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Seasonal Variation in Preharvest Fruit Drop of Florida Oranges in Relationship to Weather and Other Factors

L. GENE ALBRIGO* AND T.A. EBERT

*University of Florida/IFAS, Citrus Research and Education Center, 700 Experiment Station Road,
Lake Alfred, FL 33850*

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Variation in preharvest fruit drop of processing orange, *Citrus sinensis*, in Florida is well known. Preharvest fruit drop has been monitored by the USDA–National Agricultural Statistical Service (NASS) since 1960, but causes for year to year variation were not evaluated. An understanding of causes was thought to be helpful in understanding how much of the current heavier preharvest fruit drop should be assigned to the serious disease huanglongbing (HLB) and how much to factors leading to natural preharvest fruit drop. Statewide and citrus production district fruit drop data, yields, and tree counts for early-mid and late season cultivars were obtained from the U.S. Department of Agriculture–National Agricultural Statistical Service (USDA–NASS) for 51 years, from 1960 through 2011. Statewide and district monthly minimum and maximum average temperatures and total rainfall were obtained from the National Oceanographic and Atmospheric Administration (NOAA) records. Yields were converted to mature tree equivalents; bloom dates were obtained using the Florida Citrus Flowering Monitoring System. Multiple regression analyses were run for early-midseason and late season orange fruit drop against all other variables. Over 51 years, there was a significant but small reduction in preharvest drop for early-mid and late season cultivars. For early-midseason oranges, 69% of the year to year variation in preharvest fruit drop was significantly associated with six variables. Besides year, three of these variables were minimum monthly temperatures in late spring and early summer. For late season oranges, 65% of the variation in preharvest drop was significantly associated with six variables. Besides year, two of these were monthly average maximum temperatures in January and monthly rainfall in February. Previous and current yields were associated with variation in percentage fruit drop of the current year for both early-midseason and late cultivar drop. Temperature and rainfall variables might be associated with advancing maturation of the fruit which could have made it more vulnerable to drop, but no definite cause and effect could be ascribed to the data analyses.

Variation in fruit drop of processing oranges, *Citrus sinensis*, in Florida is well known and has been exceptionally high since the 2012–13 harvest season (USDA–NASS, 2015) when the serious disease huanglongbing (HLB) was believed to be endemic throughout Florida's citrus industry. NASS (FASS) reported that 2012–13 was the worst year for early fruit drop since 1969–70. Excepting freeze years, the last four seasons may have been the worst ever for preharvest drop.

A high or low drop year is established before the harvest season starts, with high or low years evident at the first data report for November (early-mid season cultivars) and February (late season cultivars) (Albrigo, 2006).

Drop rate increases 2% to 3% per month during harvest (Albrigo, 2006). Preharvest fruit drop has been monitored by USDA–NASS since 1960 but causes of variation were not evaluated. An understanding of causes was thought to be helpful in understanding how much of the current heavier preharvest fruit drop should be assigned to the serious disease HLB and how much to factors leading to natural preharvest fruit drop.

Possible variables related to normal drop such as previous growth temperatures, rainfall, bloom date, and yield per tree were evaluated by multiple regression analyses.

The working hypothesis of this study was as follows: "Understanding variation in normal drop can allow evaluating how much HLB contributes to drop in a given year."

Materials and Methods

Statewide and citrus production district fruit drop data, yields, and tree counts for early-midseaon and late season cultivars were obtained from NASS for 51 years, from 1960 through 2011. Early season and late season orange cultivars, respectively, are primarily the 'Hamlin' and 'Valencia' cultivars.

Only statewide preharvest fruit drop data was available from 1960–88. After the 1989 freeze, fruit drop data was available by five districts in Florida. Data was used through 2011 since HLB was clearly affecting fruit drop by 2012 (USDA–NASS, 2015). The five districts were Indian River, North, Central, West, and South and numbered 1–5, respectively. Fruit drop data were available from USDA–NASS and reported monthly starting in November for early-midseason cultivars and February for late season cultivars. Data for each harvest time class is available for three months during the harvest season of each cultivar class.

Most freezes come in December or January and primarily affect late season cultivars which are harvested after the freeze (Albrigo and Burani-Arouca, 2010). Rarely have hurricanes occurred in the citrus areas of Florida, but there were hurricanes in 1962 and 2004 and 2005 (Albrigo et al., 2005). Drop data for early or late season cultivars in some of these years were omitted due to abnormally high values related to catastrophic weather events.

Statewide and district monthly minimum and maximum average temperatures and monthly total rainfall were obtained from the National Oceanographic and Atmospheric Administration

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*Corresponding author; phone: (863) 956-8707; e-mail: albrigo@ufl.edu.

(NOAA) records for the same years plus one year previous to 1960. Yields were converted to mature tree equivalents (Albrigo and Burani-Arouca, 2010). Bloom dates were obtained using the Florida Citrus Flowering Monitoring System (Albrigo et al., 2002). Multiple regression analyses were run for early-midseason (November) and late season orange fruit drop (February) against all other variables (SAS®, 2015). Analyses used the first month of each cultivar season as high or low drop rates were already established and, subsequently, drop rates increase at about 3% per month (Albrigo, 2006). Correlation-regression analyses were run for statewide averages for all the years by averaging all the data from 1989 to 2011 in order to add this data to the 1960 to 1988 data.

Yield and bloom dates were also evaluated against the other collected and calculated data. To assess the possible effect of district, we reanalyzed the data restricting it to the period from 1989 to 2011 where district information was recorded. This model used all the weather and biological variables that were used in previous models, and the residuals were retained for further analysis. A regression model was then built to look for any pattern between district and these residuals.

Results and Discussion

The preharvest fruit drop data provides a wide range of drop values over the years for these analyses (Figs. 1 and 2). For the pre-1989 data, the average data for November, December, and January were, respectively, 6%, 9%, and 12% drop for early-mids and 17%, 22%, and 25% drop, respectively, for February, March, and April for late season cultivars (Fig. 1). For early-mids, the highest percent drop year was 1969 starting with 12% and ending with 19%. The lowest year was 1976 starting with 3% drop in November and ending with 6%. For late season cultivars, the highest year was 1962, a significant freeze year, which had 31% drop in February and increased to 45% drop. The lowest year was 1968, with a 9% drop in February and increasing to 13% in April. The general averages for early-mid and late season increased from 6% to 12% at 3% per month and 17% to 25% at 5% and 3% per month, respectively, which were similar to what was reported earlier for a small 6 year sampling of drop data (Albrigo, 2006).

For the years after the 1989 freeze, the average fruit drop across all districts for early-mid cultivars was 5%, 7%, and 10% for November, December, and January, respectively; while for late season fruit, it was 12%, 14.5%, and 17.5% for February, March, and April, respectively (data not shown). Overall, these were 2% to 3% increases in preharvest fruit drop per month. An example of the freeze effect is shown in Fig. 2. While average losses are not unusual for the coldest district (District 2, North Central District), the 1989 freeze resulted in 50% loss of late season fruit by February and 80% by April. On the other hand, District 1 (warmer Indian River District) did not have unusual drop in that year; but in another freeze year, 1998, this district had 26% drop increasing to 34% by April (Fig. 2).

Since the data set was quite extensive, multiple regression analyses were run to see if any significant associations could be found for yield (Table 1) and bloom date (Table 2) as dependent variables to establish possible predictive equations from the rest of the independent variables.

For early-mid and late season yield/mature tree equivalents (YMTE), the R^2 values were 0.46 and 0.41, respectively (Table 1). For both harvest periods, there was a significant relationship to year but the slope estimates were small, –0.027 and –0.021, respectively, for early-mid and late season cultivars. Previous yield was also related to current yield for both early-mid season and late season cultivars. For early-mid season, the YMTE from two years ago was positively related to current yield with a 0.522 slope estimate, and for late season, the YMTE from one year previously was positively correlated with a 0.346 slope estimate. November drop was negatively related to early-mid season YMTE with a 0.757 slope estimate. Weather data also was correlated to current yield for both early-mid and late season cultivars. For early-mid yield, May rainfall was correlated with a slope estimated at 0.004, while for late season yield, the rainfall in the January before bloom was related with a 0.003 slope.

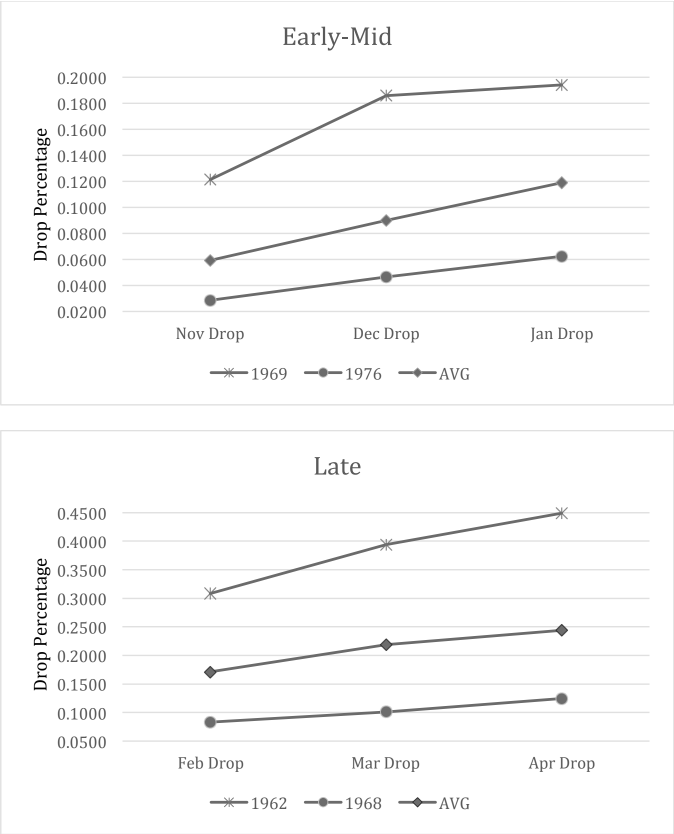

Fig. 1. Average statewide percentage preharvest fruit drop for orange, *Citrus sinensis*, for early-mid (primarily 'Hamlin') and late ('Valencia') cultivars from 1960 through 1988. The overall average data for the 3 months collected by NASS are shown, as well as the lowest and highest initial drop years during this period for each harvest season type.

These variables indicate that yield decreased slightly over the 51 years studied, only about 1/10th of a box per tree. This was a very small but highly significant change. It could reflect an increase in trees per acre over time without an increase in yield per acre. This seems unlikely since an earlier study found a significant increase in yield per tree over the 1960s with the leveling out of yield per tree only after the mid-70s when irrigation and fertilization practices became more stable (Albrigo and Burani-Arouca, 2010). More disease pressure over time seems to be a general trend, even before HLB, but there seems to be no data to support that yields have generally suffered for this. Previous yields, two years prior of early-mids and one year prior for late season, were positively related to current yields

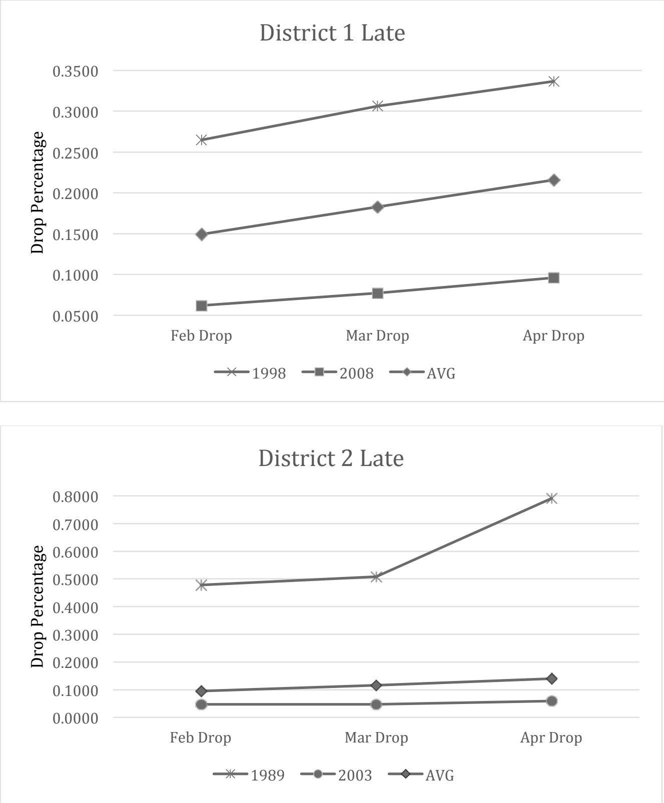

Fig. 2. Average percentage preharvest fruit drop for orange, *Citrus sinensis*, for late ('Valencia') cultivars from 1989 through 2011 for Districts 1 and 2. District 1 is the Indian River and District 2 is the northern citrus area in Florida. The overall average data for the 3 months collected by NASS are shown as well as the lowest and highest initial drop years during this period for each harvest season type.

with estimate slopes that indicated that yield increased about one-half to one-third box for a one box change in previous yield. With alternate bearing, a high crop two years ago would lead to a higher crop in the current year, but the previous year, you would expect a higher crop to lead to a lower crop. Of course, these two variables were related statistically to different harvest seasons and therefore cultivars. Even though the variables were assumed to be independent, many factors can be interrelated over time in a perennial tree crop, particularly year to year yields. Late winter and spring rains in 2 months (May and January) that are relatively dry were statistically related to higher yields.

Bloom date (not differentiated by cultivar harvest dates) was correlated with two variables, years and earlyYMTEm3 (Table 2). These two variables accounted for 46% of the variation in bloom date. Bloom date advanced one-fourth of a day per year or 13 d during the 51 years in the study. Perhaps this was related to some form of climate change. Bloom date advanced 5 1/3 d per each box of fruit 3 years previously to the current year's bloom. A current heavy crop would be expected to delay bloom as 'Valencia' bloom is delayed about 5 d due to having a current crop at bloom time compared to the early-mid season 'Hamlin' which is harvested before the bloom in February.

An evaluation of the YMTE values in previous years to bloom date (Table 3) revealed that the strongest correlation was to three years previously (YMTEm3) for both early-mid and late season values with R^2 values of 0.46 and 0.45, respectively. It is generally known that any change in practices or conditions to a perennial fruit crop requires three years to stabilize. Perhaps this three-year lag effect has something to do with that. On the other hand, yields of previous years 2 through 4 had a significant correlation to current bloom date, so the third year may not be uniquely related to the current bloom date. Specifically, why a crop load three years previously would affect bloom date is not clear.

Table 1. Predicting yield for early/mid-season orange, *Citrus sinensis*, and late season orange. Nov Drop = November fruit drop data. EarlyYMTEm2 = early season yield data from two years ago. RainMa = rain in May.

	Adjusted R^2	0.46			
	Source	DF	Sum of Squares	Mean Square	Pr > F
Early season[z]					
	Model	4	13.668	3.417	< 0.001
	Error	40	13.362	0.334	
	Corrected Total	44	27.030		
	Variable	DF	Parameter estimate	Standard Error	Pr > |t|
	Intercept	1	53.194	13.794	< 0.001
	Year	1	–0.027	0.007	< 0.001
	Nov Drop	1	–0.757	0.243	0.003
	EarlyYMTEm2	1	0.522	0.102	< 0.001
	RainMa	1	–0.004	0.002	0.017
	Adjusted R^2	0.41			
	Source	DF	Sum of Squares	Mean Square	Pr > F
Late season[y]	Model	3	11.131	3.710	< 0.001
	Error	45	13.605	0.302	
	Corrected Total	48	24.737		
	Variable	DF	Parameter Estimate	Standard Error	Pr > |t|
	Intercept	1	43.300	12.433	0.001
	Year	1	–0.021	0.006	0.002
	RainyrPJ	1	0.003	0.002	0.106
	LateYMTEm1	1	0.346	0.130	0.011

[z] 1964 was dropped.

[y] 1964 and 1963 were dropped.

Table 2. Predicting bloom date of orange, *Citrus sinensis*, based on year and yield of early/mid-season cultivars with a three-year lag. EarlyYMTEm3 = early season yield three years prior to current season. No years were deleted.

Adjusted R^2	0.46				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1709.435	854.717	21.50	< 0.0001
Error	46	1828.973	39.760		
Corrected Total	48	3538.408			
Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	–512.713	126.646	–4.05	0.0002
Year	1	0.278	0.064	4.36	< 0.0001
EarlyYMTEm3	1	5.355	1.091	4.91	< 0.0001

Table 3. The effect of using different previous (lag) years for YMTE and the effect of using early versus late season yield data on predicting bloom date of orange, *Citrus sinensis*.

	Early		Late	
Lag	Adjusted R^2	Pr > F	Adjusted R^2	Pr > F
1	0.1779	0.2912	0.2191	0.0594
2	0.3204	0.0065	0.3079	0.0104
3	0.4606	< 0.0001	0.4548	< 0.0001
4	0.2366	0.0365	0.2484	0.0243
5	0.2228	0.0319	0.1571	0.2996
6	0.1712	0.0904	0.1296	0.3758

Multiple regression runs for only the post 1988 fruit drop data, with district separation, did not provide highly significant equations. These runs accounted for less than 24% of the variation in fruit drop data. Therefore, only the combine 1960 through 2011 data is presented for the multiple regression analysis. Over the 51 years of this data set, there was a significant but small reduction in preharvest drop for early-mid (Table 4) and late season cultivars (Table 5) associated with advancing year. The year effect was of the same magnitude as the year effect on yield. For early-midseason oranges, 69% of the year to year variation in preharvest fruit drop was significantly associated with six variables (Table 4). Three of these were minimum monthly temperatures in February, June, and July. February and June were positively related to fruit drop. Higher minimum temperatures may have advanced fruit maturation so that the fruit was more mature and dropped more easily. July's temperatures were negatively related to drop rate, but no obvious physiological response easily explains this. Likewise, YMTE values from five and two years previously both positively accounted for variation in November drop of early-mid season cultivars without an obvious reason for these years being the most significant. Most of the lag year yield data related fairly well to November drop as single variables (values not shown).

The residual components were very uniformly distributed as shown by four methods of evaluation (Fig. 3). Linear predictor, residual, and quantile plots all indicate uniform distribution of residuals while the variance plot shows a uniform distribution above and below zero with equal standard errors. There was no tailing of the quantile residual plot suggesting that the combining of the 1960–88 statewide data with the averaged 1989–2011 data was a good fit.

For late season oranges, 65% of the variation in preharvest drop was significantly associated with seven variables (Table 5). Three of these were monthly average maximum temperatures in January and June plus monthly rainfall in February. These were positively associated with drop rate. Higher January and June temperatures and more rainfall in February might accelerate flower bud and fruit development which could lead to more mature fruit by February when fruit drop has begun in late season cultivars. The residual plots were nearly as good as for the early-mid season analysis, but the distribution of larger residuals was skewed slightly to the earlier years (not shown).

Table 4. Predicting preharvest orange, *Citrus sinensis*, fruit drop level in November for early-midseason cultivars using bloom date, previous or current yield, monthly min or max temperatures and monthly rainfall. The adjusted $R^2 = 0.69$. The partial R^2 values were generated as a stepwise regression analysis in Proc Reg.

Source[z]		DF	Sum of Squares	F Value	Pr > F
Model		6	4.75	15.89	< 0.0001
Error		34	1.69		
Corrected Total		40	6.44		
Variable	Partial R^2	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept		28.52	5.893	4.84	
Year	0.32	–0.01	0.003	–4.85	< 0.0001
MinC February	0.12	0.08	0.019	4.26	0.0002
EarlyYMTEm5	0.09	–0.25	0.048	–5.07	< 0.0001
MinC July	0.10	–0.11	0.030	–3.77	0.0006
EarlyYMTEm2	0.05	0.13	0.044	2.93	0.0061
MinC January	0.04	0.03	0.015	2.34	0.0251

[z] 1976 and 2004 (three hurricanes) were not used in this analysis.

Table 5. Predicting preharvest orange, *Citrus sinensis*, fruit drop level in February for late season cultivars using bloom date, previous or current yield, monthly minimum or maximum temperatures, and monthly rainfall. The adjusted $R^2 = 0.65$. Partial R^2 values were calculated using the stepwise procedure in Proc Reg.

Source[z]		DF	Sum of Squares	F Value	Pr > F
Model		7	7.02	13.8	< 0.0001
Error		42	3.05		
Corrected Total		49	10.07		
Variable	Partial R^2	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept		12.04	7.083	1.7	0.0967
Year	0.27	–0.01	0.004	–2.8	0.0076
Rain February	0.11	0.00	0.001	5.28	< 0.0001
LateYMTE	0.06	0.46	0.105	4.39	< 0.0001
EarlyYMTE	0.08	–0.21	0.082	–2.55	0.0144
MaxC June	0.07	0.13	0.032	3.9	0.0003
LateYMTEm1	0.06	–0.22	0.073	–2.98	0.0048
MaxC January	0.05	0.06	0.021	2.6	0.0129

[z] 1989 (freeze) was not used in this analysis.

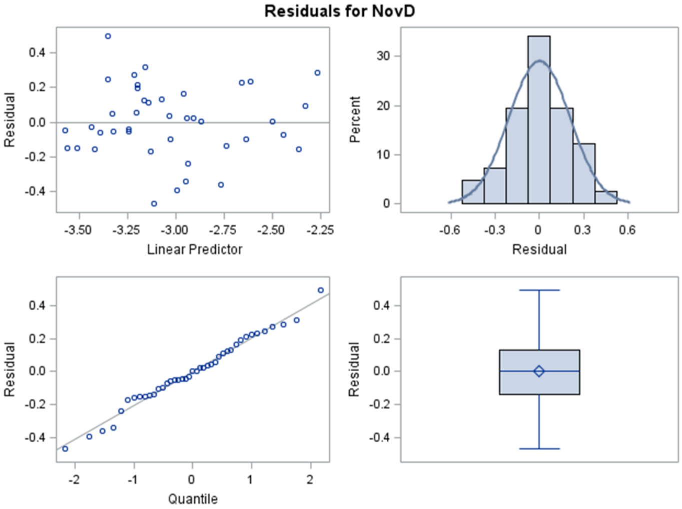

Fig. 3. Residual data from multiple regression of November orange, *Citrus sinensis*, fruit drop data (Table 4) for all years from 1960 through 2011. Linear predictor, residual, quantile, and variance plots are shown.

The yields from the previous year (YMTE) were negatively associated with variation in percentage fruit drop of the current year. The YMTE for the current season was positively associated with more drop. Higher crop load could cause a sink deficiency on stem development that leads to a weaker attachment of the fruit. A negative effect of the previous year's yield might translate into a lower crop leads to a heavier crop the following year, but that seems to already be in the equation from the current yield relationship. Previous yield may influence the survival or vigor of new growth, and it takes a few years for that new growth to influence yield. Further, new growth is only relevant to the extent allowed by pruning practices. Neither grove management nor data on shoot production were available, but this could be relevant. Finally, the relationship of more early-mid season cultivar yields being negatively related to more drop has no logical direct relationship, but may indicate that some other factor is better represented by this data than its direct relationship or some other variable was not included in the independent data array. So no ideas come forth about this relationship. All other proposals of cause and effect based on the correlations and regressions are speculative at this point.

These analyses provide some possible leads for explaining the year to year variations in fruit drop prior to HLB, pre 2012. The relationships of the independent data to yield and bloom date are also of interest, particularly if a climate change factor may be involved. The apparent relationships of yield, bloom date and years suggest that not all of the independent variables are totally independent.

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