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Influence of Nitrogen Fertilization Rates on the Performance of Strawberry Cultivars

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*Two sets of studies were conducted to examine the response of "Strawberry Festival" and "Winter Dawn" strawberries (*Fragaria x ananassa *Duch.) to different nitrogen (N) rates. The first set of studies consisted of two trials conducted during the 2005–06 and 2006–07 growing seasons. N rates were 0.5, 0.7, and 0.9 kg/ha per day (75, 105, and 135 kg/ha per season). The second set of studies was conducted during the 2006–07 and 2007–08 growing seasons. Nitrogen rates were 0.9, 1.4, and 2.0 kg/ha per day (75, 210, and 300 kg/ha per season) using the same cultivars. During the first set of studies, canopies of "Strawberry Festival" were 30% and 10% wider than "Winter Dawn" at 6 and 12 weeks, whereas N rates linearly increased canopy diameters of both cultivars. There was a significant cultivar by N rate interaction for total marketable fruit weight. Increasing N rates from 0.5 to 0.9 kg/ha per day linearly improved total marketable fruit weights of "Strawberry Festival," but not those of "Winter Dawn." For the second set of studies, N rates only influenced strawberry plant canopy diameters, but not early and total marketable fruit weight and number. There were no differences between the total marketable fruit weights of both cultivars. The data showed that the response of different strawberry cultivars depends on the range of N rates used for fertilization.*

KEYWORDS Fragaria x ananassa*, best management practices, crop nutrition, soil fertility, nitrate leaching, Strawberry Festival, Winter Dawn*

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INTRODUCTION

Strawberry is one of the most important small fruit crops throughout the world. Major planting areas occur in North America, Mediterranean Europe, Southwest Asia, and Australia. Some of the leading producing countries are the United States, Spain, and Canada with annual planting areas of about 22,000, 6,720, and 3,380 ha, respectively (Food and Agriculture Organization of the United Nations, 2008). In the United States, California, and Florida have the largest production values, which generated in 2007 about $1,340 and $330 million, respectively (U.S. Department of Agriculture, 2008). In both states, most of the acreage is established under the annual hill system, in which raised planting beds are fumigated for soilborne pest control and covered with polyethylene mulch. One or two drip lines per bed provide irrigation and fertilization according to local growing conditions, soil texture, water holding capacity, and cultivar requirements.

In Florida, the majority of the strawberry production occurs in the west central part of the state, where sandy soils with rapid infiltration and high water tables are the norm. The nutrient leaching potential is relatively high in these soils, which has important environmental and crop production implications. From the environmental standpoint, nitrate leaching to ground water and phosphate run-off are the main causes for eutrophication of rivers and lakes and subsequent changes in aquatic life (Finkl and Charlier, 2003; Florida Department of Environmental Protection, 2008; Florida Springs Task Force, 2000). In many bodies of water across Florida, nitrate levels have increased two to threefold over the past 20 years, reflecting the close link between surface and ground water (Florida Department of Environmental Protection, 2008). One of the main sources of nitrates\ in ground water is agricultural fertilizers. Therefore, reducing nutrient leaching through appropriate fertilization programs is a desired practice for strawberry production and to support the current best management practice efforts in the state. From the crop production standpoint, fertilizer prices have steadily increased during the last few years as a result of higher worldwide oil prices and transportation costs. This situation forces strawberry growers to seek more effective ways to save on fertilizer costs.

Previous research has focused on determining the effects of increasing N rates on diverse cultivars of fruit crop species. Williamson and Miller (2009), examining two blueberry (*Vaccinium corymbosum* L.) cultivars and N fertilization rates between 48 and 81 g/plant per season, found that there was no significant cultivar and N fertilizer interaction for seasonal yields, but fruit yields increased linearly with N rates. Bell et al. (1979) determined that a N fertilization rate of 114 kg/ha improved fermentation rates, concentration of esters, and wine quality of grape (*Vitis vinifera* L.) in comparison with lower N rates. In apple (*Malus domestica* Borkh.) orchards, Rease and Drake (1997) found that fruit weight increased with N rates from 28 to

170 kg/ha, but the opposite trend was observed for fruit quality characteristics, such as fruit color, firmness, soluble solid concentration, and fructose levels. Other studies with raspberry (*Rubus idaeus* L.) determined that a N rate of 120 kg/ha per season was more favorable than 60 kg/ha for fruit yields (Koszanski and Rumasz-Rudnicka, 2008), while Quezada et al. (2007) indicated that a single fertilization rate of 100 kg/ha was more beneficial for marketable fruit yields than lower N rates.

Studies with strawberry have shown the diversity of responses to changing N rates and time of application. In Mexico, N fertilization is often in excess of 597 kg/ha during the strawberry production cycle, which is two and a half times as much as the local recommendation (Cardenas-Navarro et al., 2004). In Argentina, Gariglio et al. (2000) demonstrated that 'Chandler' strawberry fruit weight and number increased with N rates up to 53 lb/acre, but no further yield increase was observed with higher N rates. A similar response was described in Canada by Lamarre and Lareau (1997), where there were no effects on 'Tribute' strawberry yields and fruit size with the application of either 50 or 100 kg/ha of N. Other studies have shown little impact of preplant N rates on strawberry early and total yields (Albregts et al., 1991; Santos and Whidden, 2007). Other crop responses can also be affected by N fertilization rates. For instance, Makkun et al. (2001) showed that a N rate of 225 kg/ha improved fruit firmness during 21 d of storage, compared to lower N rates, such as 150 kg/ha. Higher N rates increased fruit acidity and reduced sugar content.

Strawberry breeding plays a major role on the response of specific genotypes to N fertilization practices. Fruit earliness and rain-damage tolerance, total fruit yield, disease and insect resistance, flavor, and postharvest quality are among the most important traits for breeding cultivars. However, when breeding for specific traits, variations on nutritional requirements may occur, thus leading to modified fertilization practices. Two of the most commonly planted strawberry cultivars in west central Florida are 'Strawberry Festival' and 'Winter Dawn,' which possess completely different plant architectures and likely N requirements for growth and development. 'Strawberry Festival' produces high early yields and possesses a plant with large aerial biomass and deep tap root. This short-day cultivar originated from a cross between 'Rosa Linda' and 'Oso Grande,' and has a mild susceptibility to a variety of foliar and fruit diseases, such as botrytis fruit rot (caused by *Botrytis cinerea* Pers. ex Fr.) and powdery mildew (caused by *Sphaerotheca macularis* [Wallr. ex Fr.] Jacz. f. sp. *fragariae*; Chandler et al., 2000). 'Winter Dawn' is a relatively small plant with shallow root system with high early yields and is moderately resistant to botrytis fruit rot and anthracnose fruit rot (caused by *Colletotrichum acutatum* Simm.; Chandler, 2005). It is a common practice among growers planting more than one strawberry cultivar to overlap fruiting peaks, thus ensuring a steady fruit supply from December to March. If diverse cultivars had significantly different nutritional requirements, fertilization rates might need to be adjusted for each cultivar. Simonne et al. (2001) determined that there was significant cultivar by N rate interaction for marketable fruit weight of 'Camarosa' and 'Sweet Charlie' strawberries, with varying response of both cultivars throughout the season to N rates from 0.57 to 1.14 kg/ha per day. Variations on plant size, stolon and ramet production, and N distribution between parent and ramets of strawberry genotypes as the result of changing N rates have been established (Tworkoski et al., 2001).

The current N recommendation for strawberry production in Florida is for daily injections between 0.34 and 0.85 kg/ha per day, depending on the phenological stage of the crop, with a maximum of 170 kg/ha of N during the season (Hochmuth and Albregts, 1994; Hochmuth et al., 1996). This recommendation does not discriminate among cultivars. Furthermore, recent informal surveys among strawberry growers reflected that the most frequent N rates are between 1.14 and 1.70 kg/ha per day during the fruiting months of December, January, and February, regardless of the planted cultivar. This discrepancy between actual N application rates and current recommendations must be addressed across cultivars to contribute to the sustainable production of the crop and minimize the nitrate leaching potential. Therefore, the objective of this study was to determine whether there is differential growth and yield response of two strawberry cultivars to N rates.

MATERIALS AND METHODS

This research included of two separate sets of studies conducted between 2005 and 2007, and between 2006 and 2008 at the Gulf Coast Research and Education Center of the University of Florida, located in Balm, Florida. The soil at the experimental site is classified as a Myakka fine sand siliceous, hyperthermic, Oxyaquic Alorthod. The organic matter content and the soil pH of the experimental site were 1.5% and 7.3, respectively, and were measured 4 weeks before transplanting. Planting beds were 69 cm wide at the base, 61 cm wide at the top, 25 cm high, and spaced 1.22 m apart on centers. Finished beds were fumigated with methyl bromide plus chloropicrin (67:33 v/v) at a rate of 398 kg/ha to eliminate soilborne diseases, nematodes, and weeds in the soil. Simultaneously, beds were covered with black high-density polyethylene mulch (0.025 mm-thick), and a single line of drip irrigation tubing (237 L/ha per min; T-Tape Systems International, San Diego, CA) was buried 2.5 inch deep on bed centers. Plant nutrients other than N were supplied to the crop through the drip lines following statewide recommendations (Peres et al., 2006).

The first set of studies consisted of two trials conducted during the 2005–06 and 2006–07 growing seasons. Planting dates during each respective season were 12 October and 11 October. Bare-root transplants from certified nurseries in Nova Scotia, Canada were established 38 cm apart in double rows. Sprinkler irrigation was used 8 hours per day for 10 days to establish the transplants. Strawberry cultivars were ‘Strawberry Festival’ and ‘Winter Dawn,’ whereas N rates were 0.5, 0.7, and 0.9 kg/ha per day (75, 105, and 135 kg/ha per season). Calcium nitrate (9% N) was used as the N source for fertilization with a hydraulic injector (Dosatron, Clearwater, Fla.). The second set of studies consisted of two trials conducted during the 2006–07 and 2007–08 growing seasons. The location, bed preparation, soil fumigation, and establishment and production practices were similar to those previously described. N rates were 0.9, 1.4, and 2.0 kg/ha per day (75, 210, and 300 kg/ha per season). ‘Strawberry Festival’ and ‘Winter Dawn’ strawberry cultivars were transplanted on October 11 and October 14 of each season.

During all the seasons, treatments were established in a split-plot design with six replications, where N rates were the main plots and cultivars the subplots. Experimental units were 7.6 m long (40 plants per plot). Strawberry canopy plant diameters were measured perpendicular to the direction of the rows at 6 and 12 weeks after transplanting (WAT), using the 2nd, 5th, 8th, 11th, and 14th plants of the east row of each experimental unit. Early and total marketable fruit weights were collected starting at 10 WAT using every plant of each plot. Early marketable fruit weight was defined as the total marketable fruit of the first 10 harvests, whereas total marketable fruit weight consisted of 22 harvests during each season. Fruit were harvested Mondays and Thursdays of each week for 11 weeks, starting on the third week in December of each season. A marketable fruit was defined as a fruit without visible blemishes and with at least 75% of red skin. Petiole sap samples were extracted from between 10 to 15 mature petioles collected from recently open mature leaves and measured for NO_3-N concentrations with a nitrate-ion analyzer (Horiba Group, Kyoto, Japan). Main effects and interactions were examined for significance ($P < 0.05$) with the general linear model and regression analysis was used to determine linear effects of the N rates. Cultivar means were compared with a Fisher’s protected least significance difference (LSD) test at the 5% significance level.

RESULTS AND DISCUSSION

2005–07 Seasons

There were no significant season by treatment interactions for all examined variables, thus data from the two seasons were combined for analysis. Strawberry plant canopy diameters at 6 and 12 WAT were significantly affected by both cultivars and N rates, but not by the interaction between both factors (Table 1). Experimental units planted with ‘Strawberry Festival’ had 30% and 10% wider canopies than ‘Winter Dawn’ at 6 and 12 WAT,

TABLE 1 Effects of N Rates on Plant Canopy Diameter at 6 and 12 Weeks after Transplanting (WAT), Early and Total Marketable Fruit Weight, and Marketable and Non-Marketable Fruit Number of Strawberry Cultivars. Balm, FL, 2005–07

	Plant canopy diameter		Marketable fruit number		Nonmarketable fruit number	
	6 WAT	12 WAT	Early	Total	Early	Total
Cultivars	cm		no. × 10^3/ha		no. × 10^3/ha	
Strawberry Festival	23.4 a	15.1 a	682.5 a	1726.0 a	138.5	378.0
Winter Dawn	18.0 b	13.7 b	578.3 b	1537.5 b	125.5	372.0
P values	0.0001	0.0001	0.0003	0.0001	0.1589	0.2586
N rates kg/ha per day						
0.5	18.5	33.5	593.5	1530.5	130.8	372.3
0.7	21.1	36.8	623.0	1626.8	128.8	378.3
0.9	23.4	38.9	674.8	1738.0	136.5	374.5
P values for L regression	0.0002	0.0001	0.0058	0.0086	0.1628	0.1896

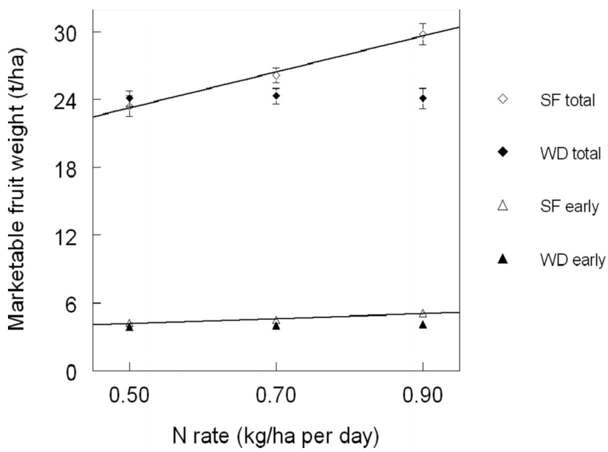

FIGURE 1 Influence of N rates on 'Strawberry Festival' (SF) and 'Winter Dawn' (WD) early and total marketable fruit weight. Balm, FL, 2005–07. N rates were 0.5, 0.7, and 0.9 kg/ha per day (75, 105, and 135 kg/ha per season). Significant linear regression equations for 'Strawberry Festival' early and total marketable fruit weights were y = 3.03 + 2.25x, r^2 = 0.97 and y = 15.31 + 15.90x, r^2 = 0.98, respectively. Vertical bars represent the SE of the mean.

respectively. Canopy diameter at 6 and 12 WAT increased linearly as N rates increased from 0.5 to 0.9 kg/ha per day.

There was a significant cultivar by N rate interaction for total marketable fruit weight (Fig. 1). Early marketable fruit weight of 'Strawberry Festival' improved linearly from approximately 9.5 to 11.6 t/ha as N rates increased from 0.5 to 0.9 kg/ha per day. Similarly, raising N rates from 0.5 to 0.9 kg/ha per day increased linearly total marketable fruit weights of 'Strawberry Festival' from 23.2 to 29.5 t/ha. In contrast, 'Winter Dawn' early and total fruit weights remained unchanged with different N rates, averaging approximately 9.1 and 24.5 t/ha, respectively. The response of petiole sap NO_3-N concentrations at 16 WAT was affected by the interaction between N rates and cultivars (data not shown). NO_3-N concentrations in petioles of 'Strawberry Festival' increased linearly from 320 to 460 ppm as N rates increased from 0.5 to 0.9 kg/ha per day, while there was no change in NO_3-N concentrations in petioles of 'Winter Dawn,' which averaged 380 ppm.

Values for early and total marketable fruit number were influenced by the cultivars and the N rates, but not by the interaction between both factors (Table 1). 'Strawberry Festival' had 18% and 12% higher early and total marketable fruit numbers than 'Winter Dawn.' There were positive linear responses on the early and total marketable fruit numbers as N rates increased from 0.5 to 0.9 kg/ha per day, representing about 13.7% and 13.6% more early and late marketable fruit with the highest N rate than with the lowest. The amounts of nonmarketable fruit were not affected by either factor or by the interaction between both factors.

2006–08 Seasons

There were no significant season by treatment interactions for strawberry plant canopy diameter, early and total marketable fruit weight and number, and early and total nonmarketable fruit number. Therefore, data from the two seasons were combined for analysis. Strawberry plant canopy diameters at 6 and 12 WAT were influenced by the cultivars. 'Strawberry Festival' had the widest plant canopies (23.9 and 38.1 cm, respectively) in comparison to 'Winter Dawn' (Table 2). N rates did not affect strawberry plant canopy

TABLE 2 Effects of N rates on plant canopy diameter at 6 and 12 weeks after transplanting (WAT), Early and total marketable fruit weight, and marketable and nonmarketable fruit number of strawberry cultivars. balm, FL. 2006–08

	Plant canopy diameter		Marketable fruit weight		Marketable fruit number		Nonmarketable fruit number	
	6 WAT	12 WAT	Early	Total	Early	Total	Early	Total
Cultivars	cm		t/ha		no. × 10^3/ha		no. × 10^3/ha	
Strawberry Festival	23.9 a	38.1 a	12.5 a	34.1	884.3 a	2170.0 a	298.8 a	610.3 b
Winter Dawn	18.3 b	35.1 b	10.0 b	31.6	592.8 b	1823.5 b	219.0 b	730.3 a
P values	0.0001	0.0008	0.0001	0.0981	0.0001	0.0006	0.0007	0.0001
N rates kg/ha per day								
0.9	20.8	34.5	11.4	31.1	742.3	1922.8	250.5	698.5
1.4	21.1	36.3	11.1	33.0	738.3	2021.8	259.3	696.5
2.0	21.3	39.1	11.4	34.3	735.0	2045.8	266.8	615.8
P values for L regression	0.1689	0.0001	0.2356	0.1478	0.2567	0.1045	0.2687	0.1640

diameters at 6 WAT. However, canopy diameters increased linearly at 12 WAT from 34.5 to 39.1 cm as N rates changed from 0.9 to 2.0 kg/ha per day.

Early marketable fruit weight was affected by cultivars, but not by the N rates (Table 2). 'Strawberry Festival' produced 12.5 t/ha of fruit during the early harvests, which was 25% higher than the early marketable yield of 'Winter Dawn' (4.4 ton/acre). Strawberry early marketable fruit yields ranged between 11.1 and 11.4 t/ha, regardless of the application of N rates. Total marketable fruit weight was not influenced by cultivars, N rates, or the interaction between both factors. Average marketable fruit weights of 'Strawberry Festival' and 'Winter Dawn' were 34.1 and 31.6 t/ha, respectively, which were not significantly different (Table 2). Similarly, total marketable fruit weights averaged 32.7 t/ha with N rates ranging between 0.9 to 2.0 kg/ha per day.

Marketable fruit numbers for early and total harvests were only affected by the planted cultivars, whereas there was no effect of either N rates or the interaction between both factors. 'Strawberry Festival' had 49% and 19% higher counts of early and total marketable fruit, respectively, in comparison with plots planted with 'Winter Dawn' (Table 2). The number of nonmarketable fruit in early harvests followed the same trend as that for early marketable fruit number, with the highest nonmarketable number in plots planted with 'Strawberry Festival.' The opposite was true for total nonmarketable fruit number, with 'Winter Dawn' having approximately 20% more than 'Strawberry Festival.'

Based on these two studies, it was evident that the response of different strawberry cultivars depends on the range of N rates used for fertilization. When N rates ranged between 0.5 and 0.9 kg/ha per day, plots planted with 'Strawberry Festival' improved linearly their marketable fruit weights as N rates increased, which did not occurred in plots planted with 'Winter Dawn.' This differential performance could be explained by the morphological differences between these two cultivars. As reflected by the plant diameter data, 'Strawberry Festival' produces a vigorous wide plant with a deep and profuse rooting system, whereas 'Winter Dawn' is a considerably smaller plant, which suggests that the former cultivar may require higher N rates (0.9 kg/ha per day) than 'Winter Dawn' to satisfy its nutritional requirements for growth and development. These results agree with those presented by Simonne et al. (2001) and Tworkoski et al. (2001), who established that N rates have major influence on yields and vegetative biomass distribution of different strawberry genotypes. On the other hand, when applied N rates were between 0.9 to 2.0 kg/ha per day, there was no significant marketable yield change in both cultivars, which indicated that N rates of 0.9 kg/ha per day or less would be sufficient to produce both cultivars.

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