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Yield and Quality of Greenhouse-grown Strawberries as Affected by Nitrogen Level in Coco Coir and Pine Bark Media

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Greenhouse-grown strawberries (*Fragaria ×ananassa* Duch.) are a new crop for the United States and Mexico. The present study was conducted to determine the nitrogen (N) requirements for strawberries produced in soilless media in a passively ventilated greenhouse. Two soilless media: 1) pine bark and 2) coconut coir, and four N levels in the nutrient solution: 40, 80, 120, and 160 mg·L^{-1} N, were evaluated in a factorial designed experiment. Plants grown at a density of 21 plants/m^2 received a complete nutrient solution at every irrigation event, the only variation being the level of N in each treatment. Increasing N level in the nutrient solution significantly increased the number of runners. Neither early nor total marketable yields were significantly affected by N level or media. Increasing N level in the nutrient solution significantly decreased fruit-soluble solids on two of the three sampling dates. Higher values of soluble solids occurred during the cooler months of the season. The soluble solids content in the fruit was reduced as the temperature increased. Thus, N levels as low as 40 to 80 mg·L^{-1} N in a constant fertigation system can be used to produce strawberries in either coconut coir or pine bark media in a greenhouse environment.

Strawberries are generally grown in soil in many countries worldwide. In temperate regions such as northern and central Europe, Korea, Japan, and some areas of China, strawberries are grown in greenhouses under soilless cultivation. In Holland, strawberries are grown in glasshouses, with climate and irrigation control, and CO_2 supply. In other countries, strawberries are grown in polyethylene-covered greenhouses, including micro or macro tunnels, using a variety of growing containers and soilless media. Greenhouse production of strawberry has the advantage of increased yield per unit area, early production when market prices are high, relatively easier pest management with reduced use of chemicals, as well as better fruit quality (Dinar, 2003).

Soilless media are free of weed seeds, have a lower risk of incidence of root pathogens, and facilitate optimal nutrition management of the crop. Management technology of strawberry under greenhouse conditions, like cultivar selection, seedling preparation, growing system, population density, and integrated pest management, has been developed in central Florida to attain marketable yields of 350 to 450 g per plant (7 to 9 kg·m^{-2}) with population densities of 20 plants/m^2 (Paranjpe et al., 2003a). Studies indicate that field-grown (Hochmuth and Albregts, 1994) and greenhouse-grown (Papadopoulos, 1987) strawberries require low N input. Although there is a great deal of information regarding optimum concentrations of nutrients under hydroponic conditions for a number of horticultural crops, very little information has been generated for strawberries and there are few reports on the response of strawberry to N under soilless conditions.

Pine bark used as a soilless media has been physically characterized (Svenson and Witte, 1987), and has performed well in ornamental crops (Tilt and Bilderback, 1983) and in strawberry under soilless conditions (Paranjpe et al., 2003a). Pine bark is less expensive than other soilless media, such as perlite or peat-moss (Paranjpe et al., 2003b), and is readily available in the United States and in many other countries. On the other hand, coconut coir is also an inexpensive soilless media, abundantly available in Mexico, and is recently gaining popularity and accessibility in the United States as well as many other countries. Coconut coir has been characterized in terms of physical properties with good water retention capacity and aeration characteristics (Abad et al., 2002; Fornes et al., 2003; Noguera et al., 2003), and has performed better as compared to other media in ornamental crops (Stamps and Evans, 1997). Even though coconut coir has been used for the commercial production of strawberries in Israel (Dinar, 2003) and Spain, there are few scientific reports evaluating the effect of this media on yield and fruit quality of this crop.

The objective of this study was to determine the effect of different N levels on yield and fruit quality of strawberries grown in either pine bark or coconut coir.

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Materials and Methods

The study was conducted from 1 Oct. 2003 to 29 Mar. 2004, at the Protected Agriculture Project, University of Florida, IFAS, Plant Science Research and Education Unit located near Citra, FL, in a passively ventilated greenhouse with a 4.5-m height to the base of the arch. The maximum and minimum temperatures in the greenhouse during the experiment are presented (Fig. 1). Average maximum temperatures for the months of November to March were 32, 28, 29, 32 and 36 °C; and the minimum temperatures were 15, 9, 9, 13, and 13 °C.

Ten-week-old greenhouse plugs of the cultivar Strawberry Festival (Chandler et al., 2000) were produced in a fan-pad cooled greenhouse located in Gainesville, FL. The plugs received a 2-week conditioning treatment in a walk-in growth chamber (25 °C day/15 °C night, 9-h photoperiod) prior to planting in the greenhouse (Paranjpe, 2004). A total of eight treatments consisting of two soilless media: 1) pine bark (Elixon Wood Products, Starke, FL) and 2) coconut coir (Millenniumsoils Coir, Vgrove Inc., Catharines, Ontario, Canada) and c) four N levels in the nutrient solution from calcium, potassium, and magnesium nitrate fertilizers: 40, 80, 120, and 160 mg·L^{-1} N, were evaluated in a factorial experiment. Each plot consisted of 1-m-long sections of PVC Hanging Bed-Pack® troughs (Polygal Plastic Industries LTD, Ramat Hashofet, Israel) (Fig. 2) with 10 plants per meter of the trough section. The rest of the nutrients had the following concentration: 50 mg·L^{-1} of P, 200 mg·L^{-1} of K, 140 mg·L^{-1} of Ca, 48 mg·L^{-1} of Mg, 56 mg·L^{-1} of S, 2.8 mg·L^{-1} of Fe, 0.4 mg·L^{-1} of Mn, 0.2 mg·L^{-1} of Zn, 0.3 mg·L^{-1} of B, 0.1 mg·L^{-1} of Cu and 0.05 mg·L^{-1} of Mo. These nutrient levels were based upon previous reports on hydroponic production of strawberry (Paranjpe et al., 2003b; Sarooshi and Creswell, 1994). To prepare the nutrient solution, the following greenhouse-grade fertilizers were used: calcium nitrate, potassium nitrate, calcium chloride, potassium chloride, potassium sulfate, magnesium sulfate, magnesium nitrate, phosphoric acid. Copper sulfate, zinc sulfate, manganese sulfate, Fe-DTPA, boric acid and sodium molybdate were used to complete the micronutrient concentration indicated above. The final nutrient solution had an EC of 1.8 dS·m^{-1} and a pH of 6.0 and the drainage had an average EC of 2.5 dS·m^{-1}.

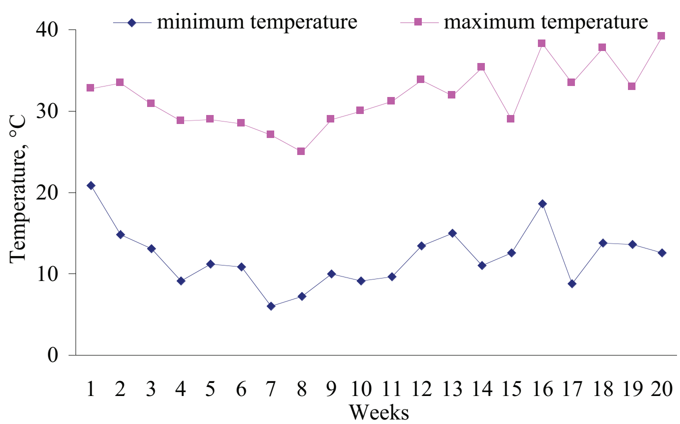

Fig. 1. Temperature inside the greenhouse during Nov. 2003 to Mar. 2004.

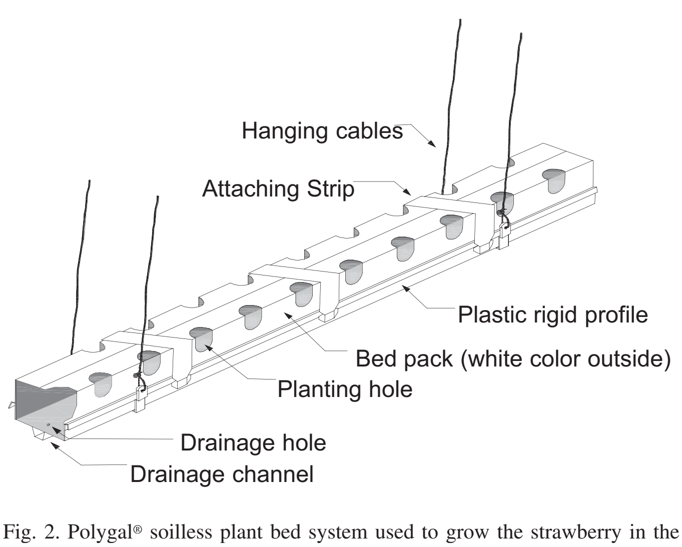

Fig. 2. Polygal® soilless plant bed system used to grow the strawberry in the greenhouse. Published with permission of Polygal Inc.

Pine bark had a bulk density of 0.22 g·cm^{-3}, total porosity of 85%, air capacity of 52%, and water retention capacity of 39%. Coconut coir had a bulk density of 0.13 g·cm^{-3}, total porosity of 91%, air capacity of 35%, and water retention capacity of 62%. One day prior to transplanting, the growing system was filled with media to a volume of 1 L per plant and irrigated for 2–3 h to wet the soilless media thoroughly and to leach any excess salts in the coconut coir media. Plugs were transplanted on 1 Oct. 2003 at a density of 21 plants/m^2. Plants received the same nutrient solution with every irrigation event, except for N, whose concentration varied for each treatment. Plants were fertigated 6 times a day delivering a total of 230 mL per plant per day with an average drainage of 25% throughout the season. The average water consumed per plant through the season was 175 mL per plant per day. An electronic timer (Superior Controls Co., Valencia, CA) was used to control irrigation events.

One class-A bumble bee hive (Koppert Biological Systems Inc., Romulus, MI), containing approximately 75–100 bumblebees (*Bombus* sp.), was introduced once the plants started to produce flowers [15 d after planting (DAP)]. Two-spotted spider mites (*Tetranichus urticae* Koch), cotton aphids (*Aphis gossypii* Glover), and western flower thrips (*Frankliniella occidentals* Pergande) were the most prominent arthropod pests. Powdery mildew (*Sphaerotheca macularis* f. sp. Fragariae) appeared in mid-November and was present at varying levels until the end of the experiment. The incidence of gray mold (*Botrytis cineria*) was negligible and was noticed occasionally on overripe fruit.

For control of aphids, parasitic wasps (*Aphidius colemani* L.) (Koppert Biological Systems Inc., Romulus, MI) were released twice at the beginning of the season, at bi-weekly intervals, at an average rate of 2.5 wasps/m^2. Sorghum (*Sorhum halepense*) banker plants infected with grain aphids were introduced in the greenhouse to maintain the presence of the parasitic wasp. *Neoseiulus californicus* McGregor predatory mites (Biotactics Inc., Perris, CA) were released at a rate of approximately 20 mites/m^2 per month to control two-spotted spider mites. Eventually soap (0.1%) (Lemon Joy; Proctor & Gamble Co., Cincinnati, OH) was applied with a hose end sprayer to help control aphids.

Data for number of runners in every plot were taken during October, November, and December and pooled to have a total number of runners per plant produced throughout the season. The 10 most recently matured leaves (MRML) were sampled in each plot every 30 d, from 30 to 120 d after planting (DAP). Samples were dried at 60 °C, ground, and analyzed for total-Kjeldahl N (TKN). Fruit with 80% red color development were harvested in 4- to 5-d intervals. Fruit that weighed more than 10 g and that were not deformed or diseased were considered marketable; the remaining fruit was considered non-marketable. For each plot, number of fruit and fruit weight were recorded for marketable and non-marketable fruit yield. For data analysis, harvests were grouped into early yield (December–January), and total yield (December–March). Crown size (diameter) and number of leaves were recorded for five plants in each plot and averaged. In this study, the term "crown diameter" was used for the irregularly shaped mass of multiple crowns measured as a whole. The number of leaves per plant was counted visually. The measurements of crown diameter and leaf number were recorded on 10 Feb. 2004. Five fruits per plot were sampled every month and frozen (–20 °C) until soluble solids could be determined.

Data were subjected to analysis of variance (ANOVA). Regression was performed when necessary. Statistical analysis was conducted using SAS (SAS Institute Inc., 1999–2001).

Results and Discussion

Vegetative development. Nitrogen level in the nutrient solution influenced the number of runners per plant ($Y= -0.16 + 0.0107X - 0.0000494X^2$, $r^2 = 0.29$). Maximum production of runners was observed in treatments with 80 and 120 mg·L^{-1} N (Table 1). 'Strawberry Festival' had a similar runner production when compared with a number of other commercial cultivars under greenhouse conditions in central Florida (Paranjpe et al., 2003c). Rodgers et al. (1985), in a study conducted in Israel, indicated that strawberry responded well to N application in the nursery but had a lower response in the production stage. Breen et al. (1981) reported a quadratic response to N supply on strawberry grown in the field. Number of leaves and crown size were not significantly affected by N level in the nutrient solution, which confirmed the low requirements of the crop for this nutrient as previously indicated (Albregts and Sutton, 1971; Albregts et al., 1973). In the current study, the type of media used did not significantly affect the number of runners, number of leaves, or size of the crown.

Marketable yield. Neither early nor total marketable yield was significantly affected by N level or media, which is consistent with the data presented for vegetative growth (Tables 2 and 3). Papadopoulos (1987) examined levels of N ranging from 50 to 150 mg·L^{-1} N in the nutrient solution and indicated that the yield obtained with 50 mg·L^{-1} N was only slightly better than that obtained with 100 mg·L^{-1} N; however, at 150 mg·L^{-1} N, yield was significantly reduced. Darnell and Stutte (2001) used levels of N ranging from 52 to 210 mg·L^{-1} N, under NFT conditions, and indicated a lack of response of this crop to N in terms of growth and yield within the range examined. These authors suggested that growth and fruit yield of strawberry is limited not by its ability to take up NO_3-N but by its ability to reduce and assimilate NO_3 in the tissue. This might be due to a lack of reductants (NADH or NADPH) or lack of available carbohydrate skeletons required for assimilation. There are no other reports evaluating the level of N in the nutrient solution under greenhouse conditions, but most crops under hydroponic conditions are supplied with 120 to 200 mg·L^{-1} N (Jones, 1996). Results from the present study indicated the possibility to reduce the level of N in the nutrient solution, without reduction in yield of this crop. It was concluded that both media could be used with similar results for the production of strawberry under hydroponic conditions in the greenhouse. The decision of using one or the other media would depend on their cost and availability to the grower.

Leaf nitrogen content. Data for N concentration in the MRML are presented for the four sampling dates (Table 4). For all

Table 1. Mean number of runners produced throughout the season, number of leaves, and crown diameter of strawberry plants as affected by nitrogen level and soilless media.

	Runners/plant (no.)	Leaves/plant (no.)	Crown diam (mm)
Nitrogen (N) level (mg·L^{-1})			
40	1.6	19.6	40.0
80	3.5	23.0	42.4
120	3.6	21.5	42.5
160	2.6	21.3	44.9
Significance[z]	Q**	NS	NS
Soilless media (M)			
Coconut coir	2.7	21.0	43.1
Pine bark	2.9	21.6	41.8
Significance	NS	NS	NS
N × M	NS	NS	NS

[z]Q = quadratic response; NS = nonsignificant. Equation: $Y= -0.16 + 0.0107X - 0.0000494X^2$, $r^2 = 0.29^{**}$. The mean values are presented.

Table 2. Main effect of N level and soilless media on early marketable yield of strawberry.

	Early marketable yield		Marketable (g/plant)
	fruit/plant	g/plant	(%)
Nitrogen (N) level (mg·L^{-1})			
40	6.9	103	86
80	6.0	93	86
120	6.5	100	87
160	6.7	107	88
Significance[z]	NS	NS	NS
Soilless media (M)			
Coconut coir	6.7	103	87
Pine bark	6.3	99	87
Significance	NS	NS	NS
N × M	NS	NS	NS

[z]NS = nonsignificant. The mean values are presented.

Table 3. Main effect of N level and soilless media on total marketable yield of strawberry.

	Total marketable yield		Marketable (g/plant)
	fruit/plant	g/plant	(%)
Nitrogen (N) level (mg·L^{-1})			
40	16.7	248	84.9
80	16.4	249	85.4
120	16.9	249	85.5
160	16.5	251	85.2
Significance	NS	NS	NS
Soilless media (M)			
Coconut coir	16.7	251	85.3
Pine bark	16.5	247	85.2
Significance	NS	NS	NS
N × M	NS	NS	NS

[z]NS = nonsignificant. The mean values are presented.

Table 4. Main effect of N level and soilless media on leaf N concentration of strawberry.

	Leaf N concn (%)			
	November	December	January	February
Nitrogen (N) level ($mg \cdot L^{-1}$)				
40	3.32	2.20	2.04	2.44
80	4.30	2.44	2.28	2.54
120	4.46	2.54	2.48	2.65
160	4.40	2.42	2.42	2.76
Significance	Q**	Q**	L**	L*
Soilless media (M)				
Coconut coir	4.06	2.40	2.31	2.50
Pine bark	4.12	2.40	2.30	2.70
Significance	NS	NS	NS	NS
N × M	NS	NS	NS	NS

[z]Q = quadratic response; L = linear response; NS = nonsignificant. November equation: $Y = 1.75 + 0.013X - 0.0000564X^2$, $r^2 = 0.54^{**}$. December equation: $Y = 1.58 + 0.012X - 0.0000474X^2$, $r^2 = 0.78^{**}$. January equation: $Y= 2.35 + 0.026X$, $r^2 = 0.48^{*}$. February equation: $Y = 2.72 + 0.01X$, $r^2 = 0.28^{*}$. The mean values are presented.

sampling dates, N concentration in the MRML was significantly affected by N level in the nutrient solution but was not affected by type of media. For the November and December sampling dates, the response of N concentration in the leaf to N supply in the nutrient solution was quadratic (November sampling: $Y = 1.75 + 0.013X - 0.0000564X^2$, $r^2 = 0.54^{**}$; and for the December sampling: $Y = 1.58 + 0.012X - 0.0000474X^2$, $r^2 = 0.78^{**}$). For the last two sampling dates, leaf N concentration increased linearly with increasing N level (January sampling: $Y= 2.35 + 0.026X$, $r^2 = 0.48^{*}$ and for the February sampling: $Y = 2.72 + 0.01X$, $r^2 = 0.28^{*}$). As observed in previous studies, N concentration in the MRML was high at the beginning of the season with concentrations ranging from 3.3% to 4.4% N, and was reduced at the end of the season to only 2.0% to 2.4% N. The values of leaf N concentration in our study are lower than those reported by Locascio and Martin (1985), and Hochmuth and Albregt (1994) for plants grown in the field, and by Papadopoulos (1987) for plants grown in a greenhouse. However, values of leaf N concentration in the current study were similar to those reported by Bould (1964) or Daugaard and Todsen (1999) in field-grown plants. The results of leaf tissue analysis again support the possibility of reducing the N concentration in the nutrient solution without negative effects on crop growth and yield.

Soluble solids. Soluble solids content in the fruit was measured at three sampling dates (Table 5). Increasing N level in the nutrient solution significantly decreased soluble solids in two of the three sampling dates (For January: $Y = 9.74 - 0.207X$, $r^2 = 0.52^{*}$ and for March: $Y = 5.15 - 0.006X$, $r^2 = 0.51^{*}$). Makkun et al. (2001) studied N rates from 150 to 600 $kg \cdot ha^{-1}$ under field conditions and reported a decrease in reducing, non-reducing, and total sugars as N rate increased above 150 $kg \cdot ha^{-1}$. Similar trends occurred in this study with acidity and shelf life of the fruit (data not shown). Our data and those of these researchers indicated a potential to increase fruit quality and savings in fertilizer N by using lower N levels in the nutrient solution, and thus reducing environmental problems from excess NO_3-N concentrations in the leachate. Higher values of soluble solids occurred during the cooler months of the season (Fig. 1) and as the temperature increased, the soluble solids content in the fruit was reduced. Similar trends were reported by Paranjpe (2004) for ‘Strawberry Festival’ as well as other strawberry cultivars under greenhouse conditions in central Florida. Wang and Camp (2000) indicated that high air temperature (30 °C day/22 ° C night) adversely affected fruit quality in strawberry, resulting in lower soluble solids.

No report was found that reported N concentration in the nutrient solution as low as 40 $mg \cdot L^{-1}$ and as we reported, there was no response of the crop to N within the range studied in this work. Our data indicate the potential to reduce the N level in the nutrient solution without adversely affecting yield and while increasing fruit quality. In fact, these results could be used to convince Florida field strawberry farmers that increasing N levels above the actual recommended rate by IFAS–UF not only would decrease crop yield and possibly negatively affect the environment, but also could adversely affect crop quality. Even though there were no significant differences among the levels of N studied in this work, we recommend using 40 to 80 $mg \cdot L^{-1}$ N under commercial hydroponic conditions to produce good fruit quality. These values are slightly lower than those used previously to produce strawberries at the Protected Agriculture Project within the Horticultural Sciences Department, University of Florida, wherein 85 $mg \cdot L^{-1}$ N has been commonly used (Paranjpe et al., 2003b). These values are far lower than recommended by other authors for the production of hydroponic strawberries in countries such as Australia (Sarooshi and Creswell, 1994), where farmers use a concentration of 120 $mg \cdot L^{-1}$ N. In future studies, it would be worth evaluating the effect of N level in the nutrient solution on plant growth and fruit yield of other strawberry cultivars.

Yield and fruit quality of plants grown in either media were similar. Neither early nor total marketable yield was significantly affected by N level or type of soilless media. However, soluble solids were decreased with increasing N level. Thus, growers should select the media in accordance with price and availability for each region. Nevertheless, it is important to point out that coconut coir has a higher water retention capacity than pine bark, which should be considered when deciding the water management practices in hydroponic systems. Due to these differences, coconut coir should be irrigated less frequently with a larger amount of water per irrigation, while pine bark should be irrigated more frequently with a lesser amount of water per irrigation. Results from this study indicated the possibility to reduce the N level in the nutrient solution without reduction in yield or fruit quality of soilless-grown strawberry.

Table 5. Main effect of N level and soilless media on soluble solids of strawberry fruit.

	January	February	March
Nitrogen level (N) ($mg \cdot L^{-1}$)	------------------ °Brix	-----------------	
40	8.8	5.8	4.8
80	8.5	4.7	4.8
120	6.2	5.4	4.3
160	6.8	5.6	4.2
Significance	L*	NS	L*
Soilless media (M)			
Coconut coir	7.3	5.4	4.5
Pine bark	7.8	5.4	4.6
Significance	NS	NS	NS
N × M	NS	NS	NS

[z] L = linear response. NS = nonsignificant. January equation: $Y = 9.74 - 0.207 X$, $r^2= 0.52^{*}$. March equation: $Y = 5.15 - 0.006X$, $r^2 = 0.51^{*}$. The mean values are presented.

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