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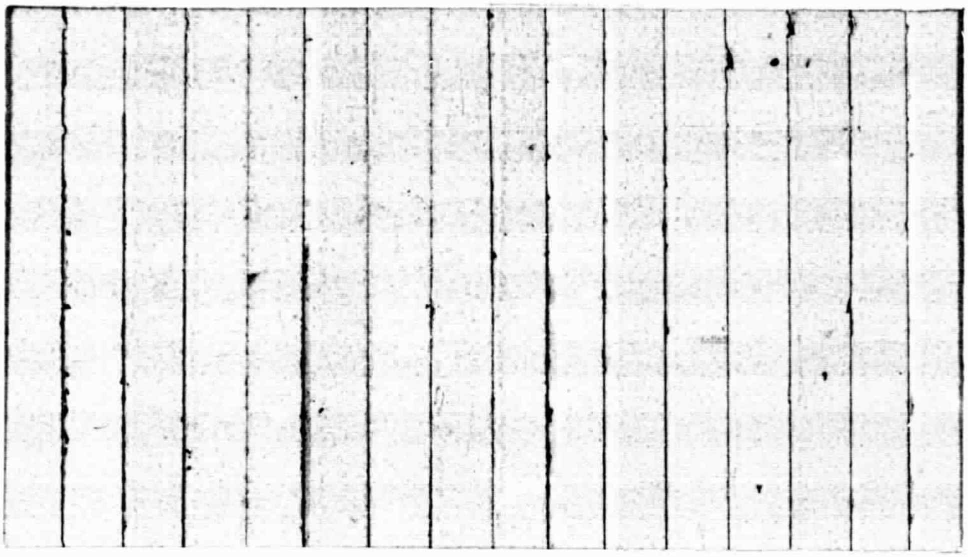

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APPLICATION OF WHEAT YIELD MODEL TO
UNITED STATES AND INDIA

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FINAL REPORT FOR PERIOD 3/77 TO 11/77

December, 1977

Prepared for: NASA/Johnson Space Center
Earth Observation Division
Houston, Texas

Prepared by: Arlin M. Feyerherm
Principal Investigator
Department of Statistics
Kansas State University
Manhattan, Kansas 66506

Support Personnel:

Dr. Gary Paulsen
Dr. Jeanne Sebaugh
Mr. Dale Fjell
Mr. John McKean
Mr. Michael Frerichs

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16. Abstract

We applied our wheat yield model to the major wheat-growing areas of the U.S.A. and India. In the U.S. Great Plains, estimates from the winter and spring wheat models agreed closely with USDA-SRS values in years with the lowest yields but underestimated in years with the highest yields.

Application to the Eastern Plains and Northwest indicated the importance of cultural factors as well as meteorological ones in the model. It also demonstrated that the model could be used, in conjunction with USDA-SRS estimates, to estimate yield losses due to factors not included in the model, particularly diseases and freezes at heading.

A fixed crop calendar for India was built from a limited amount of available plot data from that country. Application of the yield model gave measurable evidence that yield variation from state to state is due to different mixes of levels of meteorological and cultural factors.

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PREFACE

This is the third in a series of reports detailing development of a universal wheat yield model under the RT & E program of LACIE. The model expresses yearly and regional variation in grain yields as a function of weather variation and changes in cultural practices. Separate equations are used for fall and spring-planted wheat.

Our model produces yield estimates on a macro-climatic scale and has two unique features:

- It measures the separate and joint contributions to grain yield of meteorological (precipitation and temperature) and specific cultural factors (varietal improvement, amount of applied nitrogen, cropping practices).
- For a given year, it produces an estimate of yield which is independent of official government estimates.

The second feature follows from the fact that: (1) the model was developed using historical experimental plot yields and (2) regional estimates of yield are generated from observation of weather and cultural practices. By contrast, government-reported yields, in most countries, are based on direct measurement of yield through field sampling of harvested grain and/or a sample of producer's reports.

This report summarizes results from application of our model to the following wheat-growing regions:

- U.S. Great Plains (winter wheat)
- U.S. Great Plains (spring wheat)

- U.S. Eastern Plains (soft winter wheat)
- Northwest U.S.A. (winter wheat)
- India

Comparisons were made between model-generated and USDA-SRS estimates of statewide yields for the years 1965-76 and comparable comparisons were made for 1972-75 in India.

The following statements summarize results and reveal some of the model's strengths and weaknesses:

- Based on a sparse weather network (less than one station per crop reporting district), U.S. Great Plains winter and spring wheat model-generated yields were within ± 1 bu./acre of USDA-SRS estimates in those years with the lowest yields. However, the model underestimated SRS estimates by 3 to 4 bu./acre for the years with highest yields. There was a 10 bu./acre range in SRS estimates of yields for both winter and spring wheat, within the 1965-76 period.
- Changes in the specific cultural factors included in the model accounted for 5 bu. of an estimated "technological" increase of 7 bu./acre, in USGP winter wheat yields between 1960 and 1972. Comparable figures for spring wheat were 3 of 6 bu./acre.
- When applied in the humid Eastern Plains, large differences (greater than 5 bu./acre) between model and SRS estimates were traced to disease (septoria tritici) epidemics and freezing temperatures at heading; factors not in the model. In essence, application of our model, as an adjunct to "objective sampling", could produce estimates of losses due to factors not in the model.

- Application to the Northwest USA demonstrated that yield increases in that region could be accounted for by increases in levels of cultural factors; praticularly, varietal improvement and increased nitrogen application.
- Application to India showed that differences in yield between states could be accounted for by a combination of differences in levels of cultural and meteorological factors.

Finally, there is no technical barrier to real-time application of our model either for selected regions or on a global basis. However, real-time application to a region must be preceded by model application over prior seasons (at least one, preferably ten) to compute the mean of model-generated yields as a reference for future comparisons. Further testing of our model in foreign areas would be desirable and work is now underway to improve the crop calendar and to model high yields with greater accuracy.

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TASK 1.0 DEVELOP AREA-SPECIFIC MODELS FOR (a) ALL CRDs IN LACIE GREAT PLAINS STATES, (b) ALL CRDs IN OTHER IMPORTANT WHEAT GROWING U.S. AREAS, (c) STATE-EQUIVALENT AREAS FOR FOREIGN LACIE COUNTRIES FOR WHICH DATA EXISTS WITHIN LACIE OR CAN BE PRODUCED BY THE CONTRACTOR

1.1 Results

1.1.1 Statement of the problem.

Work on a previous contract (NAS 9-14282; Final Report, Feb., 1977) produced basic relations between experimental plot yields and a set of variables defined from weather-related and cultural factors. In follow-up work on the first phase of this contract (Final Report, Sept., 1977), this portion of the model is referred to as the WAC value and for a specific year would be calculated by:

$$WAC(R,S) = VYA(R) * \sum_{j=1}^{3} P_j(R)[W_j(S) + W_o(S) * NI_j(R)],$$

where

$VYA(R)$ = varietal yielding ability which is an average of VYA values for varieties planted in region (R) in the given year,

$P_j(R)$ = proportion of wheat under cropping practice $j(j=1$ = continuous, $j=2$ = fallow, $j=3$ = irrigated) in region (R),

$NI_j(R)$ = amount of nitrogen applied on cropping practice $j(j=1,2,3)$ in region (R),

$W_j(S)$ = weather-generated yield component for wheat under cropping practice $j(j=1,2,3)$ using weather at station (S),

$W_o(S)$ = weather-generated coefficient of NI based on weather at station (S).

The task of deriving area-specific models can be stated as that of relating regional yields to model-generated WAC values. We assume this relation can be represented mathematically by

$$(1.1) \qquad \mu_t(R) = \alpha(R,S) + \beta * WAC_t(R,S) + \varepsilon_t$$

where

$\mu_t(R)$ = "true" yield for region (R) in year t,

$WAC_t(R,S)$ = model-determined value for year (t) based on weather-related variable values generated at weather station (S) and levels of cultural factors associated with region (R),

β = a "universal" constant,

$\alpha(R,S)$ = a constant, independent of t but dependent on the region (R) and station (S) combination,

ε_t = a random error for year (t).

Section 1.1.2 contains a discussion of the data set used to estimate $\alpha(R,S)$ and β. The criterion to estimate β, along with results, is given in Section 1.1.3. Estimates of $\alpha(R,S)$ are given in Section 1.1.4 both for CRDs (crop reporting districts) and combination of districts. Applications of the model are presented in Section 1.1.5 for the USGP, in Section 1.1.6 for the soft winter wheat region east of the Missouri river, in Section 1.1.7 for the Northwest, and in Section 1.1.8 for five states in India.

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1.1.2 Data Set for Estimating Parameters

Certain combinations of CRDs and weather stations were chosen for parameter estimation for the major hard red winter wheat area and the spring wheat area of the USGP. These combinations are shown in Tables 1.1 and 1.2 along with the number of years of useable data for each.

The region-station (R,S) combinations were chosen by preliminary analysis which compared USDA-SRS yield estimates with values of $[a(R,S) + b*WAC(R,S)]$ for the given (R,S) and other combinations not shown in Tables 1.1 and 1.2. For a given (R,S), values of b were selectively varied in .05 increments, with a new

$$a(R,S) = \overline{SRS} - b\ \overline{WAC}(R,S)$$

calculated for each b. The averages were calculated over years. A RMSE (root-mean-square error) was calculated for each combination of b and a(R,S) values.

The preliminary analysis revealed that the RMSE was relatively insensitive to changes in combinations of b and a(R,S) as b ranged over values of 0.40 to 0.85 for winter wheat and 0.30 to 0.75 for spring wheat. The region-station combinations chosen for inclusion in Tables 1.1 and 1.2 tended to have smaller RMSEs, over a larger range of b-values, than those not included.

1.1.3 Criterion for Estimating β

A number of considerations prompted use of a constant multiplier (β) for WAC values in Equation (1.1). They were:

a. It was one more step toward development of a universal measure of wheat yield on a global basis.

b. The RMSE between SRS and model estimates of yield over years within a CRD was quite insensitive to variation in values of $\hat{b}$ over the range of values indicated in the previous section.

c. When both β and α were estimated by regressing SRS estimates on WAC values over ten-year intervals, within a CRD, the estimates of β showed wide variation as a new year was added and the oldest year deleted to the data set used for estimation. If β is set equal to a constant, the estimates of $\alpha(R,S)$ should be relatively stable when calculated, for successive intervals, by adding and deleting one year at a time.

d. The parameter $\alpha(R,S)$ is available for correcting for under or over estimates of average regional yields due to use of a single β rather than a different β for each region.

To estimate β, we first computed the least squares estimate of β when regressing SRS estimates on WAC values, within a CRD, over the number of years shown in Tables 1.1 and 1.2. Thus, the estimate for region (R) was

$$b(R) = [\sum_{t=1}^{n} (Y_t - \bar{Y})(X_t - \bar{X})]/[\sum_{t=1}^{n} (X_t - \bar{X})^2],$$

where

Y_t = the SRS estimate for year t,

X_t = the WAC value for year t.

Table 1.1 USGP winter wheat region-station combinations with some calculated statistics.

State	CRD(R)	Station (S)	Period	q(R)†	b(R)†	A(R,S)††
MT	NC	Great Falls, MT	1955-76	.042	.60	-0.7
	NE	Lewistown, MT	1955-76	.011	.83	-6.4
	C	Helena, MT	1955-76	.013	.35	6.1
	SC	Billings, MT	1955-76	.009	.74	-1.9
	SE	Miles City, MT	1955-76	.006	.62	1.2
SD	NW	Miles City, MT	1955-76	.002	.53	-1.3
	NC	Aberdeen, SD	1964-76	.002	.41	5.6
	WC	Pierre, SD	1955-76	.007	1.03	0.9
	C	Pierre, SD	1955-76	.005	.98	-2.3
	SW	Chadron, NE	1964-76	.003	.94	5.8
	SC	Valentine, NE	1964-76	.007	.74	5.7
NE	NW	Scottsbluff, NE	1955-76	.032	.78	4.8
	NE	Norfolk, NE	1955-76	.001	.87	1.1
	C	Grand Island, NE	1955-76	.004	.88	-0.1
	EC	Omaha, NE	1955-76	.011	.84	-1.2
	SW	Hill City, KS	1955-76	.025	1.02	1.0
	SC	Concordia, KS	1955-76	.012	.89	-0.1
	SE	Topeka, KS	1955-76	.017	.91	0.9
KS	NW	Hill City, KS	1955-76	.042	1.00	-0.3
	NC	Concordia, KS	1955-76	.044	.86	-1.2
	NE	Topeka, KS	1955-76	.010	.53	2.8
	WC	Hill City, KS	1955-76	.045	1.02	-3.0
	C	Salina, KS	1955-76	.060	.87	-3.2
	EC	Topeka, KS	1955-76	.012	.25	1.3

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Table 1.1 Continued

State	CRD(R)	Station (S)	Period	q(R)†	b(R)‡	A(R,S)‡‡
	SW	Dodge City, KS	1955-76	.069	.88	-1.7
	SC	Wichita, KS	1955-76	.092	.87	-1.4
	SE	Chanute, KS	1955-76	.020	.66	0.8
CO	NE	Akron, CO	1955-76	.017	.20	5.3
	EC	Denver, CO	1955-76	.053	.71	-1.4
	SE	LaJunta, CO	1955-76	.012	.45	2.8
OK	NW	Gage, OK	1964-76	.034	.46	-2.9
	NC	Ponca City, OK	1964-76	.064	.65	-1.0
	NE	Tulsa, OK	1955-76	.005	.83	-1.1
	[illegible]	Oklahoma City, OK	1955-76	.028	1.01	-3.8
	C	Oklahoma City, OK	1955-76	.023	1.06	-3.3
	SW	Hobart, OK	1964-76	.036	.45	-2.1
	SC	Wichita Falls, TX	1955-76	.002	.58	-1.8
TX	1N	Amarillo, TX	1955-76	.032	.78	-2.5
		Dalhart, TX	1964-76	.032	.46	-0.1
	1S	Lubbock, TX	1955-76	.003	.43	-1.5
		Midland, TX	1955-76	.003	.37	2.9
	2N	Childress, TX	1964-76	.017	.47	-0.9
	2S	Abilene, TX	1955-76	.014	.45	-4.8
	03	Wichita Falls, TX	1955-76	.009	.66	-0.8
	04	Waco, TX	1955-76	.005	.44	-1.7
		Dallas, TX	1955-76	.005	.32	-2.1

†q(R) = proportion of total USGP harvested acreage (1971-75)

‡b(R) = regression coefficient between SRS and WAC values for region (R)

‡‡A(R,S) = constant term for model estimate of yield for region (R) using station (S); B=0.75

Table 1.2 USGP spring wheat region-station combinations with some calculated statistics.

State	CRD	Stations	Period	q(R)†	b(R)ǂ	A(R,S)ǂǂ
MN	NW	Grand Forks, ND	1955-76	.080	.60	14.4
	WC	Fargo, ND	1955-76	.043	.62	11.7
	C	Alexandria, MN	1964-76	.006	.57	12.8
	SW	Redwood Falls, MN	1965-76	.002	.16	14.9
	SC	Rochester, MN	1955-76	.002	.32	15.8
ND	NW	Minot, ND	1955-76	.100	.42	9.0
	NC	Minot, ND	1955-76	.068	.42	8.3
	NE	Grand Forks, ND	1955-76	.115	.52	13.6
	WC	Dickinson, ND	1955-76	.048	.47	10.5
	C	Jamestown, ND	1955-76	.068	.40	12.4
	EC	Fargo, ND	1955-76	.068	.65	13.8
	SW	Dickinson, ND	1955-76	.045	.41	10.1
	SC	Bismarck, ND	1955-76	.038	.34	7.5
	SE	Fargo, ND	1955-76	.056	.73	7.4
MT	NC	Cutbank, MT	1955-76	.046	.49	7.1
	NE	Lewistown, MT	1955-76	.080	.61	8.6
	C	Helena, MT	1955-76	.005	.48	9.7
	SC	Billings, MT	1955-76	.005	.32	12.0
	SE	Miles City, MT	1955-76	.006	.66	11.3
SD	NW	Miles City, MT	1955-76	.018	.46	8.6
	NC	Aberdeen, SD	1964-76	.049	.39	8.5
	NE	Watertown, SD	1964-76	.026	.67	8.6
	WC	Pierre, SD	1955-76	.002	.48	9.3
	C	Pierre, SD	1955-76	.015	.46	8.6
	EC	Sioux Falls, SD	1955-76	.004	.40	7.7
	SC	Valentine, NE	1964-76	.002	.13	10.5
	SE	Sioux Falls, SD	1955-76	.002	.37	7.4

† q(R) = proportion of total USGP harvested acreage (1971-75)

ǂ b(R) = regression coefficient between SRS and WAC values for region (R)

ǂǂ A(R,S) = constant term for model estimate of yield for region (R) using station (S); B = 0.50

Values obtained for b(R) are shown in Tables 1.1 and 1.2.

The second step consisted of finding a weighted mean of b(R) values over all CRDs in the USGP using harvested acres for calculating weights. Thus

$$\bar{b} = \sum_{R=1}^{R_o} q(R) * b(R)$$

where

$q(R)$ = proportion of USGP harvested acres allocated to region R,

R_o = total number of regions in the USGP.

Harvested acres assigned to each R were the average SRS acreage estimates over the 1971-75 seasons. Values of q(R) are shown in Tables 1.1 and 1.2.

Results gave $\bar{b}$ = 0.75 for winter wheat and 0.51 for spring wheat. The latter was rounded off to 0.50 and the letter B will be used to designate our estimate of β. Thus to apply our model, you estimate a yield for region (R) using weather at station (S) in year (t) by the formula

$$Y_t(R,S) = A(R,S) + B * WAC_t(R,S),$$

where B = 0.75 for winter wheat and B = 0.50 for spring wheat. Values to use for A(R,S) will be discussed in the next section.

1.1.4 <u>Estimating $\alpha(R,S)$</u>

If we assume that, for all t, the expected value of ε_t $[E(\varepsilon_t)]$ is zero, then from equation (1.1), $\alpha(R,S) = E[\mu_t(R)] - \beta E[WAC_t(R,S)]$. Under this assumption, a reasonable estimate of $\alpha(R,S)$ would be

(1.4) $A(R,S) = \overline{Y(R)} - B*\overline{WAC}(R,S)$

where

$\bar{Y}(R)$ = average over years of government-reported yields,

$\overline{WAC}(R,S)$ = average value of WAC(R,S) over the same set of years used to calculate $\bar{Y}(R)$.

Values of A(R,S) when B = 0.75 and 0.50 for winter wheat and spring wheat, respectively, are shown in Tables 1.1 and 1.2.

To obtain a value of A(R) for combinations of CRDs we recommend a weighted average using the q(R) in Tables 1.1 and 1.2 for weighting. Thus, for Kansas winter wheat

$$A(R) = A(\text{Kansas}) = \sum_{R=1}^{9} q(R)*A(R,S)]/\sum_{R=1}^{9} q(R)$$

$$= -1.5 \quad .$$

The value is close to zero and explains, in part, why previous use of the single parameter "MAP" factor gave a reasonable good fit of model to data for Kansas.

Values of A(R) are shown in Tables 1.3 through 1.8 for states in the U.S. and India. For both winter and spring wheat there appears to be systematic changes that may be related to soil productivity. This was investigated under Task 4.0.

1.1.5 Applications to the USGP

To apply our winter wheat model on a CRD level for year (t), calculate

(5.1) $\hat{Y}_t(R,S) = A(R,S) + 0.75 * WAC_t(R,S)$

where A(R,S) is taken from Table 1.1 and WAC(R,S) is calculated with our WHYMOD computer program. On a state level, calculate

$$(5.2) \qquad \hat{Y}_t(\text{state}) = [\sum_R q(R)*\hat{Y}_t(R,S)]/\sum_R q(R)$$

where R goes over the regions within the state and q(R) values are found in Table 1.1. Equation (5.2) would also be used for multi-state or USGP results.

For spring wheat, Equations (5.1) and (5.2) are applied in the same way described for winter wheat with 0.75 replaced by 0.50 and values for A(R,S) and q(R) are found in Table 1.2.

Results on a state and multi-state level are shown in Tables 1.3 through 1.5 for states in the USGP. The state-level yields for winter wheat (Table 1.3) show good agreement between model and SRS estimates for Montana, Oklahoma, and Texas. Differences in excess of 5 bushels per acre are underlined. Two of the excessive overestimates of model to SRS can be traced to rather severe rust epidemics in South Dakota and Nebraska; one in Kansas was due to hard freezes in early May close to heading. The overestimate in 1967 in Colorado is unaccounted for. Excessive underestimates are confined to 1970 and 1971 in Nebraska, Colorado, and South Dakota with the exception of 1968 in Nebraska. In general, the larger underestimates are associated with high SRS yields and suggests a model deficiency. We conjecture that the model must give more weight to amount and timeliness of precipitation from emergence to jointing in the semi-arid regions. Work is underway to modify our model, accordingly.

Table 1.3 Comparison of winter wheat model (MOD) and SRS estimates of yield by states in the USGP. Entries are bushels per acre. Differences > 5b/a are underlined.

Harvest	Montana		So. Dakota		Nebraska		Colorado		Kansas		Oklahoma		Texas	
Year	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS
1965	27	28	25	17*	25	17*	18	15	22	24	23	28	20	23
1966	26	30	23	26	27	33	21	18	25	19**	23	21	19	23
1967	32	30	33	36	26	25	24	18	18	20	19	17	20	16
1968	32	31	31	36	30	30	20	20	28	23	22	22	23	22
1969	27	25	25	26	30	30	22	21	30	31	26	28	23	24
1970	28	27	29	27	30	38	22	29	29	33	25	26	23	24
1971	27	30	30	36	34	41	21	28	30	35	21	19	20	19
1972	26	26	33	36	31	35	21	24	29	34	25	23	22	22
1973	26	26	30	32	32	36	27	25	32	37	26	30	28	29
1974	25	29	32	27	34	34	27	26	32	28	24	21	20	16
1975	31	35	27	30	30	32	22	22	29	29	24	24	24	23
1976	33	32	23	18	30	32	19	22	30	29	26	24	21	23
A(R)	-0.3		2.2		1.8		0.6		-1.5		-2.2		-2.0	
RMSE	2.2		4.4		4.4		4.0		3.7		2.6		2.2	

*Rust epidemic, **Freeze at heading

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Table 1.4 Comparison of spring wheat model (MOD) and SRS estimates of yield by states in the USGP. Entries are bushels per acre. Differences > 5 b/a are underlined.

Harvest	Montana		North Dakota		Minnesota		South Dakota	
Year	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS
1965	21	26	25	26	31	27	19	18
1966	19	22	23	24	27	23	14	15
1967	18	19	20	23	27	32	22	24
1968	24	22	28	27	31	33	22	23
1969	23	27	27	30	31	30	24	20
1970	22	23	23	24	29	28	17	20
1971	21	23	27	32	34	38	<u>18</u>	<u>28</u>
1972	27	27	29	29	35	32	24	24
1973	19	21	26	28	<u>29</u>	<u>39</u>	20	23
1974	20	19	20	20	27	29	15	15
1975	24	26	23	26	30	32	17	18
1976	28	29	25	25	28	32	<u>17</u>	<u>10</u>
A(R)	7.3		9.0		12.3		8.2	
RMSE	2.3		2.2		4.1		3.9	

Table 1.5 Comparison of model (MOD) and SRS estimates of yields for USGP. Entries are bushels per acre. Differences > 3 b/a are underlined.

Harvest Year	Winter Wheat 7-States		Spring Wheat 4-States		All Wheat USGP	
	MOD	SRS	MOD	SRS	MOD	SRS
1965	22	23	24	25	23	24
1966	24	22	22	22	23	22
1967	21	20	21	24	21	21
1968	26	24	27	27	26	25
1969	27	28	27	28	27	28
1970	27	30	23	24	25	28
1971	26	30	26	31	26	30
1972	27	29	29	28	28	29
1973	29	32	24	28	28	31
1974	28	26	20	21	25	24
1975	27	28	23	25	26	27
1976	27	27	25	25	26	26

The spring wheat estimates (Table 1.4) for Montana and North Dakota are in close agreement. One year for Minnesota and one for South Dakota show excessively low model estimates. These were associated with high SRS estimates for the state of interest. The year 1971 was a relatively "good" year across the spring wheat region and we plan to take a close look at the weather events that produced the high yields.

Multi-state results are shown in Table 1.5. The high yielding years of 1970, 1971 and 1973 are flagged for further study. In particular, the years of 1971 and 1973 were good for both winter and spring wheat and the weather sequences associated with these years bear further investigation.

1.1.6 Application to the Eastern Plains

The model was applied to selected CRD's in Missouri, Illinois, Indiana, Ohio, and Michigan for which weather data were available and then aggregated over the respective CRDs within states. Statistical Reporting Service (SRS) estimates were aggregated over the identical CRDs within states.

Year-by-year results are shown in Table 1.6. Differences between Model and SRS in excess of 5 bushels per acre are underlined.

With the exception of Michigan, the model and SRS estimates show good agreement from 1965 through 1972. The yields are quite uniform with a decided increase in 1971 due to increased nitrogen application along with large-scale planting of Arthur and other semi-dwarf varieties. In 1973, 1974, and 1976, a pattern of overestimation by the model is apparent. Septoria tritici in 1973 and 1974 and a freeze at heading in 1976, factors not in the model, accounted for severe reductions in yield.

Table 1.6 Comparison of Model (MOD) and SRS estimates of yield by states in the Eastern Plains. Entries are bushels per acre. Differences > 5 b/a are underlined.

Harvest	Missouri		Illinois		Indiana		Ohio		Michigan	
year	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS	MOD	SRS
1965	29	29	32	35	33	33	33	33	32	40
1966	32	36	37	39	39	44	37	39	34	34
1967	30	34	34	38	37	37	36	34	38	40
1968	32	33	36	37	37	36	37	38	35	36
1969	34	33	39	37	37	40	37	38	38	36
1970	33	34	36	38	36	38	34	37	40	40
1971	38	41	45	45	45	46	41	44	37	39
1972	38	39	43	45	43	48	41	45	43	36
1973	32	33	41	32*	44	33*	40	32*	44	41
1974	38	29*	43	30*	43	37*	44	42		
1975	36	33	42	39	43	43	44	41		
1976	43	33*	42	39	44	36*	45	39		
A(R)	2.2		5.3		2.6		1.5		2.0	

*Septoria epidemic   **Freeze at heading

1.1.7 Application to Northwest USA

The model was applied to selected CRDs in Washington, Oregon, and Idaho for which daily weather data were available. Year-by-year comparisons are shown in Table 1.7.

No data from the Northwest were used to model the WAC quantity, so application to winter wheat yields in that region provides an independent test of this component of our model. In addition, historical data on "cropping practice" were unavailable for Washington and Oregon and "rough" estimates were used in the calculations.

Results in Table 1.7 show "good" agreement between model and SRS estimates with the exception of a few years. The model underestimate in 1971 for Oregon is not unexpected because it was a "good" crop year. The overestimate for 1973 in Washington was due to widespread winterkill. Overestimates for 1974-76 in Idaho could not be accounted for. The drop in SRS estimates from 1969-72 to 1973-76 was sizeable (approximately 10 bu./acre) in the northwest CRD and less in the southern portion of the state.

1.1.8 Application to India

The model was applied to five wheat-growing states in India for the four-year period 1972-75. Comparisons of model and government-reported yields are shown in Table 1.8 along with other pertinent data.

The model was run under the following conditions:

a. A single fixed crop calendar was used for all locations. Dates chosen to correspond to Robertson's BMTS were:

Table 1.7 Comparison of model (MOD) and SRS estimates of yield by states in the northwest winter wheat region. Entries are bushels per acre. Differences > 5 b/a are underlined.

Harvest	Washington		Oregon		Idaho	
Year	MOD	SRS	MOD	SRS	MOD	SRS
1965	36	39	35	33	41	43
1966	38	40	33	31	36	39
1967	44	40	34	30	45	44
1968	44	39	32	29	43	47
1969	43	38	35	36	44	46
1970	41	44	33	38	47	48
1971	44	49	37	43	48	52
1972	43	47	37	39	49	45
1973	40	33	32	28	47	42
1974	48	44	46	46	48	41
1975	50	48	46	50	53	40
1976	52	48	47	46	53	44
A(R)	5.1		0.1		12.2	

Table 1.8 Comparison of winter wheat model (MOD) and government-reported (SRS) yields in India using 16 weather stations.†

		States									
	Harvest year	Punjab MOD	Punjab SRS	Rajasthan MOD	Rajasthan SRS	Haryana MOD	Haryana SRS	Uttar Pradesh MOD	Uttar Pradesh SRS	Bihar MOD	Bihar SRS
Yields (b/A)	1972	32	36	19	19	26	30	17	19	22	26
	1973	34	33	18	19	26	26	16	18	--	--
	1974	36	33	16	16	27	23	16	14	21	18
	1975	36	36	19	19	27	26	19	17	21	20
A(R) (B=0.70)		-0.7		-2.6		-3.2		-9.9		-0.3	
		P_c	P_I	P_c	P_i	P_c	P_I	P_c	P_I	P_c	P_I
Cropping Practice (Percentages)	1972	13	87	33	67	17	83	33	67	47	53
	1973	12	88	27	73	16	84	31	69	--	--
	1974	12	88	34	66	14	86	30	70	41	59
	1975	12	88	30	70	14	86	30	70	40	60
		W_c	W_I	W_c	W_I	W_c	W_I	W_c	W_I	W_c	W_I
Weather Components of Yield (B/A)	1972	31	35	18	25	20	29	24	30	19	26
	1973	28	35	5	25	19	30	20	29	--	--
	1974	34	37	3	25	13	31	17	31	12	27
	1975	32	37	1	28	13	32	23	32	15	26

†Punjab: Amritser, Simla
Rajasthan: Jodhpur, Jhalawar, Bikuner, Jaipur
Haryana: New Delhi, Hissar
Uttar Pradesh: Allahabad, Mukteswar, Dehra Dun, Roorkee, Bareilly, Bahraich, Agra
Bihar: Patna

BMTS:	**0.0**	**1.0**	**1.5**	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**	**5.0**
Dates:	**11/11**	**11/25**	**12/9**	**1/9**	**2/4**	**2/19**	**3/11**	**3/31**	**4.12**

b. All dryland wheat was assumed to have continuous cropping with traditional varieties (VYA = 1.0) and no nitrogen applied.

c. All irrigated wheat was assumed planted to high yielding varieties (VYA = 1.30) with 30 pounds/acre of nitrogen applied. The coefficient of amount of applied nitrogen in the yield equation was taken to be 0.17 for all locations. No adjustment for ADTJ was made because the adjustment is unrealistic for high values of ADTJ.

d. The universal constant B was set equal to 0.70 (analysis was made prior to final decision to use B = 0.75).

Clearly, with irrigation, India has achieved rather uniform year-to-year yields in these five states. Thus, the data did not really provide a test of how well the model would reflect yearly variation. However, the model did measure differences in yield between states and pin-points some of the causes of these differences.

In Table 1.8, we show not only yield comparisons but also comparisons of the proportion of wheat under irrigation (p_I) and non-irrigated (assumed continuous) cropping (p_c). We have also included weather components (W) of WAC values, averaged over the weather stations. In addition, the A(R) values reflect relatively poor soils in Uttar Pradesh. This auxilary data helps to assess, in a quantitative form, the relative contribution of weather, cultural practices, and soils to yield differences among states in India.

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1.2 Recommendations of Directions for Further Effort

Application of our model, in a wide range of meteorological conditions ranging from near droughts to exceptionally good weather for wheat, revealed a number of changes in the model that could improve its accuracy. They are:

a. Use a crop calendar which divides the season into the following phases: fall growth, winter dormancy, pre-jointing in the spring, and remaining phases the same as used in our previous work,

b. more weight should be given to early spring moisture in semi-arid regions,

c. need terms in model to reflect need for "drying out" periods in the spring in humid regions in order to achieve optimum yields,

d. need a variable to reflect soil class differences,

e. need terms in model to express effect of extremely low temperatures (winterkill and sterility of heads).

CHAPTER 2

TASK 2.0 AS REQUIRED, DEVELOP AND TEST CROP CALENDAR MODELS NECESSARY TO PACE THE YIELD MODELS IN TASK 1.0

2.1 Results

2.1.1 Statement of the Problem

Robertson's BMTS, with KSU_F winter wheat multipliers, appeared adequate to generate crop calendars for USGP locations with average January temperatures (ADTJ) less than 30°F. For warmer winter climates, the adjusted BMTS tended to estimate jointing too early. A closer look at the behavior of the BMTS was taken and results are discussed in Section 2.1.2.

Application of Robertson's BMTS to locations in India indicated that it was not applicable in those climates. The BMTS generated a jointing date which was too early. Following simulated jointing, daylengths, at lower latitudes, were below the threshold in the BMTS. As a result, the BMTS show zero development until sufficient time passed and daylengths again exceeded the threshold. A fixed crop calendar was built from data presented in Section 2.1.3.

2.1.2 Application of BMTS in Southern Great Plains

A simulation study using Robertson's BMTS, with KSU_F winter wheat multipliers, was undertaken to study changes in the time spent in the various crop phases as the ADTJ (long-term average daily temperature in January) was varied from 6.5°F to 30°F over locations in the USGP. Average number of simulated days spent in the different phases (1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5, 2.5 to 3.0 on the BMTS) were matched against ADTJ values for 42 locations in the USGP and the Northwest (WA, OR, ID). The major findings were:

a. The average number of days from BMTS=2.5 to 3.0 (3.0=heading) using the adjusted BMTS was essentially constant over all 42 locations. The average of the averages was 16 days.

b. The ratio of average number of days from BMTS=1.0 (emergence) to 2.0 (jointing) to the average days from BMTS=1.0 to 3.0 was related to ADTJ by the formula:

$$\text{PROP.} = (\text{D\_EJ}/\text{D\_EH}) = 0.87 - 0.7746*10^{-4}*\text{ADTJ}^2,$$

$$R^2 = .57,\ \text{MSE} = .000275\ .$$

The above formula produces the following interpolated and extrapolated values:

ADTJ(°F)	10	20	30	40	50	60
D_EJ/D_EH	0.86	0.84	0.80	0.75	0.68	0.59

The results in Table 2.1 show how the average jointing dates for Dallas, Texas and Tulsa, Oklahoma would be 30 and 24 days later, respectively when using the formula in this section as opposed to that obtained by Robertson's BMTS, with the KSU_F adjustment. It should be noted that the BMTS with KSU_F adjustment still gave a reasonable heading date for these locations based on plot data from nearby agricultural experiment stations. At Denton, TX the average heading for the variety Triumph was 4/19 (compared with 4/16 at Dallas) and 4/27 at Stillwater, OK (compared with 4/29 at Tulsa). The jointing dates, based on the formula, are more in line with experience of observers in those locations.

Table 2.1 An adjust-ent of jointing date when using Robertson's BMTS.

	Planting	Emergence	Jointing	Heading
Dallas, TX BMTS:	10/12	10/18	1/24	4/16
(ADTJ=45.4) Formula:			2/24	
Tulsa, OK BMTS:	10/3	10/10	2/18	4/29
(ADTJ=36.0) Formula:			3/14	

2.1.3 A Fixed Crop Calendar for India

The second effort involved establishing a fixed crop calendar for India in order to apply our yield model in that country (see Section 1.1.8). The fixed calendar was based on phenological observations on plot data at four experiment stations over a varying number of years. The longest period of record was 1953-72 at New Delhi and the shortest was 1958-64 at Kalai. All observations were on traditional varieties designated by NP-4 and PB-591. The Indian data referred to dates of commencement of elongation, which was equated to jointing, and commencement of ear emergence. The latter data appeared to be too early for heading as measured in this country. Duration of heading was recorded so we took half of that interval and added it to commencement of ear emergence to arrive at a heading date.

The average dates of phenological observations at the four locations are given in Table 2.2.

Table 2.2 Average phenological dates at Indian agricultural experiment stations.

Location	Latitude	Planting	Emergence	Tillering	Jointing	Heading	Harvest
Nagina	29°55'	11/19	12/2	12/20	1/31	3/2	4/19
New Delhi	28°04'	11/11	11/25	12/9	1/9	2/19	4/7
Kalai	27°50'	11/1	11/9	11/20	12/22	2/1	4/7
Kanpur	26°28'	11/7	11/21	12/5	1/2	2/3	4/11

To apply our yield model, the crop calendar for New Delhi was used for all locations in a five-state area of India (see Section 1.1.8). As a test of the applicability of the formula under point (b) above, we note that the ADTJ of new Delhi is 57.7°F. By the equation the number of days from emergence to jointing should be (0.61) times the number of days from emergence to heading. Thus,

$$D\_EJ = 0.61 * D\_EH = 0.61 * 86 = 52 \text{ days.}$$

By Table 2.2, the average number of observed days from emergence to jointing was 45 days for New Delhi. Considering that the equation was developed using ADTJs less than 30°F in the USGP, the extrapolation to an ADTJ of 57.7°F in India is relatively close.

2.2 Recommendations for Further Effort

A new crop calendar with a redefinition of critical stages of development (see Section 1.2) is needed.

CHAPTER 3

TASK 3.0 DEVELOP AREA-SPECIFIC YIELD MODEL FOR THE PARTITIONS IDENTIFIED BY LACIE FOR U.S. AND FOREIGN AREAS

3.1 Results

3.1.1 Statement of the Problem

Work on this task addressed the problem of estimating wheat production (acreage and yield) using a "partition" as a geographic unit rather than a crop reporting district, county, or some political unit. Boundaries of a partition are defined so as to make units more homogeneous with respect to soils and cultural practices. Yields are expected to be more homogeneous within partitions than within political units.

Relative to our findings under Task 1.0, we now see this task as one of assigning A(R,S) values to each partition to make our model,

$$\hat{Y}_t(R,S) = A(R,S) + B * WAC_t(R,S); \quad B = \begin{cases} 0.50 \text{ for spring wheat} \\ 0.75 \text{ for winter wheat,} \end{cases}$$

partition-specific for year (t). Our investigation for Task 4.0 will indicate whether we can relate A(R,S) to observable climate and soil class differences. If so, such knowledge will be partially transferable to the problem of assigning A(R,S) values to weather station-partition combinations.

As indicated in Section 1.1.4, our present level of model-development uses average reported yields over years in region (R) combined with average values of WAC(R,S) over the same set of years to estimate A(R,S). As we compute A(R,S) for more and more regions around the globe, where historical yield, weather, and cultural data are available, the opportunity to relate A(R,S) values to observables increases, especially if the observables vary systematically from partition to partition.

There appeared little more that we could do directly on this task. Indirectly, results on Task 4.0 may give some insight.

We have provided WAC(R,S) values to LEC, NASA-JSC for the USGP. Thus a major input for continued study of this problem is available at NASA-JSC.

3.2 Recommendations for Further Effort

Under Task 1.0, we recommended incorporating a variable to reflect soil class differences in the basic data set used for model development. If successful, this would aid considerably in measuring differences in yield, from partition to partition, due to soil class variation.

CHAPTER 4

TASK 4.0 DEVELOP MODELS FOR THE MANAGEMENT AND PRODUCTION (MAP) FACTORS IN TERMS OF READILY AVAILABLE BASIC INFORMATION

4.1 Results

4.1.1 Statement of the Problem

In early stages of development of our winter wheat model, we estimated regional (CRD) yields by multiplying WAC values (see section 1.1.1) by a constant MAP (management and productivity) factor dependent on the region and weather station combination. MAP values were calculated as the ratio of average historical yields to average WAC values over a common set of years.

Task 4.0 was designed to examine the relation of MAP values to observable characteristics other than weather and cultural factors. Based on results for Task 1.0, we now recommend that regional yields for region (R), using weather at station (S), be estimated by

$$(4.1) \qquad \hat{Y}(R,S) = A(R,S) + B * WAC(R,S), \quad (B = 0.75 \text{ for winter wheat}, \; B = 0.50 \text{ for spring wheat}).$$

In essence, the former MAP quantity is taken to be a constant (B), and the quantity A(R,S) will be analyzed.

4.1.2 Factors Affecting A(R,S)

We considered two observable measures to which A(R,S) may be related. They were

$$(4.2) \qquad D(R,S) = \begin{cases} [AAPR(R) - AAPR(S)]*[30 - AAPR(S)] & \text{if } AAPR(S) \le 30'', \\ 0 & \text{if } AAPR(S) > 30'', \end{cases}$$

where

$AAPR(R)$ = average annual precipitation for region (R),

$AAPR(S)$ = average annual precipitation for station (S),

and

(4.3) $P(R)$ = measure of productivity based on an integrated soil class for region (R) as determined by a soil scientist.

Observed values for D(R,S), P(R), and A(R,S) for 59 CRD's in the winter wheat portion of the USGP are shown in Table 4.1. Values of P(R) were determined from a general soil classification map of the USGP on which the broad expanses of soils were ranked from 2 to 10. Values of A(R,S) were calculated, as in Equation (1.4), by

$$(4.4) \qquad A(R,S) = \bar{Y}(R) - 0.75\ \overline{WAC}(R,S)$$

where

$\bar{Y}(R)$ = average over years of SRS estimated yields,

$\overline{WAC}(R,S)$ = average over same set of years of WAC(R,S) values.

Parameters of the model,

$$(4.5) \qquad \hat{A}(R,S) = \underset{(1.13)}{-3.54} + \underset{(0.01)}{0.08}\ D(R,S) + \underset{(0.15)}{0.41}\ P(R)$$

were estimated by the method of least squares. The standard errors of the estimated parameters are shown in parentheses. The R^2 value was 0.45 and the standard deviation of A(R,S) for fixed values of D(R,S) and P(R) was 2.5.

In brief, both factors that we chose to observe were significantly related to A(R,S) values. The analysis points to an expected result;

namely, that A(R,S) values were in part related to:

(a) the amount by which a weather station is displaced from the "weather center" of a region, relative to precipitation, in semi-arid regions,

(b) the general productivity of the soil, a factor not in the part of the model which produces WAC values.

The measure P(R) was rather crude and more precision in this measure appears possible. While Equation (4.5) represents an alternative, Equation (4.4) is preferred if historical yield and weather data is available.

4.1.3 Variation of A(R,S) With Time

We can use Equation 4.4 to check on the stability of A(R,S) over time. Suppose that the right side consists of averages over ten-year intervals. If WAC values account for most of the variation in SRS estimates over a 20-year period, then we expect A(R,S) to be stable through time. If we find systematic change in A(R,S), as we take successive 10-year periods, we suspect that there are factors at work that are not in the model.

In Table 4.2, we look at changes in $\bar{Y}(R)$, $B * \overline{WAC}(R,S)$ ($B = .75$ for winter wheat, 0.50 for spring wheat), and A(R) where the ten-year averages are calculated over the periods 1955-64 and 1967-76. Algebraically,

$$\Delta[A(R)] = \Delta[\bar{Y}(R)] - \Delta[B * \overline{WAC}(R)]$$

or

$$A_2(R) - A_1(R) = [\bar{Y}_2(R) - \bar{Y}_1(R)] - [B * \overline{WAC}_2(R) - B * \overline{WAC}_1(R)]$$

where subscripts 1 and 2 refer to the periods 1955-64 and 1967-76, respectively. The results are interesting.

With the exception of Nebraska, the USGP winter wheat results, with small values of $\Delta[A(R)]$, indicate that the factors in the model account for most of the increase in yield over the 12-year interval from 1960 to 1972. Since 10-year averages tend to average out "normal" weather variation, most (5 bu./acre) of the 6.9 bu./acre increase for the USGP is due to cultural factors in the model and a relatively small amount (1.9 bu./acre) is due to other factors. As for Nebraska, we see from Table 1.3 that the model underestimated in high yielding years. Had the model responded to the "good weather" more accurately, the $\Delta[B^*WAC(R)]$ would have been larger and $\Delta[A(R)]$ accordingly smaller.

For the Northwest, the results indicate that the factors in the model account for all the increase in yield with the change in A(R) close to zero.

In the Eastern Plains, the increase in yields, as measured by $\Delta[\bar{Y}(R)]$, is less than we expect from "technology change", as measured $\Delta[B^*WAC(R)]$. Either our model overestimates technology effects or other factors caused drastic decreases in yield sometime during the 1967-76 period. The latter appears to be the case as shown in Table 1.6.

The results for spring wheat suggest that cultural factors in our model explain about 50% of the increase due to technology. For North Dakota we are fairly certain that much of the remaining 3.3 bu./acre is associated with a move toward later planting and increased use of herbicides between 1960 and 1972 to reduce weed population. These and other management techniques may have been responsible for changes in A(R) in the other states.

The results in Table 4.2 reiterate the importance of including specific cultural as well as weather factors in a yield model. Without the cultural factors of improved varieties and nitrogen amounts in the model, the contribution of these factors could have been underestimated by 30% in the Eastern Plains if we had looked at $\Delta[\bar{Y}(R)]$ values alone to measure "technology" effects. An obvious improvement in the model would be inclusion of disease losses, especially when they are of epidemic proportion.

The results for spring wheat show that we can look at the magnitude of $\Delta[A(R)]$ and decide whether we have to look for factors not in our model to explain changes in yield.

4.2 <u>Recommendations for Further Effort</u>

A soils factor should be included in the basic development of the model from experimental plot yields and incorporated into WAC values. Based on the above results, it should help to explain some of the spatial variation in yields.

Need for the displacement factor D(R,S) arises from sparseness of weather stations. A denser network, more representative of weather in a region (R) could eliminate this factor.

Table 4.1 Values of variables used for modeling A(R,S).

State	Region(CRD)	Station(S)	D(R,S)	P(R)	A(R,S)
MT	02	CUT	23.56	10	5.9
MT	02	GTL	-34.86	10	-0.7
MT	03	LEW	-67.13	10	-6.4
MT	05	GTL	-2.07	9	-0.9
MT	05	HEL	72.91	9	6.1
MT	05	LEW	-48.69	9	-2.0
MT	08	BIL	14.38	9	-1.9
MT	08	BOZ	32.17	9	3.8
MT	08	LIV	12.61	9	-2.2
MT	09	MLC	-2.40	9	-0.7
SD	01	MLC	23.24	5	-1.3
SD	02	ABN	6.63	8	5.6
SD	04	PIE	2.34	10	0.9
SD	05	PIE	-2.84	9	-2.3
SD	07	CHD	32.51	6	5.8
SD	08	VAL	71.71	9	5.7
CO	02	AKR	-13.41	9	5.3
CO	06	AKR	7.26	8	2.4
CO	06	DEN	16.95	8	-1.4
CO	09	LAJ	74.50	8	2.8
NE	01	CHD	38.89	7	3.1
NE	01	SCF	45.04	7	4.8
NE	03	NFK	13.97	8	1.1
NE	05	GRI	0.64	8	-0.1
NE	06	OMA	-0.20	8	-1.2
NE	07	NPT	-1.37	7	3.5
NE	08	CCD	-6.73	9	-0.1
NE	09	TOP	0.00	8	0.9
KS	01	GOD	59.65	9	6.3

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Table 4.1 (continued)

State	Region(CRD)	Stations(S)	D(R,S)	P(R)	A(R,S)
KS	01	HLC	-15.22	9	-0.3
KS	02	CON	-3.35	9	-1.2
KS	03	TOP	0.00	8	2.8
KS	04	HLC	-14.12	8	-3.0
KS	05	RUS	0.33	8	-1.9
KS	05	SAL	-1.34	8	-3.2
KS	06	TOP	0.00	8	1.3
KS	07	DGD	-19.64	8	-1.7
KS	07	GNC	4.40	8	0.2
KS	08	WIC	-1.22	7	-1.4
KS	09	CHA	0.00	7	0.8
OK	01	GAG	13.23	6	-2.9
OK	02	PNC	0.00	7	-1.0
OK	03	TUL	0.00	5	-1.1
OK	04	OKC	0.00	3	-3.8
OK	05	OKC	0.00	5	-3.3
OK	07	HOB	27.54	7	-2.1
OK	08	WFA	24.40	5	-1.8
TX	1N	AML	-4.22	6	-2.5
TX	1N	DAL	39.14	6	-0.1
TX	1S	CRL	27.55	3	5.2
TX	1S	LUB	-17.87	3	-1.5
TX	1S	MID	46.72	3	2.9
TX	1S	RSW	32.57	3	5.5
TX	2N	CHD	35.86	5	-0.9
TX	2N	WFA	-14.05	5	-6.6
TX	2S	ABL	-8.58	8	-4.8
TX	3	WFA	2.00	2	-6.8
TX	4	DAL	0.00	2	-2.1
TX	4	WAC	0.00	2	-1.7

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Table 4.2 Changes (Δ) in ten-year average SRS, Model, and A(R) values between 1960 and 1972. Entries are bushels per acre (Δ = 1967-76 ave. minus 1955-64 ave.).

Crop	State (R)	SRS $\Delta[\bar{Y}(R)]$	Model $\Delta[B*\overline{WAC}(R)]$	$\Delta[A(R)]$
Winter Wheat	Colorado	4.2	3.0	1.2
	Oklahoma	4.7	4.1	0.6
	Montana	5.3	4.2	1.1
	Texas	5.6	3.5	2.1
	Kansas	8.3	6.2	2.1
	So. Dakota	9.2	7.2	2.0
	Nebraska	10.2	5.4	4.8
	USGP	6.9	5.0	1.9
	Washington	9.3	10.0	-0.7
	Idaho	11.4	11.5	-0.1
	Northwest	9.8	10.3	-0.5
	Missouri	4.6	8.5	-3.9
	Illinois	5.2	10.5	-5.3
	Indiana	7.4	9.5	-2.1
	Ohio	8.3	8.4	-0.1
	Eastern Plains	6.3	9.3	-3.0
Spring Wheat	Montana	5.8	3.3	2.5
	So. Dakota	6.2	2.6	3.6
	No. Dakota	6.4	3.1	3.3
	Minnesota	8.3	4.0	4.3
	USGP	6.5	3.2	3.3