

Seasonal and Cropping Effects on Total and Fertilizer Nitrogen Use in June-bearing and Day-neutral Strawberries

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Abstract. Total N and fertilizer N (FN) recovery and use by June-bearing 'Redchief' strawberry (*Fragaria ×ananassa* Duch.) and day-neutral 'Tribute' grown in matted-row beds were studied over 1-year periods. Fertilizer N was field-applied as ¹⁵NH₄¹⁵NO₃ at planting in June or September, and all plants were harvested from bed sections in late autumn (November) and at the completion of the spring harvest (June). Distribution patterns of vegetative biomass were similar in both cultivars, with leaf tissue comprising the bulk of the vegetative dry weight per plant at both sampling dates. The fall and spring fruit crops each contributed >40% of the total biomass per plant. Total N accumulation from soil N and FN increased as total biomass increased. Due in part to the additional biomass of the fall fruit crop, 'Tribute' recovered 38% more total N per unit bed area than 'Redchief'. Over 30% of the fall N total in 'Tribute' and the spring N total in both cultivars was partitioned to the fruit. In both cultivars, greater recovery of FN applied in September than at planting time was observed by the postharvest sampling date. However, 'Tribute' recovered only 14.2% of the FN applied in September, much less than the amount recovered by 'Redchief' during the same interval, implying a diminished ability to absorb FN during fruiting. In all vegetative tissues, soluble reduced N (SRN) was consistently less than insoluble reduced N (IRN) in November and June. Consistent seasonal trends in SRN and IRN values were not evident in any tissue except roots, where SRN content declined from November to June. Allocation of FN to the SRN and IRN pools was related to FN application date, cropping pattern, and total biomass of the component tissue. In both cultivars, the FN content was greater in the IRN than the SRN pool and leaf IRN was the single largest vegetative sink for FN. Fruit N concentration was constant for most of the fall 'Tribute' harvest period and declined in both cultivars during spring harvest. The spring 'Tribute' fruit crop received more FN from the September than the planting application, while the fall crop exhibited the opposite pattern, suggesting the fruit crop receives more storage than newly absorbed FN. The accumulation of FN in the root SRN pool in November and its depletion through the spring harvest reveals that root SRN plays a significant role in the temporary seasonal storage and internal cycling of N remobilized during spring growth.

Absorption of N by strawberry depends on many factors including soil properties, application method, and root zone temperature (Clay et al., 1984; Ganmore-Neumann and Kafkafi, 1983). Total fertilizer N (FN) recovery in matted row culture is low following planting, but greater when applied to mature beds with developed root systems (Archbold and MacKown, 1988). Increasing FN application rates at planting increase total FN recovery, although percent recovery values are lower at higher rates. The proportion of FN partitioned to the spring fruit crop in matted row culture increases slightly when the FN is applied in September instead of 3 months earlier at planting. Thus, the partitioning pattern depends on the time of year the FN is absorbed. Weinbaum et al. (1980, 1984) found that less FN is partitioned to the current fruit crop in almond and apricot and more goes to the fruit crop in the subsequent year as FN application date is delayed.

Total tissue N content and concentration of June-bearing strawberry cultivars changeover a growing season, indirectly indicating shifting patterns of internal N cycling among competing sinks. Although N availability may influence foliar N levels (Breen and

Martin, 1981; Hunan and Kotze, 1990), high foliar N levels present in early spring decline markedly in June-bearing cultivars during harvest and in late fall (Hunan and Kotze, 1990; John et al., 1976; Kwong and Boynton, 1959; Long and Murneek, 1937). In late fall, the crown and roots accumulate significant amounts of N, possibly supplying a portion of the N partitioned to the spring fruit crop. Fruit harvest removes significant amounts of N in June-bearing matted-row and annual production systems (Albregts and Howard, 1980; Archbold and MacKown, 1988). Since annual production systems involve sustained cropping with continual N removal from the internal N cycle and replenishment from newly absorbed soil N likely, the plants may exhibit different partitioning patterns than cultivars cropped seasonally in the spring. Lower root N concentration occurs when a day-neutral cultivar is cropped into the fall (Gagnon et al., 1990).

Plant tissues contain two major pools of N, soluble and insoluble reduced N (SRN and IRN) compounds (Millard, 1988; Titus and Kang, 1982). In methanol-chloroform extraction protocols, the SRN pool includes reduced N primarily in the form of amines and amides. The IRN pool includes more complex forms of N such as nucleic acids and proteins. Undoubtedly, the regulation of the size of these two pools and their availability to sinks differ. Nitrogen may be transported in soluble forms such as nitrate and amino acids, while the IRN pool is not mobile. Both N pools may contribute to N accumulation in vegetative and reproductive sinks. Mobilization of N compounds from the foliage to stems and roots during senescence and the onset of dormancy occurs seasonally in perennial crops (Millard and Thomson, 1989; Titus and Kang, 1982). Some foliar N remains in dead leaves and may be recycled back into the soil N pool. The bark, roots, and stems are

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primary sites of N storage; the latter two may be potentially significant in strawberry.

In woody perennial fruit species, storage N continually contributes to vegetative and reproductive growth over several years, implying an important dynamic role for storage N in the N balance sheet for the perennial crop (Deng et al., 1989; Sanchez et al., 1991; Weinbaum and Muraoka, 1986). Early season vegetative and reproductive growth depend on mobilization of storage N, and only after active leaf and/or shoot growth decreases is newly absorbed N a significant contributor to tissue N pools. Although the size of a strawberry plant and a fruit tree differ markedly, relative pool sizes and N partitioning patterns may be similar. In both, the fruit and leaves constitute a significant N sink during the growing season, and the roots and stem or crown may accumulate N during late fall (Long and Murneek, 1937; Titus and Kang, 1982). The shifting patterns of N accumulation among vegetative tissues in both species may be responses to similar environmental cues.

There is a paucity of data on seasonal N and FN use in strawberry. The objective of this work was to determine the seasonal partitioning pattern of applied FN among tissues and allocation between the SRN and IRN pools and compare a June-bearing cultivar to a day-neutral cultivar to assess how fruiting pattern affects seasonal N use.

Materials and Methods

Field plots for Expts. 1 and 2 were established in a randomized complete-block design at the Univ. of Kentucky South Farm, Lexington, on a Maury silt loam soil (fine, mixed, mesic, Typic Paleudalf). Plots were fumigated several weeks before planting with 98 methyl bromide : 2 chloropicrin at 393 kg·ha⁻¹. In May 1986, June-bearing 'Redchief' plants were set for Expt. 1. In May 1987, 'Redchief' and day-neutral 'Tribute' plants were set for Expt. 2. Commercially produced dormant plants were set 0.6 m apart in rows spaced every 1.5 m. Individual beds 3 m in length were established. Inflorescences were removed from 'Redchief' plants after planting and from 'Tribute' plants until mid-July. Runner plants were manually set through September during each planting year to achieve a uniform bed density. Excess runners were directed beyond a 0.3-m bed width. In September, beds were narrowed to 0.3 m.

An aqueous solution of ammonium nitrate was banded 6 cm off-center in a single-row into each bed 1 month after planting (June) and again after bed narrowing in early September. The ammonium nitrate was applied at 22.5 kg N/ha on both dates. Each bed of 'Redchief' in Expt. 1 and 'Tribute' in Expt. 2 received ¹⁵N enriched

ammonium nitrate (6 atom % ¹⁵N, uniformly labelled, Amersham Corp., Arlington Heights, Ill.) on the June or the September application date, while 'Redchief' in Expt. 2 received FN in June only. Each cultivar and time of ¹⁵N application combination was replicated five times.

Standard cultural practices including disease and pest control were followed. Rainfall was supplemented with overhead irrigation to apply a minimum of 2.5 cm of water per week.

Ripe fruit were harvested weekly starting in late August from 'Tribute' plants during the first growing season and every 3 to 5 days from both cultivars during the following spring harvest. All fruit, ripe and unripe, were collected on the final fall harvest date for 'Tribute'. All plants within a 0.5-m section of bed were sampled for dry weight, total N, and FN analysis in late November and following the completion of the spring harvest in both experiments. Care was taken to ensure maximum recovery of the root biomass. All plants from each sampled section were counted, thoroughly rinsed under running tap water, separated into component tissues, and bulked by tissue type. All tissues were frozen, lyophilized, and weighed. Vegetative tissues were ground in a Wiley mill to pass a 40-mesh screen, then pulverized to a fine powder with a ball mill. Intact fruit were pulverized to a powdery texture except those set aside for analysis of achene and receptacle tissues. Those tissues were manually separated and subsequently pulverized.

The SRN and IRN pools were fractionated and assayed by a methanol-chloroform procedure as described by Pace et al. (1982). This procedure volatilizes nitrate in the SRN fraction before Kjeldahl digestion. Aliquots of the Kjeldahl digests (McKenzie and Wallace, 1953) were analyzed spectrophotometrically for total N. For ¹⁵N determination, an acid trap diffusion technique (MacKown et al., 1987) was used to prepare the N in Kjeldahl digests for mass spectrometry (Volk and Jackson, 1979).

Based on component tissue dry weights, N contents, and atom % ¹⁵N values, FN recovery values were calculated for each component tissue type and the entire section as described by Hauck and Bremner (1976). Mean values ±SE of the mean of component tissue dry weights and total N and total FN contents are presented.

Results and Discussion

Cultivar and environmental factors may have significant effects on dry weight accumulation and partitioning in strawberry. Plant density did not change between November and the subsequent June in Expt. 1, although total vegetative biomass increased (Table 1). Plant density in Expt. 1 exceeded that of Expt. 2, but plant density of 'Redchief' and 'Tribute' in Expt. 2 increased from

Table 1. Biomass distribution in the June-bearing strawberry cultivar Redchief and the day-neutral cultivar Tribute, 1986–88.

Date	Plants/m ²	Dry wt (g) per plant					
		Crown	Leaf	Petiole	Root	Fruit	Total
<i>Expt. 1, 1986–87, Redchief</i>							
November 1986	120 ± 9 ^a	1.1 ± 0.2	3.9 ± 0.3	1.1 ± 0.1	1.1 ± 0.3	---	7.3 ± 0.5
June 1987	120 ± 8	2.2 ± 0.1	3.7 ± 0.2	2.1 ± 0.1	1.9 ± 0.2	8.2 ± 0.4	18.6 ± 1.0
<i>Expt. 2, 1987–88, Redchief</i>							
November 1987	54 ± 3	1.2 ± 0.4	2.0 ± 0.3	0.5 ± 0.1	2.8 ± 0.2	---	6.4 ± 0.9
June 1988	86 ± 11	3.0 ± 0.3	4.2 ± 0.4	1.9 ± 0.1	3.4 ± 0.9	15.8 ± 3.4	28.6 ± 2.7
<i>Tribute</i>							
November 1987	81 ± 10	2.3 ± 0.5	2.8 ± 0.5	0.8 ± 0.2	3.1 ± 0.5	8.3 ± 1.0	17.3 ± 2.4
June 1988	99 ± 12	3.6 ± 0.4	4.9 ± 0.8	1.8 ± 0.3	3.3 ± 0.5	13.6 ± 2.5	27.3 ± 4.2

^aMean ± SE, n = 10 for 'Redchief' in Expt. 1 and 'Tribute' in Expt. 2, and n = 5 for 'Redchief' in Expt. 2.

November to June. Vegetative biomass distribution patterns of the day-neutral 'Tribute' paralleled those of the June-bearing 'Redchief'. Total vegetative dry weight per plant increased between November and the subsequent June in both experiments. In November, roots contributed less than one-third the biomass of leaves in Expt. 1 but a greater proportion of the total in Expt. 2. Leaves contributed a greater proportion of the total biomass than roots at the postharvest sampling date in both experiments. Long and Mumeek (1937) observed that root tissue of container-grown plants comprised an equal or greater proportion of the total biomass compared to foliar tissue in November, but contributed proportionally less after harvest. Olsen et al. (1985) found a 3- to 4-fold greater leaf than root biomass at late fall and postharvest sampling dates for strawberry cultured in a hill system. The spring fruit crop of 'Redchief' comprised > 40% of the total biomass per plant in Expt. 1 and 55% in Expt. 2, while the 'Tribute' fruit crops in Expt. 2 comprised nearly 50% of the total biomass values. While these values are within previously reported ranges, others have

reported that cultivar, cultural procedures, and year-to-year environmental variation can have significant effects on biomass accumulation and distribution patterns (Baumann et al., 1993; Popenoe and Swartz, 1985).

As reported by Long and Murneek (1937) and Peterson et al. (1986), greater biomass accumulation resulted in greater total N accumulation. In Expt. 1, 'Redchief' absorbed 50% more N by the spring harvest than in November (Archbold and MacKown, 1988). In Expt. 2, 'Redchief' plants acquired nearly 4-fold more N by the spring harvest than in November (Table 2). Nearly half of the N was partitioned to the fruit. 'Tribute' accumulated 20.1 g N/m² by late November, >3-fold more N than 'Redchief'. Although this was due in part to the greater plant density and resulting vegetative biomass per unit bed area of 'Tribute', 6.9 g N/m² (33%) of the November N total was partitioned to the fruit. By the end of the spring harvest, 'Tribute' absorbed an additional 5.8 g N/m². The spring fruit crop contained >30% of the total N absorbed. Although total N accumulation was similar by the two cultivars in June, the

Table 2. Total N absorbed and percent of applied fertilizer N recovered by the June-bearing cultivar Redchief and the day-neutral cultivar Tribute, Expt. 2, 1987-88.

N application date	Sampling date	Total N absorbed (g·m ⁻²)		Recovery of fertilizer N (%)	
		Vegetative	Fruit	Vegetative	Fruit
<i>Redchief</i>					
June 1987	November 1987	6.2 ± 0.9 ^y	---	8.3 ± 1.2	---
June 1987	June 1988	13.2 ± 2.4	10.6 ± 2.1	11.0 ± 4.2	10.8 ± 2.2
<i>Tribute</i>					
June 1987	November 1987	13.2 ± 1.8 ^y	6.9 ± 1.4	13.8 ± 1.1	8.1 ± 2.1
June 1987	June 1988	15.8 ± 1.1	10.1 ± 0.7	9.7 ± 0.9	4.7 ± 1.3
September 1987	November 1987	---	---	11.8 ± 4.6	2.4 ± 0.4
September 1987	June 1988	---	---	25.2 ± 6.8	8.1 ± 3.6

^yMean ± SE. For total N absorbed, n = 5 for 'Redchief' and n = 10 for 'Tribute'; for percent recovery, n = 5 for both cultivars.

^zMeans for total N absorbed across all plots at sampling date irrespective of fertilizer nitrogen application date.

Table 3. Soluble and insoluble N levels in Redchief and Tribute strawberry plant components, 1986-88.

Tissue	Sampling date			
	November		June	
	Total N content (μmol/plant) ^z			
	Soluble	Insoluble	Soluble	Insoluble
<i>Expt. 1, 1986-87, Redchief</i>				
Crown	663 ± 130 ^y	1280 ± 316	365 ± 30	1160 ± 39
Leaf	526 ± 193	5560 ± 875	200 ± 13	4430 ± 287
Petiole	50 ± 19	526 ± 62	66 ± 16	869 ± 43
Root	948 ± 64	1150 ± 94	83 ± 28	931 ± 126
Fruit	---	---	1000 ± 56	4200 ± 134
<i>Expt. 2, 1987-88, Redchief</i>				
Crown	634 ± 225	991 ± 309	935 ± 162	2080 ± 267
Leaf	189 ± 22	2620 ± 318	378 ± 6	4360 ± 335
Petiole	30 ± 4	243 ± 16	129 ± 1	746 ± 79
Root	1620 ± 186	1920 ± 80	315 ± 121	1950 ± 478
Fruit	---	---	3410 ± 1420	13600 ± 2380
<i>Tribute</i>				
Crown	954 ± 86	2000 ± 373	755 ± 104	2140 ± 262
Leaf	213 ± 26	3860 ± 716	475 ± 67	5130 ± 744
Petiole	67 ± 10	455 ± 83	93 ± 8	672 ± 94
Root	1750 ± 154	2860 ± 940	218 ± 93	2550 ± 691
Fruit	2150 ± 604	3950 ± 419	2030 ± 284	10500 ± 2110

^zTo derive percent N values, divide the sum of the soluble and insoluble means by the dry weight (Table 1) and multiply by 1.4 × 10⁻³.

^yMean ± SE. n as in Table 1.

Table 4. Influence of fertilizer N application date on fertilizer N content of the soluble and insoluble N pools of 'Redchief' strawberry plant tissues in November 1986 and after harvest in June 1987, Expt. 1.

Tissue	N application date			
	June 1986		September 1986	
	Soluble	Insoluble	Soluble	Insoluble
	<i>November 1986</i>			
Crown	713 ± 34 ^a	1230 ± 143	3870 ± 672	6850 ± 1420
Leaf	862 ± 77	21400 ± 1990	2060 ± 776	27600 ± 2910
Petiole	270 ± 58	1860 ± 213	152 ± 70	2710 ± 538
Root	406 ± 52	715 ± 97	8220 ± 1140	8430 ± 1220
	<i>June 1987</i>			
Crown	768 ± 119	3090 ± 434	1400 ± 278	4150 ± 660
Leaf	327 ± 79	8610 ± 2370	598 ± 17	13800 ± 748
Petiole	166 ± 85	2200 ± 113	133 ± 58	2470 ± 84
Root	127 ± 20	3110 ± 864	364 ± 213	2970 ± 553
Fruit	2410 ± 304	10600 ± 1450	3310 ± 1020	12900 ± 3510

^aMean ± SE, n = 5.

Table 5. Influence of fertilizer N application date on fertilizer N content of the soluble and insoluble nitrogen pools of 'Tribute' strawberry plant tissues in November 1987 and after harvest in June 1988, Expt.2.

Tissue	N application date			
	June 1987		September 1987	
	Soluble	Insoluble	Soluble	Insoluble
	<i>November 1987</i>			
Crown	3600 ± 549 ^a	7310 ± 1410	2970 ± 873	6090 ± 2680
Leaf	811 ± 147	15500 ± 1990	458 ± 158	10300 ± 5430
Petiole	269 ± 40	1870 ± 182	192 ± 83	1180 ± 574
Root	4190 ± 256	6630 ± 1011	11700 ± 4180	17200 ± 1190
Fruit	12100 ± 1680	200000 ± 6310	4260 ± 559	6400 ± 262
	<i>June 1988</i>			
Crown	1950 ± 234	6770 ± 991	4570 ± 2820	13300 ± 8110
Leaf	1030 ± 173	12700 ± 2160	2190 ± 948	25300 ± 8270
Petiole	249 ± 78	1700 ± 305	524 ± 213	3820 ± 1610
Root	752 ± 509	8600 ± 4180	790 ± 651	12000 ± 197
Fruit	3500 ± 334	19400 ± 1860	6650 ± 1040	27000 ± 4220

^aMean ± SE, n = 5.

dual fall and spring fruiting pattern of 'Tribute' contributed to a greater total N accumulation than 'Redchief'. The fall fruit plus spring vegetative and fruit N total of 32.8 g N/m² accumulated by 'Tribute' was 38% more than the June-bearing 'Redchief' spring total of 23.8 g N/m². These results indicated a greater N requirement by dual-cropped day-neutral than June-bearing cultivars when grown in matted rows. In annual strawberry production in Florida, total plant and fruit crop accumulation is nearly 60 kg N/ha over several months (Albregts and Howard, 1980), while June-bearing cultivars grown in matted rows may accumulate up to 80 kg N/ha (Archbold and MacKown, 1988; Peterson et al., 1986).

Fruiting may alter N absorption patterns. More FN was absorbed by 'Tribute' than 'Redchief' by November from the planting application in Expt. 2, although total FN recovery by 'Redchief' was comparable to 'Tribute' by June (Table 2). In November, recovery of FN applied to 'Tribute' plants in September was less than that from the planting application. In contrast to 'Redchief' in Expt. 1 when 24% of the September-applied FN was recovered by November (Archbold and MacKown, 1988), 'Tribute' recovered only 14.2% of the September FN application by late fall, but had

absorbed 33.3% by the spring harvest. Several factors may account for less FN recovery between September and November by 'Tribute' in Expt. 2 than 'Redchief' in Expt. 1. A shift in carbohydrate partitioning to the fruit crop could have reduced the carbohydrate supply to the roots, impairing energy-dependent nitrate absorption and limiting N assimilation. Root growth slows considerably during fruiting, implying a redirection of carbohydrate resources to other tissues (Olsen et al., 1985). In both experiments, 'Redchief' root biomass increased from November to June proportionally more than in 'Tribute', which produced fall fruit and may have partitioned less carbohydrate to roots. Strawberry utilizes nitrate more effectively than ammonium during flowering and fruiting, which could also influence recovery (Ganmore-Neumann and Kafkafi, 1985). Inherent cultivar variation and environmental effects on soil N conversion and recovery potential could have been factors also.

The total IRN content per plant exceeded that of SRN in vegetative tissues of both cultivars at both sampling dates, and leaf IRN content was the greatest single N pool (Table 3). Although Long and Murneek (1937) observed a seasonal decline in total N

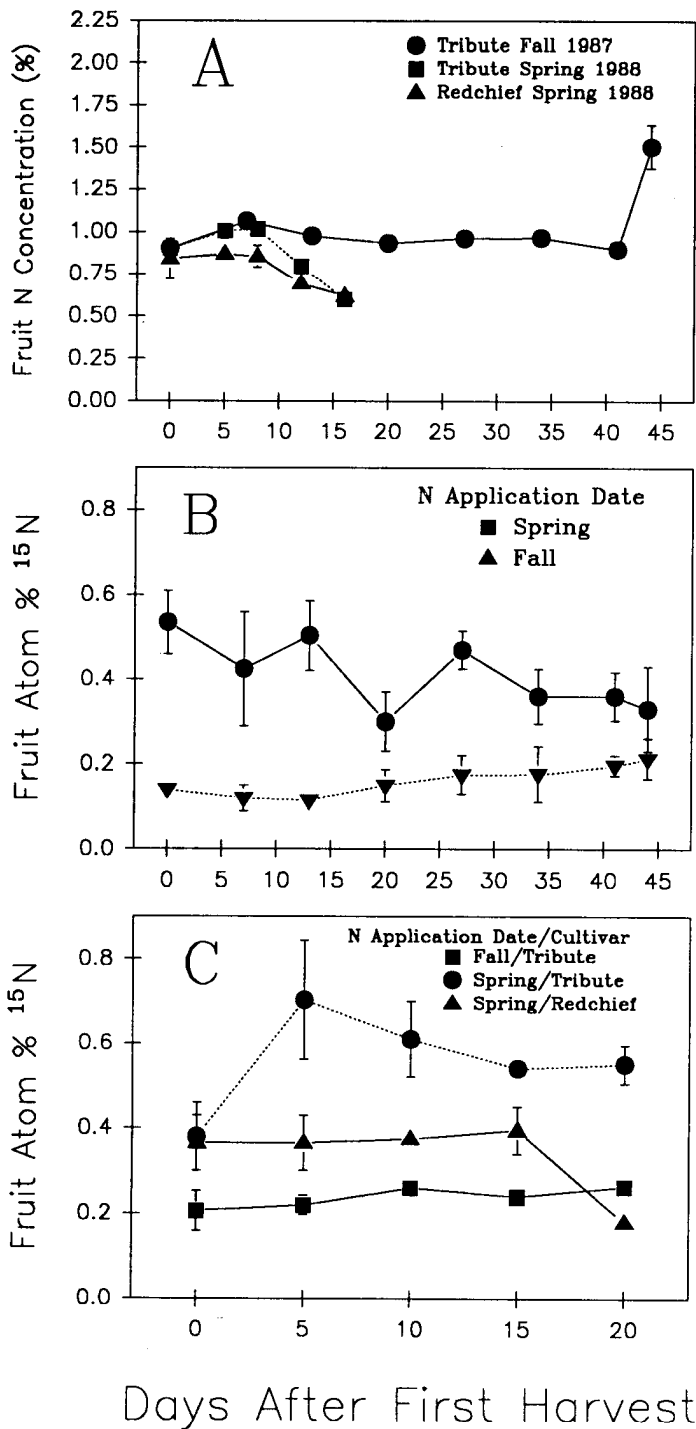


Fig. 1. Fruit N concentration and enrichment with ¹⁵N, Expt. 2, 1987–88. (A) Fruit N concentration at each harvest date in the fall 'Tribute' crop and the spring 'Tribute' and 'Redchief' crops, (B) Fruit N enrichment with ¹⁵N at each fall harvest date for 'Tribute', (C) Fruit N enrichment with ¹⁵N at each spring harvest date for 'Tribute' and 'Redchief'. Each point is the mean of three replications. If the SE bar is not evident, the SE was smaller than the symbol.

content of most vegetative tissues, consistent seasonal differences in N content of the pools were not evident in any tissue except roots across cultivars or experiments in this study. Across experiments and cultivars, root SRN content declined >80% from November to June, while root IRN content varied <20%. Root dry weight and total plant N increased in both cultivars, so more N was absorbed from November to June. The decline in root SRN content maybe

an important physiological aspect of growth resumption and fruiting in the spring. Storage N reserves contribute significantly to early season vegetative and reproductive growth in herbaceous and woody species (Birkhold and Darnell, 1993; Cyr and Bewley, 1989; Deng et al., 1989; Millard and Thomson, 1989; Sanchez et al., 1991), as well as to reproductive growth in herbaceous annual crops (Ta and Weiland, 1992; Van Sanford and MacKown, 1987). Root N as amino acids (Sagisaka, 1987) may provide a readily mobile storage reserve.

Partitioning of FN among vegetative tissues was a function of season of FN application, cropping pattern, and the total biomass of the individual tissue. Within component tissues, FN was allocated to the SRN and IRN pools (Tables 4 and 5). The leaf IRN pool was the single largest vegetative sink for FN in 'Redchief' (Table 4) as it was for total N. In November, the FN content of the IRN pool in all 'Redchief' tissues was greater than that in the SRN pool regardless of N application date. Both pools in all vegetative tissues exhibited a decline in FN content from November to June in plants receiving FN in September. However, the IRN pool of crown and root tissues of 'Redchief' plants receiving FN at planting exhibited increased FN content by June, a pattern repeated in Expt. 2 (data not shown). Continued absorption of FN from the soil and remobilization of FN from tissues exhibiting the November to June decline could account for this trend. New foliage produced in the spring probably plays a greater role as a N sink than a source, and the decline in foliar FN content likely reflects both remobilization and absorption during spring growth.

Regardless of FN application date, the FN content of the IRN pool in all 'Tribute' tissues was generally greater than the SRN pool on both sampling dates (Table 5). Although the foliar IRN pool was generally the largest vegetative sink for FN, root IRN in November contained more FN in plants receiving FN in September. However, as described previously for total FN recovery, the FN content of all tissues except the roots was less in November when FN was applied in September than at planting. In plants receiving FN in September, the pools in most tissues except roots contained more FN in June than in November. The FN content of the root SRN pool declined from November to June for both application dates, similar to the decline observed in 'Redchief' root tissue.

During the fall 'Tribute' harvest, fruit N concentration generally did not vary (Fig. 1A). Fruit N concentration of both cultivars declined slightly as harvest progressed in the spring. Fruit exhibited high levels of both N pools compared to vegetative tissues and, as in vegetative tissue, the values of IRN were greater than the SRN values (Table 3). The June FN application enriched fall fruit N in 'Tribute' more than the September FN application in spite of the latter application during the fall cropping period (Fig. 1B). Thus, fruit development was a greater sink for storage FN acquired in the months before cropping than for newly absorbed N. During the subsequent spring harvest, the September FN application enriched fruit more than the planting FN application (Fig. 1C). 'Redchief' fruit tissue ¹⁵N enrichment from FN applied at planting was generally greater than that for 'Tribute' during the spring harvest. This implies the depletion of plant FN by the fall Tribute fruit crop, since both cultivars experienced the same seasonal environments influencing N availability in the soil profile. Achene tissue from 'Redchief' fruit had a greater N concentration than receptacle tissue, 2.4% vs. 0.7%, respectively, but they had the same level of fertilizer N enrichment. Both tissues accumulated slightly more fall-applied than spring-applied FN, 0.38 vs. 0.26%, respectively. A similar pattern of late season N application accumulation by fruit tissues the subsequent season has been observed in other fruit crops (Weinbaum et al., 1980).

Some general trends were observed in this study. Total N and FN content were related to biomass production ($r = 0.81$, $P < 0.05$). Thus, the N requirement of day-neutral varieties cropped over several months would be significantly greater than that of June-bearing varieties. From total recovery (Table 2) and per plant values (Tables 4 and 5), it was evident that FN recovery occurred over a long interval after FN application, indicating that FN remained available in the soil profile through the end of the experiments. Fruiting affected FN recovery during the fall cropping period as total recovery was very low in November but increased through June when 'Tribute' received FN in September. The reduced level of FN recovery by both cultivars after planting and by Tribute during fruiting suggested that application rates and timing should be tailored to the plants' needs and their ability to absorb N.

Internal N cycling, as described for other perennial crops (Deng et al., 1989; Millard and Neilsen, 1989; Sanchez et al., 1991; Titus and Kang, 1982), was evident, especially in strawberry roots. A consideration of N cycling including the nitrate pool would be valuable, although the nitrate pool may be small in comparison to the reduced N pools. The total N in the reduced N pools was >90% of the total vegetative tissue N (data not shown). Fertilizer N distribution generally followed the patterns of total N partitioning among tissues and allocation between SRN and IRN pools. Although seasonal variation was evident, only total N and FN content of the root SRN pool consistently declined from November to June in both cultivars and experiments independent of FN application date. The SRN pool of root tissue may play a significant role in storage and internal cycling of N, which may be remobilized to vegetative and reproductive growth in the spring. Both storage and newly absorbed N and FN may be partitioned to the fruit crop although storage reserves may contribute proportionally more during the cropping period.

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