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Cultivars of Eastern Black Walnut Trees *(Juglans nigra L.)* Have Greater Nut Yields Than Native Trees at Similar Trunk Cross-Sectional Areas

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Abstract

Orchard production of eastern black walnut (*Juglans nigra* L.) cultivars may be the best way to stabilize the supply of nuts. The objective of this study was to determine if the relationship between trunk cross-sectional area (TCSA) and nut yield is different between cultivars of black walnut and native trees. Data were collected from 13 stands of black walnut (six stands of native trees and seven stands of cultivars) growing in open canopy or free-to-grow circumstances in the central United States for two consecutive years (2002-2003). The regression equations between two-year mean for nut yield per tree and trunk cross-sectional area (TCSA) were highly significant for data from native trees and cultivars of black walnut; however the slopes and Y-intercepts differed. For cultivars, the equation was: two-year mean yield (kg per tree) = 0.0071*(mean TCSA, cm^2) + 1.38. For native trees, the equation was: two-year mean yield (kg per tree) = 0.0049*(mean TCSA, cm^2) – 0.11. When various independent variables were assessed as predictors of two-year means for yield among the 13 stands, the regression equations generated by backward selection included two variables: 1) the tree stock type, i.e. cultivars versus native trees; 2) annual mean increase in TCSA. These analyses indicate that cultivars did differ from native trees in the relationship between TCSA and nut yield per tree.

Historically, most of the nut crop of eastern black walnuts (*Juglans nigra* L.) has come from native trees (4). Production from orchards planted to cultivars selected for improved nut quality characteristics is being promoted by the major processor, Hammons Products Company, Inc., who has initiated a program to buy higher quality nuts at premium prices (4). Creation of black walnut orchards by landowners will be facilitated by a clearer understanding of the economic returns of such a practice. Sound estimates of nut yield are needed to predict the income potential of black walnut orchards. Zarger (14) reported an equation to predict nut yields using tree age, diameter at breast height (DBH), crown radius and tree height as independent variables. In this study, nut yields were averaged over two 4-year periods (1940-1943, and 1944-1947). The R-square of the predictive equation with all four independent variables was 0.52; however, simple correlation coefficients were greatest with DBH and crown radius. Measurements of DBH are exceedingly easy to make. Trunk cross-sectional area (TCSA) can be readily computed from DBH. Thus, predictive equations relating DBH to nut yields would be more desirable than equations using other independent variables. Zarger (13) reported on nut yields and DBH from 1940 to 1946 for over 100 native trees growing in the Tennessee River valley. DBH values varied from 14 to 70 cm, which is equivalent to TCSA of approximately 150 to 4000 cm^2. Data from the Zarger (13) study were utilized by Kincaid (5) to derive the following predictive equation:

Nut yield (kg per tree) = 2.55*(DBH, cm) – 36.91 [Eqn. 1]

However, Ares and Brauer (1) found that the equation from Kincaid (5) did not accurately predict the observed nut yields in nine of 12 stands in 2002.

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The alternate-bearing pattern of black walnuts may be one reason why Ares and Brauer (1) found a poor relationship between the actual nut yields and those predicted by Eqn. [1]. Significant variations from year to year in nut yields from the same tree are thought to be common and textbooks state that "abundant crops are produced irregularly" (12). Many cultivars of black walnut selected for superior nut quality exhibited an alternate bearing pattern when trees were 10 to 15 years of age and beginning commercial nut production (7). Similar, Brauer et al. (3) found that most of the higher-yielding black walnut trees exhibited an alternate-bearing pattern, while trees with low average yield had either sporadic or irregular bearing patterns. Therefore, Brauer et al. (3) recommended that yield data be averaged over at least two consecutive years to determine the yield potential of an individual tree or a stand of trees. The objective of this report was to compare the relationship between TCSA and nut yield from stands of native trees and cultivars selected for improved nut quality using data from consecutive growing seasons for stands of black walnut trees in "free growth" stage (i.e., little or no competition between adjoining tree canopies for sunlight).

Materials and Methods

Stand Characterization. Twelve stands (six stands containing cultivars and six stands of native trees) were selected for inclusion in this study from the 54 stands characterized previously (1). One stand of native trees not in the previous study was incorporated into this study. All of the cultivars in this study included trees in which scions from a known cultivar were grafted onto rootstocks that was less than 5 years old. The source of the rootstock varied among the stands. The cultivar 'Kwik Krop' was the rootstock for the trees at Stands 7 and 8. Rootstocks at stands 9 and 11 were grown from nuts of native trees obtained from the Missouri Department of Conservation. The source of the rootstocks at Stands 10, 12 and 13 is not known. Each of the seven stands of cultivars contained at least four of the following six cultivars as scions: 'Emma Kay', 'Kwik Krop', 'Sauber', 'Sparrow', 'Surprise' and 'Thomas'. Table 1 provides geographical site description information. Annual precipitation data in Table 1 and soil

Table 1. Geographical description of walnuts stands used in this study. The line in between stand 6 and 7 separates stands with native trees (above line) from those with cultivars (below line).

Stand number	Latitude	Longitude	County, State	Annual rainfall (mm)
1	N35.0948	W93.9664	Logan, AR[1]	1,140
2	N35.0984	W93.9455	Logan, AR	1,140
3	N39.3209	W90.8713	Pike, MO	940
4	N38.2470	W94.5027	Bates, MO	990
5	N37.0742	W93.8781	Lawrence, MO	1,090
6	N37.0742	W93.8781	Lawrence, MO	1,090
7	N35.1009	W93.9353	Logan, AR	1,140
8	N39.1478	W90.7838	Lincoln, MO	940
9	N37.0855	W93.8703	Lawrence, MO	1,090
10	N40.7688	W92.8223	Appanose, IO	1,070
11	N38.2484	W94.4969	Bates, MO	990
12	N40.7654	W92.8224	Appanose, IO	1,070
13	N37.0748	W94.1551	Lawrence, MO	1,090

[1]Abbreviations; AR, Arkansas; IO, Iowa; MO, Missouri.

Table 2. Soil characteristics of the walnut stands used in this study. The line in between stand 6 and 7 separates stands with native trees (above line) from those with cultivars (below line).

Stand number	Soil series	Texture	Depth	Drainage	Water permeability
1	Spadra	Silt loam	Deep	Well	High
2	Enders	Silt loam	Moderate	Moderately well	Moderate
3	Menfro	Silt loam	Very deep	Well	Moderately high
4	Okemah	Silt loam	Very deep	Moderately well	Moderate
5	Hoberg	Silt loam	Deep	Moderately well	Moderate
6	Hoberg	Silt loam	Deep	Moderately well	Moderate
7	Enders	Silt loam	Moderate	Moderately well	Moderate
8	Menfro	Silt loam	Very deep	Well	Moderately high
9	Dapue	Silt loam	Deep	Well	Moderate
10	Chequest	Silty clay loam	Deep	Moderate	Moderately slow
11	Kenoma	Silt loam	Very deep	Moderately well	Moderate
12	Chequest	Silty clay loam	Deep	Moderate	Moderate
13	Rueter	Silt loam	Moderate	Well	High

Table 3. Characteristics of the walnut stands used in this study. The line between stand 6 and 7 separates stands with native trees (above line) from those with cultivars (below line).

Stand number	Year planted	Tree stock type	Stand density (tree per ha)	Basal area 2002 (m^2 per ha)	CCF[z]	Number of trees measured
1	1999	Native	373	0.8	22	19
2	1992	Native	48	0.3	4	16
3	1988	Native	605	9.2	69	20
4	1986	Native	126	3.8	36	8
5	1975	Native	257	4.2	42	8
6	1975	Native	140	6.5	57	20
7	2000	Cultivars	108	0.2	3	21
8	1999	Cultivars	508	4.0	41	21
9	1993	Cultivars	68	0.7	8	20
10	1989	Cultivars	173	3.3	31	10
11	1986	Cultivars	173	3.3	45	12
12	1984	Cultivars	173	7.3	63	9
13	1974	Cultivars	56	4.7	37	8

[z]Abbreviation: CCF; Crown competition factor

characteristics information in Table 2 were obtained from Web Soil Survey (6). Table 3 presents a summary of the tree stand characteristics. Stand density was calculated from plot size and tree number data. Trunk diameter and nut yields were determined in September in 2002 and 2003. DBH was measured 1.37 m above ground with a diameter tape. Trunk cross-sectional areas (TCSA) were calculated from DBH values assuming the trunks had

Table 4. Mean trunk cross-sectional area (TCSA) and nut yield for the stands of walnut used in this study. The line in between stand 6 and 7 separates stands with native trees (above line) from those with cultivars (below line). The stand mean TCSA at the end of growing season is reported for 2002. Mean annual increase (MAI) was calculated by dividing TCSA in 2002 by number of years since planting. Annual increment from 2002 to 2003 (AI) was calculating by subtracting TCSA in 2002 from TCSA in 2003.

	TCSA (cm^2)[z]			Nut yield			
Stand number	2002	MAI[z]	AI for 2003[z]	2002 (kg per tree)	2003 (kg per tree)	2002 (kg per ha)	2003 (kg per ha)
1	21	7	33	0.0	0.0	0	0
2	48	5	23	0.1	1.3*	5	62
3	74	5	8	0.1	0.1	61	61
4	278	17	33	0.7	0.6	88	80
5	131	5	32	0.4*[y]	0.1	100	26
6	442	16	19	3.0*	2.4	420	340
7	2	1	8	0.1	0.5*	11	54
8	41	14	30	6.2*	2.5	3,600	1,500
9	79	9	34	0.2	3.4*	14	230
10	145	11	46	2.8	3.8*	470	660
11	249	16	35	1.1	7.5*	190	1,300
12	391	22	47	14.8*	2.9	2,600	500
13	795	28	51	2.9	6.1*	160	340

[z] Abbreviations: AI, annual increase growing the 2003 growing season; MAI, mean annual increase; TCSA, trunk cross-sectional area;

[y] *Stand mean yield was significantly greater ($P < 0.05$) for this year compared to the other year, as determined by a t-test.

a circular cross-section. Crown competition factor (CCF) was calculated as described by Schlesinger (10, 11). Basal areas were calculated from DBH and plot size data. All the nuts on a tree were counted. Repetitive counts of nuts on trees with several hundred nuts were within 2% of each other. Nut yields were calculated from nut counts. Number of nuts was converted to nut weight (air dried) by using an average nut unit weight for native trees of 16.6 g (1). This value is similar to that reported by Zarger et al. (14). Nut counts for cultivars were converted to nut weight using values reported previously (2, 8).

Statistical analyses. The significance of the difference in stand mean yields between 2002 and 2003 was determined using PROC TTEST of SAS (9). Relationship between TCSA and nut yield was assessed using PROC GLM of SAS (9). For these analyses, the independent variable was an individual tree's two-year mean TCSA. The dependent variable was an individual tree's two-year mean yield. These regression analyses were conducted for three data sets: 1) all trees from all plots; 2) stands of native trees; and 3) stands with cultivars.

The effects of site characteristics on the TCSA-nut yield relationship were explored using PROC REG of SAS (9). For these analyses, TCSA and yield data from individual trees were averaged across two years. Means for each site were calculated from individual tree data and these means were utilized in PROC REG. Backward selection technique was utilized to find models in which all retained variables were significant at $P < 0.10$. The first model included tree stock type, stand density (trees per ha), two-year means for yield (kg per tree), two-year means for TCSA, mean annual increase in TCSA and annual increase in TCSA during 2003 growing season as predictors of the two-year yield average in terms of kg per ha. Tree stock type refers to plantings of either native trees or cultivars. A numerical code of either 0 or 1 was used for stands with either native trees or cultivars, respectively.

Further analyses examined the effects of site and stand characteristics on the relationship between yield (kg) per tree and TCSA using PRC REG of SAS (9). The basic model to predict two-year stand yield means per tree included independent variables of tree stock type and two-year means of TCSA. Parameters from each of Table 1, 2, or 3 were added to the basic model as predictors of nut yield. For the parameters in Table 1, data regarding latitude, longitude and annual precipitation were used directly. Soil series name was not included in the analyses. Codes were assigned to categorical data in such way as increasing values were *a priori* thought to be better, for example, greater soil depth was given a higher value. Soil texture was included with silt loam being coded as 2 and silty clay loam as 1. Soil depth was coded such that increasing soil depth was a higher value (very deep, deep, and moderate being 3, 2 and 1, respectively). Soil drainage was coded such that well drained, moderately well and moderately drained were 3, 2 and 1, respectively. Soil permeability to water was coded such that higher rates of permeability had higher values, high permeability, moderately high, moderate, and moderately slow being coded as 4, 3, 2 and 1, respectively. For the parameters in Table 3, numerical values for age in years were used directly. Stand density, basal area, CCF and the change in TCSA from 2002 to 2003 from Tables 3 and 4 were added to the basic model to predict yield (kg) per tree. Variables from each of the tables that contributed to the predictive power of the model for yield per tree were combined in the final analyses.

For all regression analyses, significance of the model was determined by the F-value, and P level of its significance is reported herein. R-square values are also reported. Significance of a parameter to a multi-regression equation was determined by its F-value.

Results and Discussion

Stand Characteristics. Stands in this study were located in southern Iowa, Missouri and western Arkansas (Table 1). Long term means for annual rainfall varied from 940 to 1140 mm. Soil characteristics varied among the 13 stands (Table 2). Tree age varied from 2 to 28 years in 2002 (Table 3). Tree stand density also varied considerably from 48 to 605 trees per ha. Both basal area and CCF varied among stands. Basal area varied among stands from 0.2 to 9.0 m^2 per ha, and CCF from 3 to 69. Schlesinger (10) indicated that black walnut growth is not reduced by among-tree competition unless the CCF exceeds 100. Thus, the values for both basal area and CCF were indicative of free-growing or open-canopy trees.

Stand mean TCSA in 2002 varied from 2 cm^2 for Stand 7 to 795 cm^2 for Stand 13 (Table 4). The mean annual increase in TCSA from planting to the end of the 2002 growing season varied from 1 to 28 cm^2 per yr (Table 4). The mean annual increase in TCSA for Stand 5 was approximately one-third that of Stand 6, despite the fact that these two stands were located at the same site. Stands 5 and 6 differed in the under-story vegetation. Tall fescue (*Festuca arundinacea* Schreb.) was present within the crown radius of the trees in Stand 5 and Kentucky bluegrass (*Poa pratensis* L.) was present in Stand 6. As expected, TCSA for each stand increased from 2002 to 2003, indicating that trees were growing. The annual increment for TCSA in the 2003 growing season was equal to or greater than the mean annual increase from planting to the end of the 2002 growing season. The annual increase for Stand 5 was high during the 2003 growing season compared to the mean annual increase, 32 versus 5 cm^2 per yr. The higher rate of TCSA increase in 2003 may have been in response to pruning in 2001. Mean nut yields in 2002 and 2003 varied from zero to 14.8 kg per tree. There were significant differences between nut yields in 2002 and 2003 for 10 of the 13 stands (Table 4). Stand yields differed in 2002 and 2003 for all seven stands with cultivars.

Effects of tree stock type on nut yields. The relationship between the two-year mean for

TCSA and nut yield per tree was highly significant (F-value 89.77, $P < 0.001$) for all trees from the 13 stands (Fig. 1). The R-square was 0.31. The regression equation was:

Two-year mean yield (kg per tree) = 0.0065*(mean TCSA, cm^2) + 0.58 [Eqn. 2]

The intercept for Eqn. [2] was significantly different from zero (t-value = 3.00, $P < 0.003$), and the slope for Eqn. [2] was significantly greater than zero (t-value = 9.47, $P < 0.001$). Examination of the data in Fig. 1 suggested that the regression equation using data from cultivars may differ from that of native trees. The equation for data from cultivars in Fig. 1 was:

Two-year mean yield (kg per tree) = 0.0071*(mean TCSA, cm^2) + 1.38 [Eqn. 3]

The F-value for Eqn. 3 was 50.90 ($P < 0.001$) and the R-square was 0.34. The t-values for the intercept and slope were 4.50 ($P < 0.001$) and 7.13 ($P < 0.001$).

The regression equation for native trees in Fig. 1 was:

Two-year mean yield (kg per tree) = 0.0049*(mean TCSA, cm^2) – 0.11 [Eqn. 4]

The F-value for Eqn. 4 was 111.88 ($P < 0.001$) and the R-square was 0.54, respectively. The t-values for the intercept and slope were –0.94 ($P = 0.34$) and 10.58 ($P < 0.001$), respectively. Thus, the regression equations between TCSA and yield (kg per tree) were highly significant, but different for cultivars and native trees. The Y-intercept and slope were significantly different between cultivars and native trees. The slope of the nut yield-TCSA regression equations was almost twice as great with cultivars compared to native trees (0.0071 ± 0.0001 and 0.0049 ± 0.0005 respectively). The R-squares for TCSA-nut yield regression equations were greater from either cultivars or native trees compared to the data set that included both types of trees.

Effects of stand characteristics on nut yield. The effects of stand characteristics and tree

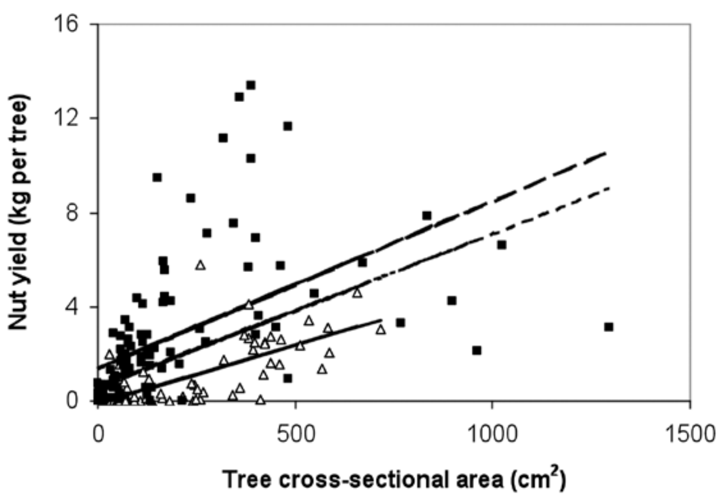

Figure 1. Relationship between nut yield and trunk cross-sectional area (TCSA) for native trees (open symbols) and cultivars (closed symbols). Nut yield and TCSA were averaged across two consecutive growing seasons (2002 and 2003), and the means for individual trees were plotted. Regression equaitons are plotted for data from all trees (- - -), cultivars (– –), and native trees (solid line). These equations correspond to Eqn. 2, 3 and 4 in the text, respectively.

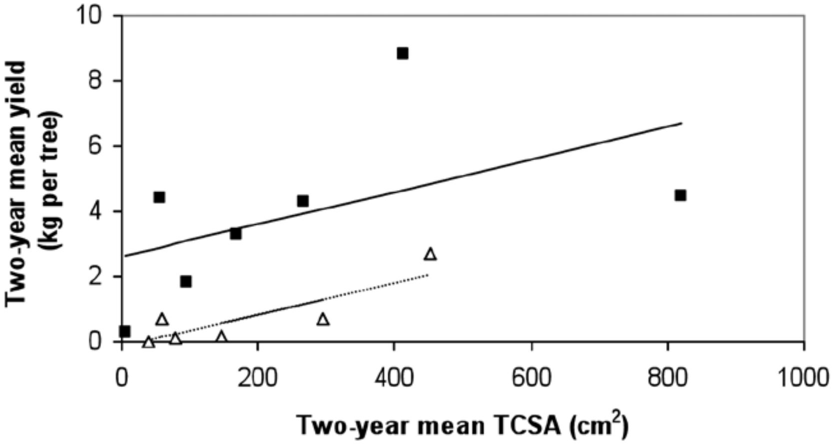

Figure 2. Relationship between stand means of nut yield and trunk cross-sectional area (TCSA) for native trees (open symbols) and cultivars (closed symbols). Nut yields and TCSA were averaged across two consecutive growing season and trees within each of 13 strands. Predictive regressions for native trees (broken line) and cultivars (solid line) were generated from Eqn. [6].

growth on nut yields were examined using means for each of the 13 stands. The independent variables of stock type, stand density, two-year mean for TCSA, change in TCSA from 2002 to 2003, mean annual increase in TCSA from planting to end of 2002 growing season and nut yield per individual trees were used to predict two-year means for nut yields on a land basis (kg per ha). The equation that resulted from backward selection was:

Two-year mean yield (kg per ha) = 1.95*(stand density, trees per ha) + 227.7*(two-year mean yield, kg per tree) – 485.7 [Eqn. 5].

The F-value for the model in Eqn. [5] was highly significant (F-value= 12.19, $P > 0.002$) and the R-square was 0.71. F-values for the contribution of stand density, and two-year mean nut yield per tree were 6.86 ($P < 0.026$) and 20.39 ($P < 0.002$), respectively. Eqn. [5] demonstrates the importance of tree stand density and yield per tree in determining nut yields on a land area basis.

The effects of stand characteristics on two-year mean yields per tree were examined because this variable was an important predictor of yield per unit land area. The first model included tree stock type (cultivar = 1 and native = 0) and two-year mean TCSA as independent variables to predict nut yield (kg) per tree. Backward selection did not eliminate either of these variables using a $P < 0.10$. The F-value for Eqn. [6] was highly significant, 7.29 ($P < 0.01$) and the R-square was 0.59. The resulting regression equation was:

Two-year mean yield (kg per tree) = 0.0049*(two-year mean TCSA, cm^2) + 2.77*(tree stock type) -0.146. [Eqn. 6]

The contribution of two-year mean TCSA and tree stock type to the model were both significant at $P < 0.05$. The F-value for the Y-intercept was not significant at $P = 0.10$ (data not shown). When the geographical descriptors from Table 1, and soil characteristics from Table 2 were included as potential independent variables to predict nut yield per tree, the resulting model after backward selection contained only tree stock type and two-year mean TCSA (data not shown). The following independent variables were added to the model in Eqn. [6] as predictors of two-year mean yield per tree: tree age in 2002, stand density, basal area in 2002, CCF, mean annual increase in TCSA prior to 2003, and change in TCSA from 2002 to 2003. Backward elimination removed all independent variables except stock type and mean annual increase in TCSA. The resulting regression equation was:

> Two-year mean nut yield (kg per tree) = 2.20 (stock type) – 0.195 (mean annual increase in TCSA, cm^2 per yr) [Eqn 7].

Eqn [7] was highly significant with F-value of 12.53 ($P < 0.002$) and R-square of 0.71. F-values for the contribution of stock type and mean annual increase in TCSA were 9.05 ($P < 0.034$) and 10.78 ($P < 0.008$), respectively. The F-value of the intercept was not significant at $P < 0.10$. It is interesting to note that mean annual increase in TCSA replaced the mean TCSA from 2002 and 2003 as a predictor of nut yield per tree and was a better predictor of nut yields than the change in TCSA during the course of the study.

General Discussion. This study represents an improvement over the earlier study (1). Nut yields averaged over two consecutive years were utilized herein because analyses performed previously indicated that such means provide a better estimate of tree and stand nut yields (3). Regression equations between TCSA and two-year mean nut yields per tree in this report were highly significant and had moderately high R-square values. The slope of the regression equation to predict nut yields from TCSA was greater with data from cultivars (0.0071) than with native trees (0.0049). Another indication that cultivars and native trees differ in the relationship between TCSA and nut yields was found with Eqn. [6] and [7]. Tree stock type (cultivars versus native trees) was one of only two retained independent variables as predictors of two-year stand means for yields. The reason for the difference in the relationship between TCSA and nut yields among cultivars and native trees was not a component of this investigation. Possible reasons may include: 1) differences in management including grafted vs. seedling trees; and 2) concomitant selection for precocious flowering when selecting cultivars for improved nut quality. Either of the above possibilities could have resulted in native trees having a longer juvenile period than cultivars, and thus lower yields at similar TCSA values.

Landowners establishing black walnut orchards and agroforestry practices for nut production are most likely to plant cultivars selected for improved nut quality because the potential income from such nuts exceeds that of nuts from native trees (4). Therefore, economic models for nut production from black walnut should probably focus on predicting yields and income from stands of cultivars. More data are needed to verify the relationship between trunk size and nut yields before models to predict economic returns from orchards of cultivars can be developed.

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Call for Wilder Silver Medal Nominations

The Wilder Committee of the American Pomological Society (APS) invites nominations for the 2009 Wilder Silver Medal Award. All active members of APS are eligible to submit nominations. The award was established in 1873 in honor of Marshall P. Wilder, the founder and first president of APS. The award consists of a beautifully engraved medal which is presented to the recipient at the annual meeting of APS, held during the American Society for Horticultural Science annual meeting.

The Wilder Medal is presented to individuals or organizations that have rendered outstanding service to horticulture in the area of pomology. Special consideration is given to work relating to the origination and introduction of meritorious fruit cultivars. Individuals associated with either commercial concerns or professional organizations will be considered if their introductions are truly superior and have been widely planted. Significant contributions to the science and practice of pomology other than through fruit breeding will also be considered. Such contributions may relate to any important area of fruit production such as rootstock development and evaluation, anatomical and morphological studies, or noteworthy publications in any of the above subjects. Information about the award, past recipients, etc. can be found on the APS web site at http://americanpomological.org/wilder1.html.

To obtain nomination guidelines, please contact committee chairperson:
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Phone: 859-257-3352; fax: 859-257-2589; e-mail: darchbol@uky.edu

Nominations must be submitted by May 1, 2009.