EVALUATION OF AERIAL PHOTOGRAPHY AS A TECHNIQUE FOR ESTIMATING CITRUS FRUIT YIELD

By

Richard D. Allen

STATISTICAL REPORTING SERVICE

U. S. DEPARTMENT OF AGRICULTURE

Published September 1977

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

Publication of this report was delayed following reassignment of the author. The report is being issued at this time to document this one-of-a-kind research study.

I wish to thank Harold F. Huddleston and Wendell W. Wilson for their assistance in reviewing the final draft and in arranging for publication.

INTRODUCTION

Considerable research has been conducted in recent years in efforts to determine improved procedures or techniques for estimating and forecasting yields of citrus and other fruit trees. Various procedures involving counts of fruit on sample limbs or on ground level photographs have been tried.

Aerial photography has been suggested as a possible technique for estimating fruit yield. Since fruit counts from ground level photographs are significantly correlated with fruit counts, perhaps counts from aerial photographs would be also. Another possibility might be the correlation of optical density measures of photography with fruit counts. That is, varying fruit sets may cause a shift in photographic response which can be detected by appropriate instruments.

At present, aerial photography is utilized mainly as a sampling frame tool. The Florida State Statistical Office updates its census of citrus trees by using current aerial photography interpretations to detect changes in tree numbers of new plantings. Aerial photography is not used for fruit counts, although fruits have been identified on selected aerial photographs in recent years.

During late 1969 and early 1970, the Research and Development Branch of the Statistical Reporting Service requested overflights over selected orchards in the Rio Grande Valley of Texas. The overflights were made as part of cooperative research efforts of SRS and the Agricultural Research Service (ARS) Remote Sensing Research Center at Weslaco, Texas. Ron Bowen of ARS took all of the aerial photographs in the study.

Two main test sites were photographed. One was a block of Valencia orange trees, approximately 20 years old. Twenty trees in this block were selected for making fruit counts. Actual counts were made on these twenty trees in November by a combined enumeration and sampling method outlined on Page 3. The other main test site was the ARS Research Farm. On the Research Farm are a number of Valencia orange trees, approximately six years old. The fruit from one-fourth of these trees was enumerated at harvest, about March 1, 1970.

DATA AVAILABLE

Overflights of the selected Valencia grove and the citrus trees on the ARS Research Farm were made on November 19, December 16 and February 16. Photography was taken at 500, 1,000 and 5,000 feet on each overflight. However, density readings were not taken for any of the 5,000 feet photography because of the extremely small size of the trees relative to the aperture of the densitometer.

In addition to the overflights, each of the 20 trees in the selected Valencia grove was photographed from a "cherry picker" on November 19 and 20. Photographs were taken from a height of approximately 50 feet above ground with a hand held Hasselblad camera using 70mm format high speed Ektachrome color film.

Table 1 summarizes the photography which was useable for taking optical density readings. All aerial photography was Ektachrome color film, 9-1/2 inch format.

Table 1.--Inventory of useable photography available for optical density readings

Date and Altitude	Selected Research Block (20 year old trees)	ARS Research Farm (6 year old trees)
November 19		
1,000 feet	2 passes[1/]	1 pass[1/]
Cherry Picker	All 20 trees	---
December 16		
1,000 feet	1 pass[1/]	1 pass[1/]
500 feet	2 passes of 4 trees	1 pass[1/]
February 16		
1,000 feet	---	1 pass[1/]
500 feet	1 pass[1/]	1 pass[1/]

[1/]All trees in the block were photographed.

FRUIT COUNTS FROM PHOTOGRAPHS

It was planned to compare photo counts from the "cherry picker" with those of higher altitude photography. However, the imagery from the November and December overlights was blurred, and it was not possible to count fruit from these images. The blurring problem was corrected on the February overflight and counts of fruit visable on color transparencies were made.

While the photographs were being taken from the cherry picker, a second individual in the "boom" or basket, acted as an observer. The observer took a Polaroid picture of each sample tree. He then counted all of the fruit visible to him and marked the location of each of the Polaroid prints. The observer counts were made from directly over the trees, as were the photographs.

Subsequent photo counts were made through an adjustable stereoscope which was used in conjunction with a light table. The interpreter could adjust the magnification as needed to make his counts.

Counts were made by two counters, independently. There was generally good agreement between counters; if a fruit could be seen at all, it was easily identified.

Analysis of Fruit Counts.

Table 2 summarizes the correlations between various fruit counts made in the research block of 20 year old trees. The 20 sample trees in the block were five clusters of four trees each. All fruit on one tree in each cluster were counted. Fruit counts for the other three trees were estimated by selection of sample limbs with probability proportionate to size and expanding the fruit counts on the selected limbs. About 20 percent of the fruit on each of the sampled trees was counted. The fruit counts were made in November during the same period as the cherry picker photographs.

Table 2.--Correlation of aerial photo counts with total fruit per tree, Valencia oranges, 20 years old

FRUIT COUNT	TOTAL FRUIT (COUNTED IN NOVEMBER BY GROUND CREW)	OBSERVER COUNT FROM 50 FEET, NOVEMBER	PHOTO INTERPRETER COUNTS	
			50 feet, November	500 Feet February
Observer Count: From 50 Feet, November	.573**	1.000		
Photo Interpreter Count: 50 Feet, November	.157	.205*	1.000	
Photo Interpreter Count: 500 Feet, February	.565**	.401*	.125	1.000
Mean	786.55	7.05	1.30	17.35
Standard Deviation	200.85	3.97	1.34	10.99

*Indicates that correlation is significantly greater than zero with P = .95, N = 20.
**Indicates that correlation is significantly greater than zero with P = .99, N = 20.

Table 2 indicates that counts of fruit made from photography in February, after the fruit color had changed from green to yellow or orange, were significantly correlated with total fruit per tree. Counts of green fruit made in November from a much lower altitude were not significantly correlated with actual fruit per tree.

Counts of fruit made by the observer in November from above the tree were significantly correlated with fruit set, but counts from photographs made at the same time and altitude were not. This suggests the observer was able to see fruit which was not visible on the outer surface of the trees. The observer, by waiting for some wind movement of the leaves and branches, could count fruit which were not continuously visible.

The instantaneous action of the lens apparently caused many fruit to be obscured by foliage. The result was that very few fruit were counted per tree on the film, and counts were poorly correlated with total fruit.

Table 3 summarizes the photo interpretation of the younger Valencia trees on the ARS Research Farm.

Table 3.--Correlation of fruit counts from aerial photography and total fruit per tree, Valencia oranges, 6 years old

FRUIT COUNT	TOTAL FRUIT (COUNTED AT HARVEST BY GROUND CREW)	PHOTO INTERPRETER COUNTS	
		500 Feet, February	1,000 Fee[t], February
Photo Interpreter Counts: 500 Feet, February	.444**	1.000	
Photo Interpreter Counts: 1,000 Feet, February	.267*	.338**	1.000
Mean	150.06	3.81	2.35
Standard Deviation	59.97	3.00	2.75

*Indicates that correlation is significantly greater than zero at P = .95, N = 48.
**Indicates that correlation is significantly greater than zero at P = .99, N = 48.

Table 3 indicates that counts of fruit from photography in February when the fruit had turned color were significantly correlated with total fruit per tree at harvest. The percent of fruit counted at 1,000-foot photography was lower, and counts were not as well correlated as were those from 500 feet.

The results in Tables 2 and 3 indicate the strength of the relationship between number of mature Valencia oranges and the aerial photography counts. However, one of the most important characteristics of objective yield surveys is in providing early season forecasts of fruit per tree. The results from the cherry picker photography in November were not encouraging. If counts of fruit from such a low altitude (50 feet) under stable conditions are not correlated with fruit per tree, it is not likely that counts from regular aerial photography early in the season can be used.

OPTICAL DENSITY READINGS

Optical density readings are made by passing light through a piece of developed film and recording with a densitometer the amount of light transmitted. An optical density reading is an inverse logarithmic relationship. A reading of 1.00 indicates that 10 percent of the originating light passes through. A reading of 2.00 indicates one percent, 3.00 means 0.1 percent, etc.

It is assumed that there is a relationship between crop vigor and aerial photography response. The hypothesis being tested in this study is whether optical density readings of citrus fruit trees are related to fruit sets on those trees.

In addition to passing white light through the film, various filters can be used. These filters allow only certain lightwaves to pass through the film. Under actual growing conditions, differences in crop vigor will cause different responses within various light wavelengths. The use of filters can approximate the responsiveness of these wavelengths.

All optical density readings for this study were made with a MacBeth densitometer using neutral (N), red (R), blue (B), and green (G) filters for each tree. All readings were made by David Wessel, a summer employee of the Research and Development Branch. The series of four readings were made for each trial without moving the machine or the film. Thus, the four readings for any tree can be thought of as "registered". That is, differences in the readings are due to response and not due to location differences.

Most correlation analyses were based on density readings and actual fruit counts. In addition to the readings themselves, optical density differences were calculated and tested as independent variables in the correlation analysis. It has been shown for some crops that optical density differences are sometimes better related to yield characteristics than optical densities themselves. In addition, the use of differences as variables tends to eliminate distortions in optical density readings due to changes in lighting conditions, film development, etc.

An aperture of 2mm was used for the density readings. Based on the scale of the photography and the size of the trees, the relationship between aperture size and tree canopy size varied.

For the 1,000 foot altitude photography, the canopy of each 6 year old tree was slightly smaller than the aperture. Thus, some soil would enter into the reading made by the machine. For the 500 foot photography, the 6 year old trees were slightly larger than the aperture.

The canopies of 20 year old trees were about the size of the aperture at 1,000 feet. At 500 feet, the aperture fit well within the canopy of the 20 year old trees. Several density readings were taken for each 50 feet transparency. A random grid of the photo was set up, and readings were taken at each point on the grid falling within the canopy of the tree.

Duplicate readings were made for selected sets of trees from each flight date in order to estimate variations inherent in the use of the densitometer. These variations occur chiefly because of the inability to locate exactly the same spot for repetitive readings.

November Photography Results - 20 year old trees.

Two photography passes were made over the selected block of 20 year old Valencia trees, approximately 15 minutes apart. Density readings were taken for all 20 sample trees from each pass. Table 4 summarizes the correlation of readings within and between the flights.

Table 4.--Correlations of density readings using different filters from two passes over 20 year old trees at 1,000 feet, November 1969

READING	Readings Pass 1				Readings Pass 2			
	N	R	B	G	N	R	B	G
Pass 1	1.000							
N	.997	1.000						
R	.945	.947	1.000					
B	.996	.989	.937	1.000				
G								
Pass 2								
N	.509	.563	.516	.469	1.000			
R	.478	.535	.506	.438	.996	1.000		
B	.470	.527	.510	.436	.984	.989	1.000	
G	.551	.601	.535	.512	.994	.981	.965	1.0
Mean	2.46	2.52	3.22	2.64	2.40	2.48	3.24	2.5
Standard Deviation	.11	.11	.07	.13	.16	.17	.10	.1

All of the correlation values in Table 4 are significantly greater than zero at the 95 percent level of confidence. The correlations between filter readings within a single pass are all very high as normally experienced in readings of this type. The correlations between passes might have been expected to be higher. All means from the second pass except for blue filter readings are lower than the first pass and all standard deviations are higher. Paired comparison tests were run on each filter. These tests indicated that the two passes differed (at the 95 percent confidence level) for the neutral and green readings, but not for the red and blue readings.

The first set of readings (pass 1) was used for correlation with number of fruit per tree. These results are presented in Table 5.

Table 5.--Correlations of optical density readings using different filters from 1,000 feet with number of fruit per tree, 20 year old trees
November 1969

Reading	Fruit Count (November)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.179										
R	-.338	.997**									
B	-.351	.945**	.947**								
G	-.219	.996**	.989**	.937**							
R-N	-.015	-.431	-.358	-.346	-.472*						
B-N	.442	-.885**	-.875**	-.684**	-.888**	.469*					
G-N	-.016	.883**	.861**	.812**	.922**	-.601**	-.814**				
B-R	.481*	-.867**	-.871**	-.667**	-.862**	.301	.983**	-.755**			
G-R	-.126	.829**	.790**	.748**	.872**	-.772**	-.785**	.972**	-.689**		
B-G	.363	-.924**	-.909**	-.760**	-.939**	.537*	.978**	-.916**	.946**	-.887**	
Mean	786.55	2.46	2.53	3.22	2.64	.06	.75	.18	.69	.12	.57
Standard deviation	200.85	.11	.11	.07	.13	.01	.05	.03	.05	.03	.07

* Correlation is significantly different from zero at P = .95, N = 20.
** Correlation is significantly different than zero at P = .99, N = 20.

The assumption that two variate density differences are more highly correlated with yield components than one variate density readings themselves, is somewhat borne out in Table 5. However, almost any two variate difference should be superior to a single density reading because more information is being used to create the two variate density differences.

Something appears to be unusual in the red minus neutral readings. All density differences are significantly correlated with original density readings at the 99 percent level, except for the R-N variable.

Table 5 indicates very low relationships between fruit count and optical densities. Only one of the optical density variables (blue minus red) is correlated with fruit counts at the 95 percent level of confidence.

Also available were the November photographs from the cherry picker at an altitude of 50 feet. Four trees were photographed in each of five positions within the block of trees. However, because of differences in the time of day photography was obtained for each position, preliminary analyses of the density readings were performed. This analysis is shown in Table 6.

Table 6.--Nested analyses of optical density readings using different filters, from 50 feet, November 1969

SOURCE OF VARIATION	DEGREES OF FREEDOM	MEAN SQUARES	F RATIOS	MEAN SQUARES	F RATIOS
		N readings		R readings	
Position.......	4	1.586	29.92**	1.487	28.06**
Tree/position..	15	.053	2.12*	.053	1.71
Reading/tree...	100	.025		.031	
		B readings		G readings	
Position......	4	1.438	30.60**	1.827	32.62**
Tree/position.	15	.047	1.57	.056	2.07*
Reading/tree..	100	.030		.027	

*Indicates that the F test is significant at the P = .95 level.
**Indicates that the F test is significant at the P = .99 level.

Table 6 indicates highly significant differences between readings made at various positions within the block. Photographs taken late in the day were much darker than those taken earlier.

The distributions of individual tree readings about the respective position means were approximately equal. Therefore, an additive transformation was indicated to adjust for position differences rather than a multiplicative adjustment. An adjustment factor was computed by subtracting the average reading for position 1 trees from the average reading for each of the other positions. This adjustment factor then was subtracted from each of the individual trees for the respective position and filter.

After adjusting for position variation, the relationship of the transformed individual tree reading and fruit counts were studied. These results of this correlation analysis are presented in Table 7.

Table 7.--Correlations of adjusted optical density readings, using different filters, from 50 feet with numbers of fruit per tree, 20 year old trees, November 1969

Reading	FRUIT COUNT (November)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.394										
R	-.280	.941**									
B	-.142	.883**	.858**								
G	-.365	.989**	.932**	.887**							
R-N	-.324	.146	-.196	.051	.141						
B-N	.524*	-.248	-.178	.235	-.217	-.198					
G-N	.185	-.054	-.044	.042	.097	-.030	.199				
B-R	.264	-.130	-.287	.245	-.105	.465*	.776**	.161			
G-R	-.225	.113	-.199	.064	.170	.914**	-.102	.379	.496*		
B-G	-.472*	-.234	-.166	.225	-.251	-.191	.950**	-.116	.735**	-.224	
Mean	786.55	1.13	1.12	1.45	1.16	.01	.32	.03	.33	.04	.29
Standard deviation	200.85	.09	.09	.09	.09	.03	.05	.01	.05	.03	.05

* Indicates that correlation is significantly different from zero at P = .95, N = 20.
** Indicates that correlation is significantly different from zero at P = .99, N = 20.

As was the case for the 1,000 foot photography, the optical density readings were not strongly correlated with fruit set. The blue minus neutral and blue minus green readings were significantly correlated (.95 level) with fruit count in this comparison, while the blue minus red readings were significant in the 1,000 foot comparison. Thus, the blue filter enters into each of the significant relationships.

There are several differences between results for the 50 and 1,000 feet altitude photography. The intercorrelations between individual filter readings are lower at 50 feet because of the position adjustments. (Intercorrelations before position adjustments were all .979 or higher.) The difference variables are not significantly correlated with the original density variables. This is probably due to the fact that the range of original variables, and hence the differences, has been limited by the adjustments for position differences. Less than half of the between differences correlations are significantly greater than zero.

November Photography Results - 6 year old trees.

Table 8 presents the correlation analysis for optical density readings from the 1,000 foot November photography and harvested fruit counts in February.

None of the optical density variables in Table 8 are significantly correlated with fruit per tree. The optical density readings are significantly intercorrelated, but some of the optical density differences are not.

December Photography Results - 20 year old trees.

Photography from 1,000 feet over the selected block of 20 year old trees was suitable for density readings from the December overflight. Table 9 summarizes these results.

Table 8.--Correlations of optical density readings using different filters from 1,000 feet with numbers of fruit per tree, 6 year old trees, November 1969

Reading	FRUIT COUNT (Harvest)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	.153										
R	.164	.992**									
B	.153	.961**	.965**								
G	.128	.990**	.969**	.951**							
R-N	.180	.769**	.842**	.798**	.688**						
B-N	-.021	-.260	-.219	-.018	-.260	.005					
G-N	-.225	-.495**	-.579**	-.478**	-.369**	-.841**	.118				
B-R	-.130	-.690**	-.704**	-.492**	-.638**	-.630**	.773**	.625**			
G-R	-.206	-.687**	-.767**	-.698**	-.594**	-.974**	.045	.941**	.654**		
B-G	.093	-.005	.086	.256	-.057	.425**	.869**	-.390**	.405**	-.427**	
Mean	150.06	2.17	2.22	2.95	2.29	.05	.79	.13	.73	.08	.66
Standard deviation	59.97	.14	.17	.14	.13	.03	.04	.02	.05	.05	.04

* Indicates that correlation is different than zero with P = .95, N = 48.
** Indicates that correlation is different than zero with P = .99, N = 48.

Table 9.--Correlations of optical density readings using different filters from 1,000 feet with numbers of fruit per tree, 20 year old trees
December 1969

Reading	FRUIT COUNT (November)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.010										
R	-.037	.997**									
B	.098	.957**	.940**								
G	.017	.998**	.992**	.968**							
R-N	-.346	.019	.095	-.166	-.027						
B-N	.368	.163	.114	.441	.204	-.623**					
G-N	.340	.695**	.649**	.819**	.735**	-.564**	.637**				
B-R	.387	.136	.079	.413	.181	.740**	.987**	.663**			
G-R	-.388	-.399	-.330	-.572**	-.447*	.874**	-.713**	-.894**	-.792**		
B-G	.326	-.020	-.062	.267	.016	-.556*	.973**	.441	.950**	-.561**	
Mean	786.55	1.66	1.84	2.27	1.67	.17	.60	.01	.43	.17	.60
Standard deviation	200.85	.20	.20	.22	.21	.02	.07	.02	.08	.03	.06

* Indicates that correlation is significantly different from zero at P = .95, N = 20.
** Indicates that correlation is significantly different from zero at P = .99, N = 20.

None of the optical density variables in Table 9 is significantly correlated with fruit per tree. The results in Table 9 are very consistent, however, with the correlations of all density differences with fruit count being larger than .3 or -.3, and the correlations of density readings with fruit counts all less than .1 or -.1.

December Photography Results - 6 year old trees.

Photography over the ARS Research Farm from both 500 feet and 1,000 feet was suitable for optical density readings during the December overflight. Tables 10 and 11 summarize these results.

The results from 500 feet and 1,000 feet are quite different. None of the optical density variables at 1,000 feet is significantly correlated with fruit count. Each of the optical density readings from 500 feet and two of the differences are significantly correlated with fruit count. This is the only data set encountered in which the optical density readings themselves were correlated with fruit count.

The average optical density readings and standard deviations do not differ greatly between the two altitudes, except for the blue readings. Thus, it is not a complete shift in optical density levels which caused the differences in correlations between the two altitudes. Table 12 examines the correlations between readingsfrom the two altitudes.

Only one of the density variables from 500 feet is significantly correlated (P = .95) with its corresponding measurement at 1,000 feet. That variable is the blue minus red variable which was not significantly correlated with fruit count at either altitude.

The negative correlations between the primary optical density readings at the two altitudes, though insignificant, imply a reversal of optical density relationships between the two altitudes. That is, a high reading at 500 feet would imply a low reading at 1,000 feet for the same filter and tree. This is only an implication, however, since the negative correlations were not significantly smaller than zero (P = .95).

Table 10.--Correlations of optical density readings using different filters from 500 feet with numbers of fruit per tree, 6 year old trees
December 1969

Reading	Fruit Count (Harvest)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	.435**										
R	.444**	.994**									
B	.443**	.969**	.983**								
G	.433**	.997**	.984**	.956**							
R-N	.385**	.729**	.802**	.829**	.690**						
B-N	.233	.350*	.425**	.572**	.310*	.719**					
G-N	-.119	-.245	-.324*	-.377**	-.174	-.667**	-.610**				
B-R	-.011	-.150	-.109	.077	-.173	.134	.785**	-.276*			
G-R	.334*	.637**	.718**	.754**	.586**	.974**	.739**	-.818**	.187		
B-G	.225	.352*	.432**	.570**	.303	.757**	.986**	-.733**	.732**	.806**	
Mean	150.06	1.66	1.76	2.05	1.70	.10	.39	.04	.29	.06	.35
Standard deviation	59.97	.17	.20	.20	.17	.03	.05	.01	.04	.04	.06

* Indicates that correlation is significantly different from zero at P = .95, N = 48.
** Indicates that correlation is significantly different from zero at P = .99, N = 48.

Table 11.--Correlations of optical density readings using different filters from 1,000 feet with numbers of fruit per tree, 6 year old trees
December 1969

Reading	FRUIT COUNT (Harvest)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N..............	-.266										
R..............	-.243	.994**									
B..............	-.224	.973**	.962**								
G..............	.267	.998**	.987**	.974**							
R-N............	.110	.263	.369**	.218	.222						
B-N............	.146	.020	.001	.250	.033	-.159					
G-N............	-.146	.442**	.377**	.470**	.503**	-.415**	.184				
B-R............	.076	-.095	-.156	.118	-.066	-.557**	.908**	.330*			
G-R............	.147	-.020	.085	-.066	-.078	.904**	-.199	-.764	-.551**		
B-G............	.195	-.128	-.126	.094	-.135	-.020	.944**	-.150	.803**	.056	
Mean...........	150.06	1.60	1.75	2.34	1.60	.15	.74	.01	.59	.14	.73
Standard deviation.....	59.97	.15	.16	.16	.16	.02	.04	.01	.04	.03	.04

* Indicates that correlation is significantly different from zero at P = .95, N = 48.
** Indicates that correlation is significantly different from zero at P = .99, N = 48.

Table 12.--Correlations between optical density readings using different filters from 1,000 feet and 500 feet, 6 year old trees
December 1969

1,000 feet readings	500 feet readings									
	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.214	-.234	-.203	-.215	-.287*	-.060	.033	.172	-.232	-.058
R	-.184	-.204	-.180	-.184	-.263	-.074	.034	.129	-.214	.071
B	-.194	-.217	-.178	-.194	-.291	-.032	.035	.214	-.236	-.035
G	-.217	-.237	-.203	-.217	-.294*	-.050	.047	.190	-.241	-.053
R-N	.195	.189	.131	.199	.115	-.057	-.225	-.097	.187	.018
B-N	.058	.041	.080	.060	-.146	.109	.085	.154	-.143	.081
G-N	-.137	-.157	-.097	-.125	.021	.012	.191	.001	-.075	-.052
B-R	-.034	-.045	.011	-.034	-.310*	.206	.321*	.305*	-.371**	.100
G-R	.202	.208	.139	.200	.082	-.048	-.231	-.075	.167	.029
B-G	.104	.094	.113	.102	-.130	.091	.033	.132	-.107	.081

* Indicates that correlation is different than zero with P = .95, N = 48.
** Indicates that correlation is different than zero with P = .99, N = 48.

February Photography Results - 20 year old trees.

The only usable imagery from the February overflight of the block of 20 year old trees was from 500 feet. Two sets of readings were made for each of the 20 sample trees. The correlation of the average readings for each tree with the number of fruit present, in November, are shown in Table 13.

The sample correlations of the primary optical density readings with November fruit count are very close to the .95 percent significance level. Since the readings used were averages of two independent trials of readings, the averaging might had reduced the correlation results.

When the X variable is measured with error (with variability in readings) as in this case, it can be shown that the resulting downward bias in the correlation can be removed by the formula[1]:

$$r = r_1 \sqrt{1 + \lambda}$$

where r = the estimate of true correlation

r_1 = the sample estimate of correlation with X subject to measurement error

λ = measurement factor $S_e^2 \ / \ (S_{X_1}^2 - S_e^2)$

e = deviation from true reading in a trial of X_1

S_e^2 = variance of e

$S_{X_1}^2$ = variance of X_1 where $X_1 = X + e$, X and e independent

[1] Snedecor, George W. and Cochran, William G., Sampling Methods, 6th Edition, Iowa State Press, 1967.

Table 13.--Correlations of optical density readings using different filters from 500 feet with numbers of fruit per tree, 20 year old trees
February 1970

Reading	Fruit Count (November)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.410										
R	-.432	.998**									
B	-.439	.983**	.986**								
G	-.393	.999**	.994**	.978**							
R-N	-.552	.597**	.645**	.644**	.560*						
B-N	.273	-.890**	-.878**	-.793**	-.901**	-.388					
G-N	.169	.345	.292	.391	-.474*	-.520*					
B-R	.373	-.929**	-.929**	-.854**	-.929**	-.581**	.976**	-.346			
G-R	-.460*	.252	.309	.326	.205	.912**	-.026	-.794**	-.240		
B-G	.220	-.862**	-.842**	-.759**	-.879**	-.273	.990**	-.635**	.940**	.107	
Mean	786.55	1.68	1.79	2.45	1.74	.11	.77	.06	.66	.05	.71
Standard deviation	200.85	.28	.29	.21	.28	.02	.08	.01	.09	.03	.09

* Indicates that correlation is significantly different from zero with P = .95, N = 20.
** Indicates that correlation is significantly different from zero with P = .99, N = 20.

The variance of e can be calculated from the two sets of readings for the same trees; $S^2_{X_1}$ is the square of the standard deviation in Table 13 for any particular optical density.

For the four filter readings the results are:

Filter	r_1	$S^2_{X_1}$	S^2_e	λ	r
N	-.410	.0770	.0007	.0092	-.412
R	-.432	.0848	.0026	.0316	-.439
B	-.439	.0430	.0001	.0001	-.439
G	-.393	.0801	.0002	.0020	-.393

Thus, the variation in readings from trial to trial have only a negligible effect on the correlation values in this data set. None of the correlations are significantly different from zero after the adjustments are made.

February Photography Results - 6 year old trees.

February photography from both the 500 feet and 1,000 feet altitudes was available for optical density readings of the Valencia orange trees at the ARS Research Farm. Table 14 presents the correlation results for the 500 feet optical density readings. Table 15 summarizes the 1,000 foot results.

The results in Tables 14 and 15 are quite reversed from those found on the December photography. In December, most of the 500 feet variables were correlated with fruit count; the 1,000 feet variables were not. In February, only some from 1,000 feet were significantly correlated with fruit count. The correlations between 1,000 feet and 500 feet readings for the same trees were negative in both months, however.

Table 14.--Correlations of optical density readings using different filters from 500 feet with numbers of fruit per tree, 6 year old trees, February 1970

Reading	FRUIT COUNT (Harvest)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N	-.272										
R	-.247	.996**									
B	-.220	.916**	.903**								
G	-.279	.997**	.989**	.927**							
R-N	.132	.427**	.505**	.294*	.385**						
B-N	.150	-.295	-.317*	.112	.262	-.358*					
G-N	-.099	.006	-.047	.187	.080	-.540**	.430**				
B-R	.105	-.361*	-.398**	.034	-.322*	-.547**	.977**	.508**			
G-R	.134	.276	.353*	.102	.213	.914**	-.442**	-.835**	-.603**		
B-G	.181	-.317*	-.329*	.083	-.296*	-.276	.984**	.261	.944**	-.306*	
Mean	150.06	1.22	1.32	2.00	1.28	.10	.79	.06	.69	.04	.72
Standard deviation	59.97	.15	.15	.14	.15	.01	.06	.01	.07	.02	.06

* Indicates that correlation is significantly different from zero with P = .95, N = 48.
** Indicates that correlation is significantly different from zero with P = .95, N = 48.

Table 15.--Correlations of optical density readings using different filters from 1,000 feet with numbers of fruit per tree, 6 year old trees, February 1970

Reading	Fruit Count (Harvest)	N	R	B	G	R-N	B-N	G-N	B-R	G-R	B-G
N..............	.317*										
R..............	.354*	.990**									
B..............	.393**	.909**	.945**								
G..............	.317*	.997**	.982**	.890**							
R-N............	.425*	.695**	.789**	.867**	.668**						
B-N............	.299*	.158	.265	.556**	.120	.665**					
G-N............	-.116	-.386**	-.437**	-.535**	-.310*	-.554**	-.497**				
B-R............	.137	-.201	-.119	.211	-.235	.274	.900**	-.317*			
G-R............	.375**	.673**	.764**	.855**	.628**	.968**	.683**	-.745**	.315*		
B-G............	.291*	.205	.310*	.591**	.157	.694**	.991**	-.609**	.872**	.739**	
Mean...........	150.06	1.14	1.23	1.74	1.20	.09	.60	.06	.51	.03	.54
Standard deviation.....	59.97	.14	.17	.17	.14	.03	.07	.01	.06	.04	.08

* Indicates that correlation is significantly different from zero with P = .95, N = 48.
** Indicates that correlation is significantly different from zero with P = .95, N = 48.

Correlation Results, 6 year old trees

Flight Month	Altitude	Correlation Summary
November	1,000 feet	No optical density variables significantly correlated at .95 level. (See Table 8)
December	500 feet	All primary optical density readings correlated at .99 level, plus two optical density differences (R-N and G-R) significant at .95 and .99 level, respectively. (See Table 10)
December	1,000 feet	No optical density variable significantly correlated at .95 level. (See Table 11)
February	500 feet	No optical density variables significantly correlated at .95 level. (See Table 14)
February	1,000 feet	All primary optical density readings correlated at .95 or .99 level, and all but two optical density differences (G-N and B-R) correlated at .95 or .99 level. (See Table 15)

Two of the five sets of data for the six year old Valencia orange trees have significant correlations between optical density variables and fruit counts. The relationships do not appear to be related to altitude, since one significant set is for 500 feet photography and the other is from 1,000 feet. Optical density reading levels do not seem to answer this phenomenon, either. The December readings for both altitudes are much higher than for February readings. The 500 feet and 1,000 feet readings are very close to the same density levels within each month.

SUMMARY OF OPTICAL DENSITY-YIELD CORRELATIONS

The preceding sections have listed correlations results for the three overflights. It may be well to summarize these results in order to draw conclusions.

Correlation Results, 20 year old trees

Flight Month	Altitude	Correlation Summary
November	1,000 feet	Only one optical density difference (B-R) significant at .95 level. (See Table 5)
November	50 feet	Only two adjusted optical density differences (B-N and B-G) significant at .95 level. (See Table 7)
December	1,000 feet	No optical density variables significantly correlated at .95 level. (See Table 9)
February	500 feet	Only one optical density difference (G-R) significant at .95 level. (See Table 13)

This summary indicates that no single optical density variable was consistently related to fruit per tree for the 20 year old trees studied. Indeed, optical density readings for these trees appear to hold promise for detecting fruit yield for this block of Valencia trees only if "sufficiently" strong multivariate relationships can be found.