ORANGE GROVE FACTORS AFFECT MANUAL HARVESTING RATES

J. D. Whitney, T. A. Wheaton, W. S. Castle, D. P. H. Tucker

ABSTRACT. *Fruit harvesting rates were measured for four pairs of pickers in orange trees with fruit yields from 30 to 76 t/ha, fruit weight from 160 to 235 g, and tree heights from 3. 7 to 5.5 m. Each picker used a conventional ladder and bag emptied the harvested fruit into 408-kg field containers. Average harvesting rates per picker ranged from 241 to 376 kg/h. A regression analysis of the data showed the harvesting rate per picker increased 40.8 kg/h (equivalent to one field box of Florida oranges per hour) for an approximate increase of either 20 t/ha in yield or 50 g in fruit weight, or a 2 m decrease in tree height.* ***Keywords.*** *Citrus harvesting, Fruit yield, Fruit weight, Tree height.*

From the late 1950s through the early 1980s, harvesting was a major concern of the Florida citrus industry because of large crops, low labor availability, and low profit margins. A research program was pursued to investigate solutions and a considerable amount of information was developed on picking aids, mechanical harvesters, and abscission chemicals. However, the industry failed to adopt the equipment and chemicals as a replacement for the manual (conventional) picker/ladder/bag method of removing fruit from the tree to a handling container (Whitney and Harrell, 1989).

Since 1991, there have been renewed concerns about harvesting for the same reasons stated above (Whitney, 1995). The average cost of harvesting (tree to processing plant or packinghouse) almost equals the cost of production and is expected to escalate to $57/t of oranges by the 2002-2003 season (Polopolus et al., 1993). Florida citrus production is expected to increase 48% to a record 14.8 Mt in the decade ahead. These increases in production will require 10,000 additional pickers and, with foreign competition, are expected to depress on-tree fruit prices by 33%.

Because Florida growers have continued to plant higher density orange groves, recent harvesting research at the Lake Alfred Citrus Research and Education Center (CREC) has included investigating the effects of high-density planting variables on manual harvesting systems for processed oranges. Whitney et al. (1994) discussed how various characteristics of a high-density grove may affect harvesting by manual means, with picking aids, and by machine.

The objective of the research reported in this article was to quantify the effects of scion variety, rootstock, tree height, tree spacing, and other pertinent variables on the manual harvesting rate.

MATERIALS AND METHODS

Harvesting data were collected during the 1993-1994 season in an established experimental orange grove described by Wheaton et al. (1986), Whitney et al. (1994), and Wheaton et al. (1995). The trees were planted in 1980 on a 10 ha site in Polk County, Florida, located between Frostproof and Babson Park. Factors in the experiment are listed in table 1. A multiple split plot design with four replications was used. Scion variety was the main plot factor followed by successively smaller subplot factors of tree height, between-row spacing, rootstock, and in-row spacing. There were two levels of each of the 5 factors for 32 factor combinations. Subplot 4 (table 1) was the experimental unit and 4 rows × 7 trees with the center 10 trees (2 rows × 5 trees) designated for data collection.

Table 1. Experimental factors, plot designations, and levels of each factor

Factor	Plot Designation	Levels
1. Scion	Main	Hamlin orange (early-maturing) Valencia orange (late-maturing)
2. Tree height	Subplot 1	3.7 m; 5.5 m
3. Between-row spacing	Subplot 2	4.5 m; 6.0 m
4. Rootstock	Subplot 3	Rusk citrange (moderately vigorous or MV); Milam (vigorous or V)
5. In-row spacing	Suplot 4 (experimental unit)	2.5 m; 4.5 m

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'Hamlin' and 'Valencia' were selected as the scion varieties to represent early- and late-maturing oranges. Rusk citrange and Milam were chosen as moderately vigorous and vigorous rootstocks, respectively. Between-row spacings of 4.5 and 6.0 m and in-row spacings of 2.5 and 4.5 m resulted in four tree densities of 370, 494, 667, and 889 trees/ha. Tree heights of 3.7 and 5.5 m were included as a treatment to determine if suitable fruit productivity could be achieved and maintained at the lower height for any scion/rootstock/tree density combinations to facilitate harvesting.

When the width and height of the tree row canopies reached containment size, they were maintained by hedging and topping. Hedging was initiated on the more vigorous canopies in 1985 and topping was initiated in 1991. During the 1993-1994 season, the annual straight hedging cut in the row middles was 213 cm wide near ground level and angled at 7° from vertical toward the tree top. The trees designated for the 3.7 m height were flat topped twice (spring, fall) to control regrowth and improve fruiting in the lower canopy of trees on the vigorous rootstock. The trees designated for the 5.5 m height were flat topped once in the spring. On the two center subplot trees, horizontal canopy diameter measurements were made near ground level in the in-row and across-row directions, and canopy height measurements were made. Tree canopy volume in each subplot was calculated and based on the center tree canopy measurements and the assumption that the canopy naturally developed as one-half an ellipsoid according to equation 1.

$$CV = (0.52)(H)(D_A)(D_I) \tag{1}$$

where

CV = canopy volume (m^3)
H = canopy height (m)
D_A = horizontal canopy dimension across-row near ground level (m)
D_I = horizontal canopy dimension in-row near ground level (m)

Modifications of canopy shape (and thus volume) by tree topping, hedging between rows, and merging canopies in-row were based on these modifications of the ellipsoid shape.

To determine the harvest rates, eight pickers (four pairs) with conventional ladders and fruit bags harvested the center five trees in the western row of each (tree-row orientation north/south) experimental unit. Each pair of pickers was assigned to pick the 32 factor combinations, 8 in each of the 4 replications, and place the fruit in 10 box (408 kg) containers. The time required for each pair to harvest each subplot was recorded and fruit yield was determined by weighing. Weight fruiting density was calculated by dividing the fruit yield by the canopy volume. (Weight fruiting density in this article is identical to cropping efficiency, a horticultural term, as defined by Whitney et al., 1994.) Number fruiting density was calculated by dividing the weight fruiting density by the average fruit weight, which was determined from a sample of 50 to 80 fruit (~14 kg) taken from each experimental unit. The weight and diameter of individual fruit in the sample were also measured and used to calculate the apparent specific gravities of individual fruit.

All data were statistically analyzed using SAS GLM procedures (SAS, 1985). Significant differences, where stated, refer to the 5% level of significance.

RESULTS AND DISCUSSION

AVERAGE HARVEST RATE

The average harvest rate of the individual pickers was expressed in two ways in each experimental unit. First, the weight harvest rate (WHR) was defined as the kg* of fruit/h or kg/h. Second, the number harvest rate (NHR) was calculated by dividing the WHR by the average fruit weight in the fruit sample. (See the nomenclature at the end of the article for definitions of terms, abbreviations, and units). The NHR (number of fruit/h or no./h) was calculated because the average fruit weight varied considerably (151 to 266 g*) among individual experimental units and, thus, would affect the WHR, assuming each picker picked similar numbers of fruit per unit time, all other factors being equal. If this assumption is valid, then the NHR is independent of fruit weight and may indicate how factors such as tree geometry and the number fruiting density (which may be confounded with fruit weight) affect the rate at which the picker harvests individual fruit.

The average WHR values of the four pairs of pickers were 253, 271, 353, and 356 kg/h with an overall average of 309 kg/h. The rates varied by 41% from low to high, and because the two lowest and two highest rates were at either end of the spectrum, data from the two lowest and two highest pairs were pooled and designated as SLOW and FAST, respectively. Including the SLOW and FAST pickers in the statistical analysis as a class in the model statement of the GLM required that the harvest rate data be analyzed as a fractioned factorial because the SLOW and FAST pickers each harvested only 64 of the 128 subplots. Both the WHR and NHR of the SLOW and FAST pickers were significantly different, averaging 262 and 355 kg/h, and 1,421 and 1,869 fruit/h.

FRUIT YIELD VERSUS FRUIT WEIGHT

Although pickers generally prefer trees with higher yields to achieve higher WHR values, the average weight per fruit tends to be inversely related to fruit yield, t/ha. Wheaton and Stewart (1973) showed a similar relationship in that fruit size was inverse to fruit yield. Figure 1 shows the relationship between fruit weight and yield in this planting. (In each of the figures in this article, the "best fit", least squares linear, exponential, logarithmic, or power regression line is shown). The mean values of each of the 32 factor combinations (averaged over replications) are plotted and show how well each of the four tree height/rootstock combinations fit the overall linear regression line. Fruit weight varied from 160 to 235 g while fruit yield varied from 30 to 76 t/ha. The NHR in the 160 g fruit would have to be 47% higher than in the 235 g fruit to maintain a given WHR.

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* The authors recognize that kg and g are SI units of mass. However, they are used as units of weight in this article because quantities of fruit and individual fruit in the industry are normally referred to as weight.

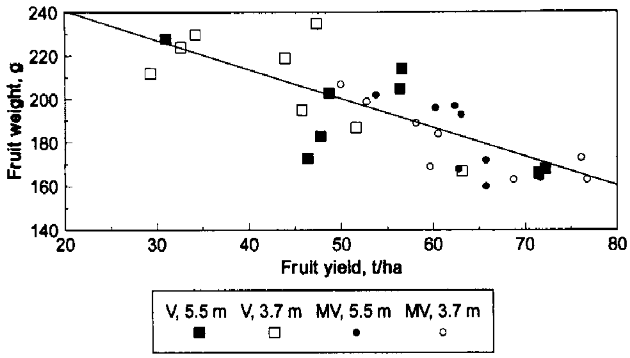

Figure 1–Fruit weight vs. fruit yield. Each point is a rootstock/tree height combination. Both MV and V are moderately vigorous rootstocks, respectively. The least squares regression line is Y = 269 – 1.39(X). $R^2 = 0.64$.

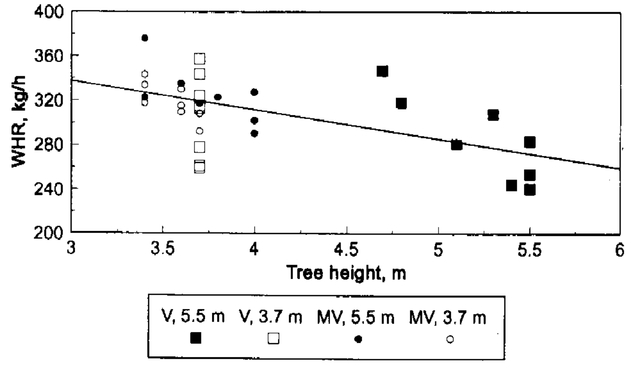

Figure 2–Weight harvest rate (WHR) vs. tree height. Each point is a rootstock/tree height combination. Both MV and V are moderately vigorous rootstocks, respectively. The least squares regression line is Y = 412 – 25(X). $R^2 = 0.32$.

FACTOR EFFECTS ON WEIGHT HARVEST RATE

In-row tree spacing was the only experimental factor which had a significant effect on WHR, being 292 and 325 kg/h in the 2.5 and 4.5 m in-row spacings, respectively. Some of the reasons for this were the fruit yield and the weight fruiting density were significantly higher for the 4.5 m in-row spacing (table 2). There was also a significant rootstock × in-row interaction for WHR. Further examination of the data (table 2) indicated the lower WHR at the 2.5 m spacing was mainly due to the vigorous rootstock and probably resulted because of the low fruit yields and weight fruiting densities of the rootstock. The changes of the WHR with in-row spacing were similar for the SLOW and FAST pickers, and there was no statistical interaction between the two.

One would normally expect WHR to be reduced with increased tree height, but the tree height factor (3.7 vs. 5.5 m) in this study did not have a significant effect on WHR, for several reasons. First, the average heights of the trees designated as 3.7 and 5.5 m were actually 3.6 and 4.5 m, respectively, because the trees on the moderately vigorous rootstock and designated for the 5.5 m height averaged only 3.7 m (fig. 2). Therefore, 75% of the trees were approximately 3.7 m high and the remaining 25% averaged 5.2 m high. Figure 2 shows the range of WHR values for both the shorter trees (316 kg/h average) on the left and the taller trees (285 kg/h average) on the right. The linear regression line shows a decrease of 25 kg/h in WHR for each 1.0 m increase in tree height or a decrease of 38 kg/h from the shorter to the taller trees. The seven lowest WHR values (<282 kg/mh) occurred in the vigorous rootstock trees—three in the shorter trees (V, 3.7 m) and four in the taller trees (V, 5.5 m). These seven low WHR values also occurred in the trees with the lowest weight fruiting densities as shown in figure 3, and these also were the vigorous rootstock trees at the 2.5 m in-row spacing. These data shown in figure 3 suggested WHR increased with weight fruiting density up to a value between 3 and 4 kg/m^3, and then became asymptotic at about 320 kg/h (the regression curve is not asymptotic). In the lower left quadrant of figure 3 below a weight fruiting density of 2.25 kg/m^3, the seven low WHR values discussed above averaged 260 kg/h or 19% less than 320 kg/h. However, in figure 3, it should be noted the three low values of WHR at weight fruiting densities above 5 resulted because of low fruit weights at high fruit yields as discussed in figure 1.

Table 2. WHR, fruit yield, and weight fruiting density values of rootstock × in-row spacing levels

	Moderately Vigorous Rootstock			Vigorous Rootstock			Averages		
In-row Spacing (m)	WHR (kg/h)	Fruit Yield (t/ha)	Weight Fruiting Density (kg/m^3)	WHR (kg/h)	Fruit Yield (t/ha)	Weight Fruiting Density (kg/m^3)	WHR (kg/h)	Fruit Yield (t/ha)	Weight Fruiting Density (kg/m^3)
2.5	316	64.5	4.19	268	39.5	1.96	292	52	3.08
4.5	327	61.7	5.49	323	57.9	3.24	325	59.8	4.37
Avg.	322	63.1	4.84	296	48.7	2.6	309	55.9	3.73

The relationship between WHR and fruit yield is shown in figure 4, and the seven low WHR values are in the lower left quadrant at a fruit yield of less than 50 t/ha. These data suggested WHR peaked between 50 and 60 t/ha, and then decreased somewhat as fruit yield increased to 77 t/ha, mainly because of the reductions in fruit weight at the highest fruit yields (fig. 1).

Overall, there was no relationship between WHR and fruit weight (fig. 5). However, if only the moderately vigorous rootstock trees are considered in figure 5, the trend is for WHR to increase with increasing fruit weight, perhaps because these trees were very similar in height and fruiting characteristics compared with the vigorous rootstock trees. Again, the seven low WHR values discussed above occurred across the range of fruit weights,

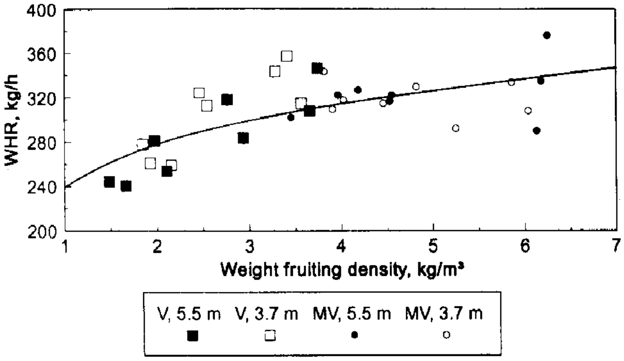

Figure 3–Weight harvest rate (WHR) vs. weight fruiting density. Each point is a rootstock/tree height combination. Both MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is Y = 240 + 55[ln(X)]. $R^2 = 0.48$.

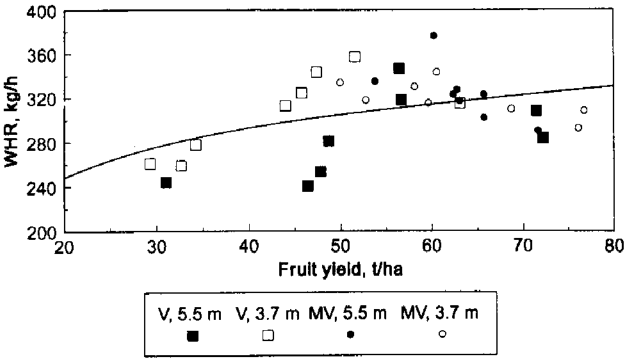

Figure 4–Weight harvest rate (WHR) vs. fruit yield. Each point is a rootstock/tree height combination. Both MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is Y = 79 + 58[ln(X)]. R^2 = 0.2.

and illustrate with figures 3 and 4 that higher fruit weights may not increase WHR if weight fruiting densities and fruit yields are low.

FACTOR EFFECTS ON NUMBER HARVEST RATE

Scion variety had a significant effect on NHR as values were 1,743 fruit/h for the early-maturing orange and 1,546 fruit/h for the late-maturing orange. In the early-maturing orange, fruit weight was significantly less (174 vs. 208 g) and number fruiting density was higher, 21.5 compared to 17.8 fruit/m^3 for the late-maturing orange. Figure 6 shows a fairly good relationship between NHR and number fruiting density. The seven low NHR values in the lower left quadrant of the figure averaged 1,271 fruit/h with an average number fruiting density of 9.2 fruit/m^3 and occurred in the same plots as the seven low WHR values discussed above in figures 2 through 5. The data in figure 6 suggested NHR increases with number fruiting density up to a value of 15 to 20 fruit/m^3, and then becomes asymptotic at a value of about 1,800 fruit/h (not illustrated by regression line). The seven low NHR values were 29% less than 1,800 fruit/mh and in fruit yields of less than 50 t/ha, as mentioned above for the seven low WHR values. Since fruit yield is a more commonly known variable, figure 7 shows its relationship with NHR, and the results are similar as one might expect with the number fruiting density.

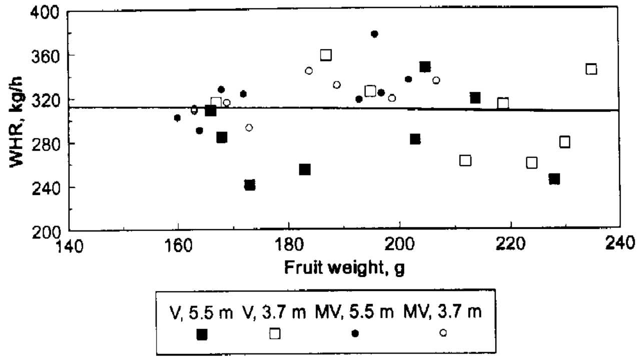

Figure 5–Weight harvest rate (WHR) vs. fruit weight. Each point is a rootstock/tree height combination. MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is Y = 322 – 0.07(X). R^2 = 0.002.

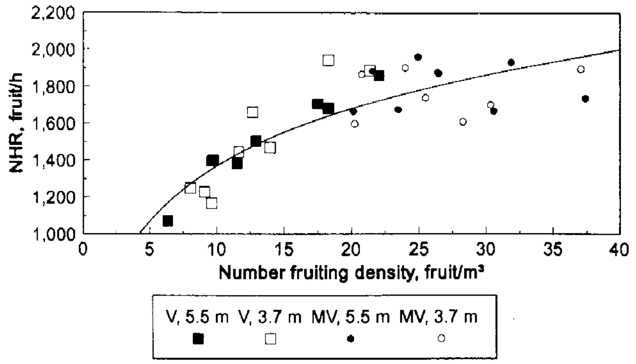

Figure 6–Number harvest rate (NHR) vs. number fruiting density. Each point is a rootstock/tree height combination. MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is Y = 366 + 441[ln(X)]. R^2 = 0.71.

The NHR of the moderately vigorous rootstock averaged 1,786 fruit/h and was significantly higher than the NHR of the vigorous rootstock at 1,504 fruit/h. In this case, the number fruiting density of the moderately vigorous rootstock was more than double that of the vigorous rootstock (26.7 vs. 13 fruit/m^3). In addition, for the moderately vigorous rootstock, fruit yield was significantly higher, and fruit weight and tree height were significantly lower.

The NHR at the 6.0 m between-row spacing was significantly greater than at the 4.5 m between-row spacing (1,692 vs. 1,597 fruit/h). The higher NHR at the wider between-row spacing was probably increased by the significantly lower fruit weight (187 vs. 195 g), but the significantly lower number fruiting density (18.3 vs. 20.6 fruit/m^3) would normally have decreased the NHR. In this case, one possible explanation is that a lower number fruiting density would not decrease the NHR if the fruit is concentrated more in the outer portion of the tree canopy volume where it is nearer and more accessible to the picker. The number fruiting density only measures an average throughout the canopy volume, and even though the canopy volume per hectare was 20% greater for the 6.0 m between-row spacing (data not shown), the fruit yields (t/ha) were similar and number fruiting densities in the outer portions of the tree canopies could have been similar.

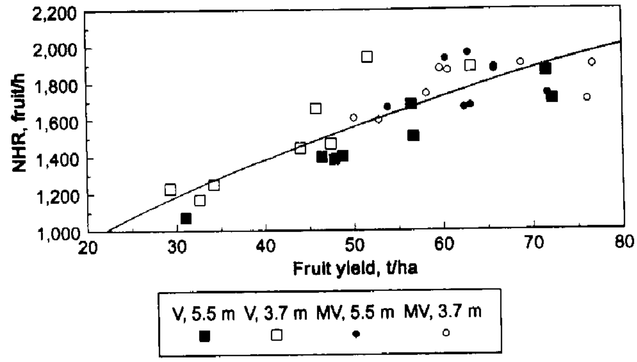

Figure 7–Number harvest rate (NHR) vs. fruit yield. Each point is a rootstock/tree height combination. MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is ln(Y) = 5.2 + 0.55[ln(X)]. R^2 = 0.75.

As with WHR, the NHR at the 4.5 m in-row spacing was significantly higher than at the 2.5 m in-row spacing, 1,745 vs. 1,545 fruit/h. The number fruiting density was likewise significantly greater for the wider in-row spacing (23.1 vs. 15.9 fruit/m^3). A significant in-row spacing × rootstock interaction resulted, as it did with WHR, because the NHR in the moderately vigorous rootstock changed little (1,770-1,802 fruit/h) with in-row spacing, while it increased markedly (1,320-1,687 fruit/h) from the 2.5 to the 4.5 m in-row spacing in the vigorous rootstock. Similarly, the number fruiting density of the moderately vigorous rootstock increased from 23.3 to 30.2 fruit/m^3 with increasing in-row spacing and that of the vigorous rootstock increased from 9.5 to 16.6 fruit/m^3. As discussed above, number fruiting densities of 15 to 20 fruit/m^3 and greater resulted in similar NHR values, and the seven low NHR values corresponded to an average number fruiting density of 9.2 fruit/m^3.

Figure 8 shows that, overall, NHR was inversely related to fruit weight, and the seven lower NHR values occurred across the range of fruit weights. If only the moderately vigorous rootstock trees (very similar in height and fruiting characteristics) are considered in figure 8, the NHR changes little with fruit weight.

Predicting Harvest Rates

Variables that could be readily measured in the field were considered for predicting harvesting rates. These were fruit yield (Y), fruit weight (W), and tree height (H). A multiple regression analysis relating these three variables to the measured NHR values resulted in the predicted number harvest rate (PNHR):

$$\text{PNHR} = 623 + 544(\ln Y) - 3{,}714(W) - 108(H) \quad (2)$$

$$R^2 = 0.84$$

Standard error of PNHR estimate = 106 fruit/h

Figure 9 shows the PNHR values from equation 2 plotted against the actual NHR values measured in this study. A linear regression analysis of these data resulted in

$$\text{NHR} = 0.999(\text{PNHR}) \quad (3)$$

$$R^2 = 0.84$$

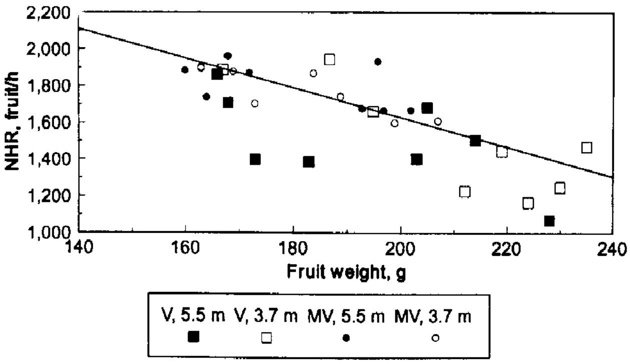

Figure 8–Number harvest rate (NHR) vs. fruit weight. Each point is a rootstock/tree height combination. Both MV and V are moderately vigorous and vigorous rootstocks, respectively. The least squares regression line is Y = 3227 – 08(X). R^2 = 0.56.

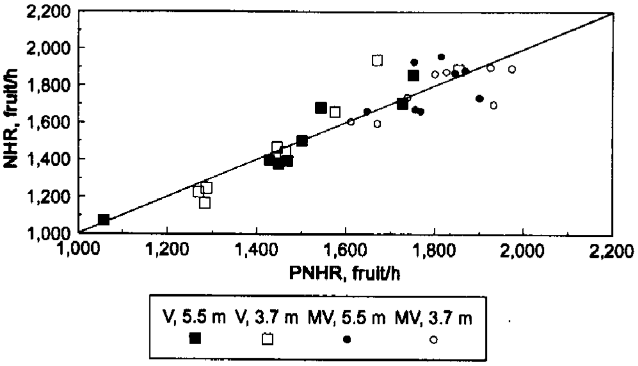

Figure 9–NHR vs. PNHR. The least squares regression line is Y = 0.99(X). R^2 = 0.84.

A multiple regression analysis relating these variables to the measured WHR values yielded equation 4 for the predicted weight harvest rate (PWHR):

$$\text{PWHR} = -233 + 114(\ln Y) + 890(W) - 20.3(H) \quad (4)$$

$$R^2 = 0.62$$

Standard error of PWHR estimate = 21.2 kg/h

As one might expect, the respective coefficients in equation 4 were approximately 20% of those in equation 2 or the average fruit weight in this study of about 0.2 kg. Further analyses of the data resulted in a better fit for PWHR than equation 4 by multiplying equation 2 by fruit weight (W), which is a logical relationship, and resulted in equation 5:

$$\text{PWHR} = W(\text{PNHR}) = 623(W) + 544(W)(\ln Y)$$

$$- 3{,}714(W^2) - 108(W)(H) \quad (5)$$

$$R^2 = 0.68$$

Standard error of PWHR estimate = 19 kg/h

Figure 10 is a plot of the PWHR values from equation 5 and the actual WHR values measured in this study. A linear regression analysis of the data with a zero intercept resulted in:

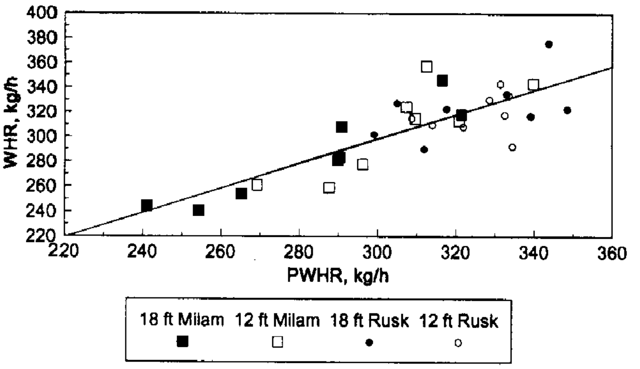

Figure 10–WHR vs. PWHR. The least squares regression line is Y = 0.99(X). R^2 = 0.68.

$$WHR = 0.999(PWHR) \qquad (6)$$

$$R^2 = 0.68$$

Although the fit for PWHR (eq. 5) was not as good as for PNHR (eq. 2), it did indicate that PWHR increased with increasing fruit yield and weight and decreasing tree height in the same way that WHR was affected by these variables.

Consider the approximate range of variable values in this study; fruit weight 160 to 235 g, fruit yield 30 to 76 t/ha, tree height 3.7 to 5.5 m. Table 3 shows the effects of these ranges on PWHR. The minimum and maximum PWHR values were 205 and 401 kg/h. In the top third of the table, PWHR changes or increases 32 to 83 kg/h when fruit weight increases from 160 to 235 g at the four combinations of end-range values for fruit yield and tree height. Similarly, in the middle third of the table, PWHR changes or increases 82 to 119 kg/h when fruit yield increases from 30 to 76 t/ha at the four combinations of end-range values for fruit weight and tree height. Finally, in the bottom third of the table, PWHR changes or decreases 31 to 47 kg/h when tree height increases from 3.7 to 5.5 m at the four combinations of end-range values of fruit weight and fruit yield.

Most of the mature Florida orange trees are similar to the trees on the vigorous (V) rootstock in this study. At maturity, they are at least 5.5 m tall. Assuming fruit weight decreases with increasing fruit yields as shown in figure 1, and fruit yield increases from 30 to 76 t/ha, fruit weight will decrease from 227 to 163 g, and the PWHR will increase from 234 to 290 or 56 kg/h as predicted by equation 5. This is a 24% increase in PWHR or approximately 1.35 Florida orange field boxes/h. If the higher yielding trees are reduced to a 3.7 m height, the PWHR increases to 322 kg/h or a 38% increase over 234 kg/h. This is an 88 kg/h or 2.2 Florida orange field boxes/h increase. Reducing only the height of the high-yielding trees increases the PWHR 32 kg/h (11%) or three-fourths of a Florida orange field box/h.

Thus, this study shows that high fruit yields on short trees can increase the PWHR more than one-third compared with low fruit yields on tall trees, or reducing the height of high-yielding trees by 1.8 m can increase the PWHR by 11%. Further, this study gives a basis to estimate PWHR using three variables (fruit weight, fruit yield, and tree height) which are measurable in the field.

Table 3. Effects of ranges in fruit weight, fruit yield, and tree height on PWHR as predicted by equation 5

Fruit weight (kg)	Fruit yield (t/ha)	Tree height (m)	PWHR (kg/h)
0.160 to 0.235	30	3.7	236 to 282 = 46 inc.
0.160 to 0.235	30	5.5	205 to 237 = 32 inc.
0.160 to 0.235	76	3.7	318 to 401 = 83 inc.
0.160 to 0.235	76	5.5	287 to 355 = 68 inc.
0.160	30 to 76	3.7	236 to 318 = 82 inc.
0.160	30 to 76	5.5	205 to 287 = 82 inc.
0.235	30 to 76	3.7	283 to 401 = 118 inc.
0.235	30 to 76	5.5	236 to 355 = 119 inc.
0.160	30	3.7 to 5.5	236 to 205 = 31 dec.
0.235	30	3.7 to 5.5	283 to 236 = 47 dec.
0.160	76	3.7 to 5.5	318 to 287 = 31 dec.
0.235	76	3.7 to 5.5	401 to 355 = 46 dec.

APPLICATIONS TO FLORIDA ORANGE HARVESTING

In Florida orange harvesting, pickers are paid on a piece rate or field box basis, and a field box of Florida oranges is defined as 90 lb (40.8 kg) of fruit. In actual practice, however, a picker is usually paid by the estimated bulk volume of fruit or the number of containers filled, such as the 10 field box (408 kg) tub which has a total volume of 0.76 m^3. Obviously, from a picker's perspective, fruit diameter is one of the most important variables, since fewer fruit are required to fill a container as fruit diameter increases, and the number of fruit required is inversely related to fruit diameter cubed. Within the normal range of orange diameters encountered in the field, the following equation is a good approximation of the number of fruit required to fill a container all in consistent units.

$$N = 1.91(PD)(CV)/D^3 \qquad (7)$$

where

N = number of fruit required to fill the container

PD = packing density of fruit in container as decimal, summation of individual fruit volumes in container/container volume

CV = container volume

D = average fruit diameter

The weight of bulk fruit in a container can be expressed as follows:

$$\text{Bulk fruit weight(kg)} = 1000(ASG)(PD)(CV) \qquad (8)$$

where ASG is the average apparent specific gravity of individual fruit and CV is the container volume (m^3). Equation 8 shows the relationship between bulk fruit weight and bulk fruit (container) volume. The main factors influencing the weight of bulk fruit occupying a container volume are the packing density and the apparent specific gravity of the fruit. The packing density of the fruit depends largely on fruit firmness. The apparent specific gravity of individual fruit is determined to a greater extent by the percentage of the fruit weight which is juice, and to a much lesser extent the soluble solids content of the juice. In this experiment, the apparent specific gravities of the fruit of the 32 factor combinations had an average value of 0.89 and ranged from 0.87 to 0.93. If a 10 field box tub (only 0.71 m^3 of the 0.76 m^3 total tub volume is used if proper headspace is maintained) contains 408 kg of fruit with an apparent specific gravity of 0.89, the packing density would be 0.65.

The only experimental factor in this study to significantly affect the apparent specific gravity was scion variety, which averaged 0.91 and 0.88, respectively, for the late- and early-maturing orange. The late-maturing orange also had a significantly higher percentage of its fruit weight which was juice content (61.2 vs. 56%) and the soluble solids content in the juice (14 vs. 12.2%). According to information presented by Chen (1993), the contribution of juice to the difference in apparent specific gravities of the two scion varieties would have been mainly due to the difference in juice contents of the fruit as compared with the difference in soluble solids contents of the juice. Even if apparent specific gravity information is not available, the PWHR values given by equation 5 should be useful in determining the relative effect of fruit yield, fruit weight, and tree height on manual harvesting rates. Caution is advised in using equation 5 to estimate harvesting rates on orange trees and fruiting characteristics outside the physical limits existing in this study. In addition, this study was conducted on uniform-sized trees within each plot and caution should be used in applying equation 5 in groves with nonuniform tree size and fruiting characteristics.

CONCLUSIONS

The WHR of conventional pickers in Florida oranges was predicted in uniform grove conditions with three variables—fruit yield per hectare, individual fruit weight, and tree height. The ranges of values for the three variables were: fruit yield, 30 to 76 t/ha; fruitweight, 160 to 235 g; tree height, 3.7 to 5.5 m. Using multiple regression analyses, the equation for the PWHR per picker accounted for 68% of the variability in the WHR, which had an overall average value of 309 kg/h. The PWHR increased with increasing fruit yield and fruit weight, and decreasing tree height. Fruit weight was inversely related to fruit yield. When the fruit yield of 5.5 m trees increased from 30 to 76 t/ha, fruit weight decreased from 227 to 163 g, and PWHR increased from 234 to 290 kg/h. Reducing the tree height of the 76 t/ha trees from 5.5 to 3.7 m increased the PWHR to 322 kg/h. Thus, the PWHR in the shorter, higher-yielding trees was greater by 88 kg/h or 38% than in the taller, lower-yielding trees.

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NOMENCLATURE

Number fruiting density	average number of fruit per unit canopy volume (fruit/m^3)
Weight fruiting density	weight of fruit per unit canopy volume (kg/m^3)
WHR	weight harvest rate per picker; expressed as weight of fruit harvested per h or kg/h
PWHR	predicted weight harvest rate per picker (weight of fruit harvested per h or kg/h)
NHR	number harvest rate per picker measured; (number of fruit harvested per h or fruit/h)
PNHR	predicted number harvest rate per picker (number of fruit harvested per h or fruit/h)
MV	moderately vigorous rootstock which is Rusk citrange
V	vigorous rootstock which is Milam
W	average weight of individual fruit (kg)
Y	fruit yield per unit area (t/ha)
H	tree height (m)