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Strain and Rootstock Effects on Spur Characteristics and Yield of 'Delicious' Apple Strains

Ian J. Warrington[1], David C. Ferree, and James R. Schupp[2]
Department of Horticulture, The Ohio Agricultural Research and Development Center, The Ohio State University, Wooster, OH 44691

Frank G. Dennis, Jr.
Department of Horticulture, Michigan State University, East Lansing, MI 48824

Tara A. Baugher
West Virginia University Experiment Farm, Box 303, Kearneysville, WV 25430

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Abstract. **The characteristics of l-year-old vegetative spurs growing on 2-year-old branches were measured on 28 'Delicious' apple *(Malus domestica* Borkh.) strains growing on M.7 rootstocks at Clarksville, Mich., and on 23 strains of 'Delicious' on M.7a rootstocks at Kearneysville, W.Va. Spur-type strains typically had densities >20 to 21 spurs/m, and high spur leaf numbers, leaf areas per spur, leaf areas per leaf, and terminal bud diameters, whereas values for standard strains were generally lower. However, for most spur quality characteristics, there was a continuous range of values between the extremes rather than any distinct grouping into either spur or standard type. At both sites, spur density was significantly and positively correlated with yield efficiency. In a related study, the spur characteristics of 'Starkspur Supreme' were measured on nine rootstocks: M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, MAC 9, MAC 24, OAR 1, and Ottawa 3. Spur leaf number and spur leaf area were both high with vigorous rootstocks, whereas spur density was low. The rootstocks MAC 9, M.9, and M.9 EMLA had the highest yield efficiencies.**

A feature of red apple cultivars in general, and of 'Delicious' in particular, is the availability of many different strains from commercial nurseries (Tukey and Ballard, 1969a). Most 'Delicious' strains have been selected primarily either for some specific fruit characteristic (mainly color and shape) or for a particular type of growth and related spur-bearing habit that is predominantly either a spur type or standard form (Fisher and Ketchie, 1981; Tukey and Ballard, 1969b). However, while fruit characteristics are well known and definable (Crassweller et al., 1985; Fisher and Ketchie, 1981; Ingle, 1972; Lord et al., 1980), few data are available on the yield performance of the different strains or on the relative performance of strains within and among apple-producing regions (Dozier et al., 1984; Ferree et al., 1975; Ketchie, 1984, 1987; Lord et al., 1980; Rom and Ferree, 1984). Therefore, the selection of the most appropriate and highest-yielding strains for a particular region is not possible unless either comparative regional trials are carried out (Ketchie, 1987) or indices can be identified that would allow a prediction to be made of relative performance.

An obvious difference in the growth characteristics of various 'Delicious' strains is the degree of spur-bearing habit. Spur leaves are critically important for fruit development (Ferree and Palmer, 1982), and differences in spur habit and form may, therefore, influence fruit yield and the distribution of fruit on a tree. Before bloom, spur leaves constitute the major leaf area on a tree and provide the majority of photosynthate available for early fruit growth and development (Hansen, 1971). During fruit set and the cell division phase of fruit growth, spur leaves play a major role in determining fruit size, shape, and fruit calcium concentration (Ferree and Palmer, 1982). The removal of spur leaves before and during bloom reduces fruit set (Dalbro, 1966), while a certain minimum spur leaf area is necessary for flower bud formation (Harley et al., 1942).

Differences among apple cultivars for spur diameter, flower number, spur leaf number, area, and individual spur leaf size have been reported, and total spur leaf area or average spur leaf size has been related to tree productivity, yield efficiency, and yield variation (Rom and Ferree, 1984). The objective of this study was to evaluate these relationships on various commercially designated spur and standard 'Delicious' strains growing in two locations. In addition, the influence of rootstock on spur quality, tree size, and yield of 'Starkspur Supreme Delicious' was investigated on trees planted at the Ohio Agricultural Research and Development Center (OARDC), Wooster.

(Throughout the manuscript, the word 'Delicious' has been deleted from each strain name to avoid unnecessary repetition.)

Materials and Methods

Twenty-eight 'Delicious' strains were evaluated at the Michigan State Univ. Clarksville Horticultural Research Station (Table 1). The trees were established in 1980 in a planting 18 trees long and 21 rows wide, with each strain represented by one tree in each of six blocks. All of the strains studied were planted on M.7 EMLA rootstock. An equal number of trees on MM.111 EMLA rootstock were randomly distributed among the study trees, and four individual trees of 'Idared' were included in each block as pollenizers. Trees of similar age and size surrounded the planting. The within/between row spacing was 3.65 × 5.5 m. The trees were part of a cooperative research program to

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[1]Present address: Plant Physiology Division, DSIR, Private Baa, Palmerston North, New Zealand.
[2]Present address: Highmoor Farm, Univ. of Maine, PO Box 178, Monmouth, ME 04259.

Table 1. ‘Delicious’ strains studied, name of the supplying nursery, plant patent number, growth type, and location of study site.

Strain	Nursery company	U.S. plant patent	Growth type	Study site
Ace	Columbia Basin*		Spur	Michigan
ACN 501	Adams County[y]		Spur	West Virginia
Aomori	Stark Bros.[x]		Standard	Michigan, West Virginia
Apex	Columbia Basin		Spur	Michigan, West Virginia
Atwood	Yakima Valley[w]		Spur	Michigan
August Red	Heath[v]		Standard	Michigan
Cascade Spur	Carlton[u]	4801	Spur	West Virginia
Classic Red	C&O[t]	3182	Standard	Michigan, West Virginia
Early Red One	Van Well[s]	3556	Standard	Michigan
Hardi-Brite Spur	Carlton		Spur	Michigan
Hardispur	Carlton		spur	Michigan
Hi-Early	Heath		Standard	Michigan
Imperial	Hilltop	1805	Standard	Michigan, West Virginia
Improved Ryanred	Carlton		Standard	Michigan, West Virginia
Improved Ryan Spur	Carlton		Spur	Michigan
Nured Royal	C&O		Standard	Michigan, West Virginia
Redchief (Campbell)	Hilltop	3578	Spur	Michigan, West Virginia
Red King Oregon Spur	Van Well	2816	Spur	Michigan
Red Prince	Hilltop	2285	Standard	West Virginia
Redspur	C&O	1822	Spur	Michigan, West Virginia
Rose Red	McCormick[q]	3485	Standard	Michigan
Ryanred Spur	Carlton		Spur	West Virginia
Sharp Red	Van Well		Standard	Michigan, West Virginia
Silver Spur	Bountiful Ridge[p]		Spur	Michigan
Spured Royal	C&O	3864	Spur	Michigan
Starking (Mood)	Stark Bros.		Standard	Michigan
Starkrimson (Bisbee)	Stark Bros.	1565	Spur	Michigan, West Virginia
Starkspur Supreme	Stark Bros.	3541	Spur	Michigan, West Virginia
Starkspur Ultrared	Stark Bros.	3557	Spur	Michigan, West Virginia
Starkspur UltraStripe	Stark Bros.	5472	Spur	West Virginia
Sturdeespur (Miller Sturdeespur)	Hilltop	2433	Spur	Michigan, West Virginia
Topred	C&O	1916	Standard	Michigan, West Virginia
Topspur	C&O	5334	Spur	West Virginia
Triple Red	Adams County		Standard	West Virginia
Wellspur	Van Well		Spur	Michigan, West Virginia

[z]Columbia Basin, P.O. Box 458, Quincy, WA 98848.
[y]Adams County Nursery, Inc., P.O. Box 108, Aspers, PA 17304.
[x]Stark Bros. Nurseries and Orchards Co., Louisiana, MO 63353.
[w]Yakima Valley Nursery, 6461 W. Powerhouse Rd., Yakima, WA 98908.
[v]Heath Nursery, Brewster, WA 98812.
[u]Carlton Plants, P.O. Box 398, Dayton, OR 97114.
[t]C&O Nursery, P.O. Box 116, Wenatchee, WA 98801-0122.
[s]Van Well Nursery, P.O. Box 1339, Wenatchee, WA 98801.
[r]Hilltop Orchards & Nurseries, Inc., P.O. Box 578, CR 681, Hartford, MI 49057.
[q]McCormick Fruit Tree Co., 6111-A Englewood Ave., Yakima, WA 98908.
[p]Bountiful Ridge Nursery, Princess Anne, MD 21853.

evaluate ‘Delicious strains at eight locations in the United States and in British Columbia (Ketchie, 1987).

Of the 23 strains at the West Virginia Univ. Experiment Farm at Kearneysville (Table 1), 15 were planted in Apr. 1981, six (‘Starkspur’, ‘Ultrared’, ‘Starkrimson’, ‘Starkspur Supreme’, ‘Aomori’, and ‘Cascade Spur’) in Apr. 1982, and three (‘Starkspur UltraStripe’, ‘ACN 501’, and ‘Redchief) in Mar. 1983. They were arranged in a single planting 45 trees long and 11 rows wide, with. each strain represented in two blocks of five trees randomly distributed within the planting. ‘Topspur’ was planted in only one block. A similar number of block of trees on rootstocks other than those on M.7a used for the study were randomly distributed throughout the planting. A tree of ‘Golden Delicious’/M.26 was planted between the two blocks of five trees within each row. The within/between row spacing was 4.9 × 6.1 m.

Trees in both plantings were trained to a central leader and lateral branches were headed. Other pruning and training were minimal, allowing the trees to grow as close to their natural form as possible. The fruit was not chemically thinned and hand thinning was minimal. Otherwise, standard cultural practices were followed.

The influence of rootstock on ‘Delicious’ performance was studied using trees in the North Central Regional Project (NC-140) planted in 1980 at the OARDC Horticulture Unit 2 at Wooster, Ohio. ‘Starkspur Supreme’ (Paganelli selection) was budded onto the following rootstocks: Ottawa 3, M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, MAC 9 (Mark), MAC 24, and OAR 1. Ten trees of each rootstock were randomly planted in a block 20 trees long and six rows wide at a spacing of 3.5 × 5.5 m. 'Macspur' and 'Starkspur Golden Delicious' were used as pollenizers.

All spur characteristics were measured on 1-year-old vegatative spurs graving on 2-year-old branches. Five spurs were removed, and leaf number, leaf area, leaf dry weight, and terminal bud diameter were measured. Spur density was determined by measuring the length of 2-year-old growth on five randomly selected branches and counting the spurs within that section.

Samples were collected at Clarksville on 17 June 1986, at Kearneysville on 23 Sept. 1986, and at Wooster on 13 Aug. 1986. Fruit were picked at the commercial harvest time in each region. At Clarksville and Wooster, harvests were made of individual trees, while at Kearneysville, values were recorded for the five-tree replicates.

Results

Density of spurs. The density of spurs on 2-year-old branches varied widely at both sites and both within and between spur and standard types. Within the commercially designated spur types at Clarksville (Table 2), spur density (all per meter length) varied from 24 in 'Starkspur Ultrared' to 34 in 'Hardi-Brite Spur'. At Kearneysville (Table 3), the range extended from 19 in 'Topspur' to 39 in 'Sturdeespur'. Among the standard types, spur density ranged from 22 in 'Improved Ryanred' to 14 in 'Sharp Red' at Clarksville and from 32 in 'Imperial' to 15 in 'Nured Royal' at Kearneysville.

Where the same strains were assessed at both sites, the ranking of strains, with respect 'to spur density, was similar, except for 'Starkrimson', which had a lower relative density at Kearneysville. With the exception of 'Starkrimson', 'Wellspur', and 'Nured Royal', spur density was consistently higher (by 13% on average) at Kearneysville than at Clarksville. At Kearneysville, only one or two strains, designated as spur or standard types, did not fit closely into the respective groups containing similar types. Spur density was greater for the standard strain 'Imperial' and less for the spur strain 'Topspur' than for other similar types.

At both sites, the spur-type strains generally had a spur density >20 to 21 spurs/m, while the standard types had a lower density. However, the classification of strains into standard or spur types was only relative; there was a steady gradation of, spur density from the most to the least spur bearing, with no major separation on between types.

***Leaf** number per spur.* The number of leaves per spur was generally higher for spur-type strains than for standard strains. At Kearneysville (Table 3), spur types ranged from 8.2 ('Redspur') to 6.9 ('Wellspur') and standard types from 6.9 ('Aomori') to 5.9 ('Sharp Red'). The same trend was apparent in the Clarksville data (Table 2). In strains common to both sites, leaf numbers per spur were similar.

Leaf area per spur. Leaf area/spur varied almost 2-fold between the highest- and lowest-ranking strains at each site. Although the ranking was not identical for those strains that were common to both sites, there were some consistent trends. For

Table 2. Characteristics of 1-year-old vegetative spurs from 28 'Delicious' apple strains growing at the Michigan State Univ. Clarksville Horticultural Research Station.[z]

Delicious strain	Type	Spur density (no./m)	Leaf no./spur	Leaf area/spur (cm^2)	Leaf area/leaf (cm^2)	specific leaf wt ($mg \cdot cm^{-2}$)	Bud diam (mm)
Hardi-Brite Spur	Spur	34	7.9	103	13.2	9.57	3.10
Improved Ryan Spur	Spur	33	7.5	99	13.1	8.56	2.97
Red King Oregon Spur	Spur	31	7.5	99	13.2	9.67	3.08
Starkrimson	Spur	31	7.2	86	12.0	9.44	2.79
Spured Royal	Spur	31	7.9	89	11.4	9.08	2.94
Redchief	Spur	29	8.2	88	10.7	9.80	2.94
Hardispur	Spur	29	7.5	96	12.9	9.66	2.88
Redspur	Spur	29	7.9	88	11.1	9.33	2.85
Silverspur	Spur	28	7.6	102	13.4	9.01	2.92
Ace	Spur	28	8.0	109	13.8	8.95	3.09
Sturdeespur	Spur	28	8.1	102	12.6	9.63	3.04
Apex	Spur	28	7.8	98	12.6	9.25	3.02
Starkspur Supreme	Spur	28	8.0	77	9.7	9.68	2.78
Wellspur	Spur	27	8.0	96	12.0	9.37	2.91
Atwood	Spur	25	8.1	92	11.3	9.33	2.97
Atwood	Spur	25	8.7	110	12.6	9.22	2.98
Improved Ryanred	Standard	22	6.7	65	9.6	9.41	2.69
Early Red One	Standard	21	7.8	66	8.4	9.19	2.82
Imperial	Standard	20	6.8	69	10.2	9.35	2.79
August Red	Standard	18	7.6	73	9.8	8.60	2.65
Nured Royal	Standard	18	7.2	95	13.1	8.53	2.95
Starking (Mood)	Standard	18	7.2	79	11.0	9.17	2.80
Rose Red	Standard	17	7.1	82	11.5	8.97	2.85
Classic Red	Standard	16	7.5	84	11.4	9.14	2.81
Aomori	Standard	15	7.1	67	9.5	9.50	2.68
Topred	Standard	15	6.8	82	12.0	8.23	2.78
Hi-Early	Standard	15	6.9	73	10.6	8.98	2.79
Sharp Red	Standard	14	6.9	74	10.9	8.99	2.82
LSD ($P < 0.05$)		6	0.8	16	1.7	0.72	0.22

[z]Data are means of six replications.

Table 3. Characteristics of 1-year-old vegetative spurs from 23 'Delicious' apple strains growing at the West Virginia Univ. Experiment Farm, Kearneysville.[z]

Delicious strain	Type	Spur density (no./m)	Leaf no./spur	Leaf area/spur (cm^2)	Leaf area/leaf (cm^2)	Specific leaf wt ($mg \cdot cm^{-2}$)	Bud diam (mm)
Sturdeespur	Spur	39	7.5	79	10.5	11.0	3.80
Redchief	Spur	38	7.6	88	11.6	11.4	3.78
Starkspur ultraStripe	Spur	36	7.9	96	12.2	11.6	4.19
Redspur	Spur	33	8.2	86	10.4	11.9	3.78
Ace	Spur	33	8.0	88	10.8	11.8	4.20
Imperial	Standard	32	6.4	61	9.4	11.3	3.96
Apex	Spur	29	8.1	86	10.6	12.0	4.05
Starkspur Supreme	Spur	29	7.7	76	9.8	12.1	3.62
Cascade Spur	Spur	29	8.0	95	11.8	12.2	4.11
ACN 501	Spur	29	7.6	105	13.7	11.6	4.18
Starkspur Ultrared	Spur	28	7.7	88	11.4	12.0	3.91
Ryanred Spur	Spur	27	7.6	95	12.5	11.9	4.04
Starkrimson	Spur	26	7.2	90	12.4	11.4	3.97
Improved Ryanred	Standard	25	6.8	57	8.4	11.7	3.71
Wellspur	Spur	24	6.9	74	10.6	11.8	3.97
Triple Red	Standard	20	6.0	67	11.2	10.7	3.81
Classic Red	Standard	20	6.6	73	10.9	11.3	3.92
Red Prince	Standard	19	6.1	71	11.5	11.3	3.81
Topspur	Spur	19	7.0	76	10.8	12.1	3.73
Aomori	Standard	18	6.9	81	11.6	11.5	3.93
Topred	Standard	18	6.4	72	11.2	11.3	3.73
Sharp Red	Standard	16	5.9	66	11.1	11.3	3.76
Nured Royal	Standard	15	6.4	73	11.3	10.9	3.72
LSD ($P < 0.05$)		9	0.6	11	1.3	---[y]	0.23

[z]Data are means of two blocks, each containing five trees.
[y]Pooled weight values; no statistical analysis possible.

example, 'Starkspur Ultrared' had a large leaf area/spur at both sites; 'Improved Ryan Red', 'Imperial', and 'Sharp Red' had small areas; and 'Redchief', 'Redspur', 'Apex', and 'Starkspur Supreme' were intermediate.

Spur-type strains generally had a greater leaf area/spur than standard strains. At Clarksville, the leaf area/spur for spur types ranged from 110 ('Starkspur Ultrared') to 77 cm^2 ('Starkspur Supreme'), while standard types, except 'Nured Royal' (95 cm^2), had values ranging from 84 ('Classic Red') to 65 cm^2 ('Improved Ryan Red'). At Kearneysville (Table 3), spur-types ranged from 105 ('ACN 501') to 74 cm^2 ('Wellspur') and standard types, except 'Aomori' (80 cm^2), from 73 ('Nured Royal') to 57 cm^2 ('Improved Ryanred').

Leaf area per leaf. Differences in leaf area per spur among strains arose from differences in both leaf number per spur and leaf area per leaf. Within each growth type, some strains had high values for both leaf number and area, including 'ACN 501', 'Ace', and 'Sturdeespur' (Clarksville only), while others, such as 'Early Red One' and 'Improved Ryanred', had low values for both characters.

Specific leaf weight. The specific leaf weight of spur leaves did not vary markedly among strains at either of the two sites (Tables 2 and 3). However, spur-type strains generally had higher specific leaf weights than standard strains, the separation between types being most apparent at Kearneysville. Although the ranking of strains was quite different between the two sites, some strains were consistent in their placement; the specific leaf weights of 'Starkspur Supreme' and 'Sturdeespur' were high at both sites, while those of 'Sharp Red' and 'Topred' were consistently low.

Bud diameter. Differences in spur bud diameter among strains were small, and variability within each sample was considerable. However, spur-type strains generally had larger bud diameters than standard types. The smaller bud diameters at Clarksville (Table 2) than at Kearneysville were probably a consequence of the earlier sampling date.

Yield efficiency. Spur-type strains generally had a higher yield efficiency (i.e., yield/trunk cross-sectional area) at both sites. At Clarksville, the spur types 'Improved Ryan Spur', 'Atwood', 'Ace', 'Sturdeespur', and 'Apex' had high yields and high yield efficiencies, and the standard strains 'Aomori' and 'Sharp Red' had low values (Table 4). However, the standard strain 'Early Red One' had both the highest yield and yield efficiency. Individual mean fruit weight was largely unrelated to strain type or tree yield. At Kearneysville, the spur types 'Sturdeespur', 'Ace', and 'Redspur' from the 1981 planting and 'Cascade Spur' from the 1982 planting had the highest yields and the highest yield efficiencies (Table 5). The standard strains 'Triple Red', 'Sharp Red', and 'Aomori' had low values. Two standard strains, 'Imperial' and 'Improved Ryan Red', had yield efficiencies similar to those in the midrange for spur types and, perhaps because of the younger trees, 'Redchief' had a low yield efficiency when compared with other spur types.

Many of the different indices that were measured to determine spur quality in this study were closely and positively interrelated (Tables 6 and 7). Spur bud diameter was significantly correlated with spur leaf number, spur leaf area (Fig. 1), and leaf area per leaf, as was spur leaf number to area. Similarly, spur density was generally significantly correlated with bud diameter, spur leaf number, and spur leaf area (Fig. 2). Although many of the correlation coefficients were small, there was no indication that high spur densities were associated with a decline in quality of other spur attributes. At both sites in our study, spur density was negatively correlated with trunk cross-sectional area (Fig.

Table 4. Trunk cross-sectional area (TCSA), fruit size, and yield of 28 ‘Delicious’ apple strains growing at the Michigan State Univ. Clarksville Horticultural Research Station.[z]

Delicious strain	Type	TCSA (cm^2)	Wt/fruit (g)	Yield/tree (kg)	Yield/TCSA ($kg \cdot cm^{-2}$)
Hardi-Brite Spur	Spur	30.6	191	23.6	0.77
Improved Ryan Spur	Spur	40.8	203	37.9	0.93
Red King Oregon Spur	Spur.	37.4	207	29.0	0.79
Starkrimson	Spur	38.4	179	22.6	0.62
Spured Royal	Spur	32.1	164	26.5	0.85
Redchief	Spur	43.9	207	23.3	0.51
Hardispur	Spur	36.0	196	27.3	0.76
Redspur	Spur	40.9	182	27.0	0.65
Silverspur	Spur	42.0	174	29.2	0.71
Ace	Spur	38.5	188	34.5	0.92
Sturdeespur	Spur	41.3	183		0.83
Apex	Spur	38.5	188	31.8	0.83
Starkspur Supreme	Spur	42.6		31.5	0.72
Wellspur	Spur	41.6	175	26.4	0.65
Wellspur	Spur	34.6	175	33.1	0.95
Starkspur Ultrared	Spur	33.1	198	11.2	0.39
Improved Ryanred	Standard	5 . 6	201	28.5	0.54
Imperial	Standard	47.7	205	28.0	0.57
Early Red One	Standard	40.3	180	44.2	1.09
August Red	Standard	55.1	206	30.3	0.56
Nured Royal	Standard	62.8	200	20.6	0.32
Starking (Mood)	Standard	64.2	212	28.9	0.48
Rose Red	Standard	59.2	210	43.9	0.80
Classic Red	Standard	62.3	206	29.9	0.48
Aomori	Standard.	57.5	201	15.3	0.27
Topred	Standard	59.0	202	23.1	0.38
Hi-Early	Standard	60.0	213	20.3	0.35
Sharp Red	Standard	51.9	149	14.2	0.27
LSD ($P < 0.05$)		12.7	28.9	11.2	0.45

[z]Data are means of six replications.

Table 5. Trunk cross-sectional area (TCSA) and yield of 23 ‘Delicious’ apple strains growing at the West Virginia Univ. Experiment Farm, Kearneysvlle.[z]

Delicious strain	Type	TCSA (cm^2)	Yield/tree (kg)	Yield/TCSA ($kg \cdot cm^{-2}$)
Sturdeespur	Spur	17.9	20.1	1.13
Redchief	Spur	7.3	2.4	0.32
Starkspur UltraStripe	Spur	5.4	3.8	0.69
Redspur	Spur	21.0	19.0	0.92
Ace	Spur	15.0	17.6	1.27
Imperial	Standard	24.6	22.4	0.87
Apex	Spur	17.1	12.4	0.76
Starkspur Supreme	Spur	20.4	9.0	0.55
Cascade Spur	Spur	15.8	17.7	1.11
ACN 501	Spur	5.0	3.3	0.69
Starkspur Ultrared	Spur	16.7	8.1	0.47
Ryanred Spur	Spur	17.5	13.8	0.82
Starkrimson	Spur	35.7	11.3	0.31
Improved Ryanred	Standard	22.4	15.7	0.70
Wellspur	Standard	26.3	12.4	0.47
Triple Red	Standard	24.5	7.6	0.31
Classic Red	Standard	29.9	11.4	0.38
Red Prince	Standard	34.6	12.4	0.37
Topspur	Spur	---	---	---
Aomori	Standard	24.5	5.7	0.26
Topred	Standard	23.7	8.1	0.35
Sharp Red	Standard	29.6	4.7	0.16
Nured Royal	Standard	26.2	11.4	0.43
LSD ($P < 0.05$)		8.1	8.7	0.46

[z]Data are means of two blocks, each containing five trees.

Table 6. Correlation coefficients between spur characteristics and yield indices of 'Delicious' strains growing at the Michigan State Univ. Clarksville Horticultural Research Station.

Spur and yield characteristics	Bud diam	Leaf no./spur	Leaf area/spur	Specific leaf wt	Leaf area/leaf	Spur density	Trunk cross-sectional area (TCSA)	Wt/fruit	Yield/tree
Leaf no./spur	0.26**								
Leaf area/spur	0.54**	0.55**							
Specific leaf wt	0.07	0.04	-0.21*						
Leaf area/leaf	0.49**	0.08	0.87**	-039**					
Spur density	0.30**	0.39**	0.35**	-0.07	0.20				
TCSA	-0.15*	-0.35**	-0.23**	-0.02	-0.05	-0.56**			
Wt/fruit	-0.09	-0.12	-0.06	-0.06	0.01	-0.16*	0.39**		
Yield/tree	0.15	0.01	0.00	0.14	-0.06	0.12	0.07	0.00	
Yield efficiency	0.19*	0.14	0.08	0.08	-0.01	0.23**	-0.55**	-0.64**	0.36**

*,**Significant at P = 0.05 or 0.01, respectively.

Table 7. Correlation coefficients between spur characteristics and yield indices of 'Delicious' strains growing at the West Virginia Univ. Experiment Farm, Kearneysville.

Spur and yield characteristics	Bud diam	Leaf no./spur	Leaf area/spur	Specific leaf wt	Leaf area/leaf	Spur density	Trunk cross-sectional area (TCSA)	Yield/tree
Leaf no./spur	0.52**							
Leaf area/spur	0.66**	0.23**						
Specific leaf w-t	0.16	0.66**	0.49*					
Leaf area/leaf	0.50**	0.19	0.78**	0.04				
Spur density	0.37	0.72**	0.45*	0.30	-0.02			
TCSA	-0.46*	-0.71**	-0.62**	-0.35	-0.28	-0.65**		
Yield/tree	0.08	0.14	-0.06	0.08	-0.35	0.33	0.17	
Yield efficiency	0.47*	0.57**	0.39*	0.36	-0.04	0.66**	- 0.43*	0.76**

*,**Significant at P = 0.05 or 0.01, respectively.

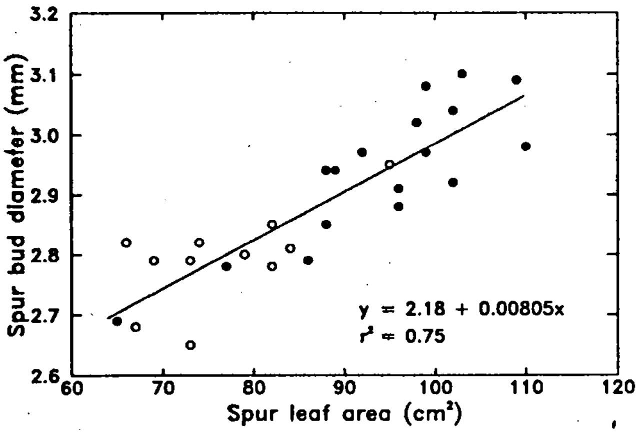

Fig. 1. Relationship between spur leaf area and terminal bud diameter for 28 'Delicious' strains growing at Clarksville, Mich. (●, spur-type strains; ❍, standard strains). Data are means of six observations.

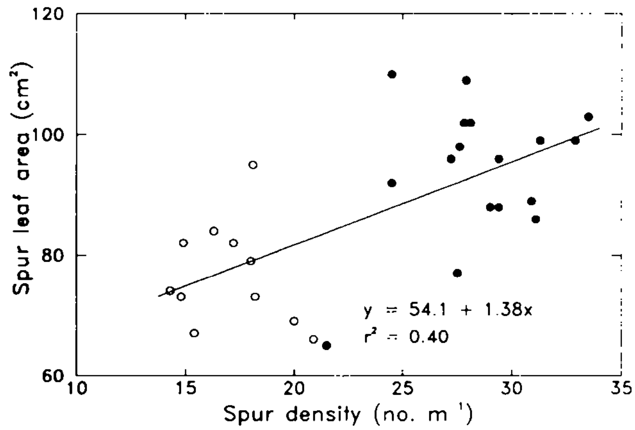

Fig. 2. Relationship between spur density and spur leaf area for 28 'Delicious' strains growing at Clarksville, Mich. (●, spur-type strains; ❍, standard strains). Data are means of six observations.

3), but positively correlated to yield efficiency (Fig. 4), indicating the value of this index in determining differences in tree performance (i.e., efficiency) among strains. In contrast, no spur characters were related to tree yield. Overall, therefore, spur-type strains had a higher density of spurs per unit limb length and were more vigorous with respect to attributes, such as spur leaf area, leaf number, and terminal bud diameter.

Rootstock effects. Rootstock had a considerable influence on the vegetative characteristics of the 'Starkspur Supreme' spurs. The number of leaves per spur, leaf area per spur, and leaf area per leaf were highest on MAC 24 and lowest on the dwarfing rootstocks MAC 9, M.9, and M.27 EMLA (Table 8). Scion vigor (trunk cross-sectional area) values showed very similar trends (Table 9). In contrast, specific leaf weight was least for the most vigorous rootstocks–MAC 24, OAR 1, and M.7 EMLA (Table 8).

Spur density differences were small. However, MAC 9, one of the least vigorous dwarfing rootstocks, had the highest density (33 spurs/m), and MAC 24, one of the most vigorous, the lowest density (19 spurs/m). The spur density on all other rootstocks was between 22 and 29 spurs/m.

Cumulative yield was highest for the most vigorous rootstock, MAC 24, and lowest for the least, M.27 EMLA. Other rootstocks followed a similar general relationship, except for OAR

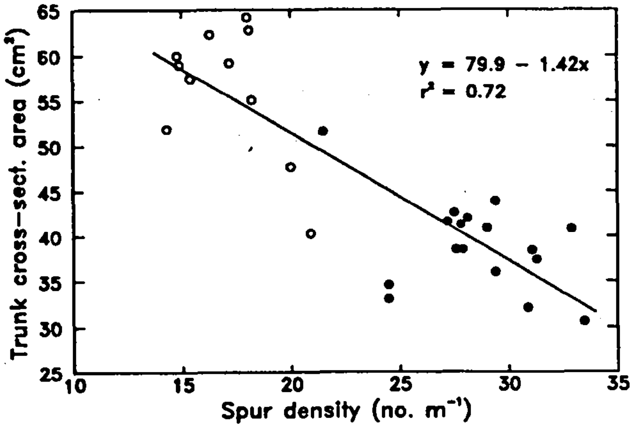

Fig. 3. Relationship between spur density and trunk cress-sectional area for 28 'Delicious' strains growing at Clarksville, Mich. (● , spur-type strains; ❍ , standard strains). Data are means of six observations.

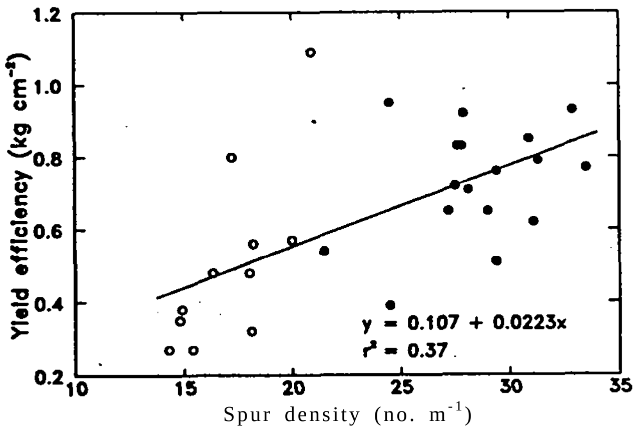

Fig. 4. Relationship between spur density and yield efficiency (i.e., yield/trunk cross-sectional area) for 28 'Delicious' strains growing at Clarksville, Mich. (● , spur-type strains; ❍ , standard strains). Data are means of six observations.

1, which had a low cumulative yield. This rootstock also had the lowest yield efficiency, while MAC 9, M.9, and M.9 EMLA had the highest (Table 9). When vegetative growth and yield of 'Starkspur Supreme' on the two closely related rootstocks M.9 and M.9 EMLA were compared, few of the differences between the two rootstocks were statistically significant. However, some indices of spur (leaf number and leaf area per spur) and tree (TCSA) vigor, together with cumulative yield, were higher with the virus-free M.9 EMLA.

Discussion

Scion effects. Previous evaluations of 'Delicious' strains and selections have focused primarily on classifying fruit quality and yield characteristics. New strains of 'Delicious' are frequently introduced to the apple industry and the promotion of these strains is largely based on the fruit color and on the timing and nature (stripe or blush) of color development (Crassweller et al., 1985). Comparisons have also been made of fruit maturity among various strains. Strains are also promoted because of their spur habit, but classification of a strain into a spur, semi-spur, or standard type has previously been qualitative rather than quantitative.

Ketchie (1984) assessed 17 strains of 'Delicious' on seedling rootstock at Columbia, Wash., and found that spur types had a significantly higher spur density than standard types. However, some spur types, such as 'Sturdeespur' and 'Earlistripe', had similar spur densities as some standard types, such as 'Ryan', 'Imperial', 'Chelan Red', and 'Red King'. Spur density (all per meter length) ranged from 32 to 42 for spur types and from 25 to 30 for standard types and was stable from year to year. These values compare with 24 to 39 and 14 to 25 spurs/m, respectively, in our study. Specific comparisons of some individual strains are possible. The respective values at Columbia, Clarksville, and Kearneysville were 40, 27, and 24 for 'Wellspur'; 39, 29, and 33 for 'Redspur'; 36, 28, and 39 for 'Sturdeespur'; 30, 20, and 32 for 'Imperial'; and 25, 14, and 16 for 'Sharp Red'. Factors such as site, rootstock, and cropping clearly influence the values obtained, and this variability may prevent classification on the basis of absolute spur density, as proposed by Ketchie (1984). However, classification on a relative basis appears possible, particularly as the ranking of strains between sites appears to be consistent within rootstock.

A characteristic feature of spur-type strains of 'Delicious' apple is their more-compact growth form and associated upright branch habit, compared with the more-open canopy form of standard strains. Consequently, spur-type strains can be planted closer together to maximize canopy development per unit land area. Assessments of productivity, therefore, must be made on the basis of both unit-tree production and unit-area production, and/or yield efficiency (i.e., yield per unit trunk cross-sectional area). Spur-type strains are frequently more productive than standard types, at least during the first 15 years of production. In a comparison of 28 strains growing at Wenatchee, Wash., in

Table 8. Influence of nine rootstocks on spur quality of 'Starkspur Supreme Delicious' (Ohio Agricultural Research and Development Center, 1986).[z]

Rootstock	Leaf no./spur	Leaf area/spur (cm^2)	Leaf area/leaf (cm^2)	specific leaf wt ($mg\cdot cm^{-2}$)	Bud diam (mm)
Ottawa 3	7.3	67.5	9.3	14.6	3.4
M.7 EMLA	6.9	78.0	11.2	12.5	3.6
M.9 EMLA	7.4	64.0	8.7	13.1	3.5
M.26 EMLA	6.9	65.5	9.5	13.2	3.6
M.27 EMLA	6.7	53.4	7.9	13.8	3.6
M.9	6.2	56.6	9.0	12.8	3.8
MAC 9	6.7	57.7	8.4	13.0	3.2
MAC 24	7.5	86.6	11.6	10.8	3.3
OAR 1	7.4	73.4	9.9	11.9	3.3
LSD $P < 0.05$	0.7	9.9	1.1	1.7	NS

[z]Data are means of 10 observations.

Table 9. Influence of nine rootstocks on tree size and yield of 'Starkspur Supreme Delicious' (Ohio Agricultural Research and Development Center, 1986).[z]

Rootstock	Trunk cross-sectional area (cm^2)	Yield/tree (kg)	Yield efficiency ($kg \cdot cm^{-2}$)	Cumulative yield (kg)
Ottawa 3	29.0	28.0	0.86	72.9
M.7 EMLA	47.3	41.2	0.82	79.0
M.9 EMLA	**29.0**	31.0	**1.09**	72.9
M.26 EMLA	**37.3**	33.2	**0.89**	69.9
M.27 EMLA	**8.1**	**4.2**	0.30	12.5
M.9	**17.7**	**21.8**	1.27	49.6
MAC 9	**23.7**	29.7	1.47	64.2
MAC 24	**86.9**	55.8	0.52	107.8
OAR 1	47.7	26.2	0.44	40.3
LSD $P < 0.05$	13.8	14.9	0.54	31.1

[z]Data are means of 10 observations.

a planting identical with that used at Clarksville, Ketchie (1987) found that of the 16 spur-type strains evaluated on M.7 EMLA, 12 were among the 14 highest yielding, based on cumulative yield per tree. In contrast, Lord et al. (1980) found that cumulative yield per tree was higher for six out of seven standard strains than for the spur-type strains 'Sturdeespur' and 'Starkrimson'. This is a surprising result, considering that these same strains produced high yields in Wenatchee (Ketchie, 1987) and in the present study at both Clarksville and Kearneysville. However, yield efficiency was considerably higher for these two spur-type strains. Similarly, Rom and Ferree (1984) found that the standard-type 'Starking' had a higher cumulative yield, but a lower yield efficiency than 'Starkrimson'. Ferree et al. (1975) found that mean cumulative yields per tree, after the first 10 growing seasons, were higher for 13 standard-type strains than for four spur-type strains. However, when tree spacing was adjusted to 7 × 4.5 m for standard types and 5.5 × 2.7 m for spur types, calculated yields per unit land area for spur types were 70% higher than for standard types.

Many of the standard strains evaluated in this study originated as limb or whole-tree variants from the original 'Delicious' (Maas, 1970; Fisher and Ketchie, 1981). These include 'Topred', 'Red Prince', and 'Starking'. Others, such as 'August Red', 'Classic Red', 'Early Red One', 'Hi-Early', and 'Rose Red', all originated less directly from 'Starking'. Of the spur types, many have been selected from 'Starking' also, including 'Redspur', 'Starkrimson', 'Starkspur Supreme', 'Starkspur Ultrared', and 'Wellspur'. Other spur strains have arisen less directly–'Ace' was a selection from 'Red King Oregon Spur' and this strain was selected from the standard strain 'Red King' that arose from 'Starking'. 'Redchief can also be traced back to 'Starking' via 'Starkrimson'. Another spur strain, 'Spured Royal', arose from 'Delicious' via the standard strains 'Richared' and 'Royal Red'; this is the same background as the standard strain 'Nured Royal'. Hence, while several of the spur strains have been selected as improved types or variants from other spur strains, many have also been selected directly from standard strains. As the different strains have arisen through spontaneous mutations from a wide range of sources, a range rather than segregation of values for each vegetative growth character might be expected. This was evident from some of the characters where individual strains did not segregate into distinctly separated spur- or standard-type categories (e.g., Figs. 1, 3, and 4), while for other characters (Fig. 2), some segregation into two distinct populations appears to have occurred.

A density of 20 to 21 spurs/m appeared to separate strains into spur and standard types on the basis of current fruit nursery descriptions and classifications, with spur types tending to have a higher and standard types a lower density. While spur characters were not correlated with tree yield, spur density and bud diameter were highly correlated with yield efficiency at both sites, suggesting that strains can be identified in regard to their yield performance from some spur characteristics.

Rootstock effects. Between two parts of this study, a major difference was identified among the inter-relationships of the various spur quality attributes. Among rootstocks, spur density was negatively related to other vigor attributes, such as spur leaf number and spur leaf area, whereas, among strains, spur density was positively correlated with these factors (Figs. 1 and 2, Tables 6 and 7). The most dwarfing rootstocks, therefore, reduced both stem extension growth (as assessed by spur density) and the vigor of individual spurs. In rootstock breeding and evaluation research, scion performance characteristics that could quantitatively indicate the capacity of a rootstock to control tree size would be particularly useful, especially if they allowed effective selection of desired types at an early stage of a program (Cummins and Aldwinckle, 1983). Previous workers have attempted to use vegetative growth characters as indices of rootstock vigor, but usually have compared leaves and shoots of the rootstock rather than those of a common scion (e.g., Miller, 1977).

In this study, close associations existed between many of the characters measured to define spur quality of the scion and the degree to which a rootstock controlled the overall vigor of the scion. While these results were limited to only nine rootstocks, they did consistently distinguish the most vigorous from the most dwarfing types. These responses were sufficiently consistent to warrant the further evaluation of spur growth responses as screening indices for vigor in rootstock breeding research.

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