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Determining nitrogen fertility status using optical sensors in geranium with controlled release fertilizer

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Abstract

Greenhouse production of geraniums is popular for sales in the spring, and monitoring plant nutrition is important for high quality plants. The objective of this study was to evaluate if nondestructive handheld sensors could be used to quantify nitrogen (N) status in *Pelargonium* × *hortorum* 'Maverick Red' using controlled release fertilizer (CRF). Fertilizer treatments of 0, 4, 8, 10, or 12 g of 16N-9P-12K were topdressed on greenhouse grown plants. Individual plants were scanned from 10 pots per treatment for Normalized Difference Vegetative Index (NDVI) and Soil-Plant Analyses Development (SPAD) over eight different sampling dates starting 7 days after fertilizer treatment application (DAT). Height, width, number of flowers, number of umbels and leaf N concentration were also recorded. Linear and quadratic trends were seen for both NDVI and SPAD. Plant height and width was highest in the 12 g treatment, but was not different than the 8 g or 10 g treatments. Number of flowers was highest in the 10 g treatment, but was not different from the 8 g and 12 g treatments. Number of umbels was not significantly different among fertilizer treatments, but all were greater than the control. For all measurement dates, a correlation was seen for fertilizer rate and leaf N concentration. Neither sensor showed correlations with leaf N concentration at 7 DAT or 14 DAT; however, both were correlated with each other and leaf N concentration starting 28 DAT. Results from this study indicated that 8 g CRF produced the best quality plants. Both NDVI and SPAD can be used to predict N status in potted geraniums grown with CRF, but consistency in sample collection and sampling time may be necessary to correlate the values with N status.

Key words: *Pelargonium,* nutrition, plant growth, reflectance sensors, NDVI, SPAD, CRF

Introduction

Geraniums (*Pelargonium* sp. L.) are a large, diverse group of mostly evergreen perennial plants or shrubs used as bedding plants. Geraniums are typically grown under greenhouse conditions during the winter and spring seasons to meet the high demand of spring commercial markets (Wang *et al.,* 2012b). Fertilizer use is an integral part of greenhouse container production. Nutrient management practices should be targeted towards maintaining adequate nitrogen (N) in the root zone and minimizing leaching of nitrates below that zone (Evans *et al.,* 2007). Nitrogen deficiency will result in slow growth, stunting, and lower leaf chlorosis (yellowing) and abscission, while excess levels of N cause reduced plant growth and delayed flowering. Over-fertilization with N will also reduce profitability and may cause contamination of ground and surface water sources. Applying water soluble fertilizers has long been the preferred way to deliver nutrients to greenhouse crops (Hulme, 2011).

A study by Morvant *et al.* (2001) found that geraniums receiving 100% controlled release fertilizer (CRF) produced greater total dry weights, and released lower concentrations of NO_3-N, NH_4-N, and PO_4-P in run-off than plants receiving 100% constant liquid fertilizer (CLF). Cox (1985) also found that N retention in potting medium was greatest for CRF, while proportion of N not accounted for by analysis (lost as a gas) was greatest with urea for all N sources tested for seed geranium. Greenhouse growers have much more control over the indoor production environment compared to outside container nurseries; therefore CRFs are adapted well to greenhouse culture (Hulme, 2008).

Nitrogen nutrition requirement of ornamental plants may vary due to the diversity of species and cultivars, plant ages, and production systems (Demotes-Mainard *et al.,* 2008). Therefore, it is important to monitor plant N status over the production period. Monitoring N status based on leaf sampling and foliar analysis is time consuming, expensive, and destructive. A Soil-Plant Analyses Development (SPAD) chlorophyll meter is a hand-held, self-calibrating, and nondestructive device used to determine the amount of chlorophyll present in plant leaves in a rapid manner. This meter records optical density measurements at two wavelengths (650 and 940 nm), converting them into digital signals, and then into a SPAD value (Rodriguez and Miller, 2000). Chlorophyll content is usually strongly related to N concentration (Nelson *et al.,* 1986; Schepers *et al.,* 1992). Leaf N and SPAD readings were found to be strongly correlated for several horticultural crops (Westerveld *et al.,* 2003; Zanin and Sambo, 2006), varied within the growing season for others (Neilsen *et al.,* 1995), and was found to have a low correlation to others (Martín *et al.,* 2007).

Normalized Difference Vegetative Index (NDVI) has also been correlated with plant properties such as chlorophyll, N content, and N concentration (Jones *et al.,* 2007; Sembiring *et al.,* 1998). GreenSeeker™ technology has been widely used for mapping NDVI in a variety crops (Bronson *et al.,* 2005; Freeman *et al.,* 2007). GreenSeeker™ technology measures NDVI by using a self-illuminated (active sensor) light source, which directs visible (VIS) red light (660 nm) as well as near infrared (NIR) light (770 nm) at the plant canopy. The amount of VIS and NIR light reflected by the plant canopy is measured to calculate NDVI. The visible light reflectance is primarily dependent on the chlorophyll contained in the palisade layer of the leaf and the NIR reflectance depends on the structure of the mesophyll cells and the cavities between these cells. Thus, greater leaf area and green plant biomass levels result in higher reflectance and higher subsequent NDVI values, which can directly related to the N concentration of the plant (Shaver *et al.,* 2011). A smaller, more cost-effective prototype handheld pocket NDVI sensor was developed to provide similar readings as the original GreenSeeker™. The prototype NDVI pocket sensor can be used to quantify plant N status in a single plant or multiple green-leafed plants in a greenhouse setting during the vegetative stage. Wang *et al.* (2012a, 2012b) demonstrated in their study that a SPAD chlorophyll meter and a prototype pocket NDVI unit could be used as rapid, inexpensive tools to estimate geranium N status when fertigated with fluid urea or a combination of CRF and urea. The objective of this study was to test if the NDVI sensor and SPAD meter could be used as indicators of N deficiency for geranium 'Maverick Red' under normal production practice with only CRF.

Materials and methods

Plant material and growth conditions: On 6 March 2012, 288 cell tray plugs (2 to 4 leaves) of geranium (*Pelargonium* × *hortorum* L.H. Bailey) cultivar 'Maverick Red' were obtained from Park Seed Co. (Greenwood, SC). Plugs were transplanted into standard (15.2 cm diameter and 1.35 L volume) pots with ~0.35 kg Metro-Mix media (Sun Gro Horticulture, Bellevue, WA) the next day. A single plant was placed in each pot and plants were grown in the Department of Horticulture and Landscape Architecture Research Greenhouses at Stillwater, OK under natural photoperiods. Temperature was set at 18°C/21°C day/night with a photosynthetic photon flux density (PPFD) range of 450 to 1400 μmol m^{-2} s^{-1}at 1200 HR.

Plants were fertigated at each watering with 200 mg L^{-1} 20N-10P-20K (Jack's Professional® General Purpose acidic fertilizer, J.R. Peters Inc., Allentown, PA) during establishment. On 4 April, 2012, fertilizer treatments of 0, 4, 8, 10, or 12 g of 5-6 month 16N-9P-12K (Osmocote® Plus, The Scotts Co., Marysville, OH) were applied on the surface of each pot, and tap water was then used during irrigations. Pots were drip irrigated at a rate that allowed media saturation and ~20% leaching. Nitrogen treatments were designed to produce plants with N status ranging from deficient to excessive.

NDVI, SPAD, leaf N concentration, and plant growth: Individual plants were scanned from 10 pots per treatment for NDVI using a prototype NDVI pocket sensor (Crain *et al.,* 2012) and a SPAD chlorophyll meter (SPAD-502, Konica Minolta, Japan) every 7 days or 14 days starting 7 days after fertilizer application (DAT). Developing panicles were removed 30 DAT. During measurements, the NDVI sensor was placed 45 cm above the plant canopy, giving the sensor a circular field of view with a diameter of ~11.85 cm. For each pot, SPAD measurements were taken from four mature leaves from the middle to upper level of the plant. Leaf foliar analysis consisted of collecting the leaves used for the SPAD meter with 10 pots bulked per treatment for an average total N concentration per treatment each week. At the last rating date, measurements on plant height (taken from the top of the pot to the highest vegetative point), width (average of two perpendicular measurements), number of flowering umbels, and number of flowers were recorded.

Statistics: The experiment, consisting of five treatments was replicated 50 times with single pot replications, thereby giving a total of 500 pots. Pots were arranged in a completely randomized design (CRD). Continuous response variables of NDVI, SPAD, height, width, number of flowers, and number of umbels were analyzed using generalized linear mixed models methods. All tests of significance were performed at the (P < 0.05) level. When significant, N means were compared using post-hoc least significant difference (LSD) methods additionally and linear and quadratic trends in fertilizer rates and across time were evaluated for each response variable. Correlation analysis of fertilizer rate, NDVI, SPAD, and leaf N concentration was also computed. Data analysis was generated using SAS/STAT software, Version 9.3.

Results

NDVI, SPAD, and leaf N concentration: NDVI values ranged from 0.5 to 0.8 and increased with increasing N rates, in agreement with Wang *et al.* (2012a, 2012b) and Wang *et al.* (2004), except at 7 DAT (Table 1). This can be explained by lack of biomass differences or initial fertility status, as plants had sufficient nutrient fertility across all fertilizer rates. Shaver *et al.* (2010) also found no difference in NDVI readings among fertilized plants at the V8 growth stage in maize. At all other sampling dates, NDVI values were higher for plants receiving N fertilizer than for plants receiving no fertilizer (Table 1). As plants grew, NDVI was able to differentiate among fertilizer rates except at 21 DAT where treatments receiving fertilizer were not different (Table 1). Wang *et al.* (2012a) noted significant differences among urea rates at 19 DAT for *Pelargonium ×hortorum* 'Horizon Deep Red'

Table 1. Normalized Difference Vegetation Index (NDVI) values for geranium 'Maverick Red' with different controlled release fertilizer rates over eight sampling dates after fertilizer treatment (DAT)

Fertilizer rate (g)	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	56 DAT	70 DAT	
0	0.694a[z]	0.651d	0.666b	0.613d	0.640d	0.623d	0.585c	0.517d	L***[y]
4	0.743a	0.685cd	0.729a	0.706c	0.764bc	0.752bc	0.682b	0.684c	NS
8	0.684a	0.731bc	0.750a	0.765b	0.809ab	0.826a	0.741ab	0.770ab	L*Q**
10	0.687a	0.742ab	0.749a	0.785ab	0.811ab	0.839a	0.762ab	0.715bc	Q***
12	0.682a	0.785a	0.772a	0.830a	0.829a	0.810ab	0.815a	0.785a	L*Q**
	-	L***[x]	L***	L***	L***Q*	L***Q*	L**	L***	

[z]Mean separation within columns using Fisher's protected least significant difference ($P \leq 0.05$). Means (n=10) within a column with the same letter are not significantly different.

[y]NS,*, **, ***Linear (L) or quadratic (Q) response across weeks either not significant, $P \leq 0.05$, $P \leq 0.001$ or $P \leq 0.0001$, respectively.

[x]NS,*, **, ***Linear (L), or quadratic (Q), or cubic (C) response across treatments either not significant, $P \leq 0.05$, $P \leq 0.001$, or $P \leq 0.0001$, respectively.

and ‘Horizon Tangerine’. Differences may be attributed to CRF release rates and distribution or by cultivar differences. Nutrient release by CRF is dependent on soil temperatures (Rutten, 1980). Dunn *et al.* (2014) also noted no significant differences among CRF treatments for *Gaillardia aristata* Pursh ‘Arizona Apricot’ at 14 DAT, indicating that NDVI is more useful for discriminating among fertilizer treatments later in crop production. With increasing fertilizer rates, linear and quadratic trends were seen (Table 1). Martin *et al.* (2007) and Raun *et al.* (2005) also reported increasing NDVI values with maize growth stage until tasseling thereafter NDVI decreased due to the light scattering off of the tassel. Within sampling dates, linear trends were seen for 14, 21, 28, 56, and 70 DAT, while quadratic trends were seen for 35 and 42 DAT. This was consistent with Wang *et al*. (2012b) and Dunn *et al.* (2014) who also reported linear and quadratic trends in *P*. ‘Horizon Deep Red’ and ‘Horizon Tangerine’ and *G*. ‘Arizona Apricot’. Across sampling times, linear and quadratic trends were significant except for the 4 g fertilizer treatment. Dunn *et al.* (2014) also reported no significant trend for the same fertilizer treatment in *G*. ‘Arizona Apricot’ and attributed the difference to N utilization.

SPAD values ranged from 23 to 56 and increased progressively with N rates, in agreement with Dunn *et al.* (2014), Turner and Jund (1994), Piekielek and Fox (1992), Wang *et al.* (2012a; 2012b), and Zhu *et al.* (2012) (Table 2). At 7 DAT, the difference of SPAD values was not significant within the five N rates (Table 2). Dunn *et al.* (2014) also noted no significant differences among fertilizer rates at 7 DAT for *G*. ‘Arizona Apricot’, indicating that sensor reading are not able to differentiate among plants with surplus N early (7 DAT) in production. Locke *et al.* (2011) suggested that N fertilization can be skipped for up to eight days in geranium ‘Maverick Red’ without loss of foliar color indicating low nutrient needs initially. Starting 28 DAT, SPAD values were significantly higher for plants receiving N fertilizer than control plants. Linear and quadratic trends were seen within sampling dates except for 14 DAT. Dunn *et al.* (2014) also found a lack of trend at 14 DAT for G. ‘Arizona Apricot’, and suggested that plants still had sufficient nutrient fertility because of initial fertigation during establishment. SPAD values showed linear and quadratic trends across sampling dates except for the 12 g treatment, which may have been influenced by nutrient uptake and mobilization for structural growth.

Leaf N concentration ranged from 0.9 to 4.1% of dry leaf mass across all samples, and increased with increasing fertilizer rates across sampling dates except for 7 and 14 DAT where N levels plateaued at 8 g (Table 3). Mills and Jones, (1996) reported geranium foliar N sufficiency range to be 3.3% to 4.8%. At all N rates, leaf N concentration fell below the sufficiency range after 7 DAT. Leaching fraction and greenhouse temperatures can affect nutrient release and availability. Wang *et al*. (2012b) suggested that optimum fertilizer rate may vary in geranium depending on plant age, leaf type, irrigation practice, and growing period. Leaf N concentration decreased over time and the decrease become less pronounced with increasing N rate. Leaf N concentration at 0 g was lower than leaf N concentration on those dates for any other N treatments except at 14 DAT where the 4 g treatment was lower.

Plant height, plant width, number of umbels, and number of flowers: Plant height and number of flowers were higher for plants receiving fertilizer than the control except for the 4 g rate (Table 4). Plants receiving 12 g were taller and wider than those receiving lower rates, but were not significantly different from plants receiving 8 g or 10 g. Plant height and width at the highest fertilizer rate was 30 cm and 28.7 cm, respectively. This may be below their full potential as plant height and width of geranium ‘Maverick Red’ is reported to range in height from 41 to 46 cm and width from 36 to 46 cm (Ball Horticulture Company, 2013). However, plants receiving 10 g N rates had the greatest number of flowers among the N treatments of this study. Research conducted on perennial species in the landscape reported that while size may increase for some species at higher fertilization rates, increasing the fertilizer rate did not always result in increased plant quality (Chen *et al*., 2011; Shurberg *et al*., 2012). Number of umbels only differed between the control and 12 g N rate. There was a greater difference in the number of flowers between the plants receiving 10 g N and plants receiving 0 g or 4 g fertilizer. Results are

Table 2. Soil Plant Analysis Development (SPAD) values for geranium ‘Maverick Red’ with different controlled release fertilizer rates over eight sampling dates after fertilizer treatment (DAT)

Fertilizer rate (g)	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	56 DAT	70 DAT	
0	48.81a[z]	50.84b	47.41c	42.93c	39.00c	37.07c	31.31c	22.76d	L***[y]
4	49.13a	53.70ab	49.12bc	47.78b	45.55b	46.15ab	42.77b	33.75c	L***Q***
8	48.70a	51.76b	52.86ab	49.99ab	52.30a	47.55ab	45.14b	46.59ab	L**
10	49.90a	55.64a	53.16a	49.95ab	51.45ab	51.74a	49.66a	44.91b	L**
12	50.85a	53.41ab	50.68abc	54.01a	51.99a	46.53ab	48.46a	50.19ab	NS
	-	NS[x]	L**	L***	L**	L***	L***Q*	L***	

[z]Mean separation within columns using Fisher’s protected least significant difference ($P \leq 0.05$). Means (n=10) within a column with the same letter are not significantly different.

[y]NS,*, **, ***Linear (L) or quadratic (Q) response across weeks either not significant, $P \leq 0.05$, $P \leq 0.001$, or $P \leq 0.0001$, respectively.

[x]NS,*, **, ***Linear (L), or quadratic (Q), or cubic (C) response across treatments either not significant, $P \leq 0.05$, $P \leq 0.001$, or $P \leq 0.0001$, respectively.

Table 3. Leaf nitrogen concentration (g kg^{-1} DM) in geranium ‘Maverick Red’ at eight sampling dates after fertilizer treatment (DAT) using a controlled release fertilizer

Fertilizer rate (g)	7 DAT	14 DAT	21 DAT	28 DAT	35 DAT	42 DAT	56 DAT	70 DAT
0	34.9[z]	20.8	12.3	12.3	11.7	9.8	9.3	9.0
4	36.8	19.7	16.3	14.9	13.3	14.9	12.2	13.6
8	40.6	29.1	20.0	20.2	21.0	19.5	16.2	16.3
10	39.0	30.4	22.2	22.4	22.6	21.6	21.8	18.7
12	39.8	29.6	24.2	26.7	21.8	22.1	21.1	20.8

[z]Values are from combining five mature leaves and no petioles from each of 10 different pots per treatment for a single composite sample.

Table 4. Response of geranium 'Maverick Red' to five controlled release fertilizer rates 70 days after fertilizer treatment (DAT)

Fertilizer rate (g)	Height (cm)	Width (cm)	Number of umbels	Number of flowers
0	25.0c[z]	19.6b	0.6b	46.3c
4	27.4bc	21.6b	0.8ab	61.0bc
8	29.1ab	26.1a	1.2ab	69.8ab
10	28.2ab	25.8a	1.0ab	86.3a
12	30.1a	28.7a	1.2a	67.3ab

[z]The means (n=10) are presented. Mean separation within columns using Fisher's protected least significant difference ($P \leq 0.05$). Means within a column with the same letter are not significantly

consistent with the higher suggested application rate of 18 g per 3.8 L pot, and Morvant *et al*. (2001) used 10.65 g (Osmocote 14-14-14) for a 15-cm diameter pot with *Pelargonium* 'Pinto Red' as part of a fertilizer source and irrigation study. Wang *et al*. (2012a) reported much greater number of flowers and umbels in geranium using a combination of CRF and urea, though differences can be explained by sampling time and N sources.

Relationships between sensors, N rates, and leaf N concentration: There was a positive correlation between N fertilizer rates and leaf N concentration at all sampling dates (Table 5). Similar results were reported by Dunn *et al*. (2014) in *G*. 'Arizona Apricot'. Wang *et al*. (2012a, 2012b) reported correlations for N rate and leaf N for *P*. 'Rocky Mountain White', 'Rocky Mountain Dark Red', and 'Horizon Deep Red' but not for *P*. 'Horizon Tangerine', which indicates nutrient uptake and utilization is cultivar specific. Neither NDVI nor SPAD were correlated with leaf N concentration at 7 DAT and 14 DAT. Correlation between NDVI versus N rates was significant starting at 14 DAT, while the correlation between NDVI and leaf N concentration became significant after 21 DAT. Readings of SPAD were significantly correlated with N rates and leaf N concentration starting at 28 DAT. Correlations between NDVI versus leaf N concentration and SPAD versus leaf N concentration were not significant at 35 DAT and 42 DAT, respectively. This period corresponds to flowering and indicated both sensors are less correlated to leaf N around flowering. Dunn *et al*. (2014) indicated that sampling date and ultimately growth stage affects correlation of NDVI and SPAD with leaf N.

The relationship between leaf N concentration and NDVI with sampling dates combined was not significant ($P < 0.05$) and the relationship between leaf N concentration and SPAD with sampling dates combined was weakly significant ($r = 0.593$) suggesting that the SPAD meter was more accurate for nondestructive N monitoring. However, the high correlation coefficient between leaf N concentration and the NDVI sensor and SPAD meter measurements at the later growth stages, *i.e.*, NDVI ($r = 0.903$ to 0.964 from 21 DAT except at 35 DAT) and SPAD ($r = 0.913$ to 0.962 from 28 DAT except at 42 DAT) suggested that both could be used to monitor N status depending on growth stage. Future research should look to optimize sensor readings earlier in production, evaluate different sensors, and determine if sensor reading can lead to fertilizer application recommendations. Although this study was not designed to determine optimum CRF application, in this study 8 g would be recommended. To develop fertilization guidelines, further research is needed evaluating different production practices and additional cultivars.

Table 5. Correlation coefficients for measured sensor parameters, fertilizer rates, and leaf N concentration for geranium 'Maverick Red'

	NDVI	SPAD	Leaf N ($g \cdot kg^{-1}$DM)
		7DAT	
Fertilizer rate (g)	-0.478	0.756	0.892*[z]
NDVI		-0.317	-0.492
SPAD			0.402
		14 DAT	
Fertilizer rate (g)	0.988**	0.609	0.892*
NDVI		0.511	0.872
SPAD			0.414
		21 DAT	
Fertilizer rate (g)	0.949*	0.787	0.999***
NDVI		0.760	0.947*
SPAD			0.778
		28 DAT	
Fertilizer rate (g)	0.992***	0.963**	0.983**
NDVI		0.984**	0.964**
SPAD			0.951*
		35 DAT	
Fertilizer rate (g)	0.936*	0.944*	0.947*
NDVI		0.974**	0.868
SPAD			0.942*
		42 DAT	
Fertilizer rate (g)	0.906*	0.805	0.990**
NDVI		0.953*	0.954*
SPAD			0.874
		56 DAT	
Fertilizer rate (g)	0.992***	0.939*	0.966**
NDVI		0.948*	0.931*
SPAD			0.913*
		70 DAT	
Fertilizer rate (g)	0.903*	0.974**	0.996***
NDVI		0.963**	0.903*
SPAD			0.962**

[z]Representing Pearson's correlation coefficient (r). *, **, *** significance at $P \leq 0.05$, $P \leq 0.01$, or $P \leq 0.001$ level, respectively.

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