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Fruit Nitrogen Content of Sixteen Strawberry Genotypes Grown in an Advanced Matted Row Production System

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Abstract. **In the perennial strawberry production system, removal of the harvested crop represents a loss of nitrogen (N) that may be influenced by cultivar. Eight strawberry (*Fragaria ×ananassa* Duch.) cultivars and eight numbered selections grown in advanced matted row culture were compared over three seasons for removal of N in the harvested crop. Replicated plots were established in 1999, 2000, and 2001 and fruited the following year. 'Allstar', 'Cavendish', 'Earliglow', 'Honeoye', 'Jewel', 'Northeaster', 'Ovation', and 'Latestar' and selections B37, B51, B244-89, B683, B753, B781, B793, and B817 were compared for yield and fruit N concentration. Harvest removal of N (HRN) was calculated from total season yield and fruit N concentration at peak harvest. There were significant differences in HRN among genotypes, ranging from 1.80 to 2.96 g N per meter of row for numbered selections B781 and B37, respectively. Among cultivars, HRN ranged from 2.01 to 3.56 g·m^{-1} for 'Ovation' and 'Jewel', respectively. The amount of HRN was largely determined by yield, however, there were also significant genotype differences in fruit N concentration, ranging from 0.608 to 0.938 mg N per gram fresh weight for B244-89 and 'Jewel', respectively. These differences indicate that N losses in the harvested crop are genotype dependent.**

Efforts to improve the sustainability of food production practices have resulted in increased interest in the conservation of soil and water resources, including the reduction of soil and nutrient losses. Many states in the northeastern U.S. have enacted nutrient management legislation to encourage reduced nutrient run-off and leaching from agricultural lands (Lea-Cox and Ross, 2001). These plans focus on nitrogen and phosphorus. Central to improving nutrient management practices is the quantification of the nutrients added to, and lost from an agricultural system. In the case of nitrogen, losses from the agroecosystem can occur through several pathways, including volatilization of reduced N, microbial denitrification, removal in the harvested crop, surface run-off and leaching. The latter two are primary concerns in determining nonpoint source nutrient pollution.

Commercial practices for N fertilization of strawberry differ depending on soil type, cultivar, and cropping system. In an annual hill system using fertigation, annual rates can range from 85 to 450 kg·ha^{-1} with much of this applied during cropping (Campbell and Miner, 1996; May and Pritts, 1990). For perennial matted row culture where N fertilizer is broadcast-applied in both spring and fall, N fertilization rates ranging from 56 to 110 kg·ha^{-1} have been reported (May and Pritts, 1990; Pritts, 1998; Strik et al., 2004). However, some reports have suggested that fertilizer N additions during the establishment year do not increase yield in the first fruiting year (Archbold and MacKown, 1995; Breen, 1979). In general, strawberry requires less N than do many vegetable and agronomic crops. A number of published studies have investigated efficiency of nitrogen acquisition by strawberry plants (Archbold and MacKown, 1988, 1995; Peterson et al., 1986; Strik et al., 2004). Several studies have provided estimates of nitrogen removed in the harvested crop, both for a winter production system in Florida (Albregts and Howard, 1978, 1980) and for conventional matted row management (Archbold and MacKown, 1988; Strik et al., 2004). However, previous studies estimating the fate of fertilizer N involved the use of only one or several cultivars, and the primary focus was not on cultivar comparison. Further, the cultivars used in many of these studies are no longer grown commercially in the U.S.

The purpose of this study was to determine the amount of nitrogen removed in a strawberry crop using modern production practices and cultivars, and to determine the extent to which harvest removal of N varied among genotypes.

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Materials and Methods

The strawberry breeding program at the USDA–ARS Fruit Laboratory, Henry A. Wallace Beltsville Agricultural Research Center, conducts replicated trials of advanced selections and commercial cultivars. New plantings are established each year and cropped for a single season. Plots are evaluated for plant health, fruit yield, fruit size and quality. These trials are conducted in two production systems, a cold-climate annual hill system (plasticulture), and a modified or advanced matted row (AMR) system. Both of these systems have been described previously (Black et al., 2002). During the 2000–02 harvests, fruit samples were collected from the AMR selection trial to compare HRN among genotypes.

The AMR system involves the use of raised beds, subsurface drip irrigation, and a killed cover crop mulch. For this study, raised beds were formed and a mixed cover crop consisting of hairy vetch (*Vicia villosa* Roth), grain rye (*Secale cereale* L.) and crimson clover (*Trifolium incarnatum* L.) was seeded over the beds in late August, at seeding rates of 45, 78, and 34 kg·ha^{-1}, respectively. Drip irrigation tape (T-tape brand irrigation tape; Trickl-eez Co., Biglerville, Pa.; 30 cm emitter spacing, 56 mL·min^{-1}·m^{-1} flow rating) was placed in the center of the bed, 5 to 8 cm below the surface. The cover crop was killed in April and dormant bare-root plants were transplanted through the cover crop mulch. Weed control was by directed herbicide application and some hand weeding. For the research plots, bed spacing was 1.5 m between row centers. However, typical spacing in a commercial planting would be about 1.2 m.

In 1999, 2000, and 2001, plots were established in three separate locations within the same field. Two soil types are found in the field, a Matawan-Hammonton Loamy Sand (Aquic Hapludult, silicios, mesic) and an Elkton-Keyport Silt Loam (Typic Endoaquult, mixed mesic). Within each year, four replicate plots of each genotype were established in a randomized complete block design, with blocking by location in the field to account for variation in soil type and other field characteristics. In a typical year, the AMR trial contains 12 to 18 numbered selections, and 6 to 10 named cultivars, however, genotypes are added to and dropped from the selection trials each year. Only those cultivars and selections that were present in at least two of the three years were included in the comparison of HRN (Table 1).

The four replicate plots of each genotype were established by planting cold-stored dormant plants at 0.3 m spacing in a single row down the center of the bed, with four plants per plot. Starting two weeks after planting, ammonium nitrate fertilizer was applied through the irrigation system in weekly applications at a rate of 210 mg N per row meter for 16 weeks, providing a season total of 3.36 g·m^{-1}. With a row spacing of 1.5 m, 3.36 g·m^{-1} is equivalent to 22.4 kg·ha^{-1} as a broadcast rate. With a matted row width of 0.45 m, 3.36 g·m^{-1} is equivalent to 75 kg·ha^{-1} on the basis of treated

Table 1. A description of cultivars and selections used in this study. Only genotypes appearing in ≥2 years of the study were included in the comparison of harvest removal of N (HRN). 'Primetime', B265-89 and B242-89 were only grown in the 1999–2000 season, but were included in comparing fruit N concentration changes within a season.

Genotype	Fruiting year			Release notice	Location selected	Vigor	Fruiting season	Parent	
								Female	Male
Allstar	2000	2001	2002	Galletta et al., 1981	MD		Mid	US4419	MDUS3184
Cavendish	2001	2002		Jamieson et al., 1991	NS		Mid	Annapolis	Glooscap
Earliglow	2000	2001	2002	Scott and Draper, 1975	MD		Early	MDUS2359	MDUS2713
Honeoye	2001	2002		Sanford et al., 1982	NY		Early-mid	Vibrant	Holiday
Jewel	2001	2002		Sanford et al., 1985	NY		Late	NY1221	Holiday
Latestar	2000	2001	2002	Galletta et al., 1996a	MD		Late	Lateglow	Allstar
Northeaster	2000	2001	2002	Galletta et al., 1995a	MD		Early-mid	MDUS4380	Holiday
Ovation	2000	2001	2002	Lewers et al., 2004	MD		Late	Lateglow	Etna
Primetime	2000			Galletta et al., 1996b	MD		Mid	MDUS4377	Earliglow
B37	2001	2002			MD	++	Late	MDUS5076	MDUS5071
B51	2000	2001			MD	++	Early-mid	MDUS5051	MDUS5199
B244-89	2001	2002			MD	+++	Mid	EB394	Allstar
B683	2000	2001	2002		MD	++	Mid	EB586	Allstar
B753	2000	2001	2002		MD	+	Mid-late	MDUS5132	NYUS113
B781	2000	2001	2002		MD	+	Early-mid	B232-89	B244-89
B793	2000	2001	2002		MD	+	Late	MDUS5393	B28
B817	2000	2001			MD	++	Late	B298	Delmarvel
B265-89	2000				MD	+++	Early-mid	NYUS113	MDUS5130
B242-89	2000				MD	++	Mid	EB172	MDUS4589

area. This rate is low relative to commercial recommendations, but has proven to be sufficient for fertigation application in this soil type and production system.

In the fall, rows were narrowed to 0.45 meters by cutting runners with tractor-mounted coulters, followed by directed application of a contact herbicide to the sides of the beds. Straw mulch was applied in late fall for winter cold protection as is the common practice in the conventional matted row system. In early March of the fruiting season, straw was removed from the tops of the beds, and placed between the beds for weed suppression. Overhead irrigation was used for spring frost protection. Starting at bloom time, the first of five weekly applications of 0.10 g N/m ammonium nitrate fertilizer was applied through the irrigation system for a total spring application of 0.5 g N per m row (11.2 kg N per fertilized ha or 3.33 kg·ha^{-1} broadcast rate).

Ripe fruit was harvested twice weekly, with yield, fruit size, and a subjective market score recorded at each harvest, as previously described (Galletta et al., 1995b). After weighing and evaluating the total fruit sample from each plot, a sub-sample of three healthy fruit including calyx and stem, was removed from each sample for N analysis. Samples for N analysis were placed in plastic bags and held on ice for transport to the laboratory where they were weighed, frozen in liquid nitrogen, and stored at –80 °C until lyophilization. Lyophilized samples were weighed and then milled with a high-speed mill equipped with a 1.0 mm screen (Tecator Cyclotec 1903 Sample Mill). Total N concentration of the dried samples was determined on duplicate subsamples by Dumas combustion using an automated N analyzer (Model 2410 nitrogen analyzer; Perkin Elmer, Boston Mass.) that was calibrated using a peach leaf standard (Standard Reference Material 1547, National Institute of Standards and Technology, Gaithersburg, Md.).

Statistical analysis was carried out using the GLM procedure of the statistical analysis software, SAS 8.2 (SAS Institute Inc., 1999). Data were analyzed as a split plot treatment structure with cultivar and year as factors. Cultivar means were separated using the PDIFF option of the LSMEANS statement.

Results and Discussion

From the 2000 harvest, four genotypes were selected for determining potential changes in fruit N concentration over the season. Fruit samples for B242-89, B265-89, 'Northeaster' and 'Primetime' were analyzed from the third harvest date to the end of the season. Fruit N concentration, on a fresh weight basis, did not differ significantly through the season except in the last few harvests (Fig. 1A). The late-season increase in fresh weight N concentration was largely due to changes in dry matter content (data not shown). However, these late harvests, when fruit N concentration was significantly higher, account for < 5% of the total harvested biomass (Fig. 1B). Based on this analysis, it was determined that fruit N concentration at peak harvest would be an adequately representative estimate for calculating N content of the total crop.

There was significant genotypic variation in fruit N concentration at peak harvest (P = 0.001). Fruit N concentration also differed significantly among years (P < 0.001), but there was no significant genotype × year interaction (P = 0.29), and values presented are averages over three years (Table 2). The highest N concentrations were found in 'Jewel' and B753, with 0.938 and 0.912 mg N/g fresh weight, respectively (Table 2), and the lowest fruit N concentration was 0.608 mg·g^{-1} found in the selection B244-89. The lowest fruit N concentration among cultivars was 0.666 mg·g^{-1} for 'Allstar'. There was no apparent pattern in fruit N concentration among genotypes with regards to pedigree or selection location. For example, 'Honeoye', 'Jewel', and 'Northeaster' share a common parent, but differ significantly in fresh weight N concentration.

Fresh weight N concentration is a function of both dry matter content of the fruit, and dry weight N concentration, and there were significant differences among genotypes for both (P < 0.001 and P = 0.002). Dry matter content of fruit ranged from 7.2% to 10.7% for B817 and 'Ovation', respectively (data not shown). N concentration on a dry matter basis ranged from 6.87 mg·g^{-1} for 'Ovation' to 10.6 mg·g^{-1} for 'Jewel' (Table 2).

Total yield differed significantly among genotypes and among years, with a significant genotype × year interaction (P < 0.001), and means are presented for genotypes in each year (Table 2). The highest yielding cultivars were 'Honeoye', 'Latestar', and 'Cavendish', while the lowest yielding cultivar was 'Ovation'. Among selections, B817 yielded an average 4.31 kg·m^{-1} while B51 produced 2.43 kg·m^{-1}. For rows spaced on 1.5-m centers, yields of 2.52 kg·m^{-1} are equivalent to 16.8 t·ha^{-1} and would be typical of this production system and location, whereas yields > 3.0 kg·m^{-1} or 20 t·ha^{-1} would be exceptional.

Harvest removal of N (HRN) differed significantly among genotypes (P < 0.001) and among years (P < 0.001), but showed no significant genotype × year interaction (P = 0.56). Values presented are averaged over years (Table 2). The highest HRN was 3.56 g N removed per m of row for the cultivar Jewel. The lowest HRN among cultivars was 2.01 g·m^{-1} for 'Ovation'. Among numbered selections, B781 had the lowest HRN with 1.80 g·m^{-1} and B37 had the highest with 2.96 g·m^{-1}.

The fruit N concentrations reported here are somewhat lower than values previously reported. In a winter production system in Florida, Albregts and Howard (1978) reported fruit N concentrations of 0.96 to 1.34 mg·g^{-1} in four genotypes over two growing seasons. In matted row production, Haut et al. (1935) found 1.03 mg N/g fresh weight of fruit from an unfertilized treatment of 'Aroma', compared to 1.53 mg·g^{-1} for plants receiving 168 kg·ha^{-1} of fertilizer N. Likewise, in a comparison of fertilized and unfertilized treatments, Shoemaker and Greve (1930) found fresh weight N concentrations of 1.11 and 0.90 mg·g^{-1},

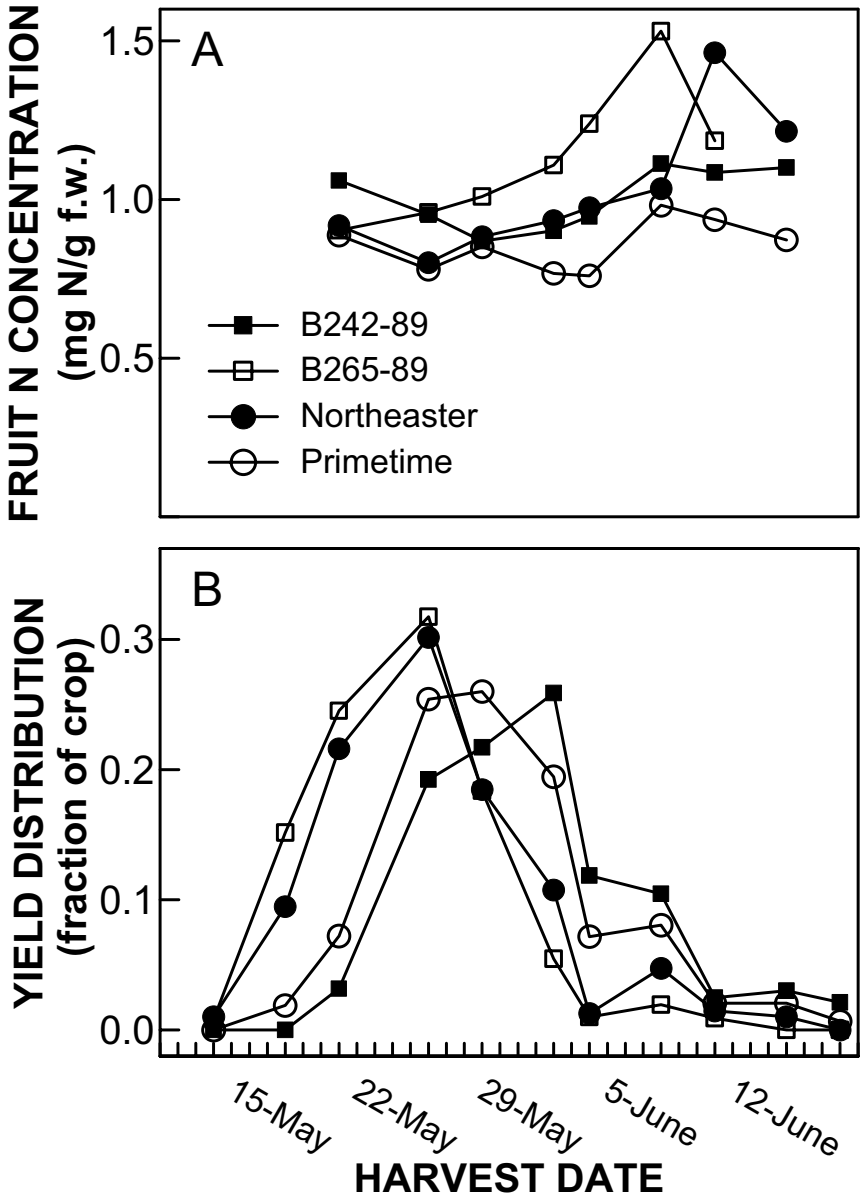

Fig. 1. Time course of fruit N concentration (**A**) and yield distribution (**B**) for four genotypes during the 2000 season.

respectively, for 'Premier' in matted row culture. Knight and Wallace (1932) reported fruit N concentration of 'Royal Sovereign' ranging from 0.97 to 1.08 mg·g^{-1} depending on source of manure N. The difference between values reported here and previous reports may have been due to differences in analytical technique. Earlier studies used kjeldahl digestion of either oven-dried samples (Albregts and Howard, 1978; Long and Murneek, 1937; Shoemaker and Greve, 1930), or of fresh fruit (Knight and Wallace, 1932). In the case of Haut et al. (1935), analytic techniques were not specified. It is unclear whether differences in drying procedure or analytical techniques could account for the differences in reported values.

Among cultivars, HRN values ranged from 13.4 kg·ha^{-1} for 'Ovation' to 23.7 kg·ha^{-1} for 'Jewel' calculated based on 1.5-m row spacing. By comparison, Strik et al. (2004) reported HRN of 30 kg·ha^{-1} for 'Totem' with matted row widths of 0.4 m, and 1 m between row centers. Archbold and MacKown (1988) reported HRN of 27.6 kg·ha^{-1} for 'Redchief' in matted rows 0.3 m wide with 1.1 m between row centers. By contrast, Albregts and Howard (1978) estimated HRN of 58.6 kg·ha^{-1} for 'Florida Belle' and "Tioga' in a winter annual-hill production system. It is interesting to note that the reports of HRN for matted row production were based on lyophilized samples analyzed either by kjeldahl (Archbold and MacKown, 1988) or presumably by combustion analysis (Strik et al., 2004). After correcting for differences in row spacing, estimates of HRN reported here are similar to previous estimates.

The basis for genotypic differences in HRN is likely attributable to several factors. B51 was among the highest in fruit N concentration, but had the lowest yields, and consequently, was among the lowest in HRN. By contrast, 'Allstar' and 'Jewel' had similar yields, but very different

Table 2. Yield, fruit N concentration and N removed in the harvested portion of the crop for 16 strawberry genotypes. Fruit N concentration was determined for fruit samples (both fruit and calyx) from the peak harvest, and used to calculated harvest removal of N (HRN). Concentrations are expressed on both fresh weight (FW) and dry weight (DW) basis.

	Yield (kg·m^{-1})			Fruit N concentration		HRN
Genotype	2000	2001	2002	(mg·g^{-1} DW)	(mg·g^{-1} FW)	(g·m^{-1})
'Allstar'	3.62	3.36	3.89	7.62	0.666	2.39
'Cavendish'		4.46	3.69	7.94	0.684	2.80
'Earliglow'	2.96	3.63	3.21	9.30	0.882	2.91
'Honeoye'		4.82	3.91	9.51	0.754	3.27
'Jewel'		4.40	3.32	10.59	0.938	3.56
'Latestar'	4.57	3.13	4.78	9.51	0.764	3.20
'Northeaster'	3.08	2.78	3.45	8.79	0.726	2.26
'Ovation'	2.75	3.17	2.39	6.87	0.726	2.01
B37		3.93	3.31	9.81	0.836	2.96
B51	2.93	1.94		10.55	0.905	2.18
B244-89		2.96	3.26	7.34	0.608	1.89
B683	3.47	3.20	2.50	8.40	0.659	2.03
B753	3.44	2.24	2.40	10.47	0.912	2.39
B781	2.99	1.88	2.46	8.60	0.750	1.80
B793	3.96	3.28	2.88	8.32	0.755	2.57
B817	4.26	4.36		9.39	0.666	2.90
LSD	0.80	0.77	0.76	1.66	0.140	0.54
Analysis of variance						
Genotype (G)		< 0.001		< 0.001	0.001	< 0.001
Year (Y)		0.003		< 0.001	< 0.001	0.001
G × Y		< 0.001		0.54	0.29	0.47

fruit N concentrations. As a result, 'Jewel' had the highest HRN, whereas 'Allstar' was not significantly different from the genotype with the lowest HRN. Among the genotypes and years compared, there was no significant correlation between fruit N concentration and yield (no dilution effect), whereas there was a slight but significant negative correlation between fruit N concentration and fruit size ($r = -0.185$; $P = 0.01$). This apparent relationship between fruit size and fruit N concentration may be the result of including all of the harvested tissue, fruit, stem and calyx, in the analysis. The calyx has a 5-fold higher N concentration than the fruit tissue (Albregts and Howard, 1978), and one might expect that the ratio of calyx to fruit tissue is inversely related to fruit size.

In breeding new cultivars amenable to sustainable production practices, it is not clear which of these genotypes is more desirable. High fruit N concentration could be due to increased N uptake efficiency, or to partitioning of a larger percent of acquired N to the fruit relative to that in vegetative tissues (Moll et al., 1982). Plants with improved N uptake efficiency may require less fertilizer inputs and therefore be better suited to reduced-input management systems. Conversely, N in the removed crop represents acquired N that could otherwise be utilized in a perennial plant, and may represent inefficient use of available N. In theory, the optimum condition would be plants with high uptake efficiency that partition a minimum amount of available N to fruit, without compromising fruit quality or nutritive value. Comparing N uptake efficiency and partitioning were not objectives of the present study. However, based on these results, specific genotypes will be selected for more detailed analysis to determine whether genotypic differences result from differences in uptake efficiency, partitioning, or both. Genetic differences in N uptake efficiency and partitioning could then be exploited to select cultivars that are more N efficient, and consequently, better adapted to reduced N growing conditions. From the results presented here, it is clear that genetic differences in both yield and fruit N concentration influence the amount of N that is removed from a perennial strawberry production system in the harvested crop.

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