REMOTE SENSING

A Study of Optical Density Responses As An Indicator of Corn Yields South Dakota - 1969

by

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INTRODUCTION

A small study of the relationship of aerial photography optical densities as measured by a McBeth densitometer to corn yields was conducted by the Research and Development Branch of the Statistical Reporting Service (SRS). The study was a cooperative project with the South Dakota Remote Sensing Institute[1/] at Brookings, South Dakota, during the 1969 growing season. Several types of aerial photography were taken by the Institute, as well as thermal scanner imagery. Ground truth was collected by personnel of the Institute, Research and Development Branch and the South Dakota State Statistical Office of the Statistical Reporting Service (SRS).

The project objectives were to study (a) relationship of optical density to corn yields and (b) to look for factors that might be used in a yield estimating model. Secondary objectives were to study plot marking, instruments for measuring optical density and the variance of optical density measurements.

Review of Related Research

A previous study [1] in the Texas Rio Grande Valley on cotton and sorghum was made by the Research and Development Branch of SRS in cooperation with the Agricultural Research Service Remote Sensing Laboratory (RSI) at Weslaco, Texas in 1968. The cotton and sorghum data for July, suggested a lack of significant differences for yields among quarters of individual fields.

1/ The author wishes to acknowledge the contribution of Fred Waltz in preparing the data for computer processing.

For August, the cotton data had significant differences between fields and between plots within fields and suggested a positive relationship between optical density readings and certain yield parameters. The study also showed definite correlations between various types (colors) of filters used. The 4' x 4' plywood panels used were quite sufficient for determining plot locations.

Day to day differences in exposures led the ARS Remote Sensing Laboratory to suggest a method of calibrating film density measurements using polynomials to predict the difference of the neutral filter response minus the color filter response. The coefficients of the polynomial were determined by regressing the neutral response polynomially against the observed neutral minus color response. This analysis is still in progress.

Research by Texas A&M University, [2] under a cooperative agreement with SRS, reported the logarithm of optical density measurements did not result in homogeneous variance and a large day-to-day effect between means was observed. Other findings were significant camera and film differences. Control panels helped, but did not satisfactorily reduce the large day-to-day effect and only slightly improved the discrimination of crops. The altitude of photography by film interaction was not significant; but, the altitude by camera interaction was significant.

Laboratory studies at the ARS Remote Sensing Laboratory showed that a typical cotton leaf has an absorption coefficient similar to water over the 0.7 to 1.3 micrometer portion of the spectrum. Reflection from a crop canopy is a difficult measurement because: O_2, CO_2 and H_2O (vapor) absorption reduces incoming radiation in the above bands, (b) illumination from the sun varies in intensity with numerous climatic conditions, (c) radiance from field crops is affected by plant geometry, background soil reflectance, and other factors, (d) the sun intensity peaks at above 0.5 micrometers and falls off rapidly at shorter and longer wavelengths.

SAMPLE SELECTION

Three corn fields were selected near the RSI and photographed. The fields were not selected randomly, but were purposely selected to reflect differences in yield potential between fields and different farming practices. Since the fields were not randomly selected inferences are limited and can only be made about the three selected fields. Sample plots for counting and measuring yield indicators were located randomly within quarters of each field. The number of rows was counted and the length of the field was paced. The fields were then divided into quarters and two plots were located within each quarter using random coordinates. The quartering was done to force an even distribution of sample plots over the field, for measuring within field variation.

More sample plots within a field were used rather than adding more fields to reduce the amount of extraneous variation. Such variables as variety, planting date, soils fertilizer use, cultivation practices and etc., may affect optical density.

FIELD PROCEDURES

Ground truth (Corn)

On July 24 and 25, eight plots in each of the three fields called fields X, Y, and Z, were measured, marked, and plant characteristics counted. The markers were 4' x 4' foot plywood panels painted white with 3 foot red numerals. They were mounted about 7 feet above the ground on two inch galvanized pipes. At this time, 4 row spaces and 1 row space were measured, 15 feet of row length was measured, in each of two rows. The panel was placed 5 feet in front of the plot. In these 15 foot row lengths, the number of stalks and the number of stalks with tassels, were counted.

On August 19 and 21, the plots were re-visited and similar plant counts made. The number of stalks and stalks with silked ear shoots, silked ear shoots and ears with kernel formation, were counted. The lengths of ears over husks were measured in row 1 of plot 4 in field X, Y and all plots in field Z. Beyond the unit, 5 ears were examined for maturity and length of ears over husks and the length of kernel rows were measured.

On September 16, field Z was visited and the same data was recorded as on the August visit. This visit was made because part of field Z was to be harvested for silage.

On October 8, after a freeze (26°F), all three fields were visited, plots

2, 3, and 4 of field Z had been cut for silage. At this time, the number of stalks with silked ear shoots, number of ears and silked ear shoots, and number of ears with evidence of kernel formation were counted. Total length of ears over husks in row 1 was measured for all plots. Beyond the unit using another, 5 ear sample, the stage maturity and the length of kernel rows were measured. The corn in row 1 and row 2 was harvested and weighed in the ear. Ears 3 and 4 from each row were bagged in plastic bags and used for determining shelling percent and moisture content. Since the corn was quite wet, the corn was weighed upon arrival at the laboratory and dried. It was again weighed at the time of shelling and the shelled corn was weighed immediately after shelling. In some cases more drying was necessary before moisture testing could be done. In these cases the shelled corn was again weighed at the time of moisture test. The estimated yield per acre at 15.5 percent moisture was determined. For the plots harvested for silage, a forecast yield per acre was calculated using SRS's Objective Yield Procedures.

Detailed procedures and definitions used may be found in the Supervising and Editing Manual, 1969, Corn Objective Yield, U.S.D.A. - SRS [3].

Flight Data:

Flights were made between July 5 and October 8. There were two distinct types of data gathered; thermalimagery (See Appendix F) and photographic.

The thermal data were obtained by recording continuous data from the thermal scanner on magnetic tape. The magnetic tape was then read through a signal processor and recorded on film. The plots were located on the film and read with a MacBeth densitometer (See Appendix E).

The photographic data were obtained with either a K-17 aerial camera with $9\frac{1}{2}$ x $9\frac{1}{2}$ Ektachrome infrared film or a Hasselblad 70mm four camera cluster. Camera 1 used Ektachrome infrared aerial film (Kodak 8443). Camera 2 used Ektachrome medium speed aerial film (Kodak 2448). Camera 3 with black and white infrared aerial film (Kodak 2424) and Camera 4 with Tri-X Panchromatic film (Kodak 2403). A G-15 plus 30M filter, 21M filter, 89B filter and 25A filter were used respectively with the Ektachrome infrared, Ektachrome medium speed, black and white infrared and Tri-X films. Of this data collected, only the infrared film is reported on in this paper.

Useable photography was obtained on July 31, August 12, August 15, September 10, and October 8. The altitude of the aircraft was 2,000 feet. Photography was also taken at 4,000 feet, but density readings of this film were not made.

Table I.--Corn: Optical density readings per plot for corn fields by dates of photography, South Dakota, 1969.

Field	Date of photography				
	July 31	August 12	August 15	September 10	October 6
	Number	Number	Number	Number	Number
X	2	2	2	2	2
Y	2	4	2	2	2
Z	2	2	**	2	2

** No photography for field Z on August 15.

Five variables were selected for ground truth studies. The variables fall into two categories, (1) measurable plant characteristics before crop matures and (2) measurable plant characteristics only when crop is mature. Category (1) variables were (a) number of stalks per acre July 24, 1969 and (b) number of ears per acre, August 20, 1969. The category (2) variables were: (a) number of stalks per acre, October; (b) number of ears per acre, October; and final estimated yield per acre, October.

Analysis of variance showed highly significant differences between field means for all five variables. Bartlett's test showed no differences in variability between fields for each of the variables. So the assumptions regarding techniques for pooled variances for analysis purposes were met.

Analyses showed that the five ground data variables were all highly correlated. Analyses of ground data lead to these conclusions:

1. Sample selection process were successful in meeting their objectives (difference between fields, plots within fields).
2. Variances may be pooled for model building.
3. For the models studied, the same variable appeared to give nearly the same result for each model although coefficients were different.

Tables showing the results of these analyses are found in Appendix B.

Optical Density Measurements

Four primary optical density variables were selected for study. Neutral, red, green, and blue filters on a MacBeth densitometer (see Appendix D) were used for measuring optical density on Ektachrome infrared film type 8443 and were labeled X_1, X_2, X_3, and X_4, respectively.

It had been suggested that differences in optical density between filter colors could be used to remove day-to-day variation for incoming radiation. To investigate this, all possible differences were set up as: neutral minus red, green minus neutral, blue minus neutral, green minus red, blue minus green, and were denoted X_5 through X_{10}, respectively.

Correlations were computed between each X variable and with the Y variables. The Y variables were: number of stalks per acre July 24, number of stalks per acre October 8, number of ears per acre August 20, number ears per acre October 8, and yield bushels per acre. The correlations are presented in Appendices C and D. The X variables were highly correlated among themselves. The correlations of the X's with the Y's were calculated by dates.

The August 12 film was not as dense as the July 31, September 10, and the October 6 as can be seen from (Table C-I-Appendix C) the table of means of the X's. The inter relationships of the X's on August 12 are quite different from other days (Tables C-II through C-VI-Appendix C). This different relationship also held for the correlations with the Y's.

The August 15 film density was also much less than the densities for July 31, September 10, and October 6 but was more dense than the August 12 data. The relationship of the August 15 correlation between the X's and the X's with Y's are similar to the dense films. See Appendix D, Tables D-II and D-III. The consideration of variables was restricted to only X variables that had similar correlations for July, August, and September.

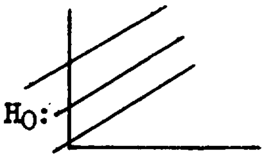
Thus X_5 (neutral-red), X_6 (neutral-green), X_8 (green-red) and X_9 (blue-red) were used in the analysis. The correlations between these variables, on the chosen film, varied from .971 to .999. The variable X_5 (neutral-red) had the highest average correlation with Y_5 (yield). Based on these findings Y_5 and X_5 were chosen for developing a potential model.

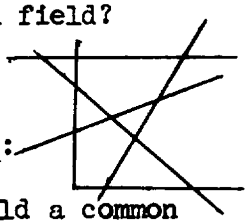
Table II, III, IV, V, VI are analysis of variance (AOV) summaries which test various hypotheses about the suitability of regression lines when combining data gathered from different fields. The test is terminated with the first significant F value encountered. Read the AOV tables starting at the bottom. Tests to be made are the following:

1. Can an average within field slope be used for all pooled data, or is a different slope and intercept necessary for each field?

   H_0: $Y_{ij} = a_i + b X_{ij}$

   H_a: $Y_{ij} \neq a_i + b_i X_{ij}$

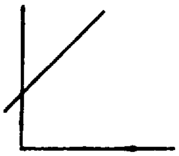
   H_0: 

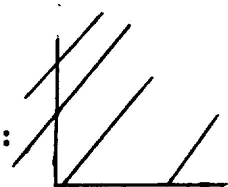
   H_a: 

2. Can one intercept (or mean) and slope be used or should a common slope but separate intercept be used for each field?

   H_0: $Y_{ij} = a + b X_{ij}$

   H_a: $Y_{ij} = a_i + b X_{ij}$

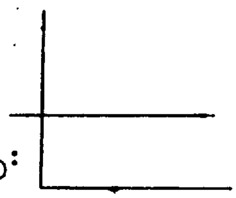
   H_0: 

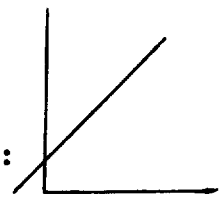
   H_a: 

3. Is a regression equation useful or would the mean, $\overline{Y}$, be appropriate, i.e., is b = 0?

   H_0: $Y_{ij} = \overline{Y}$

   H_a: $Y_{ij} = a + b X_{ij}$

   H_0: 

   H_a: 

Once these questions are answered, the basic estimating model is established.

X_5 vs Y_5

Table II.--1969 South Dakota corn, July 31 - an analysis of variance testing various hypotheses about suitability of regression lines 1)

Source of Variation	Degrees of freedom	Sums of Squares	Mean Square	F Test	Hypotheses
Regression (a, b)	1	14479.3	14479.3	45.60*	H_0: $\hat{Y}_{ij} = \bar{Y}$
Error 1	22	6985.3	317.5		H_a: $\hat{Y}_{ij} = a + b X_{ij}$
Regression ($a_1 \ldots a_3$, b)	2	1587.3	793.7	2.94	H_0: $\hat{Y}_{ij} = a + b X_{ij}$
Error 2	20	5397.8	269.9		H_a: $\hat{Y}_{ij} = a_i + b X_{ij}$
Regression ($a_1 \ldots a_3$, $b_1 \ldots b_3$)	2	258.1	129.1	.45	H_0: $\hat{Y}_{ij} = a_i + b X_{ij}$
Error 3	18	5139.6	285.5		H_a: $\hat{Y}_{ij} = a_i + b_i X_{ij}$

1) Correlations may be found in Appendix D, Table D I

* Significant at .99 level

X_5 vs Y_5

Table III.--1969 South Dakota corn, August 12 - an analysis of variance testing various hypotheses about the suitability of regression lines [1)]

Source of Variation	Degrees of freedom	Sums of squares	Mean square	F Test	Hypotheses
Regression (a, b)	1	198.9	198.9	.21	H_0: $\hat{Y}_{ij} = Y$
Error 1	22	21265.7	966.6		H_a: $\hat{Y}_{ij} = a + b X_{ij}$
Regression ($a_1 \ldots a_3$, b)	2	17053.2	8326.6	40.48*	H_0: $\hat{Y}_{ij} = a + b X_{ij}$
Error 2	20	4212.6	210.6		H_a: $\hat{Y}_{ij} = a_i + b X_{ij}$
Regression ($a_1 \ldots a_3$, $b_1 \ldots b_3$)	2	285.3	142.7	.65	H_0: $\hat{Y}_{ij} = a_i + b X_{ij}$
Error 3	18	3927.2	218.2		H_a: $\hat{Y}_{ij} = a_i + b_i X_{ij}$

1) Correlation may be found in Appendix D, Table D II

* Significant at .99 level

5 vs Y_5

Table IV.--1969 South Dakota corn, August 15 - an analysis of variance testing various hypotheses about the suitability of regression lines 1)

Source of Variation	Degrees of freedom	Sums of squares	Mean square	F Test	Hypotheses
Regression (a, b)	1	3684.3	3684.3	40.38*	H_0: $\hat{Y}_{ij} = \bar{Y}$
Error 1	14	1277.5	91.2		H_a: $\hat{Y}_{ij} = a + b\ X_{ij}$
Regression ($a_1 \ldots a_3$, b)	1	108.8	108.8	1.21	H_0: $\hat{Y}_{ij} = a + b\ X_{ij}$
Error 2	13	1168.7	89.9		H_a: $\hat{Y}_{ij} = a_i + b\ X_{ij}$
Regression ($a_1 \ldots a_3$, $b_1 \ldots b_3$)	1	296.3	296.3	4.08	H_0: $\hat{Y}_{ij} = a_i + b\ X_{ij}$
Error 3	12	872.3	72.7		H_a: $\hat{Y}_{ij} = a_i + b_i\ X_{ij}$

1) Correlation may be found in Appendix D, Table D III.

* Significant at .99 level

X_5 vs Y_5

Table V.--1969 South Dakota corn, September 10 - an analysis of variance testing various hypotheses about the suitability of regression lines 1)

Source of Variation	Degrees of freedom	Sums of squares	Mean square	F Test	Hypotheses
Regression (a, b)	1	14191.3	14191.3	42.93*	H_0: $\hat{Y}_{ij} = \bar{Y}$
Error 1	22	7273.3	330.6		H_a: $\hat{Y}_{ij} = a + b X_{ij}$
Regression ($a_1 \ldots a_3$, b)	2	2106.2	1053.1	4.08	H_0: $\hat{Y}_{ij} = a + b X_{ij}$
Error 2	20	5167.2	258.4		H_a: $\hat{Y}_{ij} = a_i + b X_{ij}$
Regression ($a_1, a_2, a_3, b_1, b_2, b_3$)	2	45.1	22.6	.079	H_0: $\hat{Y}_{ij} = a_i + b X_{ij}$
Error 3	18	5122.0	284.6		H_a: $\hat{Y}_{ij} = a_i + b_i X_{ij}$

1) Correlation may be found in Appendix D, Table D IV

* Significant at .99 level

X_5 vs Y_5

Table VI.--1969 South Dakota corn, October 6 - an analysis of variance testing various hypotheses about the suitability of regression lines 1)

Source of Variation	Degrees of freedom	Sums of squares	Mean square	F test	Hypotheses
Regression (a, b)	1	9844.1	9844.1	18.66*	H_0: $\hat{Y}_{ij} = \bar{Y}$
Error 1	19	10024.2	527.6		H_a: $\hat{Y}_{ij} = a + b X_{ij}$
Regression (a_1, a_2, a_3, b)	2	3245.3	1622.7	4.07	H_0: $\hat{Y}_{ij} = a + b X_{ij}$
Error 2	17	6778.9	398.8		H_a: $\hat{Y}_{ij} = a_i + b X_{ij}$
Regression (a_1,a_2,a_3,b_1,b_2,b_3)	2	1955.7	977.8	3.04	H_0: $\hat{Y}_{ij} = a_i + b X_{ij}$
Error 3	15	4823.2	321.5		H_a: $\hat{Y}_{ij} = a_i + b_i X_{ij}$

1) Correlation may be found in Appendix D, Table D V

* Significant at .99 level

In Tables II thru VI, the first F-values are not significant. H_0: $Y_{ij} = a_i + b X_{ij}$ is accepted for all five dates. For July 31, (Table II), August 15, (Table IV), September 10, (Table V), October 6, (Table VI), the second F-value is not significant, thus H_0: $Y_{ij} = a + b X_{ij}$ is accepted at the .99 level. That is, the third F-value is highly significant on these dates indicating that H_a: $Y_{ij} = a + b X_{ij}$ is the proper model. For August 12, the second F-value was significant at the .99 level and the alternative model was selected.

The computations for the slopes and intercepts were made as follows:

Where $X = X_5$ and $Y = Y_5$

Assuming the .01 level of significance use:

$Y = a + bX$ for July 31, August 15, September 10, October 6 and $Y = a_i + bX$ for August 12.

For the .05 level of significance

$Y = a + bX$ for July 31, August 15 and

$Y = a_i + bX$ for August 12, September 10, October 6.

Tests for regression coefficients on all possible pairs of Y vs X values for each date of photography were obtained. On dependent variable Y, count of stalks, July 24, 22 pooled models were significant and the remaining 28 showed no regression. On dependent variables Y_2, count of stalks October 8, again 22 pooled models were significant. Six more pairs showed significance for the separate intercept model. On Y_3, number of ears August 20, 16 pooled regression were significant, separate intercept models were significant for 6 and its remaining 24 showed no regression. On Y_4,

Table VII.--1969 South Dakota corn -- intercepts and slopes for various dates.

Model $Y_{ij} = a + b X_{ij}$

Date	Intercept	Slopes
July 31	33.36	180.74
August 15	10.14	163.20
September 10	73.34	257.82
October 6	32.53	-218.32

$Y_i = Y_5$ Final yield bushels per acre; $X_i = X_5$ (Neutral - red)

Table VIII.--1969 South Dakota corn -- intercepts and slopes for various fields and dates

Model $Y_{ij} = a_i + b X_{ij}$

Date	Field	Intercept	Slope
August 12	X	64.90	
	Y	55.65	326.65
	Z	1.40	
September 10	X	69.92	
	Y	57.41	169.66
	Z	87.93	
October 6	X	61.75	
	Y	51.54	45.95
	Z	123.95	

$Y_i = Y_5$ Final yield bushels per acre; $X_i = X_5$ (Neutral - red) number of ears October 8, 26 regressions were significant of which 20 were the pooled model. On dependent variable Y_5, final yield, 32 pooled models and thirteen separate intercept models were significant. The remaining five showed no significant regression. Dependent variable Y_5 final yield had by far more significant regression on the average than the other variables.

Table IX.--1969 South Dakota corn- Number of significant* regression models or lack of regression models in repeated regression analysis between all possible pairs (50).

Dependent Variable	No Regression $\hat{Y}_{ij} = \bar{Y}$	Model 1 $\hat{Y}_{ij} = a + bX_{ij}$	Model 2 $\hat{Y}_{ij} = a_i + bX_{ij}$
Number of stalks/A July 24	28	22	0
Number of stalks/A October 8	22	22	6
Number of ears/A August 20	24	16	10
Number of ears/A October 8	24	20	6
Plot yield BU/A	5	32	13

* Significant at .99 level

Considering the independent variables, the variables based on filter differences showed more regression than the individual filter readings.

Table X.--1969 South Dakota corn-number of significant* regression models or lack of regression models in repeated regression analysis between all possible pairs.

Independent variable	No Regression $\hat{Y}_{ij} = \bar{Y}$	Model 1 $\hat{Y}_{ij} = a + b X_{ij}$	Model 2 $\hat{Y}_{ij} = a_i + b X_{ij}$
X_1 Neutral filter	15	7	3
X_2 Red filter	12	6	7
X_3 Green filter	10	12	3
X_4 Blue filter	11	9	5
X_5 $(X_1 - X_2)$	8	16	1
X_6 $(X_3 - X_1)$	8	15	2
X_7 $(X_4 - X_1)$	8	11	5
X_8 $(X_3 - X_2)$	8	16	1
X_9 $(X_4 - X_2)$	8	15	2
X_{10} $(X_4 - X_3)$	15	5	5

* Significant at .99 level

A polynomial regression to predict the (neutral - red) variable was computed, but the correlation between predicted and actual was so poor this analysis was abandoned. Further, discriminant analysis was tried but apparently the intercept differences between fields caused very poor results and this analysis was also abandoned.

After looking at the various models some question was raised on whether the optical density varied between samples within fields, between fields within days. To look at this, an analysis of variance was computed. Highly significant differences were found between samples within fields, between fields within days and for all but X_7 and X_9 between days. The variable X_7 (blue minus neutral) was not significant between days and X_9 (blue minus red) was significant at the 95 percent level between days (See Appendix C).

Bartlett's test for homogeneity of variance was computed to test if the assumption for making the analysis of variance held. The Bartlett's tests indicated the variances of optical density measurements were not homogeneous between fields or between days. Differences between optical density measurements for pairs of filters variables (X_5 to X_{10}) did not improve the homogeneity of variance (See Table XI). The variance of optical density measurements seems to be a complex function of crop maturity and overall film density plus many other variables. Since the regression coefficients and correlation coefficients were determined by pooled variances and covariances the interpretation of results must be viewed with caution.

To alleviate this heterogeneity several transformations were tried. Optical density is the $\log_{10}$ of the inverse of transparency [trans = 1 antilog_{10} (optical density)]. Since transparencies range from $.0 < t < 1$ the arc sin transformation seemed logical. The variances after the transformation were more heterogeneous. Other transformations tried were: the square root of X, the cube root of X, the fourth root of X and the log X. None of these transformations decreased the heterogeneity.

Table XI.--1969 South Dakota corn: Bartletts test of homogenity of variance - chi-square values by dates and by X variables

Date	DF	X_1 Neutral: filter	X_2 Red filter	X_3 Green: filter	X_4 Blue filter	X_5 (X_1-X_2)	X_6 (X_3-X_1)	X_7 (X_4-X_1)	X_8 (X_3-X_2)	X_9 (X_4-X_2)	X_{10} (X_4-X_3)
		OPTICAL DENSITY MEASUREMENTS									
Between fields											
July 31	2	0.12	0.79	7.74*	14.35**	8.33*	5.49	1.78	7.22*	.13	1.84
August 12	2	3.61	2.55	9.44**	5.57*	18.58**	15.56**	7.80*	16.59**	9.68**	3.89
August 15	1	0.68	0.01	6.81**	6.64**	7.98**	4.79*	6.73**	5.66*	7.27**	5.13*
September 10	2	6.66*	0.01	4.24	8.61*	13.67**	4.56	11.27**	7.91*	12.61**	8.15*
October 6	2	7.25*	7.13*	7.84*	6.75*	.38	.89	3.59	.12	1.10	5.13
Between days	4	14.28**	179.92**	16.97**	5.15	22.58**	54.15**	42.40**	34.21*	34.02**	4.16

* Significant at 95 percent level.
** Significant at 99 percent level.

Summary and Conclusions

The August 12 and August 15 photography were at different density levels than the other dates. No density values were in the overall neutral density range .75 to 1.50 for any dates or fields. There was a great loss of yield information when the overall density was less than .75.

The difference between filter readings of optical density was more highly correlated to yields in this experiment than individual readings themselves. But they do not account of the large difference in films between days that was obtained in this experiment. This indicates that more than one band is needed for yield models.

The final yield showed a stronger relationship to the optical density measurement than the number of stalks per acre or the number of ears per acre.

Since the sample was selected purposely no inference can be made about using any particular model for an estimate beyond the three sample fields but the results show that optical density difference and final yield might be practical if the overall density can be held in the proper range.

The results of the Bartletts test would indicate that the variance of the optical densities measurements and their pairwise differences are related to their respective magnitudes. This means that linear regression estimates will be biased when based on these variables. Since the values larger in magnitude will over weight a linear model. This experiment demonstrates four factors that are important in developing a infra-red photography system for predicting crop yields. The information contained on the transparencies are attenuated by over-exposure. The variances of optical density measurements tend to be heterogeneous. The difference between two filter measurements shows significant improvement over single filter readings. Infra-red photography images can be digitized by using a densitometer and processed on a digitital computer.

Instruments for reading optical density are sufficient for yield work. The MacBeth densitometer has advantages over the Joyce Lobel microdensitracer in that the latter is harder to calibrate and has more resolution than necessary, but has the disadvantage of not being able to read the corresponding unit on the ground. The MacBeth machine used has a digitized output and gives more accuracy than the dial type machine.

Need for Further Studies

Overall film density should be studied to find the loss point or curve since very thin films show much poorer relationships than denser films. The relationship of maturity of the crop and optical densities needs further study. The expense and weather dependent nature of aerial photography dictates that we determine the variance and reliability of different maturity categories. This was one of the objectives of this study but unfortunately was obscured by the overall film density variation between days.

A technique needs to be developed for eliminating the differences in intercepts by the addition of another variable or stricter control of the taking and processing of the photography. The heterogenity of variance for the optical densities needs to be eliminated by transformations and/or a way found to estimate the bias caused by this and/or a non linear model developed. Independence between days for individual optical densities should be established or denied.

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[(2)] Progress report on cooperative agreement between the USDA, Statistical Reporting Service, and The Institute of Statistics of Texas, A&M University, October 1 through December 31, 1969 unpublished report.

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1969 South Dakota Corn

APPENDIX A - RAW DATA

Table AI.--1969 South Dakota corn--ground data

Field	Sample	Y_1 Number of stalks/A. July 24	Y_2 Number of stalks/A. Oct. 8	Y_3 Number of ears/A. Aug. 20	Y_4 Number of ears/A. Oct. 8	Y_5 Yield Bu/A.
X (Madison)	1	4,522	4,677	4,054	4,366	56.0
	2	7,304	8,163	2,578	7,733	40.4
	3	4,488	4,488	1,208	4,661	43.4
	4	7,333	9,452	5,370	8,593	76.4
	5	6,050	6,885	5,633	6,676	83.0
	6	6,139	6,985	4,022	6,562	50.3
	7	5,478	5,639	1,772	5,317	47.1
	8	5,634	5,469	3,811	4,971	55.1
Y (Madison)	1	6,811	6,811	1,977	6,591	54.8
	2	4,966	5,164	199	5,164	46.6
	3	4,215	5,227	5,564	5,564	66.6
	4	5,940	6,289	2,446	6,114	68.5
	5	4,167	4,500	167	4,500	35.7
	6	3,731	3,731	170	3,901	4.5
	7	6,015	6,015	430	6,659	58.5
	8	3,679	4,761	216	4,761	44.4
Z (Redfield)	1	8,258	9,987	9,411	8,066	112.9
	2	9,984	6,893	8,795	8,320	83.8
	3	10,208	6,728	9,048	8,120	91.8
	4	8,816	7,656	10,208	8,352	94.1
	5	9,992	10,723	10,966	11,210	73.4
	6	8,529	10,235	9,260	9,017	122.5
	7	8,220	8,906	12,331	9,591	136.0
	8	7,555	9,504	9,748	9,504	103.5

Table AII.--1969 South Dakota corn - optical densities

Flight - July 31 - Aero infrared film

Field	Sample	Neutral filter	Red filter	Green filter	Blue filter
X	1	1.8850	1.6800	2.2500	2.9050
	2	1.9000	1.6950	2.2550	2.9200
	3	1.9850	1.8650	2.2300	2.8950
	4	1.9150	1.6900	2.2700	2.9200
	5	1.8200	1.6150	2.2050	2.7200
	6	1.8000	1.5900	2.2050	2.8650
	7	2.1150	2.0050	2.2900	2.9450
	8	1.8500	1.6250	2.2600	2.9100
Y	1	2.2450	2.1700	2.3350	2.9600
	2	2.3500	2.3200	2.3750	2.9650
	3	2.1900	2.0800	2.3500	2.9400
	4	2.3400	2.7500	2.4000	2.9850
	5	2.2650	2.1950	2.3550	2.9600
	6	2.2450	2.3200	2.2050	2.8950
	7	2.4200	2.3700	2.4450	3.0150
	8	2.4600	2.4550	2.4100	3.0000
Z	1	0.9150	0.5700	1.5850	2.1400
	2	0.8850	0.5200	1.6050	2.3150
	3	0.8650	0.4850	1.6300	2.3850
	4	0.8950	0.5350	1.6200	2.3600
	5	1.0800	0.7400	1.8100	2.6050
	6	1.0850	0.7500	1.8200	2.6300
	7	0.9500	0.5750	1.7050	2.4750
	8	1.0250	0.6600	1.7950	2.6250

Table A-III.--1969 South Dakota corn - optical densities

Flight - August 12 - Aero Infrared film

Field	Sample	Neutral filter	Red filter	Green filter	Blue filter
X	1	0.5350	0.2350	1.2775	1.5075
	2	0.5350	0.2400	1.3175	1.5075
	3	0.5400	0.2450	1.2625	1.4975
	4	0.5650	0.1700	1.2925	1.4350
	5	0.5400	0.2000	1.4525	1.7700
	6	0.5050	0.2225	1.4450	1.7975
	7	0.5700	0.2900	1.4475	1.7675
	8	0.5350	0.2075	1.3375	1.5450
Y	1	0.5875	0.2100	1.2000	1.4000
	2	0.6025	0.2200	1.6000	1.3100
	3	0.5900	0.1750	1.2950	1.4750
	4	0.5350	0.1900	1.3400	1.5600
	5	0.6050	0.2150	1.1700	1.3650
	6	0.6175	0.3300	0.8300	0.9200
	7	0.6725	0.2200	1.2850	1.5250
	8	0.5750	0.2450	1.1150	1.3450
Z	1	0.5050	0.1950	1.1300	1.1750
	2	0.4750	0.1800	1.0650	1.1150
	3	0.5050	0.2050	1.1100	1.1550
	4	0.5000	0.2050	1.0900	1.1200
	5	0.5350	0.2150	1.1800	1.2800
	6	0.5450	0.2250	1.1800	1.2900
	7	0.5250	0.2050	1.1800	1.2450
	8	0.5200	0.2100	1.1650	1.2800

Table A-IV.--1969 South Dakota corn - optical densities

Flight - August 15 - Aero Infrared film

Field	Sample	Neutral filter	Red filter	Green filter	Blue filter
X	1	0.7850	0.4600	1.4150	2.1950
	2	0.8600	0.5700	1.4300	2.2850
	3	0.7650	0.5250	1.2400	1.9850
	4	0.7150	0.3850	1.3700	2.1150
	5	0.7950	0.4450	1.5050	2.3750
	6	0.8250	0.5500	1.3800	2.2350
	7	0.7850	0.5200	1.3000	2.0700
	8	0.7250	0.4150	1.3350	2.0800
Y	1	0.7450	0.4900	1.2850	2.1250
	2	0.7600	0.5000	1.2550	2.1050
	3	0.7250	0.3900	1.4000	2.2300
	4	0.7200	0.4100	1.3350	2.1500
	5	0.7150	0.5050	1.0900	1.8700
	6	0.5450	0.6000	0.6050	1.0250
	7	0.6950	0.4850	1.1050	1.8750
	8	0.7050	0.5150	1.0750	1.8750

Table A-V.--1969 South Dakota corn - optical densities

Flight - September 10 - Acro Infrared film

Field	Sample	Neutral filter	Red filter	Green filter	Blue filter
X	1	1.6150	1.6150	1.7300	2.3100
	2	1.5900	1.7050	1.5900	2.2000
	3	1.4650	1.6000	1.4600	2.1200
	4	1.6350	1.6650	1.7200	2.3900
	5	1.6150	1.7100	1.6550	2.2700
	6	1.5950	1.7050	1.6200	2.2900
	7	1.5100	1.6250	1.5200	2.2000
	8	1.6150	1.6500	1.6950	2.3650
Y	1	1.5750	1.6350	1.6450	2.3200
	2	1.6600	1.7050	1.7300	2.4600
	3	1.5900	1.6100	1.6800	2.3300
	4	1.6850	1.6350	1.8700	2.5550
	5	1.3200	1.5300	1.2500	1.8200
	6	1.3800	1.5800	1.3100	1.8650
	7	1.6500	1.6200	1.7450	2.4600
	8	1.6450	1.6600	1.7300	2.4850
Z	1	1.6450	1.5350	1.9450	2.6850
	2	1.5700	1.4900	1.8300	2.5800
	3	1.5200	1.4150	1.7850	2.5400
	4	1.5050	1.4400	1.7200	2.5200
	5	1.9150	1.8500	2.1050	2.8500
	6	1.8900	1.8300	2.0700	2.8150
	7	1.6400	1.5450	1.9050	2.6950
	8	1.9200	1.8300	2.1250	2.8650

Table A-VI.--1969 South Dakota corn - optical densities

Flight - Oct. 6 - Aero Infrared film

Field	Sample	Neutral filter	Red filter	Green filter	Blue filter
X	1	2.0100	2.0750	2.0350	2.6950
	2	2.1400	2.2400	2.0900	2.7350
	3	2.0300	2.0850	2.0300	2.6450
	4	1.8400	2.0100	1.7900	2.4450
	5	2.2100	2.3700	2.1050	2.3000
	6	2.2150	2.3550	2.1150	2.7850
	7	2.0900	2.1700	2.0650	2.6100
	8	1.8850	2.0350	1.8450	2.4800
Y	1	1.9250	2.0950	1.8750	2.5250
	2	1.9250	2.0150	1.9400	2.5100
	3	1.9300	2.0050	1.9550	2.5700
	4	1.8100	1.8600	1.8750	2.4550
	5	1.8700	1.9400	1.9000	2.4900
	6	1.8200	1.9500	1.8200	2.4250
	7	1.7700	1.8450	1.8100	2.3950
	8	1.6450	1.7000	1.6850	1.9900
Z	1	1.0550	1.2950	0.9650	1.4750
	2	1.5150	1.8900	1.3550	2.0450
	3	1.6100	1.9550	1.4650	2.2200
	4	1.1950	1.4700	1.0850	1.6450
	8	1.8150	2.1350	1.6650	2.4350

APPENDIX B

SOUTH DAKOTA CORN STUDY, 1969

Tables of Ground Data

Y_1 = Number of stalks/A. July 24, 1969

Y_2 = Number of stalks/A. October 6, 1969

Y_3 = Number of ears/A. August 20, 1969

Y_4 = Number of ears/A. October 6, 1969

Y_5 = Final yield Bu./A. October 6, 1969

(Forecast for samples 2, 3, 4, Field Z)

Field X Madison Soil and Water Research Farm

Field Y Madison Soil and Water Research Farm

Field Z Redfield Irrigation Research Farm

Table B-I: Means

Variable field	Y_1 (000)	Y_2 (000)	Y_3 (000)	Y_4 (000)	Y_5 Bu./A.
X	5.8685	6.4697	3.5560	6.1099	56.462
Y	4.9405	5.3222	1.3960	5.4067	47.450
Z	8.9452	8.8290	9.9708	9.0225	102.250
Overall Means	6.5847	6.8703	4.9743	6.8464	68.721

Table B-II: 1969 - South Dakota corn - correlations**

Field	Y_2	Y_3	Y_4	Y_5
Y_1	.794	.818	.898	.705
Y_2		.772	.933	.750
Y_3			.846	.874
Y_4				.760

** All highly significant at the .01 percent level.

Table B-III: 1969 - South Dakota corn - ANOVA Y_1 (Number of stalks July 24, 1969)

Source	Degrees of freedom	Sums of squares	Mean squares	F value
Between fields	2	279.8	139.89	27.9 1/
Within fields.	21	105.4	5.02	
Total.........	23	385.2		

1/ F 6.89 significant at the 99.5 percent level.

Table B-IV: 1969 - South Dakota corn - ANOVA Y_2 (Number of stalks October 8, 1969)

Source	Degrees of freedom	Sums of squares	Mean squares	F value
Between fields	2	206.1	103.07	11.9 2/
Within fields.	21	181.0	8.62	
Total.........	23	387.1		

2/ F 6.89 significant at the 99.5 percent level.

Table B-V: 1969 South Dakota corn - ANOVA Y_3 (Number of ears August 20, 1969)

Source	Degrees of freedom	Sums of squares	Mean squares	F value
Between fields	2	1292.5	646.24	62.1 3/
Within fields	21	218.6	10.41	
Total............	23	1511.1		

3/ F > 6.89 significant at 99.5 percent level.

Table B-VI: 1969 South Dakota corn - ANOVA Y_4 (Number of ears October 8, 1969) 4/

Source	Degrees of freedom	Sums of squares	Mean squares	F value
Between fields	2	235.9	117.92	19.6 5/
Within fields	21	126.2	6.01	
Total............	23	362.1		

4/ September 16, 1969 for samples 2, 3, 4, Field Z

5/ F > 6.89 significant at 99.5 percent level.

Table B-VII: 1969 South Dakota corn - ANOVA Y_5 (Final yield bu./A.) 6/

Source	Degrees of freedom	Sums of squares	Mean squares	F value
Between fields	2	138.15	68.09	19.0 7/
Within fields	21	76.49	3.64	
Total............	23	214.64		

6/ Forecast for samples 2, 3, 4, Field Z

7/ F > 6.89 significant at 99.5 percent level.

Table B-VIII: 1969 South Dakota corn - Bartlett's Test

Variable field	Mean Squares				
	Y_1	Y_2	Y_3	Y_4	Y_5
X	5.47	12.05	10.19	9.39	2.37
Y	5.63	4.12	15.46	4.05	4.26
Z	3.95	9.69	5.57	4.59	4.30
Pooled	5.02	8.62	10.41	6.01	3.64
X^2 (2 df)	0.246	1.886	1.648	1.437	0.711

X^2 (2 df) > 4.61 significant at 90 percent level. (None significant)

APPENDIX C

SOUTH DAKOTA CORN STUDY, 1969

Tables of Optical Densities:

X_1 = Neutral filter

X_2 = Red filter

X_3 = Green filter

X_4 = Blue filter

$X_5 = (X_1 - X_2)$

$X_6 = (X_3 - X_1)$

$X_7 = (X_4 - X_1)$

$X_8 = (X_3 - X_2)$

$X_9 = (X_4 - X_2)$

$X_{10} = (X_4 - X_3)$

Table C-I.--Means

Day	Field	Variables									
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
July 31	X	1.91	1.72	2.25	2.88	.19	.34	.98	.52	1.16	.60
	Y	2.31	2.27	2.36	2.96	.04	.05	.65	.09	.69	.60
	Z	.96	.60	1.70	2.44	.36	.73	1.48	1.09	1.84	.75
	Day	1.73	1.53	2.10	2.76	.20	.48	1.04	.57	1.23	.66
Aug. 12	X	.54	.23	1.35	1.60	.37	.76	1.01	1.13	1.38	.19
	Y	.60	.23	1.17	1.36	.32	.63	.82	.95	1.14	.25
	Z	.61	.20	1.14	1.21	.31	.62	.69	.93	1.00	.07
	Day	.56	.22	1.26	1.44	.34	.69	.88	1.03	1.22	.19
Aug. 15	X	.78	.48	1.37	2.17	.30	.59	1.39	.89	1.68	.80
	Y	.70	.49	1.14	1.90	.21	.44	1.21	.66	1.42	.76
	Day	.74	.49	1.26	2.04	.25	.52	1.29	.77	1.55	.78
Sept.10	X	1.58	1.66	1.12	2.27	-.08	.04	.69	-.04	.61	.69
	Y	1.56	1.62	1.62	2.29	-.06	.04	.72	-.00	.66	.67
	Z	1.70	1.62	1.93	2.69	.08	.23	.99	.32	1.08	.76
	Day	1.61	1.63	1.73	2.42	-.02	.11	.80	.09	.78	.69
Oct. 8	X	2.05	2.17	2.00	2.65	-.12	-.04	.60	-.16	.48	.64
	Y	1.84	1.93	1.85	2.42	-.09	.02	.58	-.07	.49	.56
	Z	1.44	1.75	1.30	1.96	-.31	-.13	.53	-.44	.22	.66
	Day	1.82	1.97	1.78	2.39	-.15	-.04	.57	-.19	.42	.61
[illegible]		1.27	1.13	1.62	2.17	.14	.35	.90	.49	1.03	.55

Table C-II.- 1969 - South Dakota corn - optical densities - correlations** - July 31

Field	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	.998	.979	.929	-.950	-.977	-.964	-.971	-.969	-.663
X_2		.967	.916	-.967	-.987	-.970	-.983	-.978	-.658
X_3			.968	-.873	-.913	-.902	-.903	-.902	-.623
X_4				-.825	-.848	-.797	-.843	-.812	-.434*
X_5					.988	.958	.994	-.978	.610
X_6						.985	.999	.995	.675
X_7							.979	.997	.770
X_8								.992	.656
X_9									.731

** All correlations significant at .01 level except the one marked * which is significant at the .05 level.

Table C-III.- 1969 - South Dakota corn - optical densities - correlations** - August 12

Field	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	.315	-.048	.099	-.107	-.131	.081	-.124	.042	.874
X_2		-.118	.056	-.245	-.283	-.007	-.271	-.056	.459*
X_3			.963**	.977**	.972**	.967**	.975**	.981**	.052
X_4				.906**	.895**	.994**	.901**	.988**	.233
X_5					.991**	.926**	.996**	.953**	-.034
X_6						.921**	.999**	.948**	-.063
X_7							.924**	.997**	.206
X_8								.951**	-.054
X_9									.158

** Significant at the .01 level.
* Significant at the .05 level.

Table C-IV.--1969 South Dakota corn - optical densities - correlations** August 15

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	-.033	.848**	.873**	.749**	.703**	.798**	.723**	.787**	.824**
X_2		-.538**	-.494*	-.687**	-.709**	-.601*	-.704**	-.628**	-.349
X_3			.982**	.974**	.973**	.975**	.977**	.979**	.835**
X_4				.962**	.938**	.991**	.951**	.987**	.924**
X_5					.981**	.978**	.993**	.989**	.830**
X_6						.961**	.997**	.971**	.762**
X_7							.973**	.998**	.910**
X_8								.982**	.791**
X_9									.892**

* Significant at the .05 level
** Significant at the .01 level

Table C-V.--1969 South Dakota corn - optical densities - correlations** September 10

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	.741**	.909**	.856**	.628**	.516**	.534**	.573**	.575**	.493**
X_2		.400*	.306	-.058	-.177	-.140	-.121	-.111	-.063
X_3			.984**	.887**	.826**	.823**	.861**	.855**	.710**
X_4				.917**	.865**	.895**	.896**	.912**	.824**
X_5					.972**	.955**	.992**	.982**	.805**
X_6						.968**	.994**	.979**	.791**
X_7							.968**	.994**	.920**
X_8								.987**	.804**
X_9									.887**

* Significant at the .05 level
** Significant at the .01 level

Table C-VI.--1969 South Dakota corn - optical densities - correlations** October 6

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	.942**	.978**	.982**	.537**	.267	.582**	.437*	.717**	.298
X_2		.856**	.936**	.224	-.052	.594**	.115	.500*	.539*
X_3			.962**	.691**	.462*	.578**	.612**	.824**	.154
X_4				.501*	.271	.725**	.417*	.772**	.416*
X_5					.909**	.199	.985**	.829**	-.490*
X_6						.193	.967**	.761**	-.560**
X_7							.201	713**	.705**
X_8								.819**	-.530*
X_9									.052

* Significant at the .05 level
** Significant at the .01 level

Table C-VII.--1969 South Dakota corn - optical densities - correlations** all dates

	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
X_1	.981**	.888**	.854**	-.690**	-.800**	-.436**	-.761**	-.578**	.456**
X_2		.791**	.782**	-.814**	-.892**	-.529**	-.868**	-.691**	.453**
X_3			.926**	-.298**	-.436**	-.102	-.383**	-.193	.403**
X_4				-.356**	-.469**	-.093	-.427**	-.090	.710**
X_5					.969**	.709**	.989**	.887**	-.331*
X_6						.719**	.994**	.881**	-.362**
X_7							.720**	.954**	.372
X_8								.890**	-.352**
X_9									.103

* Significant at the .05 level
** Significant at the .01 level

Table C-VIII.--1969 South Dakota corn - optical densities: ANOVA X_1 neutral filter

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	69.634	17.4085	8.681**
Between fields within days	9	18.047	2.0052	83.877**
July 31	(2)	(15.399)	7.699	
August 12	(2)	(0.378)	0.016	
August 15	(1)	(0.052)	0.003	
September 10	(2)	(0.181)	0.090	
October 6	(2)	(2.328)	1.164	
Between samples within fields	103	2.462	.024	45.261**
Within samples	117	.062	.001	
Total	233	90.206		

Table C-IX.--1969 South Dakota corn - optical densities: ANOVA X_2 red filter

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	116.179	29.045	10.76**
Between fields within days	9	24.290	2.699	97.389**
July 31	(2)	(23.125)	11.562	
August 12	(2)	(.005)	.003	
August 15	(1)	(.001)	.001	
September 10	(2)	(.017)	.009	
October 6	(2)	(1.141)	.057	
Between samples	103	2.854	.028	29.105**
Within samples	117	.111	.001	
Total	233	143.434		

** Significant at the .01 level

Table C-X.--1969 South Dakota corn - optical densities - ANOVA X_3 green filter

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	25.520	6.380	6.15**
Between fields within days	9	9.320	1.036	27.73**
July 31	(2)	(4.044)	2.022	
August 12	(2)	(.638)	.319	
August 15	(1)	(.416)	.416	
September 10	(2)	(1.048)	.524	
October 6	(2)	(3.174)	1.587	
Between samples within fields	103	3.850	.037	39.32**
Within samples	117	.110	.001	
Total	233	38.800		

Table C-XI.--1969 South Dakota corn - optical densities - ANOVA X_4 blue filter

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	56.318	14.079	13.13**
Between fields within days	9	9.652	1.072	14.60**
July 31	(2)	(2.5400)	1.270	
August 12	(2)	(1.8140)	.907	
August 15	(1)	(.5430)	.543	
September 10	(2)	(1.8500)	.925	
October 6	(2)	(2.9020)	1.451	
Between samples within fields	103	7.567	.074	30.03**
Within samples	117	.286	.002	
Total	233	73.823		

** Significant at the .01 level

Table C-XII.--1969 South Dakota corn - optical densities - ANOVA X_5 $(X_1 - X_2)$ neutral minus red

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	7.963	1.991	11.899**
Between fields within days	9	1.506	.167	27.915**
July 31	(2)	(.801)	.400	
August 12	(2)	(.056)	.0283	
August 15	(1)	(.056)	.561	
September 10	(2)	(.253)	.126	
October 8	(2)	(.337)	.168	
Between samples within fields	103	.617	.006	13.088**
Within samples	117	.054	.001	
Total	233	10.40		

Table C-XIII.--1969 South Dakota corn - optical densities - ANOVA X_6 $(X_3 - X_1)$ green minus neutral

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	17.496	4.374	8.309**
Between fields within days	9	4.738	.526	39.371**
July 31	(2)	(3.798)	1.899	
August 12	(2)	(.260)	.130	
August 15	(1)	(.174)	.174	
September 10	(2)	(.361)	.180	
October 6	(2)	(.142)	.071	
Between samples within fields	103	1.377	.013	20.415**
Within samples	117	.077	.001	
Total	233	23.688		

** Significant at the .01 level

Table C-XIV.--1969 South Dakota corn - optical densities - ANOVA X_7 (X_4 - X_1) blue minus neutral

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	10.819	2.705	3.093
Between fields within days	9	7.869	.874	25.902**
July 31	(2)	(5.578)	2.789	
August 12	(2)	(1.112)	.556	
August 15	(1)	(.259)	.259	
September 10	(2)	(.886)	.443	
October 6	(2)	(.032)	.0163	
Between samples within fields	103	3.4769	.034	17.950**
Within samples	117	.2200	.002	
Total	233	22.3852		

Table C-XV.--1969 South Dakota corn - optical densities - ANOVA X_8 $(X_3 - X_2)$

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	48.815	12.204	9.809**
Between fields within days	9	11.197	1.244	35.076**
July 31	(2)	(8.095)	4.047	
August 12	(2)	(.562)	.281	
August 15	(1)	(.427)	.427	
September 10	(2)	(1.219)	.609	
October 6	(2)	(.891)	.445	
Between samples within fields	103	3.6533	.036	18.956**
Within samples	117	.2189	.002	
Total	233	63.8840		

** Significant at the .01 level

Table C-XVI.--1969 South Dakota corn - optical densities - ANOVA X_9 $(X_4 - X_2)$ blue minus red

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	31.443	7.861	4.570*
Between fields within days	9	15.479	1.720	28.286**
July 31	(2)	(10.606)	5.303	
August 12	(2)	(1.657)	.828	
August 15	(1)	(.556)	.556	
September 10	(2)	(2.090)	1.045	
October 6	(2)	(.568)	.284	
Between samples within fields	103	6.263	.061	19.286**
Within samples	117	.369	.004	
Total	233	53.555		

Table C-XVII.--1969 South Dakota corn - optical densities - ANOVA X_{10} $(X_4 - X_3)$ blue minus green

Source	D. F.	Sum of Squares	Mean Squares	F
Between days	4	11.730	2.933	36.864**
Between fields within days	9	.716	.080	7.597**
July 31	(2)	(.176)	.088	
August 12	(2)	(.343)	.171	
August 15	(1)	(.008)	.008	
September 10	(2)	(.117)	.058	
October 6	(2)	(.071)	.036	
Between samples within fields	103	1.0785	.010	9.560**
Within samples	117	.1281	.001	
Total	233	13.6528		

** Significant at the .01 level
* Significant at the .05 level

APPENDIX D

1969 South Dakota Corn - Correlations X_i vs. Y_i

Y_1 = Number of stalks per A. July 24

Y_2 = Number of stalks per A. October 8

Y_3 = Number of ears per A. August 20

Y_4 = Number of ears per A. October 8

Y_5 = Yield Bu. per A.

Optical Densities

X_1 = Neutral filter

X_2 = Red filter

X_3 = Green filter

X_4 = Blue filter

$X_5 = X_1 - X_2$

$X_6 = X_3 - X_1$

$X_7 = X_4 - X_1$

$X_8 = X_3 - X_2$

$X_9 = X_4 - X_2$

$X_{10} = X_4 - X_3$

Table D-I.--1969 South Dakota corn - correlation X_i vs Y_i - July 31, 1970 - df 23

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	-.852**	-.859**	-.819**	-.776**	.854**	.848**	.832**	.852**	.845**	.479*
Y_2	-.670**	-.715**	-.627**	-.579**	.751**	.744**	.726**	.749**	.739**	.414*
Y_3	-.938**	-.944**	-.892**	-.844**	.931**	.942**	.923**	.941**	.933**	.608**
Y_4	-.779**	-.791**	-.721**	-.649**	.807**	.806**	.806**	.809**	.813**	.528**
Y_5	-.787**	-.800**	-.739**	-.735**	.821**	.801**	.757**	.810**	.781**	.397**

Table D-II.--1969 South Dakota corn - correlation X_i vs Y_i - August 12, 1970 - df 23

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	-.615**	-.413*	-.152	-.356	-.064	-.023	-.328	-.637	-.277	-.772**
Y_2	-.459*	-.429*	.030	-.161	.095	.141	-.137	.126	-.091	-.631**
Y_3	-.690**	-.581**	-.156	-.365	-.068	-.021	-.336	-.036	-.284	-.796**
Y_4	-.483*	-.509**	-.076	-.274	.001	.051	-.244	.035	-.196	-.691**
Y_5	-.536**	-.709**	-.004	-.212	.096	.143	-.172	.129	-.118	-.725**

* Significant at .05 level
** Significant at .01 level

Table D-III.--1969 South Dakota corn - correlation X_i vs Y_i - August 15, 1970 - df 15

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	.460	-.230	.542*	.513*	.487*	.528*	.504*	.515*	.502*	.394
Y_2	.459	-.294	.573*	.547*	.528*	.569*	.548*	.556*	.545*	.437
Y_3	.384	-.629**	.719**	.617**	.696**	.799**	.654**	.764**	.669**	.337
Y_4	.413	-.282	.525*	.518*	.487*	.525*	.524*	.513*	.516*	.445
Y_5	.434	-.824**	.797**	.784**	.862**	.881**	.847*	.878**	.854**	.669**

Table D-IV.--1969 South Dakota corn - correlation X_i vs Y_i - September 10, 1970 - df 23

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	.427*	-.061	.649**	.685**	.705**	.756**	.750**	.737**	.741**	.643**
Y_2	.701**	.376	.761**	.747**	.606**	.616**	.615**	.616**	.618**	.532**
Y_3	.497**	-.016	.725**	.740**	.757**	.819**	.779**	.795**	.779**	.617**
Y_4	.646**	.234	.764**	.777**	.688**	.696**	.711**	.697**	.710**	.642**
Y_5	.545**	-.002	.771**	.796**	.813**	.847**	.829**	.837**	.832**	.694**

* Significant at .05 level
** Significant at .01 level

Table D-V.--1069 South Dakota corn - correlation X_i vs Y_i - October 8, 1970 - df 20

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	-.480**	-.220	-.616**	-.446*	-.843**	-.805**	-.173	-.847**	-.702**	.436*
Y_2	-.497*	-.236	-.635**	-.473*	-.852**	-.820**	-.223	-.858**	-.737**	.404
Y_3	-.579**	-.326	-.708**	-.541**	-.864**	-.808**	-.219**	-.860**	-.743**	.399
Y_4	-.483*	-.218	-.618**	-.455*	.858**	-.803**	-.199	-.855**	-.727**	.413
Y_5	-.613**	-.429*	-.701**	-.576**	-.704**	-.530*	-.247	-.689**	-.644**	.247

Table D-VI.--1969 South Dakota corn - correlation X_i vs Y_i - all year - df 108

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}
Y_1	-.158	-.165	-.059	-.048	.151	.229*	.218*	.200*	.207*	-.025
Y_2	-.094	-.094	-.014	-.001	.074	.162	.156	.128	.146	.006
Y_3	-.170	-.174	-.071	-.059	.139	.235*	.219*	.198*	.202*	-.024
Y_4	-.117	-.122	-.032	-.017	.101	.187	.194	.153	.169	.003
Y_5	.138	-.152	-.032	-.024	.148	.225*	.221*	.196*	.207*	-.016

* Significant at .05 level
** Significant at .01 level

APPENDIX E

MACBETH DENSITOMETER TD-102

1. General Description

The TD-102 is a single-unit transmission densitometer equipped with four selectable filters for color and visual density measurements within a range of 0-4.0 density units. Separate mechanical trimming controls enable precise individual zeroing of each of the selectable filters contained in the instrument. The readings taken with the TD-102 indicate American Standard diffuse transmission density.

2. Optical System

Optical Geometry: Meets ASA standard PH2. 19-1959 for measuring diffuse transmission density.

Color filters:

Turret Position	Filter Wratten
Red	92
Green	93
Blue	94
Visual (neutral)	106

3. Operation

The TD-102 is always turned on so no warm up time is involved. Positive transparencies are placed on the instrument so that readings may be taken at specific points. These points are ascertained by location of panel markers in the transparency. A reading for each turret position or filter is taken without raising the snout.

APPENDIX E

THERMAL SCANNER

1. General Description

The thermal scanner is an optical-mechanical scanning device with an InSb detector (filter 4.5-5.5 micrometers). The equipment consists of scan head, detector, preamplifier, gyrostabilization, control panel, monitor oscilloscope, signal processor, and camera.

The result of this equipment is an infrared heat picture of the scene stored on ordinary black and white film. The density of the film has a direct relationship to the temperature of the scene. Calibration is achieved with a separate instrutment. This instrument is the Precision Radiation Thermometer.