VS. PETIOLE NITRATE CONCENTRATION. In both 2007 and 2008, there was always a significant relationship between chlorophyll content and nitrate concentration in petiole sap. That was best described by a linear function (Fig. 5). This is because chlorophyll is closely associated with N rate (Table 2). The latter has a positive proportional relationship with nitrate concentration in petiole sap (Fig. 5). However, snap bean is a leguminous crop that can biologically fix N from the air. Even though it is not a very strong N fixer its proportion of N derived from biological N fixation is approximately 50% (Rondon et al., 2007). Excess N fertilization does not make sense for profitability. Particularly, the plants' ability for N uptake and assimilation is low in the earliest growth stage because their leaf area is small. In fact, the curves for 2007 in Fig. 3 show that Stage 1 had the greatest nitrate concentration because in that stage, the plants were small with small leaves and had less reducing power than those in any of other growth stages from Stage 2 across Stage 4. For example, Stage 3 had the lowest nitrate concentration. In Stage 4, the plants had similar size but were senescing and the leaf area did not function as well as those in Stage 3. The difference in NO_3 -N concentration among the four growth stages was not as obvious in 2008 compared to 2007 because the total radiation in 2008 was 54.4% more than that in 2007 (Table 1).

REGRESSION BETWEEN CHLOROPHYLL CONTENT AND MARKETABLE BEAN YIELD. There were significant positive linear relationships between SPAD and MKY in each of the four growth stages in 2007 (Fig. 6), but not in 2008. The crop had greater chlorophyll content in 2008 than in 2007 (Table 2 and Fig. 6) and the solar

radiation energy in 2008 was 54% greater than in 2007. Chlorophyll content is closely associated with N bioavailability in the soil where the crop is grown (Dordas and Sioulas, 2008; Evens, 1983). Chlorophyll content determines light energy harvest and yield formation because it is the key pigment converting solar energy into active chemical energy (i.e., reducing power) in the plants. Generally speaking, there is a close relationship between chlorophyll content and crop yield. The difference in MKY between 2007 and 2008 was attributable to the significant rain event during bloom in 2008 (Fig. 1). These data suggest that overhead irrigation needs to be carefully monitored, particularly at the blooming stage. To avoid any negative impact on pollination and fertilization, center-pivot irrigation should be run in the later afternoon hours during the blooming stage because most of the plants bloom in the morning (Stanley and Linskens, 1974).

Petiole-sap nitrate concentration was positively proportional to N rates. Chlorophyll content was closely associated with N rate and with petiole nitrate concentration. Forty and 80 lb/acre (45 and 90 kg/ha) N rates produced maximum marketable snap beans. SPAD reading objectively reflected N status of the crop and was able to be correlated with the N rate applied to the crop. SPAD reading was closely associated with N status, but was a good predictor of MKY for only one out of two crops. Hence, these results are insufficient to recommend the use of SPAD readings as a reliable in-season monitoring of yield prediction.

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