REMOTE SENSING

RELATIONSHIP OF AERIAL PHOTOGRAPHY REFLECTANCE TO CROP YIELDS

1968 TEXAS COTTON AND SORGHUM STUDY

by

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INTRODUCTION

A study to test the relationships between measurements of plant characteristics from remote sensing techniques and yield determinants from actual field counts and measurements was conducted by the Research and Development Branch of the Statistical Reporting Service (SRS).. This study was a cooperative project with the Agricultural Research Service (ARS) Remote Sensing Laboratory at Weslaco, Texas, covering the 1968 growing season. Several types of aerial photography were taken by ARS of cotton and grain sorghum fields in the Rio Grande Valley. Work on this project was done in conjunction with the 1968 citrus research project conducted in the same area by the two agencies.

The project objectives were to study (a) relationships of optical density 1/ of aerial photo transparencies to yield determinants and (b) methods of collecting ground data needed for analysis.

This project was the first attempt to relate information available from aerial photography to physical crop yield. Research of this type will be needed in order to use the vast amount of information soon to become available from satellite photography.

Analysis of photography yield relationships was mainly limited to within field comparisons. That is, by using small plots within fields the number of photographs needed was reduced. Also, nuisance variables are reduced, such as differences in management, soil types, maturity, and other factors which might mask moderate correlations between optical density and yield determinants. Therefore, small plots were established in each field and

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1/ Optical density as used in this report is the direct reading or count as obtained from the isodensitracer. However, if the actual optical density is desired the following transformation is necessary: Optical Density = (Count-Baseline) .00914 + Step Wedge. Where Baseline = 40, Step Wedge 2 = .83d and the factor .00914 is the average density value of each count. For example, Count = 96.4, Optical Density = (96.4 - 40) .00914 + .83 = 1.35.

only a small number of fields were included in the project. Between field analysis was limited since lighting conditions and similar factors varied considerably between fields and may have affected optical density more than yield potential.

METHODS AND PROCEDURES

Sample fields were selected on the basis of soil types and farming practices within regular ARS test flight lines to obtain different yield potentials. Field work was started in early July with a second visit to cotton fields about a month later.

July

Five fields each of cotton and grain sorghum were observed in the July study. Each field was divided into quarters with two plots randomly located in each quarter. Plots in the grain sorghum fields were two adjacent rows 15 feet long; cotton plots were two adjacent row 10 feet long. For sorghum, stalks, stalks with heads or shoots, heads and shoots, and heads with kernels were counted. All cotton plants were counted within each plot. Cotton fruit counts such as squares, blooms, large unopened bolls and small bolls were made on the first and last plant of each row within the plot.

The grain sorghum fields were almost mature on July 1. The cotton fields were immature with no open or partially opened bolls present on that date.

August

Four of the five cotton fields used in July were included in the August survey. In two fields, the eight plots were marked for aerial identification by placing a 4-foot square plywood marker in front of the plot. These markers were mounted on a tripod which was about 5 feet high. Unfavorable weather conditions limited photography to just the fields containing markers.

During the August survey the number of plants per plot was recorded as in July. The number of squares, blooms, small bolls, large bolls, partially opened bolls, open bolls and burrs were counted for the first and last plant in each row.

An isodensitracer, scanning an area of the field which included the sample plot, produced optical density readings for each plot in the two marked fields. Scanning was done by ARS with equipment in the Remote Sensing Laboratory at Weslaco, Texas.

RESULTS AND DISCUSSION

Grain Sorghum, July

The number of heads with kernel formation for sample plots were expanded to estimate the number per acre. Field V which was planted in double rows averaged about twice as many heads per acre as compared to the other four fields. (See Table 1.)

Table 1.--Grain sorghum: Estimated number of heads with kernels per acre, July 1968

Sample number	Field number				
	I	II	III	IV	V
	Thousands	Thousands	Thousands	Thousands	Thousands
1	43	49	49	85	93
2	70	30	54	88	117
3	39	37	61	41	102
4	27	52	46	70	99
5	63	50	50	51	110
6	38	84	49	34	93
7	30	33	62	49	127
8	51	57	57	40	111
Average.....	45.1	49.0	53.5	57.2	106.5

An analysis of variance, (AOV) using a hierarchicial classification, shows the variation sources among the estimated number of heads. The sample fields were divided into four parts of about equal size. Two plots were established in each "quarter" of the field so the importance of variability between "quarters" could be tested. Estimates of number of heads per acre were derived for each plot in the quarters and were rounded to the nearest thousand prior to calculations for the analysis of variance.

Table 2.--Grain sorghum: Analysis of variance of heads with kernels, July 1968

Source	Degrees of freedom	Sums of squares	Mean square	F-ratio	Critical F-value
Fields.....	4	20227.60	5056.9	16.55	F(4, 15, .05) = 3.06
Quarters/fields..	15	4582.87	305.5	1.78	F(4, 15, .01) = 4.89
Plots/quarters..	20	3441.50	172.1		
Total.....	39	28251.97			

This analysis of variance indicates a significant field effect; that is, we would reject a null hypothesis of no differences in number of heads per acre between field means. The effect of quarters within fields was not significant. This indicates the number of heads with kernels does not differ from quarter to quarter within the same field.

This lack of variability within fields suggests that unless the correlation between film density and yield characteristics are quite high it is unlikely a significant correlation will result.

Duncan's New Multiple Range Test was used to compare field means. This test indicated that field V, the double-rowed field, differed from each of the other fields but no other significant differences exist among field means.

Since double-row planting may not be a normal sorghum cropping practice, data from field V was removed and an AOV performed on the remaining 4 fields. This AOV is shown in Table 3.

Table 3.--Grain sorghum: Analysis of variance of single-rowed sorghum fields, July 1968

Source	Degrees of freedom	Sums of squares	Mean square	F-ratio	Critical F-value
Fields.....	3	669.094	223.03	.64	F(3, 12, .05) = 3.49
Quarters/fields..	12	4143.875	345.32	1.92	F(12, 16, .05) = 2.42
Plots/quarters..	16	2876.500	179.78		
Total.....	31	7689.469			

This analysis indicates no significant differences between the fields or between quarters within fields.

Because of cloud cover difficulties, photography for only one field (I) was useable for analysis. Several scans were made across the image of the field with the isodensitracer. Readings for the field were divided into quarters with an average value calculated for each quarter. Correlation of these isodensitracer readings with estimated number of heads with kernels per quarter was r = .429. This correlation is not significant because of the small sample size but does suggest some positive relationship might exist.

July results demonstrate that some better method of locating units must be found for aerial photography interpretation. Thus, isodensitracer readings could be associated directly with plot indications rather than associating density averages per quarter with plot averages per quarter.

Ground information collected for sorghum during the July survey seemed reasonable. That is, plant counts, head counts, and row spacings seem to be best variables to measure, at least for nearly mature sorghum. Ground cover of plots and plant height were relatively uniform in sample fields. Height of plants and percent of ground covered might be worthwhile variables to measure if later work is done on immature sorghum.

Cotton, July

Procedures for analysis of the cotton data were similar to those for the sorghum analysis. Estimated number of small and large unopened bolls per acre were the yield indicators used for analysis. Number of plants per acre could have been used and may have been a better indicator since plant numbers generally remain stable. However, in the August analysis plant numbers alone showed virtually no relationship to optical density. Estimated number of bolls per acre was based on average number of bolls on four plants counted multiplied by number of plants per acre estimated from plot counts. So in the analysis the number of small and large bolls was not independent of plant numbers. Expanded boll counts rounded to thousands are listed in Table 4.

Table 4.--Cotton: Estimated large and small bolls per acre, July 1968

Sample number	Field number				
	A	B	C	D	E
	Thousands	Thousands	Thousands	Thousands	Thousands
1	118	44	41	252	253
2	83	32	12	306	11
3	128	37	155	327	69
4	110	128	61	236	92
5	86	64	18	356	84
6	188	141	79	216	60
7	18	74	73	213	27
8	270	47	46	275	41
Average.....	136.4	70.9	60.6	272.6	79.6

An analysis of variance of these expansions is summarized in Table 5.

The analysis indicates significant differences between fields but no significant differences between quarters within fields. Duncan's New Multiple Range Test was used to test for significant differences among field means. This test indicated field D was significantly different than each of the other field means. Since the difference in expansion might indicate variations in maturity rather than a difference in actual yield potential, no effort was made to exclude the one extreme field and analyze the remaining ones. No attempt was made to study maturity classifications.

Table 5.--Cotton: Analysis of variance of large and small bolls, July 1968

Source	Degrees of freedom	Sums of squares	Mean square	F-ratio	Critical F-value
Fields.....	4	248402.600	62100.65	33.29	F(4, 15, .05) = 3.06
Quarters/fields..	15	27981.875	1865.46	.35	F(4, 15, .01) = 4.89
Plots/quarters..	20	105256.500	5262.82		
Total.....	39	381640.975			

July photography was useable for only one field and coverage was not quite complete for that field. Optical density was estimated for each quarter from a sample of isodensitracer readings. Correlation (r) value of the density estimates and number of large and small bolls per quarter was -.816 which is not significant. Again this is a correlation of four pairs of variables only and can only suggest that there may be a relationship worthy of study.

Procedures used for ground data in the July survey seemed reasonable. A better yield indication per plot could be obtained if all fruit per plot could be counted but this would require considerably more time. As mentioned for sorghum, percent of ground cover and height of plants might be measured. These additional variables may explain some variation in density readings of cotton fields but may not have any relationship to yield.

Cotton, August

Fields observed during the August survey period were A, B, C, and E. Counts were made and expanded to an acre basis. Expanded counts for each sample plot are listed in Appendix I. Several analyses of variance were computed to identify sources of variation in factors related to yield. These are summarized in Table 6.

The analyses of variance indicate plant population varies between fields but not greatly within field. Factors related to maturity and plant characteristics did differ within fields. The total number of open, partially open and large unopened bolls per quarter did not vary significantly within fields but number of large unopened bolls and open and partially open bolls did. Thus, this indicates that portions of fields varied in maturity (as measured by percent of bolls opened).

A measure of optical density was obtained by making a series of isodensitracer readings on areas approximating the location of each plot in the two fields photographed. A 4' x 4' plywood marker was placed in front of each plot so plots could be readily identified on the aerial photograph.

Readings were made using no filter, a red filter, a green filter and a blue filter. About 70 readings were made for each plot in the two fields with each of these four filters. The average reading for each field and the standard error of the average is listed in Table 7. Average readings for each plot are shown in Appendix II.

Table 6.--Cotton: Analysis of variance of yield indicators, August 1968

Source	Degrees of freedom	Sums of squares	Mean square 1/	F-ratio
Total fruit				
Fields	3	121728	40576	1.19
Quarters/fields	12	407856	33988	1.95
Plots/quarters	16	279088	17443	
Total	31	808672		
Open bolls				
Fields	3	4530	1510	3.68**
Quarters/fields	12	4920	410	.85
Plots/quarters	16	7696	481	
Total	31	17146		
Large bolls				
Fields	3	36720	12240	1.04
Quarters/fields	12	141720	11810	2.56*
Plots/quarters	16	73920	4620	
Total	31	252360		
Plants				
Fields	3	2310	770	9.59**
Quarters/fields	12	960	80	.49
Plots/quarters	16	2624	164	
Total	31	5894		
Partially open bolls				
Fields	3	2208	736	2.43*
Quarters/fields	12	3636	303	1.40
Plots/quarters	16	3456	216	
Total	31	9300		
Open and partially open bolls				
Fields	3	15309	5103	1.67
Quarters/fields	12	36624	3052	2.75*
Plots/quarters	16	17744	1109	
Total	31	69677		
Open, partially open and large bolls				
Fields	3	40371	13457	1.05
Quarters/fields	12	153504	12792	1.74
Plots/quarters	16	117840	7365	
Total	31	311715		

1/ Mean squares are in terms of data rounded to nearest thousand.
* Critical F - values at 5 percent level are F (3, 12) = 3.49 and F(12, 16)=2.42.
** Critical F - values at 1 percent level are F (3, 12) = 5.95 and F(12, 16)=3.55.

Table 7.--Cotton: Average optical density readings by filter with respective standard errors for fields A and B, August 1968

Filter	Field number					
	A		B		Combined	
	Average	S.E.	Average	S.E.	Average	S.E.
No.	71.22	5.60	96.28	6.54	83.75	5.27
Red	40.01	8.89	58.38	11.81	49.19	7.53
Green	96.40	4.13	121.56	6.75	108.98	4.73
Blue	69.45	7.52	107.46	5.52	88.46	7.00

Each color filter "reads" or is sensitive to one of the three layers of aerial infrared film. Readings with no filter would measure light transmission through all three layers. Thus, each of the four combinations could be sensitive to a certain phenomenon in a different way. To obtain a measure of filter effect, average readings with each filter possibility were correlated with all other filters. The green filter produced readings consistently higher than readings with other filters. The red filter produced lower and more variable readings than other filters.

Table 8 lists the correlations between the four filter types. The readings using a (red, green or blue) filter were highly correlated with readings when no filter was used. Comparisons of red with blue and red with green were the least correlated.

Indicators of production considered were estimates of number of open bolls per acre, number of open and partially open bolls per acre, and the combined number of open, partially open and large bolls per acre. These indicators are products of the estimated number of plants per acre and of the estimated fruit per plant. Correlations between average readings for filter combinations and yield indicators expanded to a per acre basis are given in Table 9. Correlations were not always consistent between the two fields. The green filter readings tended to show the lowest correlation, especially when both fields were combined.

In field A the relationship of number of open bolls and number of open and partially open bolls to density readings were statistically significant for no and red filters but in field B none of the yield indicators were significant. When both fields were combined a significant relationship ($r = 0.64$) was found between open plus partially open bolls and optical density readings. Figure 1 expresses graphically the relationship of density and number of open and partially open bolls using no filter to obtain the optical density readings. The slopes for the three regression lines shown in Figure 1 were not significantly different. A surprising result was that the number of plants per acre was not significantly related to density in any of the three comparisons.

Table 8.--Cotton: Correlations between average optical density readings for red, green, blue and no filters by fields and fields combined, August 1968.

Field number and type filter	Filter		
	Red	Green	Blue
Field A			
No	.95**	.94**	.97**
Red		.73*	.88**
Green			.98**
Field B			
No	.94**	.87**	.81**
Red		.76*	.67*
Green			.59
Combined			
No	.90**	.93**	.91**
Red		.81**	.70*
Green			.82**

* Correlations exceeding .67 are significant at the 5 percent level.
** Correlations above .80 are significant at the 1 percent level.

Table 9.--Correlations between average optical density readings and yield indicators by field and filter, August 1968

Field number and yield indicator	Filter			
	No	Red	Green	Blue
Field A				
Open bolls	.89**	.77*	.87**	.83**
Open and partially open	.79*	.79*	.64	.66
Open, partially open and large	-.39	-.42	-.45	-.46
Number of plants	-.23	-.15	-.46	-.36
Field B				
Open bolls	.18	.40	.14	.03
Open and partially open	.50	.66	.23	.22
Open, partially open and large	.10	.27	-.02	-.20
Number of plants	.06	.01	.00	.04
Combined				
Open bolls	.55*	.56*	.34	.52*
Open and partially open	.64**	.73**	.45	.48*
Open, partially open and large	-.24	-.13	-.27	-.38
Number of plants	.12	.04	.08	.09

* Indicates r is significantly different than zero at P .05.
** Indicates r is significantly different than zero at P .01.

CONCLUSIONS

The July cotton and sorghum data suggested a lack of significant differences in yield potential among quarters of individual fields but the August survey showed there were some differences between quarters within cotton fields. In order to properly study the correlation of optical density readings of individual plots and ground data from these plots, significant differences should exist between plots. It is important to determine if optical density readings can indicate differences between high and low yielding plots. Because of the lack of differences in quarters within fields, conclusions from the July data are limited.

The August optical density readings did vary between fields and within fields; these data suggest there may be a positive relationship between optical density readings and the number of open bolls and partially opened bolls. If this relationship does indeed exist it might be possible to estimate cotton yields using remote sensing techniques. Plant population did not appear to be related to the optical density readings.

The filters used in obtaining the optical density reading were all related. Readings using no filter and a red filter produced the highest correlations when related to the yield indicators. The red filter seemed to be the most sensitive in detecting differences in plant characteristics.

In order to measure relationships between plant characteristics and the optical density readings the sample plots must be readily identified on the aerial photograph. The 4' x 4' plywood markers which were used made plot location easy to identify.

RECOMMENDATION FOR FUTURE WORK

The 1968 work revealed that exact plot location is a necessity. This can be done by using the 4' x 4' plywood markers placed in the fields or by measurements along the field edges scaled to the photography. Another possibility is the use of aluminum foil in place of the plywood markers.

To study relationships between optical density of transparencies and yield determinants, plots should be selected to obtain maximum within field variation. This could be accomplished by classifying the field into strata or it may be done by scanning the field with the isodensitracer prior to laying out the sample plots and grouping areas of similar optical density into strata.

In grain sorghum the head characteristics should be studied from close up ground photography. The possibility of stratifying by head size within plot based on the photo should be explored. Also, it may be possible to relate number of kernels counted and other head measurements from the photograph to head weight.

The cotton maturity categories that SRS presently uses in Texas may not be precise enough for remote sensing techniques. Because of obvious contrast between plant, soil, and lint color after machine picking, the possibility of using optical density readings to determine harvest loss should be investigated.

Field procedures used for obtaining yield indications should again be used. If very immature crops are studied, plant height and percent of ground cover should be estimated. For cotton plants in a pre-bloom stage, all squares per row should be counted rather than only those on sample plants.

Appendix I.--Cotton: Estimated per acre field counts for yield indicators by field, August 1968

Field and sample number	Plants	Blooms	Squares	Small bolls	Large bolls	Partially open	Open bolls	Open and partial and large	Total fruit
	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.
Field E									
1	45	111	11	45	223	11	0	233	401
2	13	3	3	60	107	0	3	111	177
3	3	10	4	20	61	0	0	61	95
4	33	50	0	17	167	0	33	200	267
5	3	5	0	16	29	0	0	29	50
6	39	19	0	68	117	10	19	146	233
7	7	47	2	42	83	3	3	90	180
8	17	9	0	83	131	0	0	131	222
Average	19	32	2	44	115	3	7	125	203
Field B									
1	31	85	23	109	225	23	47	295	513
2	29	161	15	29	59	7	14	80	285
3	12	117	21	72	13	0	24	37	246
4	30	52	0	0	0	52	45	97	150
5	33	83	25	208	441	8	8	457	773
6	29	111	7	66	199	22	7	228	413
7	42	10	10	63	220	10	0	231	315
8	25	31	6	38	163	31	19	213	301
Average	29	81	13	73	165	19	21	205	374

Appendix I.--Cotton: Estimated per acre field counts for yield indicators by field, August 1968 --Continued

Field and sample number	Plants	Blooms	Squares	Small bolls	Large bolls	Partially open	Open bolls	Open and partial and large	Total fruit
	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.	Thou.
Field B									
1	33	106	0	16	229	41	65	334	457
2	37	9	0	9	150	19	28	197	215
3	27	73	0	27	127	53	73	253	353
4	39	10	0	39	68	48	29	145	194
5	30	329	0	7	37	0	0	37	374
6	33	382	24	73	98	0	57	154	634
7	26	64	6	6	13	6	13	32	51
8	46	0	0	0	79	23	34	136	136
Average	33	122	4	22	100	24	37	161	302
Field D									
1	30	83	0	15	7	0	0	7	105
2	42	250	0	0	42	10	10	62	312
3	36	109	0	18	109	9	45	163	290
4	43	119	22	32	76	0	43	119	292
5	36	187	0	0	80	0	27	107	294
6	46	162	16	81	139	46	69	254	508
7	46	252	34	34	69	0	11	80	401
8	67	202	0	17	50	0	67	118	337
Average	43	170	8	25	71	8	34	114	317

Appendix II.—Cotton: Average optical density readings by plot within fields A and B by filter, August 1968

Field number & filter	Plot number 1	2	3	4	5	6	7	8	Average
Field A									
No....	85.3	66.1	79.6	101.0	61.7	55.8	61.4	58.9	71.2
Red...	46.1	32.9	46.4	97.4	27.4	21.7	26.1	22.1	40.0
Green.	108.5	92.6	110.2	111.6	88.4	83.3	87.9	88.6	96.4
Blue..	86.8	60.6	92.1	103.1	55.5	46.0	59.2	52.3	69.4
Field B									
No....	91.2	75.6	121.5	120.1	87.5	72.4	96.2	105.7	96.3
Red...	44.7	31.4	121.7	90.6	35.1	26.8	45.8	70.9	58.4
Green.	116.8	107.1	134.8	136.5	117.2	105.8	126.7	127.6	121.6
Blue..	105.4	78.8	120.9	131.7	115.5	77.5	114.5	119.4	107.5

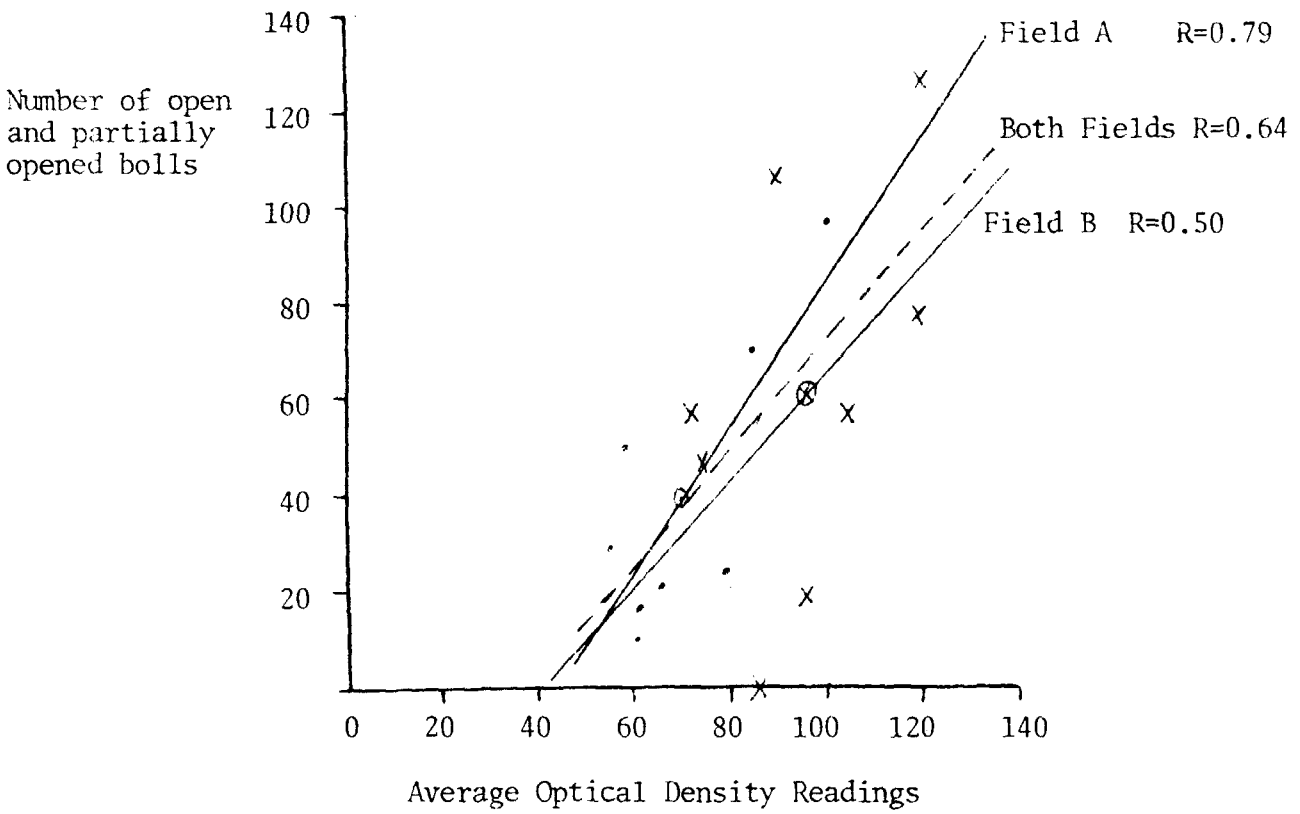

Figure 1.--Cotton: Relation of average optical density to number of open and partially opened bolls using no filter