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Relationship Between Trunk Cross-sectional Area, Harvest Index, Total Tree Dry Weight and Yield Components of 'Starkspur Supreme Delicious' Apple Trees

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Abstract

The relationship between trunk cross-sectional area (TCSA) and total tree dry weight (DW), and between harvest index (HI) and yield efficiency (YE) of 'Starkspur Supreme Delicious' (*Malus domestica* Borkh.) apple trees on nine different rootstocks was examined. In general, as tree size increased, the reliability of TCSA as a predictor of total tree DW decreased. A log transformation increased the accuracy of the estimate. The relationship between YE and HI was improved when a log transformation of TCSA is used to compute the YE. A comparison of tree evaluations based on TCSA and total tree DW revealed that trees on M.27 EMLA had a greater partitioning of dry matter to flowers and fruit when actual DW was used in calculations. The larger trees on MAC.24 and M.7 EMLA rootstocks, ranked higher in YE and flower density when TCSA was used instead of DW as a basis for accounting for tree size. The rootstocks with the highest HI's, ranging from 0.46 to 0.48, were M.9, M.27 EMLA, M.9 EMLA, MAC.9, and O.3. OAR1, M.26 EMLA, M.7 EMLA, and MAC.24 were contained in a second grouping with HI's ranging from 0.33 to 0.39. M.27 EMLA had one of the lowest YE's but had a high HI. M.7 EMLA had a relatively high YE but a low HI. OAR1 had the lowest YE but not the lowest HI.

Clonal rootstocks are widely used to provide size control, induce precocity, and increase productivity in tree fruit species. Evaluations of rootstocks commonly include yield efficiency (YE), a measure of productivity defined as the fresh weight (FW) yield divided by the trunk cross-sectional area (TCSA) (6). TCSA has been positively correlated with the total above-ground tree FW (7). Therefore, YE provides an estimate of the FW yield (kg) per kg of above-ground tree FW.

A widely used measure of productivity of annual crops is the harvest index (HI), defined as the fraction of the total plant DW that is partitioned to the harvested sink, or the ratio of the yield DW to the total plant DW. The similarity in theory of YE and HI is apparent, since both are a measure of yield relative to the total plant weight. However, the relationship between these terms has not been studied. Destructive sampling of trees in the 1980-81 NC-140 apple rootstock trial provided an op-

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portunity to investigate the relationship between YE and HI, and the reliability of TCSA as a predictor of total tree DW.

Materials and Methods

In March and Oct./Nov. 1990, FW, DW, and TCSA data were obtained from 36 ten- and eleven-year-old 'Starkspur Supreme Delicious' apple trees on nine different clonal rootstocks (O.3, M.7 EMLA, M.9 EMLA, M.26 EMLA, M.27 EMLA, M.9, MAC.9, MAC.24, and OAR 1.) Trunk circumference was measured at 20 cm above the graft union and TCSA calculated. In March, the above-ground portions of the trees were partitioned into frame, 2-yr wood, 1-yr wood, and spurs. Components were oven-dried at 60C, until weight was constant, and weighed. In October, a second group of trees was partitioned into the aforementioned components and additionally into spur and shoot leaves, current season's growth and fruit. Fruit weight for each tree was recorded and 50-fruit random subsamples were weighed, sliced, dried for 4 days at 30C and then completely dried at 60C. Roots were excavated with a backhoe by sifting the contents of each bucket of soil taken from a 1.5m radius around each tree to a 1.5m depth. Only a few of the largest trees had roots extending outside the excavation zone, so loss of roots was minimal. Roots were also dried at 60C. Total tree DW was calculated as the sum of all of the components at each sampling date. Total fruit FW, and fruit and total tree DW data were used to calculate the YE [fruit FW (kg)/TCSA (cm^2)] and the HI [fruit DW (kg)/total tree DW (kg)]. Flower clusters were counted and weighed from dried spurs. The number of fruit per tree used in crop density calculations was estimated based on the total fruit FW and the weight of 50-fruit subsamples. The GLM procedure of Statistical Analysis Systems (SAS) (5) was used to examine the relationships between TCSA and total tree DW, YE, and HI, crop density and fruit per tree DW, and flower density and flower cluster number per tree DW.

Results and Discussion

Tree DW was linearly related to TCSA ($R^2 = 0.92$, $p > 0.0001$), although the variance increased as TCSA increased. In other words, as total tree DW increased, the accuracy of TCSA as a predictor of DW decreased. A log transformation improved the fit (Fig. 2), making variance more constant ($R^2 = 0.95$, $p > 0.0001$).

An examination of the equations used in the estimation of tree weight helps to clarify the reason for this improvement and the relationship between TCSA and total tree weight. The relationship is described by Equation 1:

$$\text{Equation 1:}\quad W = AC^b \quad (1)$$

where W = tree weight, A = a constant, C = trunk circumference, and b = a power of circumference. This equation has provided good results within a given trial, but

Table 1. Flower and crop density, yield efficiency, and harvest index of 'Starkspur Supreme Delicious' apple trees on nine rootstocks.

Rootstock	TCSA (cm^2)	Total tree DW (kg)	Flower cluster density[y] no/TCSA (cm^2)	no/DW (kg)	Crop density no/TCSA (cm^2)	no/DW (kg)	Yield efficiency FW/TCSA (kg/cm^2)	Harvest index DW/DW (kg/kg)
MAC.24	162a[z]	92a	22.1b	50.2d	11.3b	3.9	1.35bcd	0.33b
M.7 EMLA	132b	83a	20.9b	58.6d	11.4b	3.5	1.52abc	0.34b
M.26 EMLA	115b	53b	27.6b	97.6c	10.5b	5.8	1.23cd	0.38b
OAR 1	64c	25c	25.8b	97.9c	10.5b	5.2	1.11d	0.39b
O.3	50cd	27c	33.2ab	111.1bc	16.0a	5.5	1.79a	0.45a
M.9 EMLA	53cd	26c	28.4b	112.9bc	13.9ab	5.3	1.68ab	0.47a
MAC 9	36d	18cd	44.7a	172.6a	15.0a	5.9	1.71ab	0.46a
M.9	36d	20c	30.8ab	107.6bc	16.6a	5.8	1.86a	0.48a
M.27 EMLA	12e	4d	30.6ab	146.1ab	10.6b	5.8	1.19cd	0.47a

[z]Mean separation in columns by Waller-Duncan k-ratio t-test, k-ratio = 100. Means are of 4 replications.
[y]Flower density calculated from March 1990 sampling, all other variables from the October 1990 sampling.

the value b calculated across many studies has ranged from 1.97 to 2.87 (4), making it unreliable as a practical predictor of tree weight.

The relationship between TCSA and tree weight can be described by Equation 2:

Equation 2: $W = k\,(TCSA)$

where W = tree weight and k = a constant. Since $C = 2\pi r$ and $TCSA = \pi r^2$, Equation 2 can be rewritten as:

Equation 3: $W = k/4\pi(C^2)$.

Equation 3 is the same as Equation 1, where A in Equation 1 is equal to $k/4\pi$ in Equation 3 and b is arbitrarily set to equal 2. Using TCSA as a predictor of total tree DW is equivalent to using the circumference with b set at 2 regardless of research which has shown that b is not constant across different trials, scion cultivars, or rootstocks. The danger of comparison of tree performance based on TCSA is obvious.

With this background, an examination of why the log transformation improves the estimate of total DW is possible. The relationship between TCSA and tree FW can also be defined by Equation 4:

Equation 4: $W = k_1(TCSA)^{b/2}$,
where $k_1 = 2\pi/\pi^{1/2}(k)$.

The log of both sides gives:

Equation 5:
$\log(W) = \log(k1) + b/2 \log(TCSA)$

which fits the linear regression model where log k is the y intercept and b is the slope of the line. Using the log transformation of TCSA therefore allows for the use of the value of b = 2.28 for this trial instead of the arbitrary value of 2, thereby increasing the accuracy of our prediction of W and resulting in the improved R^2. This b value is in the range previously reported (4).

YE was linearly related to HI ($R^2 = 0.27$, $p > 0.001$) although individual points were scattered (Fig. 3). This is a consequence, in part, of the high variance within TCSA as a predictor of total tree FW. Modified YE (mYE) was defined as the log of fruit FW divided by the log TCSA. When mYE was plotted against the HI (Fig. 3), the scatter was greatly reduced and the R^2 increased to 0.45 ($p > 0.0001$), suggesting that the mYE is a better predictor of HI.

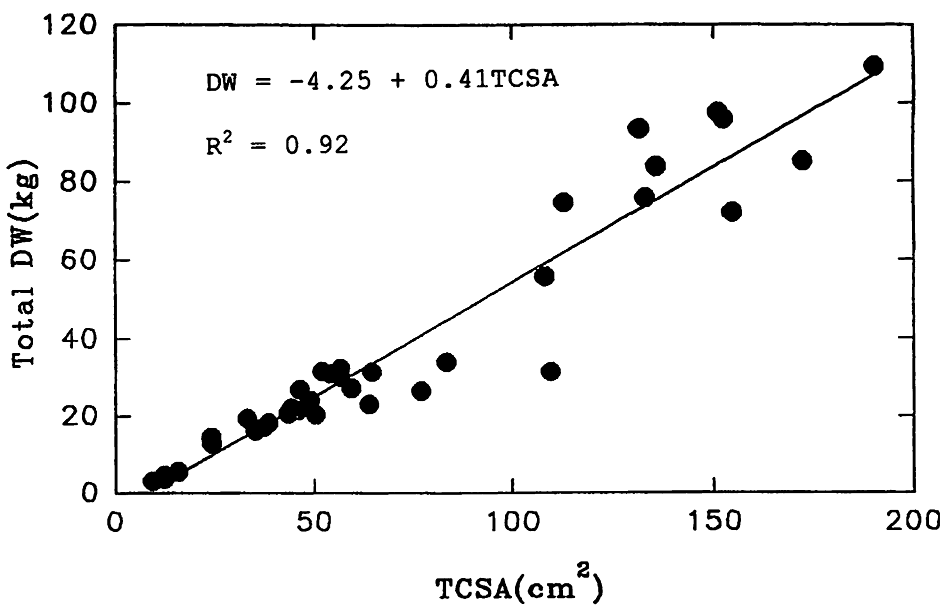

Figure 1. Linear regression of trunk cross-sectional area (TCSA) against total tree dry weight (DW) for 36 ten and eleven-year-old 'Starkspur Supreme Delicious' apple trees on nine rootstocks.

The potential inaccuracy of evaluations using TCSA can be demonstrated by comparing parameters calculated with TCSA vs. total tree DW. In general, use of TCSA in the evaluations tended to overrate the larger trees and underrate the smaller trees relative to the same evaluations using the total tree DW (Table 1). This may be due to differences in tree shape and size. It is possible that the relationship between TCSA and total DW changes as a tree grows, regardless of rootstock. The larger trees, those on MAC.24 and M.7 EMLA ranked low for HI but ranked much higher for HI when YE was used as the evaluation criteria. In contrast, the smallest trees on M.27 EMLA, had a high HI but relatively low YE. Trees on OAR 1, which has consistently rated low in YE (2, 3), had the lowest YE in this study, but not the lowest HI. These differences could be explained by the inability of TCSA to take into account growth characteristics of a tree. For example, if a canopy is more branched with more extension growth, the TCSA could be relatively smaller because of the resources required to maintain the radial growth of the newer wood. This would result in a higher YE since TCSA would be smaller. Yet HI might be low because the calculation would include actual weight of all other vegetative portions of the tree. In contrast, M.27 EMLA could have a low YE because only radial growth of the frame (i.e. TCSA) occurs with very little extension growth for fruiting wood. The observed "runting-out" effect of M.27 EMLA, where the tree fruits on a relatively thick frame of many spurs with virtually no extension growth, adds credence to this explanation. Although the total tree DW of OAR 1 is similar to M.9 EMLA and O.3, the TCSA is larger, resulting in a much lower YE. Again, this corresponds to an observed growth form with little extension growth and proportionately more frame and/or root growth.

More variation was observed between rootstocks when tree DW was used to calculate flower density (Table 1) than when

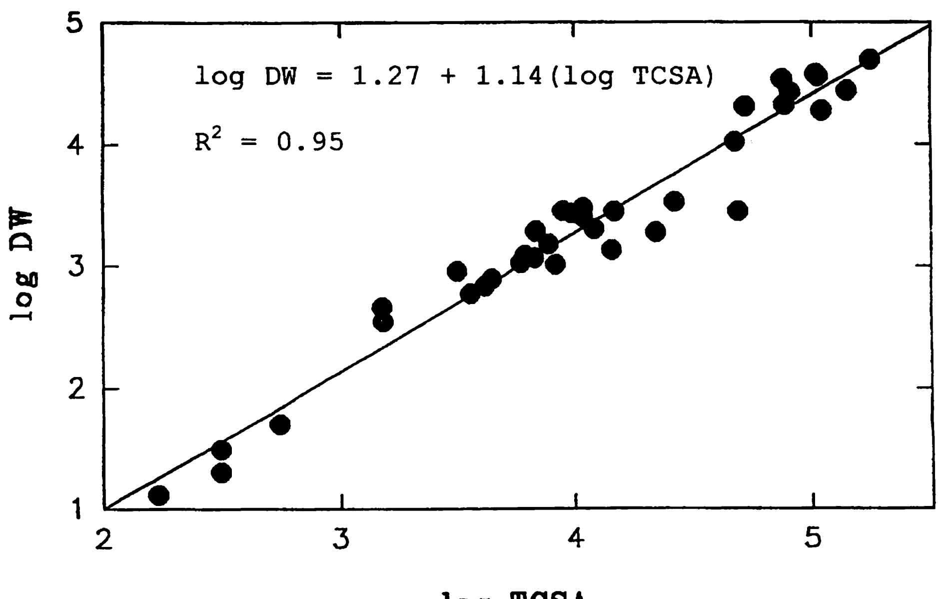

Figure 2. Linear regression of log [trunk cross-sectional area (TCSA)] against the log [total tree dry weight (DW)] for 36 ten and eleven-year-old 'Starkspur Supreme Delicious' apple trees on nine rootstocks.

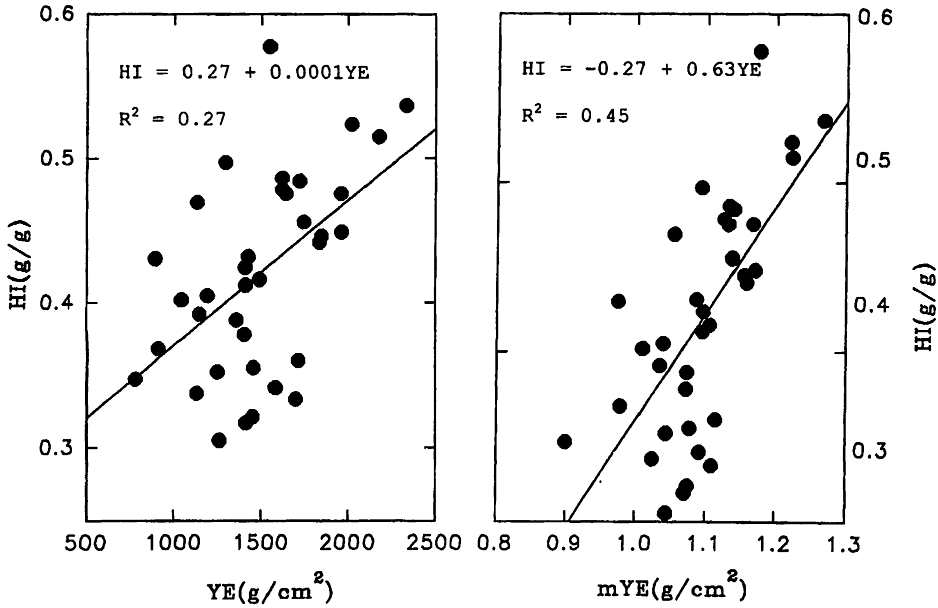

Figure 3. Linear regressions of a.) yield efficiency (YE) and b.) modified YE against harvest index (HI) for 36 ten and eleven-year-old 'Starkspur Supreme Delicious' apple trees on nine rootstocks.

TCSA was used. For example, when TCSA was used as a basis for the flower density comparisons, the flower density of MAC.24 and M.7 EMLA was only different from MAC.9. In contrast, four fairly distinct categories were apparent when total tree DW was used as a basis for comparison. The ranking for M.27 EMLA was higher when total tree DW was used in the calculation. The differences between the two ways of expressing crop density were smaller. Clearly, relying on TCSA to adjust the flower cluster number for tree size is very conservative.

Some caution is required when comparing rootstocks based on TCSA, but comparisons are still valid if the limitations are understood. The modified YE presented here may prove superior within a particular trial, but it is still based on a fixed value of b and will only serve to decrease the variance of the estimates of efficiency within a trial. It is important to understand that b will vary across trials, across scion varieties, and possibly across rootstocks. As more data accumulates, it may become possible to more accurately predict the values of b under a particular set of conditions and improve evaluations of growth and productivity. We can expect the TCSA to underestimate the total tree DW of larger, more branched trees relative to smaller trees and overestimate the total tree DW of more compact, spurry trees. The underestimation of total tree DW could result in a higher and less precise calculation of YE, while the partitioning of dry matter to fruit of trees which are more 'spurry' could be underestimated with the YE calculation.

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Behmi – A Wild Fruit From Himalayan Cold Desert Region

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Behmi (*Prunus* species), is a common plant of the dry temperate region of the Western Himalayas growing at an altitude between 2500 and 3000 m above sea level. This region is characterized by lack of vegetation owing to low annual rainfall (15 to 20 cm.), temperature extremes (–40° to 40°c) and a growing season of less than five months.

The fluit of **Behmi** is unusually juicy. Due to this character, the local people call it **TIRUL**, which literally means "watery fruit." These fruits are relatively smaller and a little more tart than the peach. The fruits are sun-dried after maturity, which usually takes place in October. The dried fruits are later used for the preparation of an alcoholic liquor.

In most of trees, the kernel is sweet and edible. An oil is extracted from the kernel which is used for cooking. It is also used as a hair oil. The local people believe the oil from **Behmi** kernels can cure arthritis and joint pains and a massage of this oil is prescribed against these ailments.

Behmi seedlings are used as a rootstock for peach, almond and plum. Trees make good graft unions with 'Santa Rosa' and 'Satsuma' plums (1). It is resistant to powdery mildew caused by *Podosphaera leucotricha* Ell. and Fr. (2).

Origin

The trees of **Behmi** are found growing in the dry temperate region of the Western Himalayas (Fig. 1). There is no report about its occurrence in any other area. This suggests that **Behmi** might be a native of this region only.

Description

Trees are drooping with a domed top and a height of about 10 m, spreading to about 10 m. They have a trunk cross-sectional area of 90 cm^2, with grey-brown bark.

Leaves are lanceolate with an aristate apex, round base, finely serrate margin, upright to intermediate position, flat lamina and are yellow-green in emerging leaves to grey-green in mature leaves. The upper surface is glabrous and the lower surface is pubescent along the mid-rib. The length is 10 cm with a length/width ratio of 4:6. The petiole is yellow-green with the upper side red. It has a length of 2.2 cm with 7 yellow-red to brown orbicular and reniform glands.

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