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The Use of Nondestructive Sensors to Assess Nitrogen Status in Potted Dianthus (*Dianthus chinensis* L.) Production

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Abstract

Optical sensors are a fast and nondestructive new technology used to estimate plant chlorophyll content by measuring leaf reflectance or absorbance of light. The objective of this study was to evaluate the reliability of normalized difference vegetative index (NDVI) values calculated by the GreenSeekerTM hand held sensor as an indirect indicator of dianthus (*Dianthus chinensis* L.) N status, and investigate nutrient supplementation on deficient 'TelstarTM White' and 'TelstarTM Red Picotee' plants. Pots were supplemented

with 0, 5, 10, 15, and 20 g of 15N-9P-12K controlled release fertilizer (CRF). Soil and plant analysis development (SPAD) chlorophyll meter, GreenSeeker™ NDVI sensor, and atLEAF meter readings were recorded for four consecutive weeks. At 49 days after planting (DAP), the 0 g and 5 g treatments were found deficient and half of the pots were supplemented with extra fertilizer for treatment correction (C 0 and C 5, respectively). The SPAD and atLEAF readings showed stronger correlation to actual leaf N concentration compared to the GreenSeeker™. The GreenSeeker™ readings were less correlated with leaf N concentration at early stages of establishment due to plants small size and background noise, as well as at later stages of establishment due to anthesis. Dianthus quality responses generally increased as fertilizer rates increased. The additional correction treatment showed a significant improvement in C 5 and no significant improvement on C 0, indicating that the correction treatment was beneficial for dianthus when initial amount of fertilizer was applied.

Keywords: Optical sensors, NDVI, SPAD, atLEAF, CRF

1. Introduction

Dianthus L., in the *Caryophyllaceae* family, is a group of herbaceous perennials originating from the Mediterranean area. When dianthus were first discovered in the wild, plants only flowered in early spring. Nowadays, annual dianthus cultivars are produced in greenhouses, and production is extended over several months to meet the high demand for use as cut flowers and bedding plants (Dole et al., 2005). In 2013, the total wholesale value of bedding and garden herbaceous perennials was estimated at \$1.96 billion (USDA-NASS, 2013). According to a 2009 USDA-NASS census, the

wholesale value of potted dianthus was estimated at \$17,156,000 (USDA-NASS, 2010). Dianthus require weekly fertilization of $150 \text{ mg} \cdot \text{L}^{-1}$ of 15N-5P-15K after establishment (Pan American Seed, n.d.). Conventional Pour-Thru method and tissue nitrogen (N) analysis are generally used in monitoring nutrient levels in dianthus (Whipker et al., 2001).

Nondestructive optical sensors are being investigated for nutrient monitoring instead of traditional destructive and time consuming methods. Three of the commonly used optical sensors available on the market are the GreenSeekerTM handheld sensor (Trimble Navigation LTD, CA), the soil plant analysis development (SPAD) meter (SPAD-502, Konica Minolta, Japan), and the atLEAF chlorophyll sensor (FT GREEN LLC, DE). The GreenSeekerTM handheld sensor measures normalized difference vegetation index (NDVI), and is nondestructive, affordable, and simple to use (Basyouni and Dunn, 2013). The NDVI values are measured by calculating the reflectance of high intensity light emitted by two electroluminescent diodes (LEDs) at 660 nm in red and at 770 nm in near infrared (NIR) wavebands (Basyouni and Dunn, 2013). Recent studies have shown a correlation between NDVI and leaf N concentration in field crops and trees, such as corn (*Zea mays* L.), wheat (*Triticum aestivum* L.) (Raun et al., 2005), and pecan (*Carya illinoensis* (Wang.) K. Koch) (Hardin et al., 2012). For greenhouse crops, NDVI has proven to correlate well with leaf N concentration for geranium (*Pelargonium ×hortorum* L.H. Bailey) (Wang et al., 2012a, 2012b) and cabbage (*Brassica oleracea* L.) (Dunn and Goad, 2015). No previous research has been conducted on the use of GreenSeekerTM NDVI sensor to assess N status in dianthus.

The SPAD meter is another handheld sensor commonly used to estimate the amount of chlorophyll present in a plant leaf through emitting light beams from two LEDs at two wavelength regions, red at 650 nm and NIR at 940 nm. The measured difference in absorbance is processed giving a value ranging between 0 and 99, and this value has been found to be proportional to the chlorophyll concentration in the leaf (Basyouni and Dunn, 2013; Uddling et al., 2007). Like the NDVI sensor, the SPAD meter has also shown to be correlated with leaf N content in multiple field crops, vegetables, and ornamentals like corn, wheat ‘Dragon’ and ‘Laanteve’, potato (*Solanum tuberosum* L., cv. Bintje), and silver birch (*Betula pendula* Roth) (Bullock et al., 1998; Uddling et al., 2007). In previous research, SPAD was used to measure dianthus chlorophyll degradation to maximize postharvest vase life (Kazemi et al., 2012; Seglie et al., 2011). The SPAD meter was also used to measure chlorophyll content in dianthus in response to different fertilizer rates (Shurberg et al., 2012). The atLEAF chlorophyll meter is a cheaper alternative to the SPAD chlorophyll meter (Zhu et al., 2012). Following the same principle as the SPAD meter, the atLEAF meter measures the absorbance of leaf chlorophyll in two photospectral regions, at red at 660 nm and NIR at 940 nm (Basyouni and Dunn, 2013). Zhu et al. (2012) showed that atLEAF readings were strongly correlated with the SPAD meter readings in five crop species: canola (*Brassica napus* L.), wheat, barley (*Hordeum vulgare* L.), potato, and corn. The atLEAF chlorophyll meter proved to correlate with poinsettia in greenhouse settings (Basyouni et al., 2015). No previous use has been reported for the atLEAF chlorophyll meter to assess nutrient status in dianthus. The objective of this experiment was to determine 1) efficiency of the GreenSeeker™ handheld NDVI sensor in estimating leaf chlorophyll and leaf N

concentration in potted dianthus, 2) correlation of the GreenSeekerTM NDVI sensor with other sensors available on the market, 3) and efficiency of fertilizer supplementation at the time of sensor sampling to determine if nutrient deficiencies could be corrected.

2. Materials and methods

2.1. Plant material and experimental setup.

Plugs of *Dianthus chinensis* 'TelstarTM White' and 'TelstarTM Red Picotee' were obtained from Park Seed Co. (Greenwood, SC) in 288 cell trays, then potted into standard 15.24 cm diameter and 1.35 L volume pots filled with about ~0.35 kg of Metro-Mix 902 media (Sun Gro Horticulture, Bellevue, WA). Each pot was planted with a single plug. Pots were irrigated with tap water through drip emitters, and were grown in the Department of Horticulture and Landscape Architecture Research Greenhouses at Stillwater, OK under natural photoperiods. Temperature was set at 22°C/17°C day/night with a natural light photosynthetic photon flux density (PPFD) range of 148-1136 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at 1200 HR.

2.2. Growth conditions.

On 7 August 2013, 400 plugs (three to five leaves) were received and put under mist until being transplanted into 15.24 cm diameter and 1.35 L volume pots 5 d later. A sample of the potting media and tap water were analyzed, and both showed a total N content of < 1 $\text{mg}\cdot\text{L}^{-1}$ dry mass (DM). On 5 September 2013, five different rates of CRF were added to the surface of the pots. Treatments were 0, 5, 10, 15 and 20 g of 15N-3.9P-10K (Osmocote® Plus 3-4 month Everris NA, Inc. Dublin, OH). Rates were selected based on previous years observation of plant responses to provide treatments that ranged from

deficient to excessive levels of fertilizer. Pots were drip irrigated with tap water at a rate that allowed media saturation and ~25% leaching. Irrigation frequency was determined by water evaporation rate from the pots in response to temperature and was approximated by checking the weight of the pots by hand every day. The average irrigation volume was 600 mL per irrigation per plant and average frequency was three irrigations per week. Electrical conductivity and pH were recorded weekly starting 11 days after planting (DAP) (Table S1). The experiment consisting of five treatments replicated 40 times with single pot replications with a total of 200 pots per cultivar. Treatments and cultivars were assigned to pots in a completely randomized design (CRD). At 49 DAP, plants were assessed and the 10 g treatment was considered to produce higher readings in height and width, and greater sensor readings. Therefore, the 10 g treatment was set as the optimum level to supplement to for the second part of the experiment to improve final plant quality and increase salability.

2.3. NDVI, SPAD, atLEAF, and N concentration determination.

After 31 DAP, on 12 September 2013 individual plants were assigned and scanned from 10 pots per treatment for NDVI, using the GreenSeekerTM handheld NDVI sensor, SPAD chlorophyll meter, and an atLEAF chlorophyll meter. Readings were taken for the assigned pots once a week for four consecutive weeks. During measurements, the NDVI sensor was held 61 cm above the plant canopy, giving an oval field of view with an area of 0.41 m². The SPAD readings were taken as an average of three different leaf readings located in the middle to upper level of the plant, and in the middle of the leaf excluding the midrib. Three atLEAF readings were taken from three different leaves located in the middle to upper level of the plant, and in the middle of the leaf excluding the midrib. To

assure that sensor readings and the foliar N concentration represent the same individual plant, 10 pots were randomly assigned and numbered for each treatment. Those pots were sensed weekly in the same order with leaves from two plants being sent to the lab for leaf N concentration analysis. Readings of the first three sensing date were ran in a statistical program designed to detect significant difference between the five different fertilizer rates (Data not shown). Leaf samples were analyzed for total-N concentration ($\text{g}\cdot\text{kg}^{-1}$ DM) by the Soil, Water and Forage Analytical Laboratory (SWFAL) at Oklahoma State University, using a LECO TruSpec Carbon and Nitrogen Analyzer (LECO Corporation, St. Joseph, MI).

2.4. Treatment correction growth conditions.

On 30 September, 2013, using the pots from the first experiment, the 0 g pots were supplemented with either 0 or 10 g 15N-9P-12K (where the 0 + 10 g correction treatment were referred to as C 0), and the 5 g pots were supplemented with 0 or 5 g 15N-9P-12K fertilizer applied on the surface of each pot (where the 5 + 5 g correction treatment were referred to as C 5). Pots were drip irrigated with tap water at a rate that allowed media saturation and ~25% leaching. The experiment consisting of seven treatments (0, C 0, 5, C 5, 10, 15 and 20 g, respectively) replicated 15 times with single pot replications with a total of 105 pots per cultivar. Fertilizer supplements were added to pots in a CRD.

2.5. Post treatment correction, NDVI, SPAD, and atLEAF values.

After fertilizer correction, individual plants were scanned from 10 pots per treatment for NDVI, SPAD, and atLEAF readings using the three sensors mentioned above at the same placement. On 25 October 2013, 74 DAP, plant quality was assessed by recording height (from the media to the highest point), width (average of two perpendicular

measurements), fresh weight (whole canopy was cut at media level and weighed immediately), and total number of flowers (only flowers fully opened were counted, no wilted or dead flowers were included).

2.6. Statistical analysis.

Data were analyzed using SAS® v9.3 software (SAS Institute, Cary, N.C.). The SAS/CORR procedure was used in the correlation analysis among sensor readings and leaf nitrogen. Sensor readings were analyzed using linear mixed model methods for repeated measures (SAS/GLIMMIX procedure). The least square means were used in the trend analysis of the nitrogen fertilizer rates 0, 5, 10, 15, and 20 (correction treatments excluded), to detect early separation among the five groups of fertilizer, to indicate the deficient nitrogen rates. For final plant assessment traits, means of 15 pots per nitrogen fertilizer rate were analyzed for height, width, and fresh weight response variables. These variables were analyzed using normal (or Gaussian) distribution methods. The number of flowers were analyzed using generalized linear model methods with a Poisson distribution. Means separations of significant effects were performed using the least significant difference method. All tests of significance were done at the 0.05 level.

3. Results

3.1. Effects of cultivars and fertilizer rate on NDVI, SPAD, atLEAF, and leaf N concentration values.

Sensors readings followed linear and quadratic trends as fertilizer rates increased and over time (Tables 1-3). With increasing N rate, the quadratic, and linear trends of NDVI, SPAD, atLEAF and leaf N concentration were significant. Comparing the corrected

treatments sensors readings to the control treatments readings in ‘TelstarTM Red Picotee’, the GreenSeekerTM NDVI showed no significant difference between corrected treatments (C 0 and C 5) compared to the deficient control treatments at 66 DAP (Figure 1). However, C 0 was significantly different from the 0 g control treatment in ‘TelstarTM White’ at 66 DAP. The SPAD meter showed a significant difference between both corrected treatments and deficient control treatments at 59 DAP, and only between C 0 and the 0 g deficient control treatment at 66 DAP in ‘TelstarTM Red Picotee’. As for ‘TelstarTM White’, the SPAD showed a significant difference only in C 0 and the 0 g deficient control treatment at both 59 and 66 DAP. Lastly, the atLEAF meter showed significant differences between C 0 and the 0 g deficient control treatment at 59 DAP, and between both corrected treatments and deficient control treatments at 66 DAP in ‘TelstarTM Red Picotee’. As for ‘TelstarTM White’, only C 0 showed a significant difference from the 0 g deficient control treatment at 59 and 66 DAP.

3.2. Relationship between NDVI, SPAD, atLEAF, and leaf N concentration values.

Sensor readings generally correlated better with fertilizer rate than with leaf N concentration (Table 4.). In ‘TelstarTM Red Picotee’, SPAD and atLEAF correlated significantly with fertilizer rate at all sensing dates. However, SPAD and atLEAF correlated with leaf N only at 38 and 52 DAP. All sensors correlated with fertilizer rate at 45 DAP, but only atLEAF correlated with leaf N on the same day. Later in sensing, at 52 DAP, all sensors correlated with fertilizer rate. All sensors correlated with others readings at all sensing dates with an exception at 31 DAP, where only SPAD and atLEAF were correlated. As for ‘TelstarTM White’, fertilizer rate correlated with all sensors all sensing dates. Leaf N concentration did not correlate significantly with any of the sensors readings at 31 DAP, but leaf N values were correlated with all sensors readings at 38 DAP, with the GreenSeekerTM NDVI only at 45 DAP, and with GreenSeekerTM NDVI and atLEAF at 52 DAP. Readings of the different N rates showed no significant separation when ran in SAS at 31 and 38 DAP. Visual quality was detected in biomass at 49 DAP, so correction treatment phase was started (Data not shown).

3.3. Effects of cultivar and fertilizer rate on plant assessment traits.

Plant final measurements values varied across different fertilizer rates (Table 5). For ‘Telstar™ Red Picotee’, only the 15 and 20 g treatments had the highest values for height, while the C 5, 10, 15 and 20 g treatments had the highest significant values in width. The C 5, 10, 15 and 20 g treatments had the highest values for fresh weight, and the 5, 10, 15 and 20 g treatments had the highest significant numbers of flowers. The C 0 treatment showed greater results than the 0 g control treatment in all assessment parameters except for number of flowers, which was the same. None of the C 0 treatment qualities were as good as the 10 g treatment. Meanwhile, the C 5 treatment had similar response to the 10 g treatments in all assessment parameters. As for ‘Telstar™ White’, the 5, C 5, 10, 15 and 20 g treatments had the highest values in height and width, while the 10, 15 and 20 g treatments had the highest significant numbers of flowers, and only the 15 and 20 g treatments had highest significant fresh weight. The C 0 showed higher values compared to the control treatment in width and fresh weight, and were not different than the 10 g treatment in height, and width. The C 5 treatment had similar significant values to the 10 g treatment in all assessment parameters.

4. Discussion

All sensor readings followed a positive quadratic and linear trends as fertilizer rates increased, which corresponds with similar findings in other ornamental crops like dianthus, vinca (*Catharanthus roseus* (L.) G. Don), zinnia, geranium, and poinsettia (Altland et al., 2002; Basyouni et al., 2015; Khan et al., 2004; Schuch et al., 1996; Smith

et al., 2004; Wang et al., 2012). The linear response in all sensors readings across treatments over time can be attributed to the increased nutrient release from the CRF granules with increased temperatures (temperature data not shown), and irrigation frequency (Tables 1-3). However, the quadratic responses could be explained by plant photosynthesis efficiency decreasing as plants aged, which led to readings plateauing in later sensing dates (Basyouni et al., 2015; Constable and Rawson, 1980). Also, data collection overlapped with plants anthesis, which interfered with the GreenSeekerTM NDVI values and decreased readings in later phases of establishment (Table 1) (Basyouni and Dunn, 2014; Basyouni et al., 2015; Shen et al., 2010). In addition, the flowering progress might have consumed leaf N, which decreased sensors readings at later stages (Lawrie and Wheeler, 1974). The quadratic trends across treatments within sampling dates could be explained by plants reaching maximum N capacity at higher fertilizer rates, which made differences in the sensors values between higher fertilizer rates smaller, leading to a plateau in sensors readings (Tables 1-3). When comparing correction treatments sensor readings to the deficient control treatments, the GreenSeekerTM did not show any significant improvement in the corrected treatments compared to the deficient control treatments in ‘TelstarTM Red Picotee’, and only showed a significant difference in C 0 at 59 and 66 DAP in ‘TelstarTM White’ (Figure 1). This could be attributed to the interference of flower colors with the NDVI readings at later stages of plant development (Basyouni and Dunn, 2014; Basyouni et al., 2015; Shen et al., 2010). As for the SPAD meter, the corrected treatments showed significant differences between corrected treatments and deficient control treatments at 59 and 66 DAP in both cultivars, indicating that the SPAD readings were more accurate as the

device measured individual leaves and was not affected by flowers color (Figure 1) (Basyouni and Dunn, 2014; Basyouni et al., 2015; Dunn and Goad, 2015). The atLEAF meter showed a significant difference in C 0 at 59 and 66 DAP in both cultivars, while C 5 was only different at 59 and 66 DAP in ‘TelstarTM Red Picotee’ (Figure 1). Similar to SPAD, atLEAF might have better detection of correction treatment improvement due to the devices mechanism of measuring individual leaves without being affected by flowers color. Visual separation in plant size was detected before any significant separation in the collected sensor readings, this can be attributed to the small unit range that the readings fell into for the specific species and cultivar which made it harder to separate treatments.

Sensor correlations with fertilizer rate and leaf N were not significant ($p < 0.05$) at 31 DAP, but increased on the following sensing dates in both cultivars (Table 4). This can be related to the small size of plants at early stages of establishment, which caused background noise to interfere with the NDVI readings (Basyouni and Dunn, 2014; Basyouni et al., 2015; Wang et al., 2012b). As plants grew and filled the pots with time, correlations between leaf N concentration and sensor readings was still poor. This corresponds with Altland et al. (2012) results on SPAD meter correlation with leaf N concentration in vinca. However, Wang et al. (2012) and Dunn et al. (2014) showed a strong correlation between GreenSeekerTM NDVI and SPAD meter readings, and leaf N content in geranium and ornamental cabbage. Difference in the correlation strength could be caused by leaf morphology and pigmentation, irrigation frequency and quantity, or environmental factors (Wang et al, 2012b).

Final plant height, width, fresh weight and number of flowers increased with increased fertilizer rates due to higher nutrient availability released from the CRF (Table 5), this was similar to previous literature findings in like dianthus, geranium, poinsettia, and zinnia (Basyouni et al., 2015; Ecke et al., 1990; Hardin et al., 2012; Khan et al., 2004; Schuch et al., 1996; Shurberg et al., 2012; Smith et al., 2004; Wang et al., 2012a, 2012b). For the C 0 treatment, final plant qualities improved in height, width, and fresh weight due to increased availability of nutrients that are released from the supplemented fertilizer. Plant assessment qualities for the C 5 treatment were not significantly different from the 5 g treatment in both cultivars. However, the 5 g treatment was significantly different to the 10 g treatment in fresh weight and number of flowers in ‘TelstarTM White’, and the correction treatment increased the C 5 treatment assessment height, width, and fresh weight values to be closer to the 10 g treatment values, indicating that dianthus are light fertilizer feeders, and that correction treatments can be marginally efficient whenever an initial amount of fertilizer was applied prior to correction. Number of flowers did not improve in any of the corrected treatments as no variations between the different rates of N for this specific trait were observed.

In conclusion, all sensors showed a poor correlation with leaf N concentration in early stages of establishment in dianthus. As plants grew, both SPAD and atLEAF chlorophyll meters correlated better than GreenSeekerTM NDVI with leaf N concentration and final plant assessment traits, as both have proven to be less affected by plant small size at early phases of establishment, and by bracts color change in later phase of establishment. Even though all sensors failed in separating nitrogen rates at early stages of development to detect deficiency and initiate correction treatment, the SPAD and atLEAF values in

weeks two and up after establishment can be compared to literature values as an indicator of the plant leaves N status. Sensors showed differences in readings among cultivars, which should be taken into consideration when applying a correcting treatment. For dianthus 'TelstarTM Red Picotee' and 'TelstarTM White', 10 g of 15N-9P-12K controlled release fertilizer is recommended for good final salability traits at an economical cost. The corrections applied to deficient treatments showed no improvement in the C 0 treatment, while the C 5 treatment had a marginal improvement indicating that a correction treatment could possibly help during dianthus production if an initial amount of fertilizer had been supplemented. Optical sensors have good potential to be used as an indirect indicator for plants N status, however, additional studies needed to be conducted on different cultivars and various scheduling for correction treatment application to provide fertilizer recommendation based on sensor readings. Further studies are suggested on adjusting the GreenSeekerTM by improving reflectance wavelengths formulas to account for canopy greenness only and avoid surrounding noise.

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Table 1. GreenSeeker™ NDVI means, standard deviation, and trend analysis on two dianthus cultivars at six dates of days after planting (DAP) and five 15N-3.9P-10K controlled release fertilizer rates for fall 2013 study, (n=10).

N rate (g)	31 DAP	38 DAP	45 DAP	52 DAP	59 DAP	66 DAP	
‘Telstar™ Red Picotee’							
0	0.335 ± 0.008	0.378 ± 0.011	0.374 ± 0.012	0.398 ± 0.014	0.381 ± 0.017	0.349 ± 0.019	L*** ^a
5	0.351 ± 0.008	0.431 ± 0.011	0.449 ± 0.012	0.513 ± 0.014	0.405 ± 0.017	0.426 ± 0.019	L*Q***
10	0.356 ± 0.008	0.434 ± 0.011	0.466 ± 0.012	0.490 ± 0.014	0.447 ± 0.017	0.397 ± 0.019	L***Q**
15	0.356 ± 0.008	0.436 ± 0.011	0.453 ± 0.012	0.527 ± 0.014	0.445 ± 0.017	0.408 ± 0.019	L**
20	0.344 ± 0.008	0.399 ± 0.011	0.430 ± 0.012	0.480 ± 0.014	0.420 ± 0.017	0.403 ± 0.019	L***
	L*Q*** ^b	Q***	L*	L***	NS	L*	
‘Telstar™ White’							
0	0.338 ± 0.008	0.377 ± 0.011	0.378 ± 0.012	0.416 ± 0.014	0.387 ± 0.017	0.378 ± 0.019	L***Q***
5	0.367 ± 0.008	0.449 ± 0.011	0.475 ± 0.012	0.532 ± 0.014	0.456 ± 0.017	0.394 ± 0.019	L**
10	0.345 ± 0.008	0.456 ± 0.011	0.477 ± 0.012	0.552 ± 0.014	0.485 ± 0.017	0.458 ± 0.019	L***
15	0.388 ± 0.008	0.469 ± 0.011	0.497 ± 0.012	0.568 ± 0.014	0.477 ± 0.017	0.457 ± 0.019	L*
20	0.385 ± 0.008	0.436 ± 0.011	0.473 ± 0.012	0.531 ± 0.014	0.482 ± 0.017	0.444 ± 0.019	L***
	L*Q***	Q***	L*	L***	NS	L*	

^a*, **, *** Linear (L), or quadratic (Q) response across treatments at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

^b*, **, *** Linear (L), or quadratic (Q) response within DAPs at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

Table 2. Soil plant analysis development (SPAD) chlorophyll meter means, standard deviation, and trend analysis on two dianthus cultivars at six dates of days after planting (DAP) and five 15N-3.9P-10K controlled release fertilizer rates for fall 2013 study, (n=10).

N rate (g)	31 DAP	38 DAP	45 DAP	52 DAP	59 DAP	66 DAP	
‘Telstar™ Red Picotee’							
0	52.9 ± 0.88	52.9 ± 1.02	52.0 ± 1.26	45.1 ± 1.30	45.6 ± 1.32	47.5 ± 1.25	L*** ^a
5	56.7 ± 0.88	57.7 ± 1.02	57.2 ± 1.26	59.3 ± 1.30	60.2 ± 1.32	63.2 ± 1.25	L*Q***
10	58.2 ± 0.88	59.8 ± 1.02	60.5 ± 1.26	59.9 ± 1.30	62.4 ± 1.32	64.1 ± 1.25	L***Q**
15	56.6 ± 0.88	58.6 ± 1.02	59.3 ± 1.26	60.7 ± 1.30	60.0 ± 1.32	64.2 ± 1.25	L**
20	58.4 ± 0.88	58.0 ± 1.02	61.5 ± 1.26	61.7 ± 1.30	64.2 ± 1.32	67.4 ± 1.25	L***
	L*Q*** ^b	Q***	L*	L***	NS	L*	
‘Telstar™ White’							
0	49.7 ± 0.88	50.1 ± 1.02	46.5 ± 1.26	43.9 ± 1.30	40.2 ± 1.32	40.5 ± 1.25	L***Q***
5	55.0 ± 0.88	56.4 ± 1.02	57.1 ± 1.26	55.9 ± 1.30	59.3 ± 1.32	60.3 ± 1.25	L**
10	53.9 ± 0.88	55.4 ± 1.02	57.4 ± 1.26	55.8 ± 1.30	58.6 ± 1.32	60.7 ± 1.25	L***
15	54.7 ± 0.88	57.4 ± 1.02	59.1 ± 1.26	59.8 ± 1.30	62.6 ± 1.32	65.2 ± 1.25	L*
20	55.5 ± 0.88	57.4 ± 1.02	58.8 ± 1.26	58.7 ± 1.30	61.5 ± 1.32	62.8 ± 1.25	L***
	L*Q***	Q***	L*	L***	NS	L*	

^a*, **, *** Linear (L), or quadratic (Q) response across treatments at P ≤ 0.05, P ≤ 0.01, or P ≤ 0.001, respectively.

^b*, **, *** Linear (L), or quadratic (Q) response within DAPs at P ≤ 0.05, P ≤ 0.01, or P ≤ 0.001, respectively.

Table 3. The atLEAF meter means, standard deviation, and trend analysis on two dianthus cultivars at six dates of days after planting (DAP) and five 15N-3.9P-10K controlled release fertilizer rates for fall 2013 study, (n=10).

N rate (g)	31 DAP	38 DAP	45 DAP	52 DAP	59 DAP	66 DAP	
'Telstar™ Red Picotee'							
0	52.9 ± 0.88	52.9 ± 1.02	52.0 ± 1.26	45.1 ± 1.30	45.6 ± 1.32	47.5 ± 1.26	L*** ^a
5	56.7 ± 0.88	57.7 ± 1.02	57.2 ± 1.26	59.3 ± 1.30	60.2 ± 1.32	63.2 ± 1.26	L*Q***
10	58.2 ± 0.88	59.8 ± 1.02	60.5 ± 1.26	59.9 ± 1.30	62.4 ± 1.32	64.1 ± 1.26	L***Q**
15	56.6 ± 0.88	58.6 ± 1.02	59.3 ± 1.26	60.7 ± 1.30	60.0 ± 1.32	64.2 ± 1.26	L**
20	58.4 ± 0.88	58.0 ± 1.02	61.5 ± 1.26	61.7 ± 1.30	64.2 ± 1.32	67.4 ± 1.26	L***
	L*Q*** ^b	Q***	L*	L***	NS	L*	
'Telstar™ White'							
0	49.7 ± 0.88	50.1 ± 1.02	46.5 ± 1.26	43.9 ± 1.30	40.2 ± 1.32	40.5 ± 1.25	L***Q***
5	55.0 ± 0.88	56.4 ± 1.02	57.1 ± 1.26	55.9 ± 1.30	59.3 ± 1.32	60.3 ± 1.25	L**
10	53.9 ± 0.88	55.4 ± 1.02	57.4 ± 1.26	55.8 ± 1.30	58.6 ± 1.32	60.7 ± 1.25	L***
15	54.7 ± 0.88	57.4 ± 1.02	59.1 ± 1.26	59.8 ± 1.30	62.6 ± 1.32	65.2 ± 1.25	L*
20	55.5 ± 0.88	57.4 ± 1.02	58.8 ± 1.26	58.7 ± 1.30	61.5 ± 1.32	62.8 ± 1.25	L***
	L*Q***	Q***	L*	L***	NS	L*	

^a*, **, *** Linear (L), or quadratic (Q) response across treatments at P ≤ 0.05, P ≤ 0.01, or P ≤ 0.001, respectively.

^b*, **, *** Linear (L), or quadratic (Q) response within DAPs at P ≤ 0.05, P ≤ 0.01, or P ≤ 0.001, respectively.

Table 4. Correlation coefficients between sensors readings and fertilizer rate with leaf N concentration for two dianthus cultivars measured at four dates of days after planting (DAP).

	NDVI ^a	SPAD	atLEAF	Leaf N %
‘TelstarTM Red Picotee’				
31 DAP				
Fertilizer rate	0.12	0.47** ^b	0.44**	0.89***
NDVI ^z		0.26	0.30*	0.57
SPAD			0.81***	0.49
atLEAF				0.31
38 DAP				
Fertilizer rate	0.16	0.39**	0.32*	0.570
NDVI		0.42**	0.32*	0.74*
SPAD		1.00	0.73***	0.64*
atLEAF				0.41
45 DAP				
Fertilizer rate	0.33*	0.56***	0.60***	0.83**
NDVI		0.40**	0.46***	0.12
SPAD			0.78***	0.54
atLEAF				0.68*
52 DAP				
Fertilizer rate	0.43**	0.66***	0.70***	0.83**
NDVI		0.52***	0.57***	0.61
SPAD			0.86***	0.91***
atLEAF				0.90***
‘TelstarTM White’				
31 DAP				
Fertilizer rate	0.54***	0.50***	0.32*	0.80**
NDVI		0.29*	0.35*	0.37
SPAD			0.58***	0.58
atLEAF				0.36
38 DAP				
Fertilizer rate	0.41**	0.56***	0.57***	0.73*
NDVI		0.53***	0.43**	0.79**
SPAD			0.75***	0.70*
atLeaf				0.66*
45 DAP				
Fertilizer rate	0.53***	0.66***	0.65***	0.86**
NDVI		0.66***	0.61***	0.84**
SPAD			0.90***	0.480
atLEAF				0.55

		52 DAP		
Fertilizer rate	0.53***	0.71***	0.78***	0.80**
NDVI		0.60***	0.66***	0.84**
SPAD			0.88***	0.31
atLEAF				0.87**

^aNDVI refers to the commercial GreenSeeker™ NDVI handheld sensor.

^b*, **, *** Representing correlation coefficient (r) significant at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$, respectively.

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Table 5. Final plant quality measurements for two dianthus cultivars to five nitrogen (N) rates, and two fertilizer correction treatments of 15N-3.9P-10K controlled release fertilizer at 74 days after planting (DAP) for fall 2013 study.

N rate (g)	Height (cm) ^a	Width (cm) ^a	Fresh weight (g) ^a	No. of flowers ^b
'Telstar™ Red Picotee'				
0	18.2e	17.9d	18.2d	9.4b
5	22.3bc	24.1bc	50.0b	31.1a
10	21.8bc	24.8ab	53.6ab	34.3a
15	23.9ab	27.5a	59.9a	39.3a
20	25.0a	26.0ab	55.6ab	33.4a
C 0 ^c	18.9d	21.6c	39.3c	12.9b
C 5 ^c	20.9cd	26.5ab	51.0ab	33.6a
'Telstar™ White'				
0	19.8c	18.4c	20.3e	8.3c
5	22.8ab	26.9ab	66.4cd	30.7b
10	23.9ab	28.2ab	78.2b	42.4a
15	24.3ab	29.1a	91.1a	36.6ab
20	25.3a	27.9ab	91.7a	41.6ab
C 0	21.6bc	26.3b	57.6d	10.7c
C 5	24.5a	27.9ab	75.5bc	31.8ab

^aMeans (n=10) are presented using Gaussian distribution. Mean separation within columns at $P \leq 0.05$. Means within a column in each cultivar with the same letter are not significantly different from one another.

^bMeans (n=10) are presented using Poisson distribution. Mean separation within columns at $P \leq 0.05$. Means within a column in each cultivar with the same letter are not significantly different from one another.

^cC 0, and C 5 represent fertilizer treatment correction 0 + 10 g, and 5 + 5 g, respectively.

A)

B)

C)

Figure 1. Fertilizer correction treatments response.

Note: The least significant means (LSM) values for deficient nitrogen (N) treatments (0 and 5 g) of 15N-9P-12K controlled release fertilizer compared to the correction treatments (C 0 and C 5) at several dates of days after planting (DAP) for dianthus 'Telstar™ Red Picotee' and 'Telstar™ White'. C 0 and C 5 represent correction treatments 0 + 10 g, and 5 + 5 g, respectively. A) Representing the GreenSeeker™ NDVI values, B) representing the SPAD meter values, and C) representing the atLEAF meter values.

*Overlapping standard error (SE) bars are not significantly different from one another. The SE was calculated at 95% confidence interval.