ANNUAL SUMMARY REPORT

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CROP STATUS EVALUATIONS AND YIELD PREDICTIONS

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Introduction - The work reported herein was based on the program outlined in the reference NASA Headquarter's Y-No. 41-001-043. During the course of this work it was decided to extend the contract to include the remaining portion of the 1974-75 winter wheat season and to collect data on a second season of both spring and winter wheat.

Administrative and personnel arrangements - Interviews prior to employment and subsequent training procedures were carried out for the following positions reporting to the Principal Investigator at Clemson.

Research Analyst II - The person in this position has a BA degree with major in mathematics.

Graduate Assistants - One, with a BS degree is a PhD candidate and has been active during the report period. Another, with an MS degree, also a PhD candidate, has been tentatively accepted to work on this contract.

Laboratory Technician - University students have been employed part time during the school term and full time during the summer months.

Data collection - Arrangements were made with the following stations of the University of North Dakota: Minot, Dickinson and Williston, and with an ASCS employee at Williston to collect daily data on spring wheat development and environmental variables. Spring wheat plots were also grown in the field and in the greenhouse at Clemson to provide data from conditions widely different climatically from commercial spring wheat areas. For winter wheat data, arrangements were made with the following stations of Kansas State University: Colby, Garden City, Parsons and Manhattan. Winter wheat plots were also planted in November 1974 at Clemson and the collection of growth data is currently still being taken for the 1974-75 season at all locations. Visits were made to all locations to discuss procedures, observe experimental conditions, and provide instructions for observers.

Tables 1-5 of the Appendix present the data collected on spring wheat for the first season (1974). The variable GRO represents the daily growth rate as calculated for the average change in growth stage from the previous day of 25 tagged plants. The remaining abbreviations are explained in the list preceding these tables.

Long-term weather records for North Dakota and Kansas were obtained on magnetic tape from the National Climatic Center at Asheville, N. Carolina. Much work was necessary to develop procedures for decoding and/or interpreting these records.

Plan of data processing and analyses - Figs. 1 and 2 detail the various steps or phases of programming and analysis, with an indication of their sequence. At the date of this report items 1-15, and 19 for 1974 in North Dakota (Fig. 1 is for spring wheat analyses which include the data from Clemson) and items 1, 2, 4, 5, 7, and 8 for 1974-75 Kansas (Fig. 2 is for winter wheat also including Clemson data) have been obtained and/or completed.

Progress and results on specific phases -

A. Comparison of growth-environment relationships for wheat, barley and rye - Figs. 3 and 4 show the comparative growth rates of these crops in greenhouse and field conditions. Obviously differences in response among these cereals are very small.

Growth rate prediction models were developed for the greenhouse data on wheat, barley and rye by the step-down multiple regression procedure. This procedure begins with all of the independent variables and sequentially removes variables that are below a predetermined level of significance after each step. The daily growth rate (see Fig. 3) was used as the dependent variable and the following basic independent variables were used: maximum temperature (TX), minimum temperature (TN), Langleys (LN), relative humidity hours above 30% (RH), soil temperature at 8:00 a.m. (ST), degree hours above 15.6° C. (60° F.) (DH). The data for each basic variable for each of the two preceding days were also used as independent variables (i.e. lagged variables). The basic and lagged variables were used as additional independent variables in the form of the following transformations: square and cube; and cross products of all basic and lagged variables that were relatively more prominent in preliminary analyses using only untransformed, squared, and cubed variables. Cumulative growth (CUM) was used as an independent variable in the total of 133 variables.

Tables 1, 2, and 3 show the statistics for the final steps of these analyses. These three analyses are similar in that they contain the same number of independent variables, similar F and R^2 values, and are based on the same number of degrees of freedom. They are dissimilar with respect to the nature of the independent variables. However, since many of these variables closely resemble each other (e.g. LN12 and LN13) this is not conclusive evidence that these combinations represent significant differences in the response of these crops to the environment.

Growth rate prediction models were developed for Clemson field data of 1971-72 for wheat, barley and rye by the step-down multiple regression procedure. The daily growth rate was used as the dependent variable (see Fig. 4) and the same independent variables as for the greenhouse study except soil temperature. Lagged and transformed variables were also used as in the greenhouse study.

Tables 4, 5, and 6 show the statistics for the final steps of these analyses. An evaluation of these results with tests of prediction equations on the other two crops are presented in Figs. 8, 9, and 10. Figures 5, 6, and 7 show the observed and predicted growth rates for the equations in Tables 4, 5, and 6. These data are also presented in the form of dot diagrams in the upper left portion of Fig. 8, upper right portion of Fig. 9, and lower left portion of Fig. 10 with the correlation coefficients shown for the relationship of predicted to observed, and the regression line for predicted on observed. The remaining portions of Figs. 8, 9, and 10 show results of the equation applied to the other two crops. In each Fig. it may be noted that the coefficient is lower when the equation for one crop is applied to another, e.g. in Fig. 8, r = .926 for wheat on wheat, .863 for wheat on barley and .650 for wheat on rye. It may be concluded from this study that the responses of these three crops to environmental factors are quite similar. Although the equations involve different variables they are not necessarily unique for each crop. Additional testing would be necessary to confirm significance of the particular combinations. In the event it becomes possible to differentiate acreage of these three crops by remote sensing it will be desirable to perfect appropriate equations for each crop.

B. Evaluation of plant observation techniques - This study was made on spring wheat grown at Clemson to further evaluate the established procedure for daily plant observations. The usual procedure has been to observe the growth stage (number of leaves and fraction of the emerging leaf) on a single culm (stalk), the first to develop, on each of 10 or more individual plants. The average of the 10 culms is then used as the stage of development. Since each plant later produces many tillers (branches) that also become culms quite similar to the original one, but with fewer nodes, the adequacy of a single culm observation per plant was questioned, i.e. does the growth stage of a single culm sufficiently represent the growth stage of an entire plant with 5 to 10 tillers? In order to answer this question, all of the tillers on 10 plants were observed daily for 25 days. Growth rates calculated from the 10 main culm observations (one culm per plant) were compared with growth rates involving the tillers combined with main culms. A graph of these calculations is presented as Fig. 11. In general, the two methods compare favorably. The number of tillers is indicated in the lower line of this graph. This number varied since some of the tillers died and later others developed. Since the growth rates for the two methods are not completely identical another study is currently under way on winter wheat. It is possible that the sample size for the main culm method was not large enough in the study on spring wheat. All of the growth observations from field locations in North Dakota and Kansas (1974) are now based on the main culms of 25 plants per location. Based on previous experience this should provide excellent indices of plant development.

C. Development of model for predicting the date on which 50% of the spring wheat crop is planted - Eight years of ASCS-USDA weekly crop status reports were checked for data on percentage of acreage planted in each division. These data were regressed on days of the year in order to place regression lines and then select an estimated time of 50% planting for each division. An example of this procedure is included as Fig. 12. The regression line was based on the five reports indicated by the plotted points. The estimated time of 50% planted is shown by the circled point on the line corresponding to April 27 (day 117 of the year). These estimated dates (for 9 divisions for 7 years, leaving one year for a test) were then regressed on 49 variables by the step-down procedure. Data for 1973 was omitted for use in testing the later model. 1974 data were used in the analysis since the year was very atypical and therefore broadened the scope of data for the analysis.

The following basic independent variables were used: running three, six, and nine day sums of average minimum and maximum temperature values (C°) (N3S, N6S, N9S, X3S, X6S, X9S), estimated soil moisture (E0 in %), preseason precipitation (PP in cm), and location (LOC). The basic variables were used as additional independent variables in the form of the following transformations: square and cube; and cross products of all basic variables. Table 7 shows the statistics for the final step of the analysis, with Fig. 13 showing the relationship of the predicted values to the actual values.

The prediction equation (Predicted planting date = 136.7 + 0.0055(E0 X N9S) - etc.) was tested on daily data not used in the analysis for 1973. An example of the predicted values for one division (represented by dots) is presented in Fig. 14. The curved line is the line of best fit (considering only 1st and 2nd order equations) through the points. The straight line (45°) passes through points where actual and predicted values are equal. The objective of the procedure is to find the date where the value predicted by the equation is equal to the actual Julian date. Thus, the point where the regression line crosses the 45° line is chosen as the predicted planting date. For the Northwest division of North Dakota, the actual date was missed by 8 days using this method. Results for all divisions are as follows:

Division	Predicted Julian Date	Actual Julian Date
Northwest	123	131
North Central	138	133
Northeast	124	127
West Central	116	124
Central	138	118
East Central	124	111
Southwest	126	126
South Central	100	116
Southeast	126	112
Avg.	124	122

The accuracy of this model is considered satisfactory for the purpose of finding the historic dates (i.e. years when no USDA reports were available) on which to initiate our yield prediction model. The model was used to obtain divisional dates of planting for the years 1965 and 1966. The predicted divisional average Julian day of 50% planted was 143 (May 23) for 1965 and 119 (April 2[illegible]) [illegible] 1966. These values compare with 133 for 1965 and 125 for 1966 as calculated from the recent USDA report, N. D. Wheat Historic Estimates 1955-1970, Ag. Statistics No. 33. The values for 1965 and 1966 were added to the values for 1967-72 to obtain 72 divisional planting dates on which to begin calculations for the weekly growth indices represented by box 17 in Fig. 1. 1973 and 1974 data were omitted since the tapes obtained from Asheville do not contain daily weather data for these years.

D. Development of growth-rate prediction models for spring wheat - Models have been developed for spring wheat for weekly periods of the 1974 season (box 16 of Fig. 1). These were developed from analysis of 1974 data from Dickinson, Williston (2 locations), Minot, North Dakota and Clemson, South Carolina. Since observations were not begun on the exact date of emergence at each location, it was necessary to establish a stage of development in common for all locations on which to base the subsequent weekly increments of data for analysis. The stage 2.4 was used as the point in common to represent the end of the first week of development. Successive 7-day increments were used for the subsequent weekly analyses. Each analysis combines the current week's data with all previous weeks. Growth rates were regressed on the following independent variables: maximum air temperature (C°), minimum air temperature (C°), precipitation (cm), estimated soil moisture (100% by Thornthwaite method), solar radiation (Langleys); at 0, 1, 2, and 3 day lag periods; squared, cubed; and 45 selected cross products of the basic lagged variables; for a total of 93, by the step-up multiple regression procedure. This procedure selects the most highly correlated individual independent variable in the first step, and in successive steps variables are added or removed to maintain significance at a designated level (considering all possible combinations). Due to the fact that errors have been detected in the processing of this data, as well as in the initial stages of the analyses, all models previously reported must be corrected. Analyses are currently being repeated with the necessary changes.

E. Development of model for predicting the date when spring wheat emerges in North Dakota - Values representing initial emergence dates were obtained by reading the SRS-USDA Crop Status Reports, 1967-74, for North Dakota. When possible, values were obtained for each county within a division (some counties never made mention of emergence). These values were then averaged within each division to obtain the day of initial emergence. The exactness of these values, however, cannot be determined since the terminology used by the reporting agents varied greatly and interpretation of these reports is quite subjective. Statistics for this model are presented in Table 8, with Fig. 15 showing the relationship of the predicted values to the actual values. The model was based on data for 1967-72, 74, leaving 1973 as the test year. An example of the predicted values for one division (represented by dots) is presented in Fig. 16. The curved line is the line of best fit (considering only 1st and 2nd order equations) through the points. The straight line (45°) passes through points where actual and predicted values are equal. The objective of the procedure is to find the date where the value predicted by the equation is equal to the actual Julian date as in the case of the 50% planting date model. Thus, the point where the regression line crosses the 45° line is chosen as the predicted emergence date. The test yielded the following divisional results:

Division	Predicted Julian Date	Actual Julian Date
Northwest	153	137
North Central	160	140
Northeast	146	130

West Central	142	130
Central	152	119
East Central	144	133
Southwest	140	128
South Central	140	126
Southeast	141	130
Avg.	146	130

Since all of the predictions were too high (average 16 days) it is probable that some standard adjustment will have to be applied if sufficient basis can be obtained. The accuracy of this model will be further considered.

Table 1. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of Blueboy II wheat in Clemson greenhouse, January-April 1974.

Source	df	MS	F	Prob.> F	R^2
Regression	7	0.003846	6.097	0.0002	0.523
Error	39	0.000631			
Corrected total	46				

	Partial Regression Coefficients	Student's t for H0: B=0	Probability > |t|
Intercept	0.15037445	7.01	0.0001
TX2LN1	0.00001765	4.61	0.0001
LN12	-0.00000193	4.95	0.0001
RH32 / 1000	-0.00001435	2.42	0.0203
LN02 / 1000	0.00040631	2.40	0.0215
TX2ST2	-0.00015439	2.50	0.0169
DH2	0.00057213	1.94	0.0601
DH2TN1	-0.00002263	1.67	0.1034

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared(2) or cubed(3). Two variables combined indicates a cross product.

Table 2. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of Keowee barley in Clemson greenhouse, January-April 1974.

Source	df	MS	F	Prob. > F	R^2
Regression	7	0.004246	7.094	0.0001	0.560
Error	39	0.000599			
Corrected total	46				

	Partial Regression Coefficients	Student's t for H0: B=0	Probability > |t|
Intercept	0.01598093	0.48	0.6326
RH1	0.00005502	2.79	0.0080
ST13 / 1000	0.03579227	5.64	0.0001
ST1TN2	-0.00061063	4.21	0.0001
LN13 / 1000	-0.00000378	4.18	0.0002
LN1	0.00234788	3.91	0.0004
CUMBA	0.00490153	3.15	0.0031
ST1LN1	-0.00012143	3.12	0.0034

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared (2) or cubed (3). Two variables combined indicates a cross product.

Table 3. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of McNair Vita-Graze Rye in Clemson greenhouse, January-April 1974.

Source	df	MS	F	Prob.> F	R^2
Regression	7	0.005707	7.42	0.0001	0.571
Error	39	0.000769			
Corrected total	46				

	Partial Regression Coefficients	Student's t for H0:B=0	Probability > |t|
Intercept	0.14169892	6.53	0.0001
ST03/ 1000	-0.01763732	-2.88	0.0065
CUMRY	0.00714499	4.65	0.0001
DH3	-0.00025372	-2.07	0.0451
TN23/ 1000	-0.00960439	-2.82	0.0075
LN12	-0.00000153	-4.70	0.0001
TX3LN1	0.00001761	4.72	0.0001
TX3RH1	0.00000148	2.88	0.0064

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared (2) or cubed (3). Two variables combined indicates a cross product.

Table 4. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of Blueboy wheat in Clemson field, November 1971-March 1972.

Source	df	MS	F	Prob.> F	R^2
Regression	8	0.05875	96.468	0.0001	0.859
Error	127	0.00061			
Corrected total	135				

	Partial Regression Coefficients	Student's t for H0: B=0	Probability > |t|
Intercept	0.05516383	1.48	0.1403
TX12	0.00020298	11.05	0.0001
TN02	0.00015460	3.28	0.0013
TN22	-0.00009994	-1.83	0.0696
ESM22	-0.00000442	-1.22	0.2254
DH23/1000	-0.00000292	-3.45	0.0008
DH13/1000	0.00000146	1.82	0.0710
TN0RH3	0.00000129	2.95	0.0037
DH2RH3	0.00000016	2.82	0.0056

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared (2) or cubed (3). Two variables combined indicate a cross product.

Table 5. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of Keowee barley in Clemson field, November 1971-March 1972.

Source	df	MS	F	Prob.> F	R^2
Regression	7	0.05009	44.9982	0.0001	0.854
Error	54				
Corrected total	61				

	Partial Regression Coefficients	Student's t for H0: B=0	Probability > |t|
Intercept	-0.01871615	-1.31	0.1956
RH1TX1	0.00000381	4.35	0.0001
RH1TN0	0.00000170	1.79	0.0784
RH1DH1	-0.00000113	-3.20	0.0023
LN1ESM1	-0.00007089	-3.76	0.0004
LN1ESM0	0.00007193	3.80	0.0004
TX1DH1	0.00007634	3.62	0.0006
TN0DH1	0.00005901	3.16	0.0026

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared (2) or cubed (3). Two variables combined indicate a cross product.

Table 6. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable growth rate of Wren's Abruzzi rye in Clemson field, November 1971-March 1972.

Source	df	MS	F	Prob.> F	R^2
Regression	8	0.05946	40.703	0.0001	0.723
Error	125	0.00146			
Corrected total	133				

	Partial Regression Coefficients	Student's t for H0: B = 0	Probability > |t|
Intercept	-0.00164599	-0.17	0.8678
TX1	0.00314308	3.26	0.0015
LN1	0.00006702	2.28	0.0241
TN32	-0.00010073	-2.10	0.0377
DH03/1000	-0.00000802	-6.40	0.0001
LN03/1000	-0.00056888	-3.12	0.0023
TN0TX1	0.00032625	5.30	0.0001
DH0TX2	0.00001083	1.68	0.0945
LN0TX2	0.00000789	3.02	0.0030

The first number following each basic variable indicates the lag period. The second number indicates that the variable is squared (2) or cubed (3). Two variables combined indicate a cross product.

Table 7. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable, day of 50% planted in North Dakota, 1967-72, 1974.

Source	df	MS	F	Prob>F	R^2
Regression	4	1918.5994	59.7372	0.0001	0.8129
Error	55	32.1173			
Corrected total	59				

	Partial regression coefficients	Student's t for H0:B = 0	Prob.>|t|
Intercept	136.6887	54.99	0.0001
Product of E0 and N9S	0.0055	12.84	0.0001
Product of LOC and X9S	-0.1177	-7.54	0.0001
Product of LOC and X3S	0.2777	6.24	0.0001
Product of PP and X3S	-0.0138	-4.71	0.0001

N9S - Running nine day sum of average minimum temperature values (C°)
X3S - Running three day sum of average maximum temperature values (C°)
X9S - Running nine day sum of average maximum temperature values (C°)
LOC - Location (north, central, south)
PP - Preseason precipitation
E0 - Estimated soil moisture

Table 8. Analysis of variance, regression coefficients, and statistics of fit for the dependent variable, day of emergence in North Dakota, 1967-72, 1974.

Source	df	MS	F	Prob. > F	R^2
Regression	8	749.19227	37.495	0.0001	0.852
Error	52	19.98114			
Corrected total	60				

	Partial regression coefficients	Student's t for H0:B = 0	Prob > $\|t\|$
Intercept	-1.026×10^{2}	-1.435	0.1573
E0	9.257×10^{0}	3.063	0.0035
E0 squared	-1.044×10^{-1}	-2.516	0.0150
E0 cubed	3.582×10^{-4}	1.928	0.0593
N9S	3.208×10^{-1}	7.777	0.0001
PP squared	8.364×10^{-2}	6.313	0.0001
Product of PP and N3S	3.584×10^{-2}	4.507	0.0001
Product of PP and X9S	-1.564×10^{-2}	-7.121	0.0001
Product of LOC and N3S	-2.281×10^{-1}	-5.496	0.0001

E0 - Estimated soil moisture
PP - Preseason precipitation
LOC - Location (north, central, south)
N3S - Running three day sum of average minimum temperature values (C°)
N9S - Running nine day sum of average minimum temperature values (C°)
X9S - Running nine day sum of average maximum temperature values (C°)

Fig. 1. Programming and Analysis Phases - North Dakota Data
Boxes enclosed by heavy lines indicate original or source data.

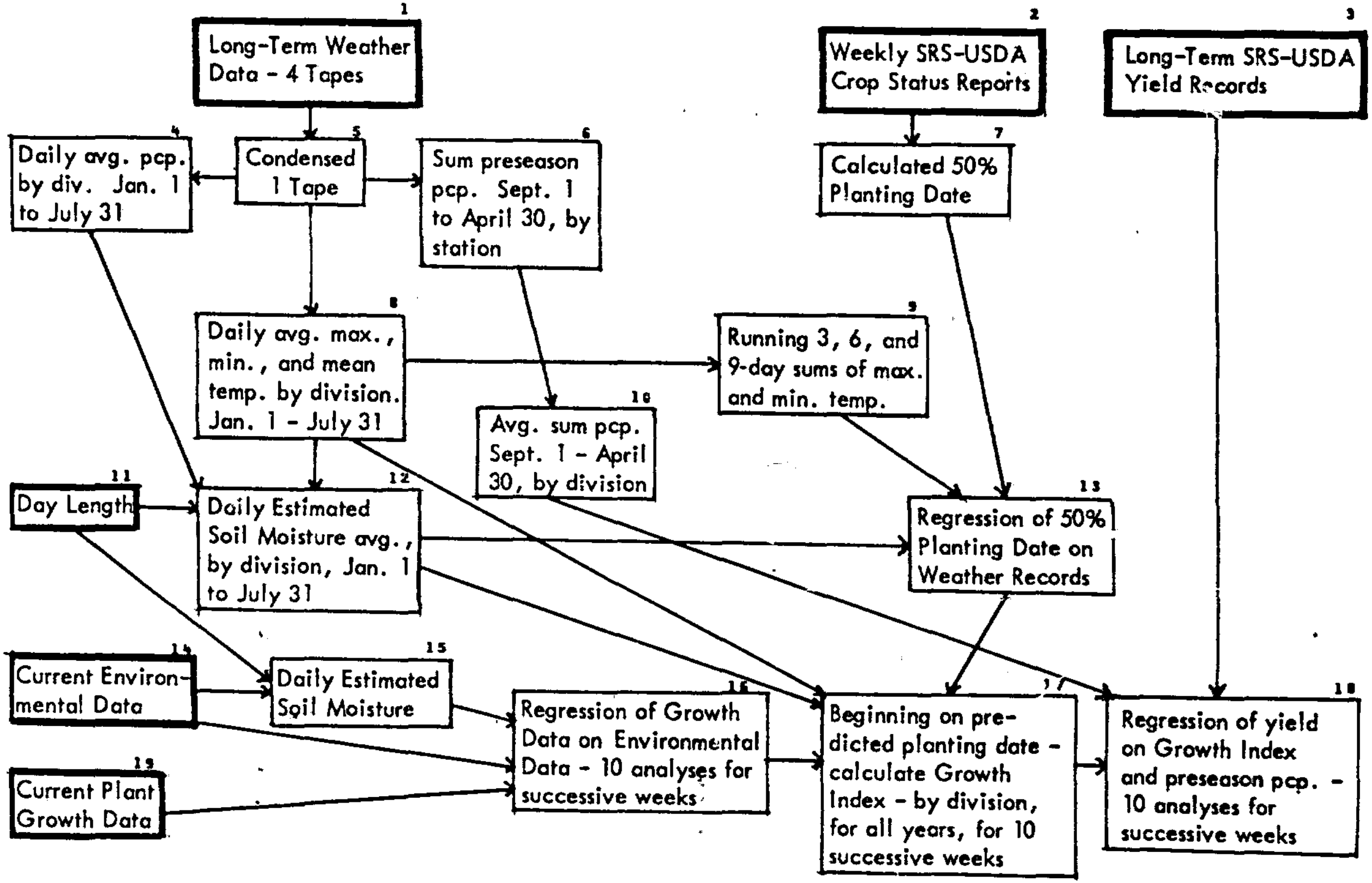
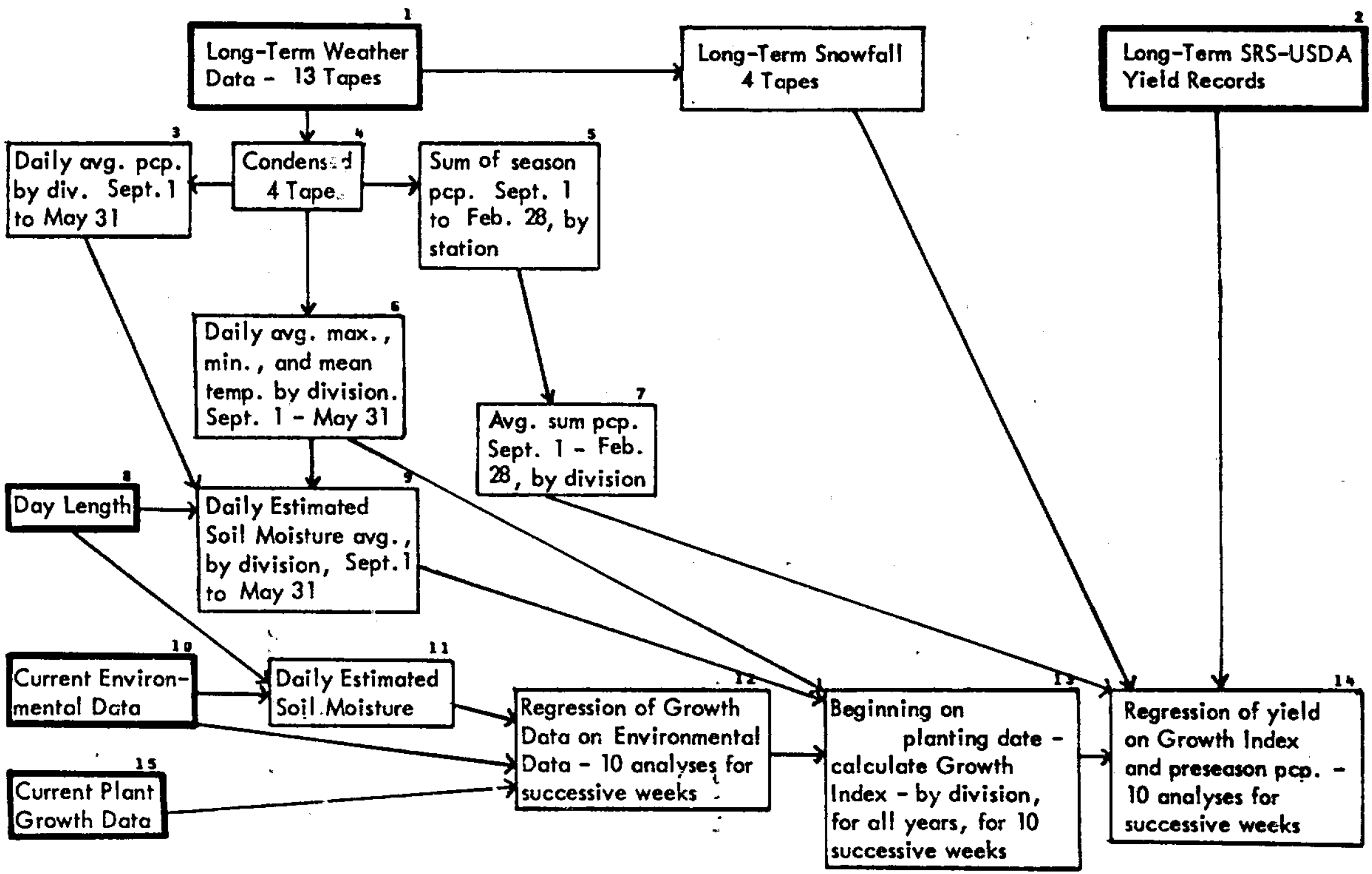


Fig. 2. Programming and Analysis Phases - Kansas Data
Boxes enclosed by heavy lines indicate original or source data.



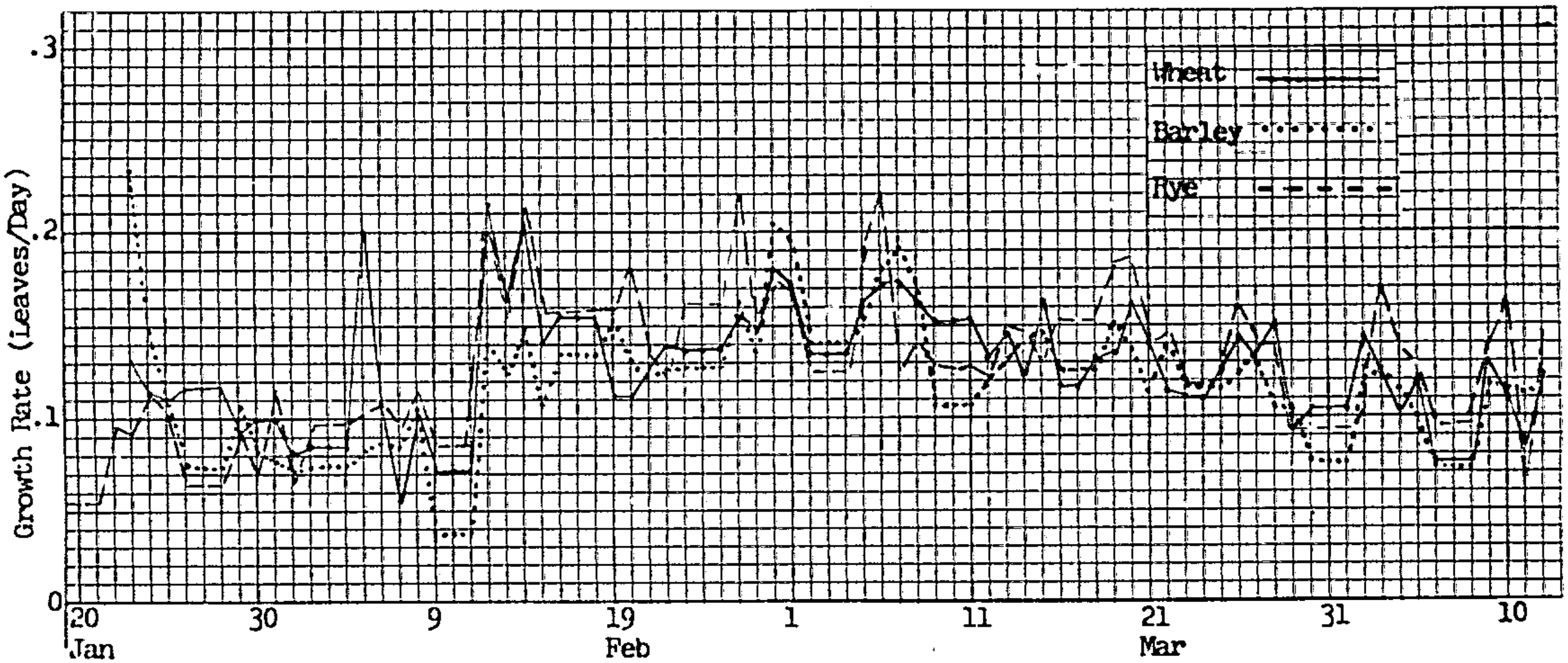


Fig. 3. Growth Rate of Wheat, Barley and Rye in Greenhouse, Clemson, S. C. 1974

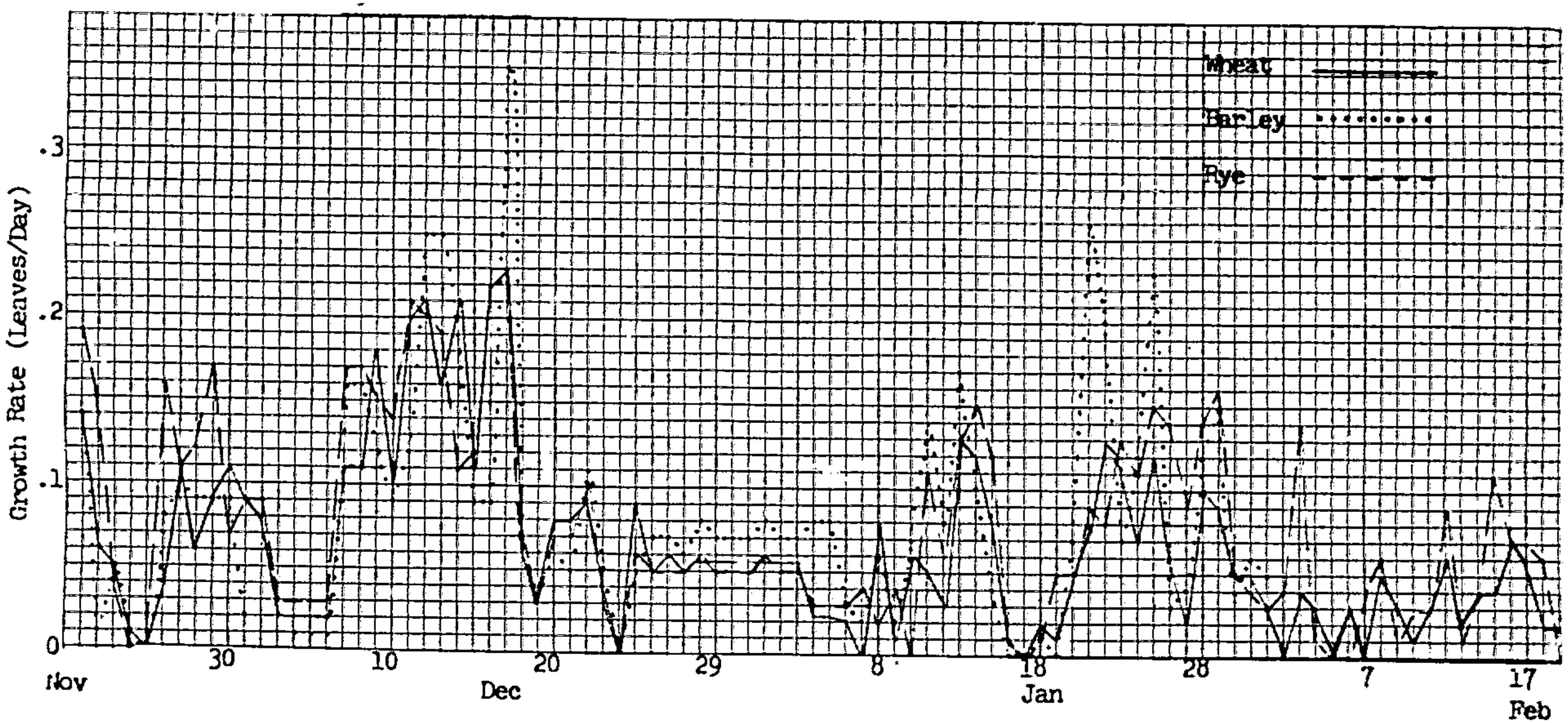


Fig. 4. Growth Rate of Wheat, Barley and Rye
in Field, Clemson, S. C. 1971-72

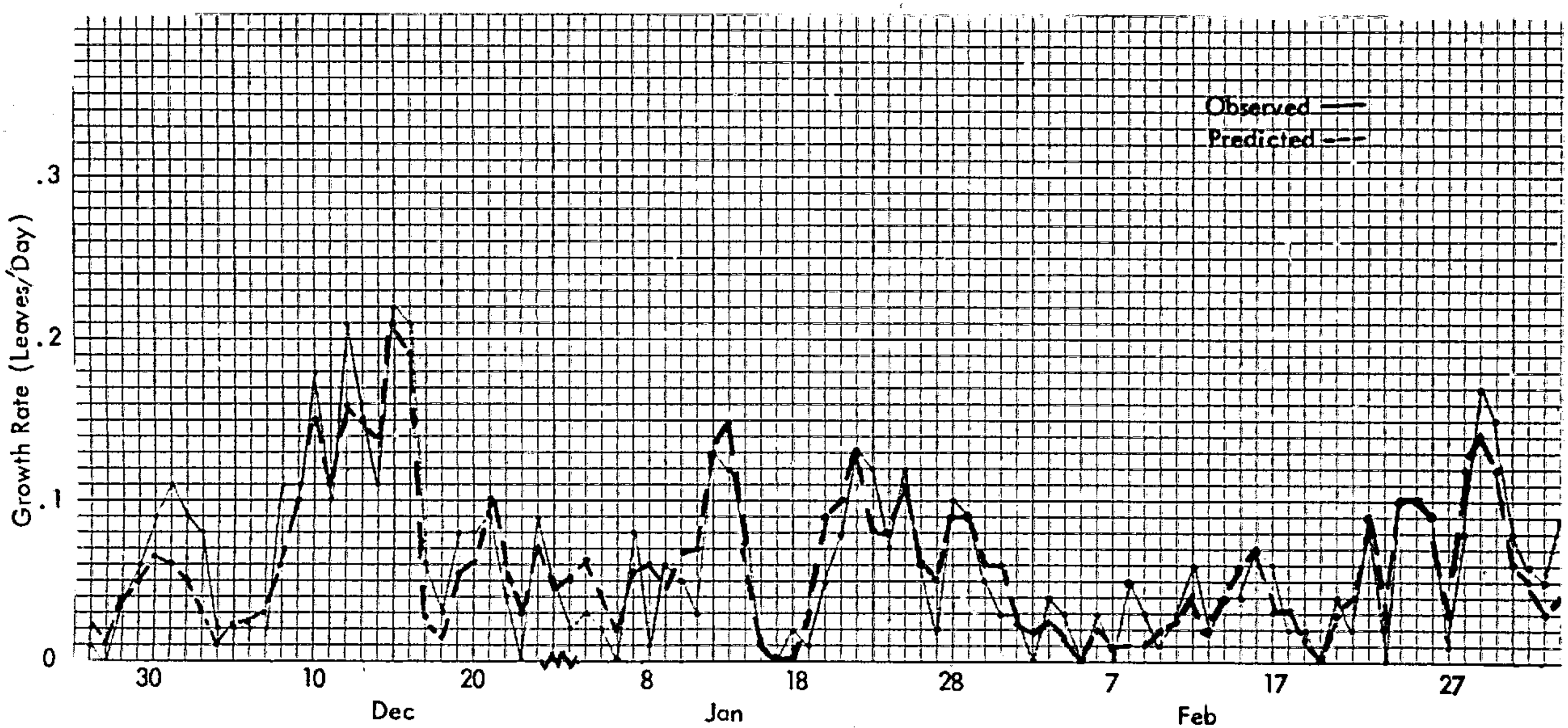


Fig. 5. Observed and predicted growth rate of wheat in field, Clemson, S. C. 1971-72.

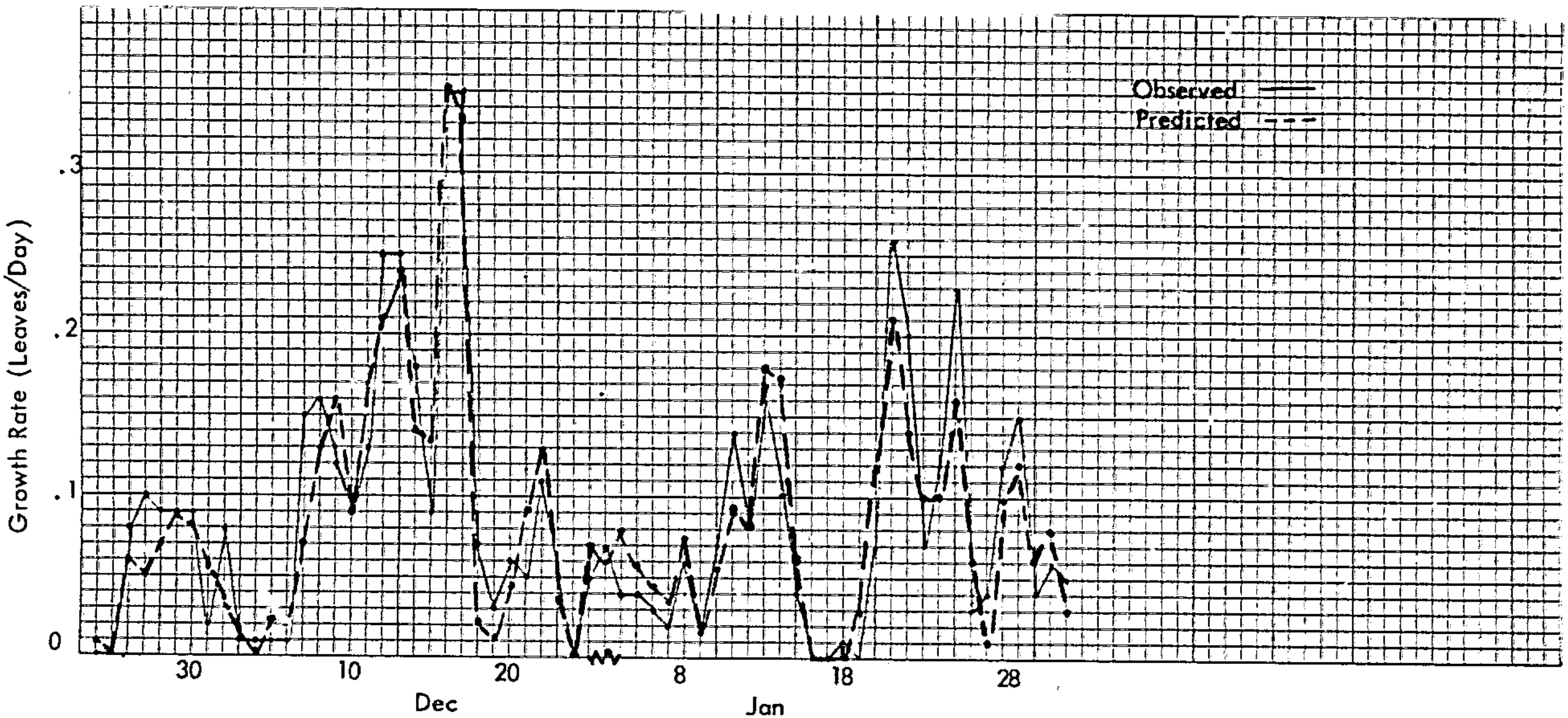


Fig. 6. Observed and predicted growth rate of barley in field, Clemson, S. C. 1971-72.

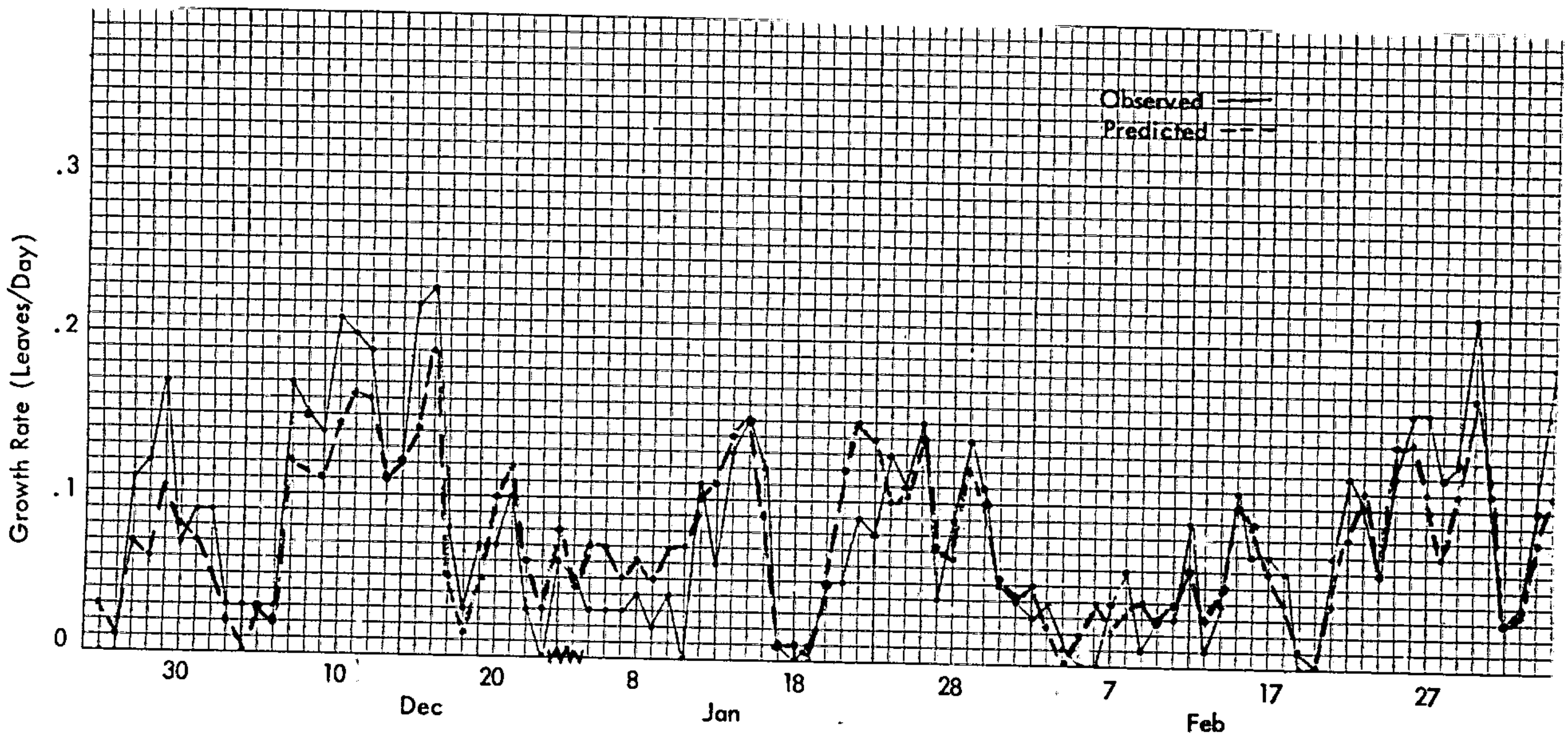


Fig. 7. Observed and predicted growth rate of rye in field, Clemson, S. C. 1971-72.

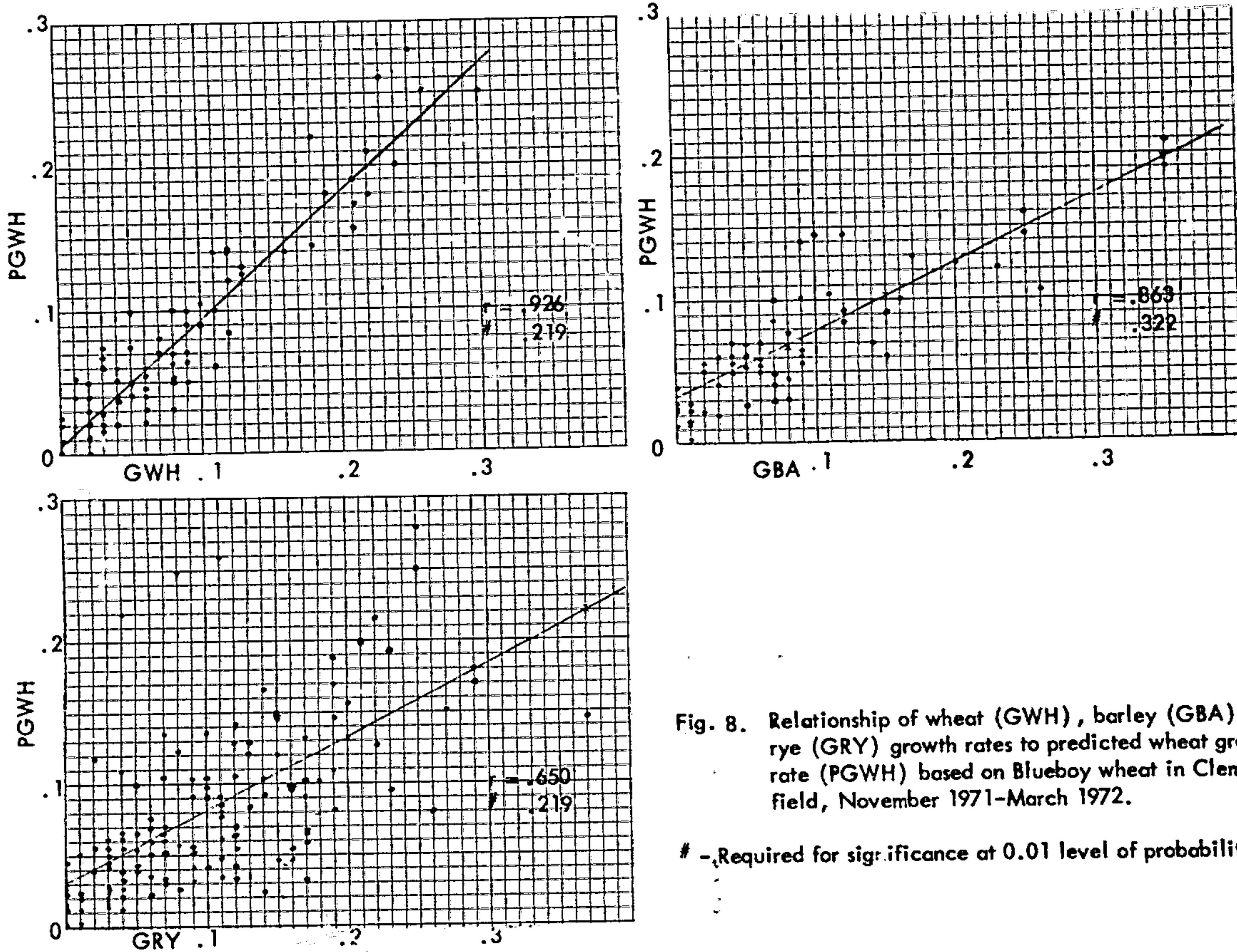


Fig. 8. Relationship of wheat (GWH), barley (GBA), and rye (GRY) growth rates to predicted wheat growth rate (PGWH) based on Blueboy wheat in Clemson field, November 1971–March 1972.

– Required for significance at 0.01 level of probability

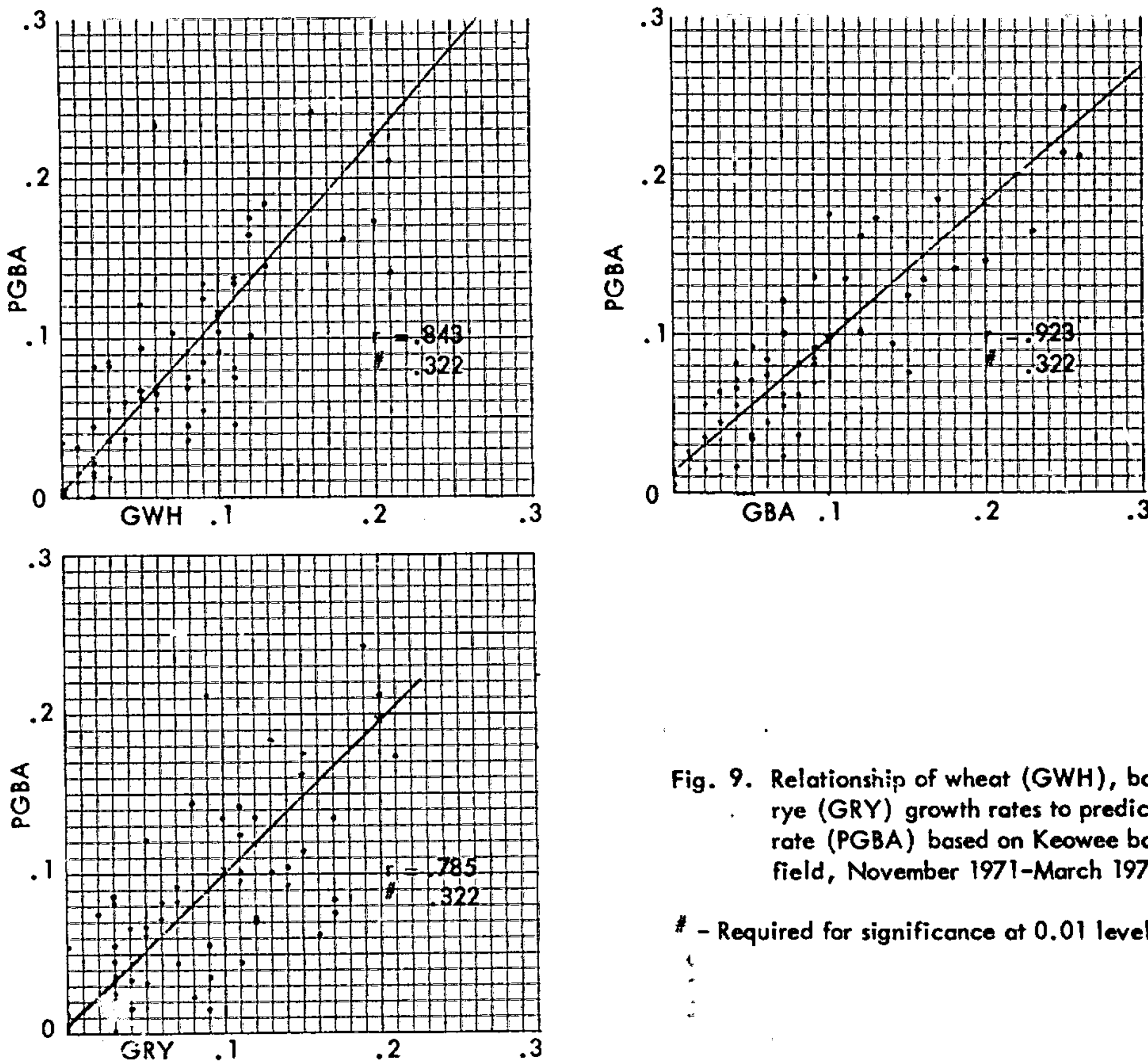


Fig. 9. Relationship of wheat (GWH), barley (GBA), and rye (GRY) growth rates to predicted barley growth rate (PGBA) based on Keowee barley in Clemson field, November 1971–March 1972.

– Required for significance at 0.01 level of probability

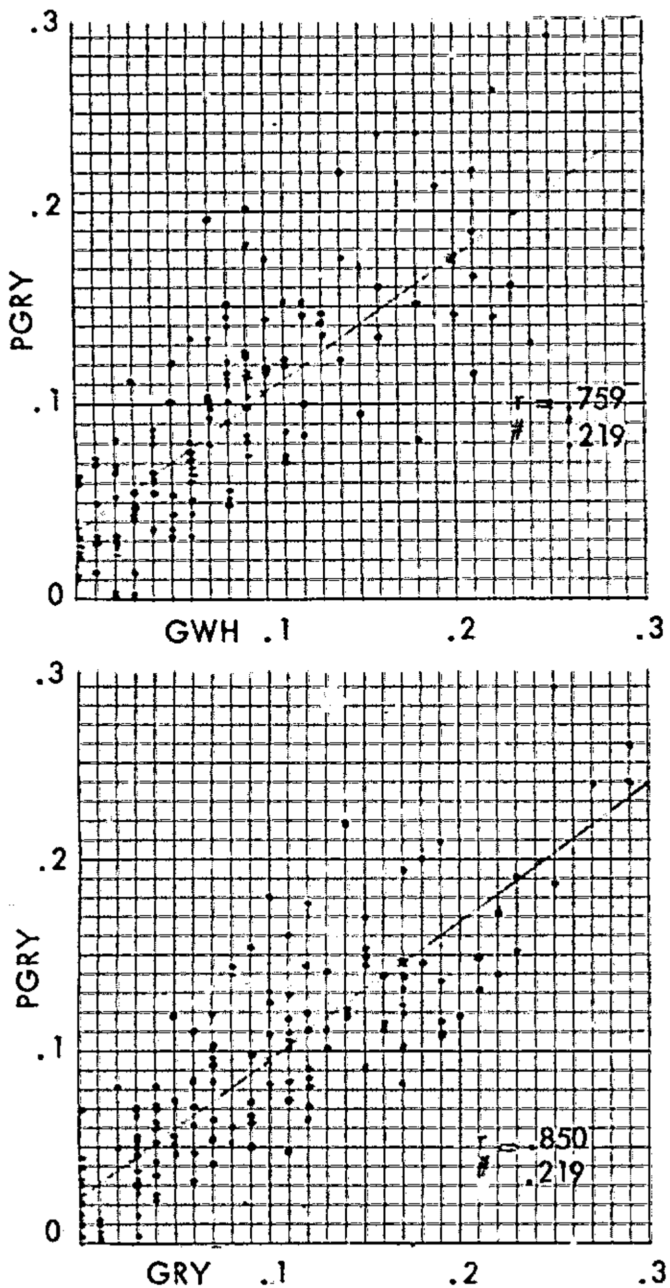


Fig. 10. Relationship of wheat (GWH), barley (GBA), and rye (GRY) growth rates to predicted rye growth rate (PGRY) based on Wren's Abruzzi rye in Clemson field, November 1971–March 1972.

– Required for significance at 0.01 level of probability

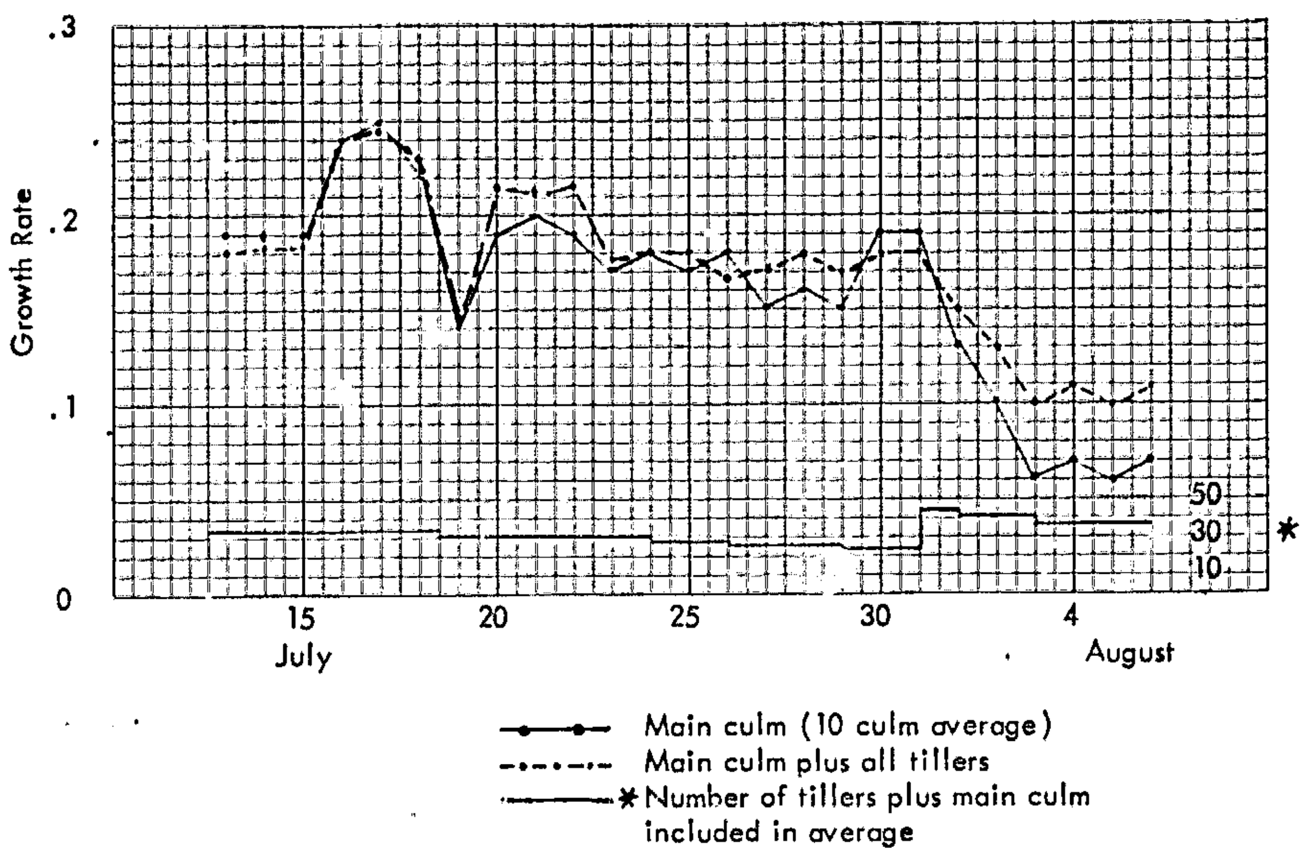


Fig. 11. Comparison of main culm growth rate (average of 10 plants) with main culm and all tillers combined.

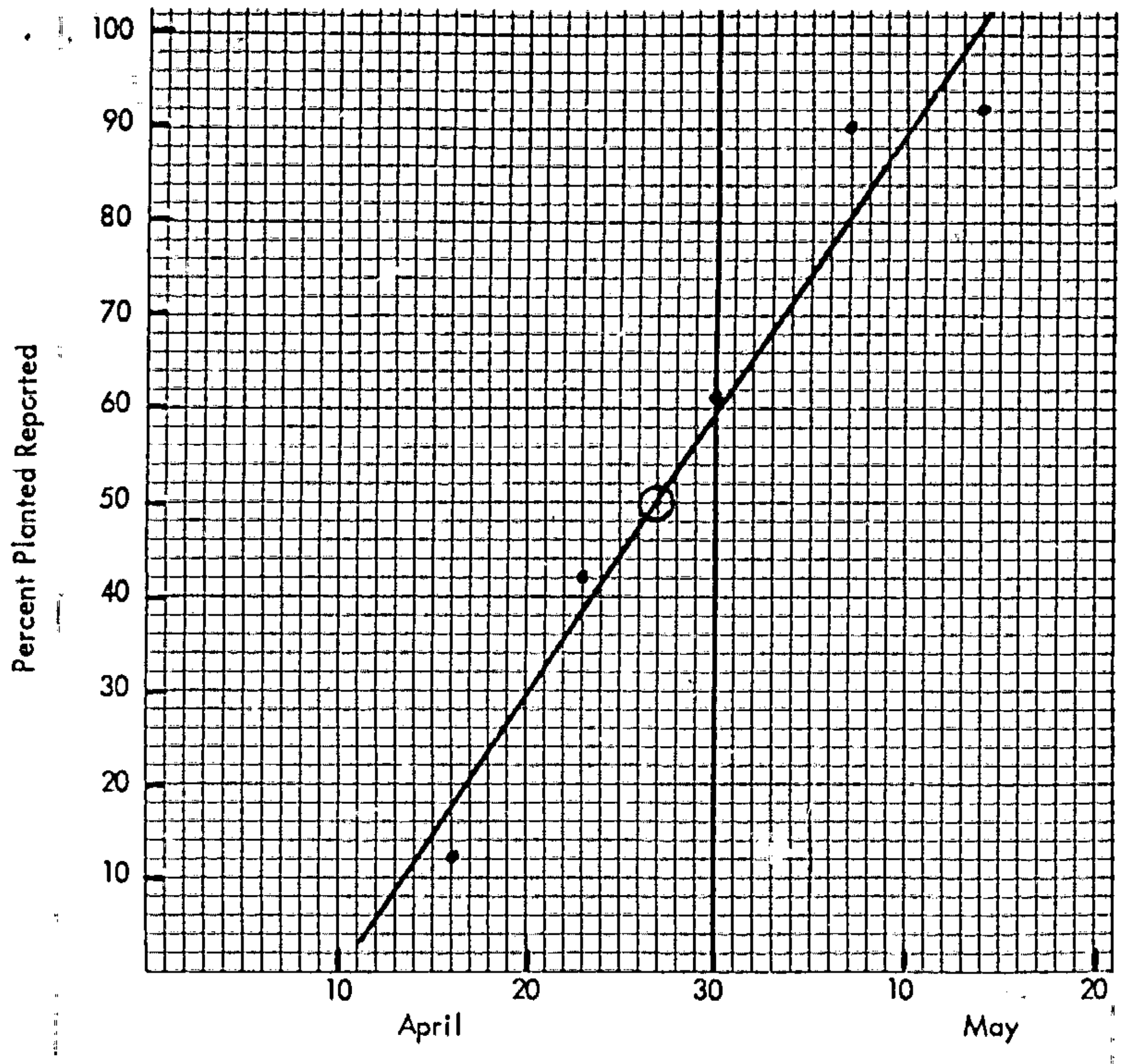


Fig. 12. SRS-USDA Reports on Percentage of Acreage Planted in the East Central Division of North Dakota in 1968.

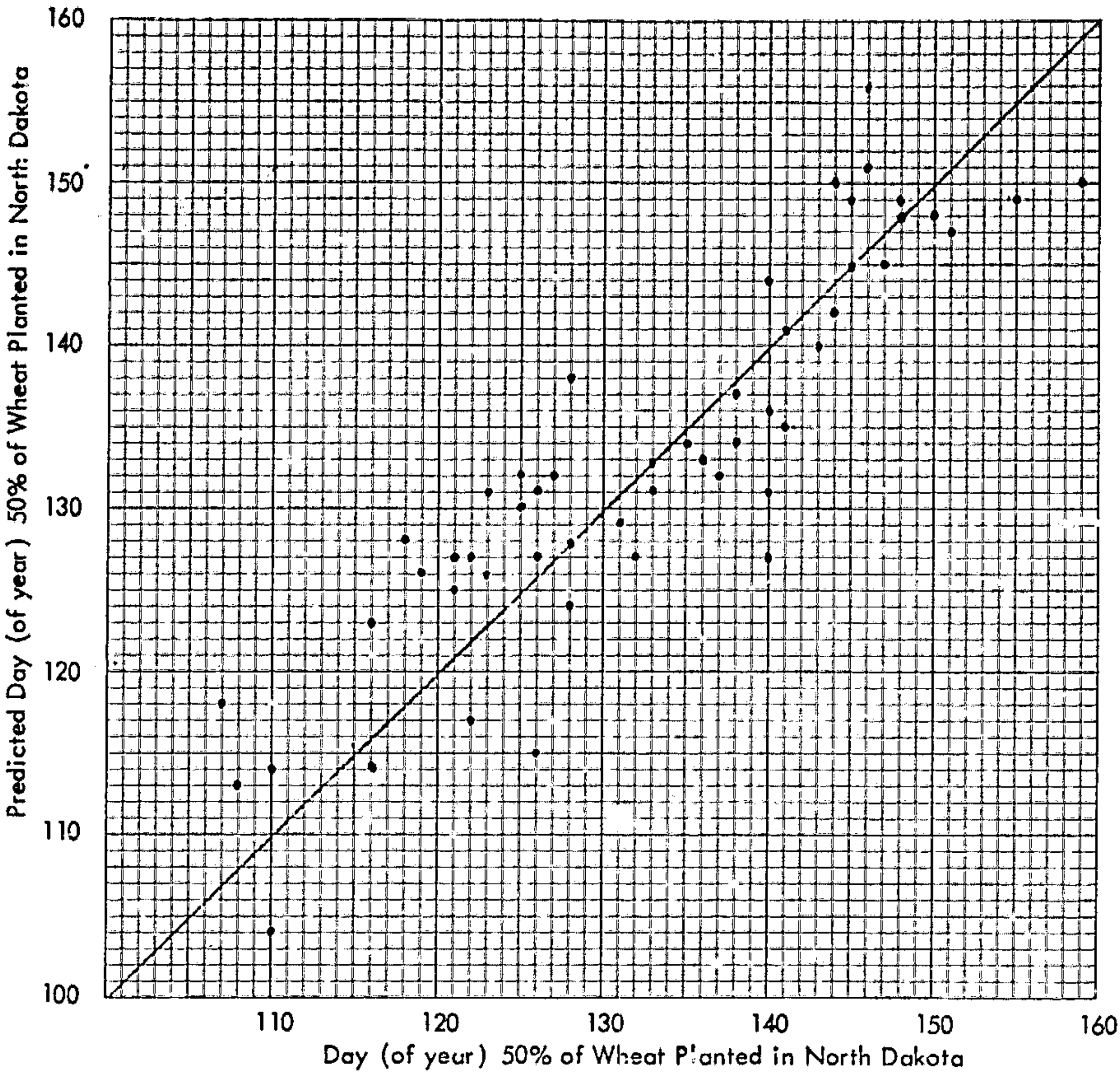


Fig. 13. Relationship of predicted date on which 50% of wheat was planted to actual date for the period 1967-72, 1974, based on equation from Table 7.

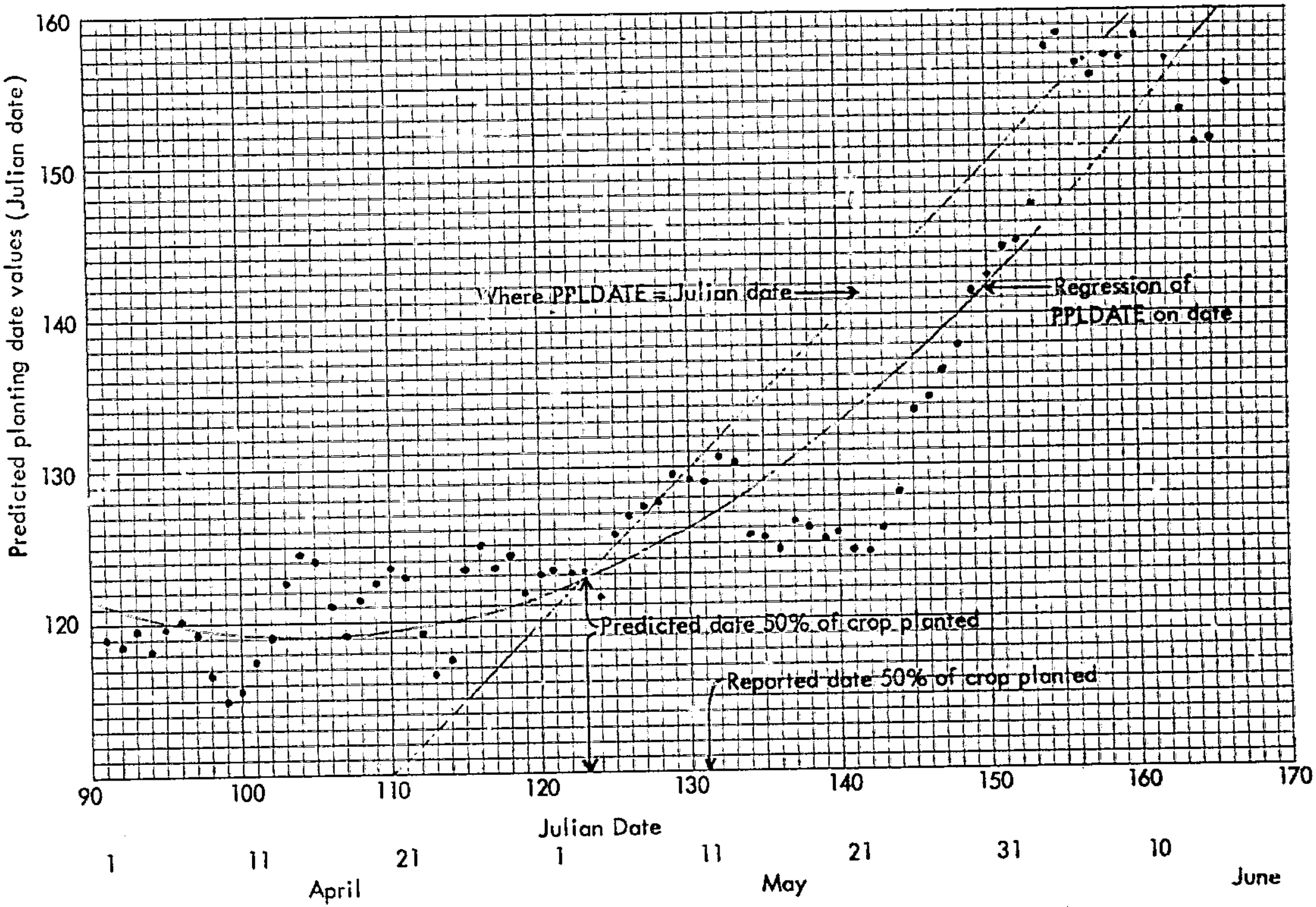


Fig. 14. Predicted planting date (PPLDATE) model applied to all dates from April 1, to June 15 in 1973 for the Northwest Division of North Dakota.

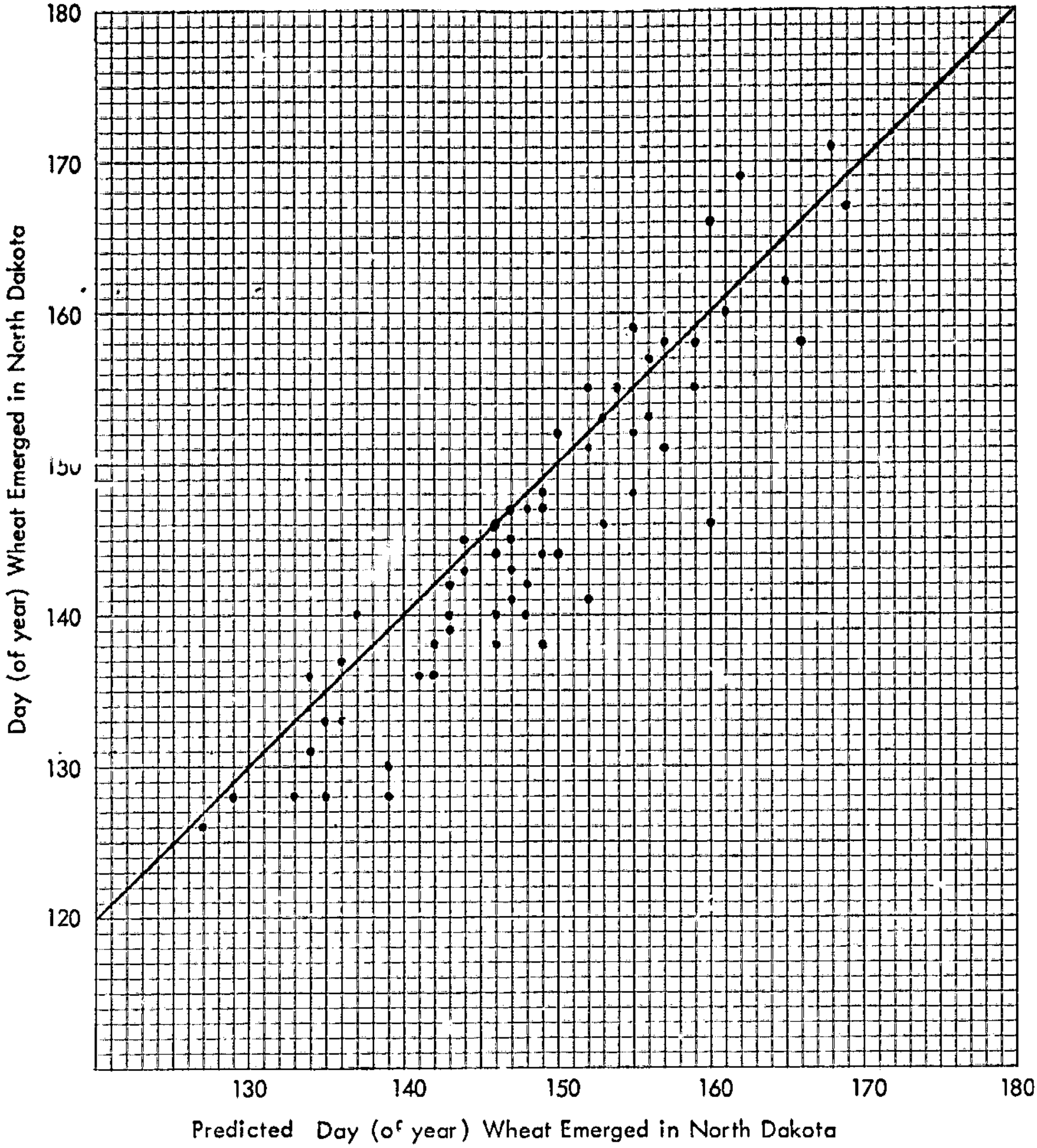


Fig. 15. Relationship of predicted date on which wheat emerged to actual date for the period 1967-72, 1974, based on equation from Table 8.

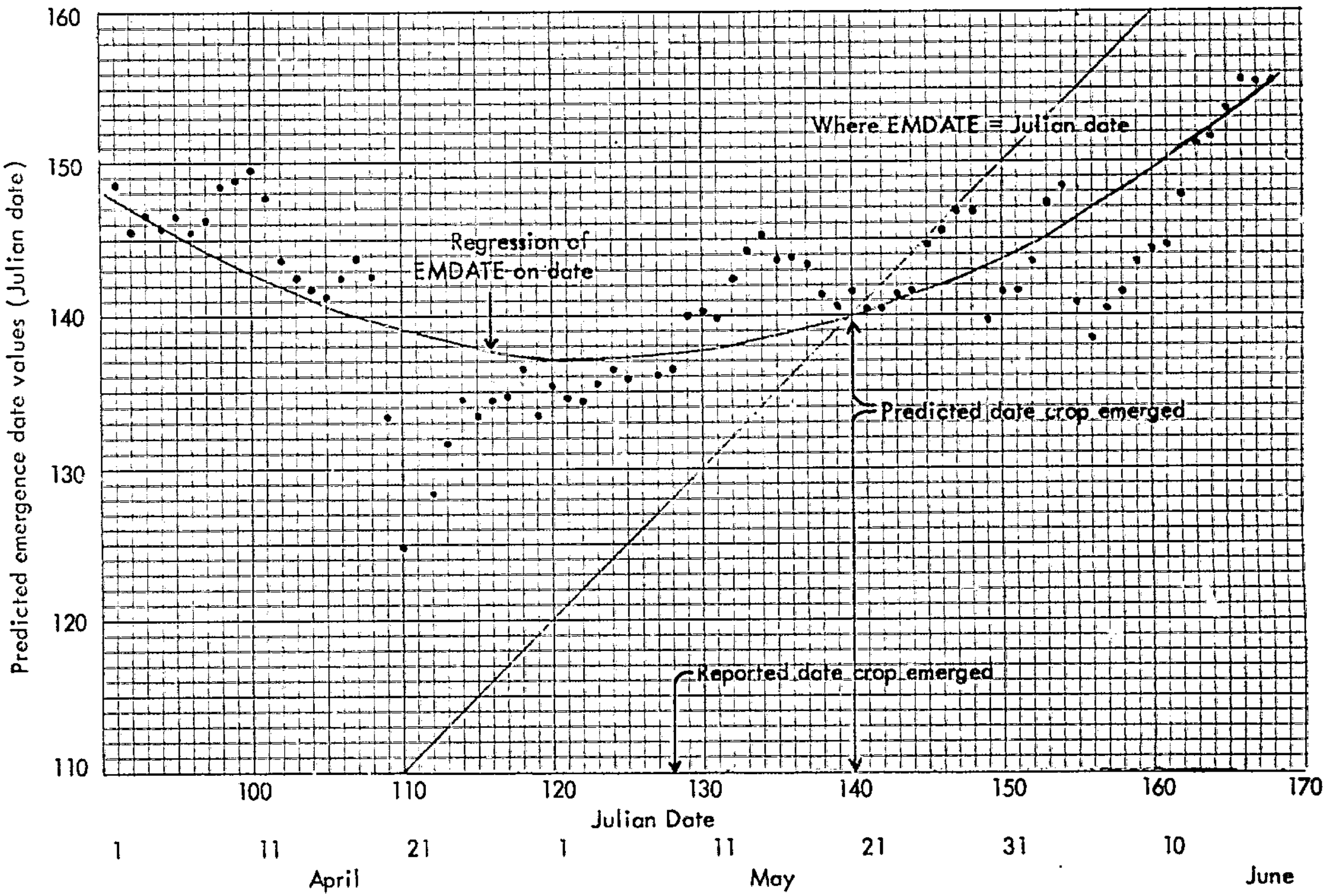


Fig. 16. Predicted emergence date (EMDATE) model applied to all dates from April 1, to June 15 in 1973 for the Southwest Division of North Dakota.

Abbreviations used in Appendix Tables

GR0 - Daily growth rate

CUM - Cumulative growth rate

FTX0 - Maximum temperature (°F)

FTN0 - Minimum temperature (°F)

L0 - Langleys

P0 - Precipitation (inches)

E0 - Estimated soil moisture

Appendix Table 1. Spring wheat growth rate and environmental factors at Williston, North Dakota, 1974 (ASCS field)

GRD	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
	1.56	64	45	260	.07	93.5	05 28 74	WDAHLND
.1880	1.75	65	37	351	.02	92.0	05-29-74	WDAHLND
.1920	1.94	65	46	403	.00	89.5	05-30 74	WDAHLND
.2110	2.15	65	46	286	.00	87.1	05 31 74	WDAHLND
.1920	2.35	70	41	481	.00	84.7	06 01 74	WDAHLND
.2650	2.61	81	46	494	.00	81.6	06 02-74	WDAHLND
.2490	2.86	83	50	520	.00	78.2	06 03 74	WDAHLND
.2440	3.11	75	48	325	.04	76.5	06 04-74	WDAHLND
.1920	3.30	71	47	390	.00	74.0	06 05-74	WDAHLND
.1870	3.49	72	46	390	.09	73.9	06 06 74	WDAHLND
.2060	3.69	74	38	481	.00	71.9	06-07-74	WDAHLND
.2900	3.98	72	43	390	.54	83.2	06 08 74	WDAHLND
.1995	4.18	66	47	260	.98	100.0	06-09-74	WDAHLND
.1995	4.38	67	46	442	.04	98.1	06 10-74	WDAHLND
.1380	4.52	69	42	507	.00	95.4	06-11-74	WDAHLND
.2250	4.75	80	51	520	.05	92.8	06 12-74	WDAHLND
.2600	5.01	90	53	585	.00	88.3	06 13-74	WDAHLND
.2460	5.25	79	48	611	.00	85.0	06 14-74	WDAHLND
.2710	5.52	73	45	624	.00	82.3	06 15-74	WDAHLND
.1950	5.72	72	49	585	.00	79.4	06-16-74	WDAHLND
.1950	5.91	82	54	520	.00	76.0	06 17 74	WDAHLND
.2390	6.15	84	58	585	.00	72.4	06 18-74	WDAHLND
.1990	6.35	91	51	585	.00	68.9	06 19 74	WDAHLND
.2430	6.60	92	65	520	.00	65.0	06-20-74	WDAHLND
.1508	6.75	71	58	169	.14	65.9	06-21-74	WDAHLND

Appendix Table 1 cont.

GRO	CUM	FTXD	FTND	LO	PO	EO	DATE	PLACE
.1508	6.90	81	50	533	.00	63.3	06 22 74	WDAHLND
.1508	7.05	82	56	585	.00	60.4	06-23-74	WDAHLND
.1508	7.20	92	58	520	.00	57.2	06 24 74	WDAHLND
.1508	7.35	93	64	611	.00	54.0	06-25-74	WDAHLND
.219[illegible]	7.57	92	62	559	.00	51.0	06 26 74	WDAHLND
.2030	7.77	87	50	624	.00	48.7	06 27 74	WDAHLND
.1720	7.95	86	54	585	.00	46.5	06 28 74	WDAHLND
.2063	8.15	80	47	663	.00	44.7	06 29-74	WDAHLND
.2063	8.36	89	47	611	.00	42.8	06 30 74	WDAHLND
.2063	8.56	87	59	520	.00	40.7	07-01 74	WDAHLND
.3920	8.96	75	60	221	.00	38.9	07 02-74	WDAHLND
.4740	9.43	81	57	481	.00	37.2	07 03 74	WDAHLND
.3180	9.75	92	53	546	.00	35.4	07-04-74	WDAHLND
.3960	10.14	90	61	533	.00	33.5	07 05 74	WDAHLND
.2963	10.44	87	60	468	.05	33.1	07 06-74	WDAHLND
.2963	10.74	89	62	637	.03	32.1	07 07 74	WDAHLND
.2963	11.03	86	60	442	.22	35.9	07-08-74	WDAHLND
.1820	11.22	93	65	507	.00	33.9	07 09 74	WDAHLND
.5160	11.73	95	70	624	.00	31.8	07-10 74	WDAHLND

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Appendix Table 2. Spring wheat growth rate and environmental factors at Williston, North Dakota, 1974 (N. D. State Univ. Exp. Sta.)

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
	0.7	54	42	260	.00	98.2	05-23-74	WILL ND
.108	0.8	70	37	442	.00	95.8	05-24-74	WILL ND
.252	1.1	73	44	377	.00	92.9	05-25-74	WILL ND
.264	1.3	76	50	312	.06	91.0	05-26-74	WILL ND
.248	1.6	76	54	390	.00	87.5	05-27-74	WILL ND
.228	1.8	63	48	260	.10	87.6	05-28-74	WILL ND
.172	2.0	64	41	351	.02	86.1	05-29-74	WILL ND
.148	2.1	63	49	403	.03	84.4	05-30-74	WILL ND
.200	2.3	64	48	286	.00	82.1	05-31-74	WILL ND
.264	2.6	68	41	481	.00	80.0	06-01-74	WILL ND
.336	2.9	80	48	494	.00	76.9	06-02-74	WILL ND
.192	3.1	81	55	520	.00	73.6	06-03-74	WILL ND
.236	3.3	74	52	325	.08	72.9	06-04-74	WILL ND
.180	3.5	68	49	390	.00	70.6	06-05-74	WILL ND
.216	3.7	71	49	390	.00	68.3	06-06-74	WILL ND
.228	4.0	72	44	481	.04	67.2	06-07-74	WILL ND
.240	4.2	72	48	390	.00	65.0	06-08-74	WILL ND
.224	4.4	70	51	260	.27	69.5	06-09-74	WILL ND
.128	4.6	67	48	442	.23	73.2	06-10-74	WILL ND
.148	4.7	71	46	507	.07	72.6	06-11-74	WILL ND
.224	4.9	78	55	520	.00	69.6	06-12-74	WILL ND
.244	5.2	92	54	585	.00	66.2	06-13-74	WILL ND
.328	5.5	78	50	611	.00	63.6	06-14-74	WILL ND
.220	5.7	72	46	624	.00	61.6	06-15-74	WILL ND
.236	6.0	75	49	585	.00	59.3	06-16-74	WILL ND

Appendix Table 2 cont.

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
.188	6.1	78	53	520	.00	56.9	06-17-74	WILL ND
.224	6.4	80	58	585	.00	54.4	06-18-74	WILL ND
.212	6.6	88	51	585	.00	51.9	06-19-74	WILL ND
.252	6.8	87	61	520	.00	49.2	06-20-74	WILL ND
.194	7.0	62	54	169	.29	55.0	06-21-74	WILL ND
.194	7.2	76	48	533	.00	53.0	06-22-74	WILL ND
.232	7.5	79	54	585	.00	50.8	06-23-74	WILL ND
.352	7.8	91	55	520	.00	48.2	06-24-74	WILL ND
.236	8.0	94	63	611	.00	45.5	06-25-74	WILL ND
.752	8.8	92	56	559	.00	43.1	06-26-74	WILL ND
.328	9.1	86	51	624	.00	41.2	06-27-74	WILL ND
.356	9.5	85	58	585	.00	39.2	06-28-74	WILL ND
.356	9.8	78	50	663	.00	37.7	06-29-74	WILL ND
.340	10.2	86	50	611	.00	36.1	06-30-74	WILL ND
.328	10.5	88	60	520	.00	34.3	07-01-74	WILL ND
.208	10.7	76	62	221	.00	32.7	07-02-74	WILL ND
.180	10.9	82	61	481	.00	31.2	07-03-74	WILL ND
.206	11.1	93	68	546	.00	29.3	07-04-74	WILL ND
.206	11.3	90	62	533	.00	27.7	07-05-74	WILL ND
.084	11.4	86	61	468	.06	27.8	07-06-74	WILL ND
.216	11.6	88	64	637	.03	27.1	07-07-74	WILL ND

Appendix Table 3. Spring wheat growth rate and environmental factors at Dickinson, North Dakota, 1974

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
	1.8	0	36	325	0.00	98.1	05-22-74	DICK ND
.080	1.9	55	37	260	0.00	96.6	05-23-74	DICK ND
.108	2.0	72	30	442	0.00	94.5	05-24-74	DICK ND
.140	2.1	73	39	377	0.00	91.9	05-25-74	DICK ND
.176	2.3	71	44	312	0.28	96.2	05-26-74	DICK ND
.164	2.5	72	34	390	0.05	95.2	05-27-74	DICK ND
.488	3.0	72	50	260	0.00	92.0	05-28-74	DICK ND
.220	3.2	60	39	351	0.05	91.4	05-29-74	DICK ND
.116	3.3	61	39	403	1.12	100.0	05-30-74	DICK ND
.100	3.4	60	40	286	0.15	100.0	05-31-74	DICK ND
.188	3.6	66	35	481	0.00	97.9	06-01-74	DICK ND
.236	3.8	79	43	494	0.00	94.5	06-02-74	DICK ND
.268	4.1	84	45	520	0.00	90.9	06-03-74	DICK ND
.220	4.3	82	45	306	0.00	87.5	06-04-74	DICK ND
.228	4.5	61	49	390	0.00	85.1	06-05-74	DICK ND
.120	4.7	71	43	403	0.03	83.4	06-06-74	DICK ND
.212	4.9	71	40	514	0.00	81.1	06-07-74	DICK ND
.176	5.0	72	44	390	0.00	78.6	06-08-74	DICK ND
.224	5.3	64	47	280	0.00	76.4	06-09-74	DICK ND
.156	5.4	67	43	345	0.52	87.4	06-10-74	DICK ND
.136	5.6	68	40	481	0.04	86.1	06-11-74	DICK ND
.168	5.7	77	49	533	0.00	82.9	06-12-74	DICK ND
.212	5.9	84	45	520	0.00	79.7	06-13-74	DICK ND
.304	6.2	76	51	631	0.00	76.7	06-14-74	DICK ND
.204	6.5	67	41	637	0.00	74.7	06-15-74	DICK ND

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Appendix Table 3 cont.

GRD	CUM	FTXU	FTNU	LO	PO	EO	DATE	PLACE
.176	6.6	79	39	624	.00	72.3	06-16-74	DICK ND
.160	6.8	80	47	553	.00	69.5	06-17-74	DICK ND
.232	7.0	84	54	585	.00	66.4	06-18-74	DICK ND
.236	7.3	91	51	605	.00	63.3	06-19-74	DICK ND
.260	7.5	94	59	514	.00	59.8	06-20-74	DICK ND
.228	7.7	76	62	280	.62	72.6	06-21-74	DICK ND
.216	8.0	77	48	540	.79	89.7	06-22-74	DICK ND
.176	8.1	79	52	598	.00	86.1	06-23-74	DICK ND
.356	8.5	86	58	559	.00	81.9	06-24-74	DICK ND
.432	8.9	89	60	603	.00	77.6	06-25-74	DICK ND
.540	9.5	93	61	527	.00	73.3	06-26-74	DICK ND
.292	9.8	86	45	631	.00	70.4	06-27-74	DICK ND
.328	10.1	85	53	572	.00	67.2	06-28-74	DICK ND
.272	10.4	85	53	650	.00	64.2	06-29-74	DICK ND
.264	10.6	86	44	572	.00	61.7	06-30-74	DICK ND
.336	11.0	92	60	494	.00	58.4	07-01-74	DICK ND
.236	11.2	67	57	247	.00	56.3	07-02-74	DICK ND
.168	11.4	74	53	358	.60	69.2	07-03-74	DICK ND
.176	11.5	87	48	520	.37	75.5	07-04-74	DICK ND
.144	11.7	83	55	514	.00	72.1	07-05-74	DICK ND
.116	11.8	86	61	488	.00	68.5	07-06-74	DICK ND
.080	11.9	89	64	488	.00	64.8	07-07-74	DICK ND
.096	12.0	89	61	500	.00	61.4	07-08-74	DICK ND

Appendix Table 4. Spring wheat growth rate and environmental factors at Minot, North Dakota, 1974

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
	0.5	79	50	286	.00	76.4	06-04-74	MINOT E
.192	0.7	69	48	390	.10	76.5	06-05-74	MINOT E
.356	1.1	71	47	416	.01	74.3	06-06-74	MINOT E
.204	1.3	75	44	546	.00	71.9	06-07-74	MINOT E
.212	1.5	72	49	390	.00	69.5	06-08-74	MINOT E
.192	1.7	65	49	299	.00	67.4	06-09-74	MINOT E
.152	1.8	62	44	247	.02	66.3	06-10-74	MINOT E
.100	1.9	72	40	455	.12	67.4	06-11-74	MINOT E
.228	2.2	78	60	546	.00	64.4	06-12-74	MINOT E
.220	2.4	80	50	455	.00	61.8	06-13-74	MINOT E
.180	2.6	73	48	650	.27	66.5	06-14-74	MINOT E
.192	2.8	71	44	650	.00	64.5	06-15-74	MINOT E
.284	3.0	71	40	663	.00	62.7	06-16-74	MINOT E
.196	3.2	76	45	585	.00	60.5	06-17-74	MINOT E
.220	3.5	82	46	585	.00	58.2	06-18-74	MINOT E
.340	3.8	89	55	624	.00	55.4	06-19-74	MINOT E
.260	4.1	87	64	507	.00	52.4	06-20-74	MINOT E
.248	4.3	80	55	390	.00	50.2	06-21-74	MINOT E
.204	4.5	80	52	546	.00	48.1	06-22-74	MINOT E
.296	4.8	82	50	611	.00	46.1	06-23-74	MINOT E
.220	5.0	87	55	598	.00	43.9	06-24-74	MINOT E
.240	5.3	90	63	559	.00	41.5	06-25-74	MINOT E
.304	5.6	94	63	494	.00	39.2	06-26-74	MINOT E
.300	5.9	88	53	637	.00	37.3	06-27-74	MINOT E
.272	6.1	87	57	559	.00	35.5	06-28-74	MINOT E

Appendix Table 4 cont.

GRO	CUM	ETXO	ETNO	LO	PO	EO	DATE	PLACE
.224	6.4	77	52	637	.00	34.1	06-29-74	MINOT E
.244	6.6	84	51	533	.00	32.7	06-30-74	MINOT E
.224	6.8	91	59	468	.00	30.9	07-01-74	MINOT E
.236	7.1	78	57	273	.00	29.6	07-02-74	MINOT E
.272	7.3	76	58	234	.00	28.4	07-03-74	MINOT E
.216	7.6	86	51	494	.03	27.9	07-04-74	MINOT E
.316	7.9	87	59	494	.00	26.5	07-05-74	MINOT E
.288	8.2	85	59	507	.00	25.2	07-06-74	MINOT E
.312	8.5	85	64	338	.00	23.9	07-07-74	MINOT E
.492	9.0	85	61	520	.00	22.7	07-08-74	MINOT E
.468	9.4	88	59	507	.00	21.6	07-09-74	MINOT E
.416	9.9	90	61	520	.00	20.5	07-10-74	MINOT E
.316	10.2	90	69	416	.00	19.3	07-11-74	MINOT E
.328	10.5	87	57	585	.51	31.1	07-12-74	MINOT E
.228	10.7	85	55	546	.00	29.7	07-13-74	MINOT E
.204	10.9	83	54	637	.00	28.4	07-14-74	MINOT E
.204	11.1	93	57	494	.00	26.9	07-15-74	MINOT E
.201	11.3	92	60	338	.09	27.8	07-16-74	MINOT E

Appendix Table 5. Spring wheat growth rate and environmental factors at Clemson, South Carolina, 1974

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
	0.60	84	50	547	0.42	84.7	06-17-74	CL SC
.324	0.90	79	51	404	0.00	81.7	06-18-74	CL SC
.250	1.10	78	50	481	0.00	78.8	06-19-74	CL SC
.190	1.30	87	62	329	0.00	75.1	06-20-74	CL SC
.192	1.50	90	63	256	0.38	80.9	06-21-74	CL SC
.231	1.74	86	65	511	0.00	77.1	06-22-74	CL SC
.231	1.97	91	71	419	0.00	72.9	06-23-74	CL SC
.231	2.20	84	59	318	0.00	69.7	06-24-74	CL SC
.176	2.40	79	57	407	0.02	67.4	06-25-74	CL SC
.164	2.50	80	52	461	0.00	64.9	06-26-74	CL SC
.152	2.70	81	52	419	0.61	77.7	06-27-74	CL SC
.182	2.90	75	54	528	0.07	76.7	06-28-74	CL SC
.225	3.10	79	53	533	0.00	73.9	06-29-74	CL SC
.225	3.30	83	56	504	0.00	70.8	06-30-74	CL SC
.225	3.50	85	61	451	0.00	67.6	07-01-74	CL SC
.206	3.80	89	62	482	0.00	64.4	07-02-74	CL SC
.154	3.90	93	64	497	1.55	99.9	07-03-74	CL SC
.318	4.23	91	67	473	0.16	98.7	07-04-74	CL SC
.318	4.54	84	67	485	0.88	100.0	07-05-74	CL SC
.318	4.86	84	66	326	0.67	100.0	07-06-74	CL SC
.318	5.18	85	65	389	0.15	99.0	07-07-74	CL SC
.318	5.50	87	66	411	0.36	100.0	07-08-74	CL SC
.182	5.70	87	66	449	0.00	95.1	07-09-74	CL SC
.218	5.90	89	67	365	1.75	100.0	07-10-74	CL SC
.194	6.10	90	66	318	0.03	95.7	07-11-74	CL SC

Appendix Table 5 cont.

GRO	CUM	FTXO	FTNO	LO	PO	EO	DATE	PLACE
.180	6.30	88	65	414	0.00	91.0	07-12-74	CL SC
.195	6.50	85	67	420	0.00	86.7	07-13-74	CL SC
.195	6.70	88	67	501	0.00	82.4	07-14-74	CL SC
.195	6.90	92	68	512	0.00	78.1	07-15-74	CL SC
.198	7.10	91	68	418	2.50	100.0	07-16-74	CL SC
.193	7.30	89	67	469	0.00	94.9	07-17-74	CL SC
.194	7.40	88	66	427	0.00	90.3	07-18-74	CL SC
.162	7.60	88	66	272	0.00	85.9	07-19-74	CL SC
.183	7.80	91	69	387	0.00	81.5	07-20-74	CL SC
.183	8.00	93	67	409	0.00	77.3	07-21-74	CL SC
.183	8.20	89	62	310	0.20	78.6	07-22-74	CL SC
.171	8.35	82	64	109	0.32	83.2	07-23-74	CL SC
.171	8.50	80	63	303	0.13	82.9	07-24-74	CL SC
.156	8.70	83	66	295	0.02	79.7	07-25-74	CL SC
.177	8.80	82	68	272	0.00	76.0	07-26-74	CL SC