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CROP WEATHER MODELS OF BARLEY AND SPRING WHEAT YIELD FOR AGROPHYSICAL UNITS IN NORTH DAKOTA

3 - SHARON LEDUC

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16. Abstract Models based on multiple regression were developed to estimate barley yield and spring wheat yield from weather data for Agrophysical Units (APU) in North Dakota. The predictor variables are derived from monthly average temperature and monthly total precipitation data at meteorological stations in the cooperative network. The models are similar in form to the previous models developed for Crop Reporting Districts (CRD). The trends and derived variables were the same and the approach to select the significant predictors was similar to that used in developing the CRD models. The APU's were selected to be more homogeneous for crop production than the CRD's. The APU models show slight improvements in some of the statistics of the models, e.g., explained variation. These models will be independently evaluated and compared to the previously evaluated CRD models. The comparison will indicate the preferred model area for this application, i.e., APU or CRD.					
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Crop Weather Models of Barley and Spring Wheat Yield
for Agrophysical Units in
North Dakota

Sharon LeDuc

Previous crop weather models for North Dakota crop reporting districts and the entire state were developed for spring wheat (LeDuc, 1981) and for barley (Motha, 1980). This report documents spring wheat yield models for agrophysical units in North Dakota. Agrophysical units (APU's) are areas defined to be homogeneous with respect to soils and climate, manifested in crop yield. The definition of these areas is contained in a memorandum of understanding from Strommen and Dragg (Jan. 10, 1980). Three APU's or groups of counties, were defined in North Dakota (Figure 1): west (21), central (19) and east (20).

Data

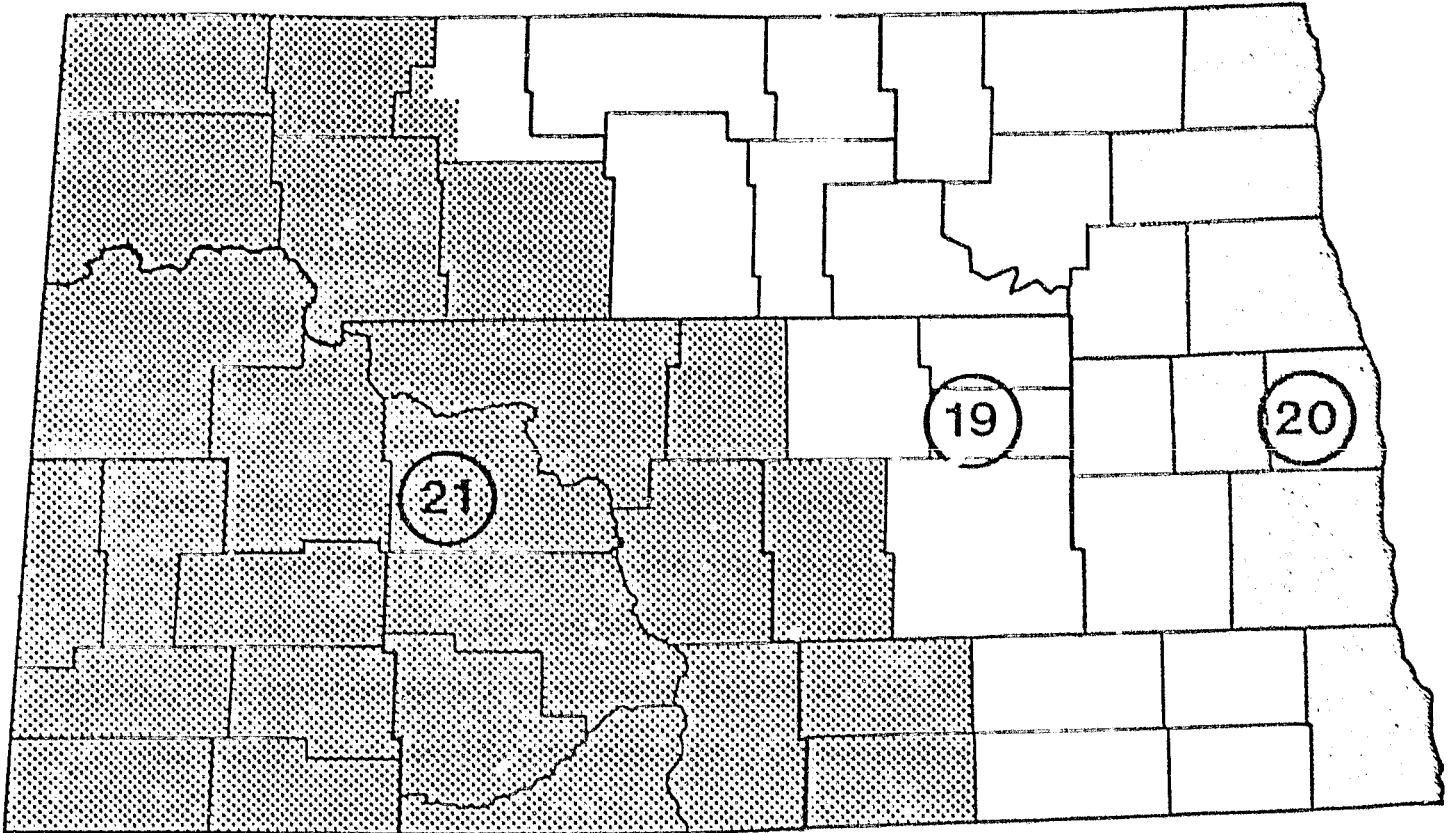
Data were developed for these APU's specifically for use in crop yield modeling efforts. Monthly temperature and precipitation observations for cooperative stations (stations within 5 nautical miles averaged and considered as a single station) were used to estimate the temperature and precipitation appropriate for each county. Counties are the small political subdivisions in Figure 1.

The inverse distance method and the Thiessen method (Linsley, Kohler and Paulhus; 1958), were used for averaging the cooperative weather station data. Both methods used a weighted average of stations within 50 nautical miles of the county's geographic center. This included stations in neighboring states but not from Canada. The number of stations for a county was zero for a few counties in some of the early years but was five for most of the estimates.

Figure 1.

North Dakota Agrophysical Units (APU's) and Counties

NORTH DAKOTA



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Each station was weighted accordingly in the averaging. The weight (w_1) for the i th station with the inverse distance method is $w_1 = d_1^{-1}$, where d_1 is the Euclidean distance from the geometric center of the county to that station. The Thiessen method uses weights based on the area closest to that station (Figure 2). The measure of the area closest to station 3, shown by the lightest shaded area in the county (Figure 2), is the weight assigned to station 3, i.e., $w_3 = A_3$.

This same procedure is used with all three weather variables: maximum temperature, minimum temperature and precipitation. Let V_1 represent one of these variables for station i and let station 1, 2, ..., n be all of the stations within fifty nautical miles of the center of the county of interest. The estimate of this variable for this county is:

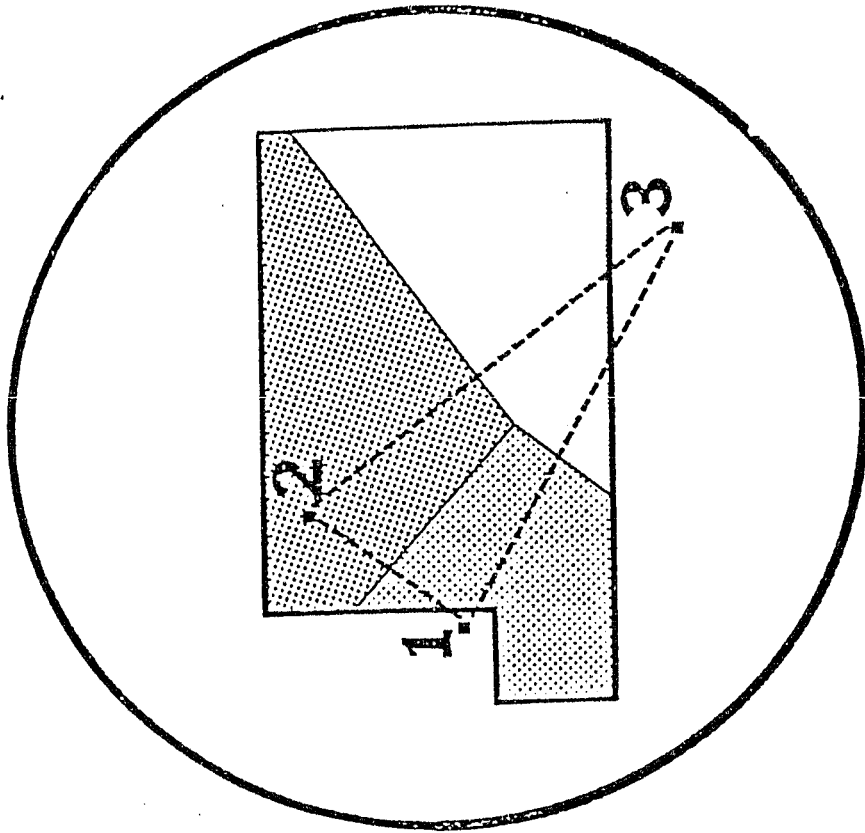
$$V = \frac{\sum_{i=1}^n w_i V_i}{\sum_{i=1}^n w_i},$$

where the weight corresponds to one of the two methods. These data were developed under the supervision of Dr. Wayne Decker, Atmospheric Science Department, University of Missouri, Columbia.

The two methods produced similar results. The biggest differences occurred for temperature during the winter, due to frontal movements. These differences were not of concern since the crops are not planted prior to or during the winter. There is no direct physical explanation that would suggest winter temperature should be included in the model. The estimates of weather variables from the inverse distance method were used in the models because the method is much simpler. The counties were assigned to one of the three APU's and the value for a single APU was calculated as the simple average of each meteorological variable for each month of each year. These variables formed the basic data from which the derived variables were calculated.

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Figure 2
Thiessen Method of Estimating the Value for an Area from the Value at Several Points



Selection of Variables

Predictor variables were selected from the list of potential predictors described earlier. The method of selection involved the use of stepwise regression. An attempt was made to examine predictor variables selected for a particular APU by the stepwise regression procedure using several selection methods: stepwise, forward and backward. The significance level for entry with the forward selection was .50, the significance level for remaining in the model with backward elimination was .10. Stepwise used the same significance levels. The results of the three methods were compared and variables included by all three methods were considered as potential variables. The maximum R^2 improvement method was used and the model selected for which all variables were significant at the .10 level. Several of these models contained a number of related variables for the same month. Various combinations were tried in an attempt to include information from other months and to reduce the number of variables containing information from the same month. It is not possible to document here all the combinations which were examined nor why many were rejected. The statistical significance in the end of season model was a prime consideration. The need to include information from different periods in the growing season was recognized but not at the expense of including a statistically insignificant variable.

The problem of near collinearity of variables will have to be addressed in the evaluation of the models. Unless the nature of this near collinearity changes, the precision of the predicted value should not be affected (Mandel, 1982). Variables significant for adjacent APU's were checked and included in other APU's if statistically significant and physically meaningful. Variables included in the final model were used for the truncated models, i.e., models

which use only the weather variables for a stated month and the preceding months. These models are used for obtaining estimates within the growing season without making assumptions about future weather conditions. In one case an extra predictor variable was included for May and June truncations but was not in the July final model. The variable plus May precipitation minus potential evapotranspiration was not significant in the model for the end of the season. Variables were considered for inclusion or elimination as a result of comments received from the review of the first draft of this document. This was the spring wheat model for the western APU. This additional variable improves the earlier truncations but do not add significantly to later truncations.

The estimated coefficients of the squared terms are negative. This is intuitively appealing since extrapolation in either direction should at some point be associated with a decrease in yields.

Barley Models

The statistics defining the models for various truncations are shown in Table 1. The more important months for estimating the impact of weather on barley yields appear to be June and July. Evapotranspiration appears to be a good indicator of final yield for June in all APU's and also in July for the Central and Western APU's. Temperature in July is important in the Eastern APU. May variables did not seem to be important and there are no truncated models for the month of May. The squared deviation of cumulative precipitation (Sept-Apr) is important in the Central and Eastern APU's. The coefficient is negative indicating that too much or too little precipitation during the fall, winter and spring just prior to planting are two conditions which can be associated with decreased yield.

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Table 1

Coefficients and R² for Barley Models (Yield in qu/ha)

Coefficients for

Area	Variables Thru	R ²	TREND1	TREND2	DSQ4	ETP6	EIHAT6	EIHAT7	DEF7	XDD7
19 Central	Trend	.68	.507	.399						
	April	.78	.491	.502	-.000747					
	June	.83	.500	.478	-.000496	10.2				
	July	.94	.511	.504	-.000295	12.9		-.176	.0337	
20 Eastern	Trend	.80	.359	.558						
	April	.85	.315	.620	-.000364					
	June	.89	.348	.624	-.000311			-.112		
	July	.94	.361	.626	-.000227			-.107		-.916
21 Western	Trend	.51	.459	.336						
	June	.75	.305	.331		17.3				
	July	.91	.443	.358		15.7		-.109	1.0586	

TREND1 is year minus 1930 up to a maximum of 31.

TREND2 is year minus 1960 down to a minimum of 1.

DSQ4 is the squared departure of the Sept thru Apr cumulative precipitation from the APU average (mm).

ETP6 is the ratio of actual to potential evapotranspiration for June (unitless).

EIHAT6, EIHAT7 are the "climatically appropriate" evapotranspirations for June and July, respectively (mm).

DEF7 is precipitation minus the potential evapotranspiration in July (mm).

XDD7 is the July temperature minus the average (°C).

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The western APU does not appear to have the problem with excessive precipitation. Extremely hot temperatures and moisture stress at heading, usually in July, are strongly related to yield. Similar variables are found in the models for the separate APU's with the central APU showing similarity to both the eastern and western APU's.

The trend variables selected were the same for each model. As mentioned earlier, the only trend variables considered were those defined by Motha (1980). TREND1 is year minus 1930 until 1961 and is 31 after that. TREND2 is one until 1961 and is year minus 1960 after that.

The coefficients for TREND1 ranged from .315 to .511 for the various models and for TREND2 from .331 to .626. This surrogate for technology indicates the contribution from 1948 to 1981 for the end of the season models are:

central APU, + 16.7 quintals/hectare;

eastern APU, + 17.2 quintals/hectare;

western APU, + 12.9 quintals/hectare.

This corresponds to the fact that larger yield increases have been possible where more moisture is available, i.e., the eastern part of the state. Graphs of the fit of the full season models are shown in Figures 3-5. The standard errors range from 1.60 to 2.49 q/ha for the CRD end of season models which were developed with data from 1931-1978. The standard errors for end of season APU models are 1.36, 1.29 and 1.69 q/ha for the east, central and west, respectively.

Spring Wheat Models

The statistics defining the models for various truncations are shown in Table 2. The multicollinearity problem is obvious in the July truncation for APU 19 and 20. The coefficient for XDD7 has a large negative coefficient and EIHAT7 a large positive coefficient. These effects are offsetting because the two variables are highly correlated.

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Table 2

Coefficients and R² for Spring Wheat Models (Yield in qu/ha)

Area	Variables Thru	R ²	TREND1	TREND3	CP4	DSQ4	DEF5	XDD5	XDD6	DEF6	XDD7	EIHAT7	DEF7
19 Central	Trend	.72	.884	-.054									
	April	.77	.915	.137			-.000495						
	June	.80	.939	.134			-.000438		-.579				
	July	.89	.903	.424			-.000386		-.510		-678	134	
20 Eastern	Trend	.74	.784	.328									
	April	.79	.795	.453			-.000324						
	June	.81	.808	.461			-.000292		-.431				
	July	.89	.763	.738			-.000269		-.400		-322	62	
21 Western	Trend	.65	.732										
	April	.70	.647		.296	-.000156							
	May	.82	.653		.0391	-.000549	.0381	1.10					
	June	.85	.642		.0361	-.000407	.0363	0.970		.0239			
	July	.92	.684		.0271	-.000291		.665		.0278	-.46		.0292

TREND1 is 1 until 1956, then is year minus 1954 through 1966 and 12

TREND3 is 1 until 1974, then is year minus 1972;

CP4 is cumulative precipitation (mm) from previous September through April;

DSQ4 is the square of the quantity, CP4 minus the average CP4;

DEF5(DEF6,DEF7) is precipitation minus potential evapotranspiration (mm) for May, June, July);

XDD5, XDD6 (XDD7) is the temperature minus the average temperature for May (June,July) in °C;

EIHAT7 is the climatically appropriate evapotranspiration for July in mm.

May truncation is included for the western APU only while all three APU's have a truncation for April. July, the month of heading, would appear to be the month when weather has the most impact on yield. The explained variation (R^2) increases with the model for the July truncation in comparison to the models for the previous truncation, i.e., June.

The temperature in July is important in the models for all three APU's and the coefficient has a negative sign indicating hotter weather in July is associated with decreases in spring wheat yield across the state. The climatically appropriate evapotranspiration is in the model for the central and eastern APU. The western APU includes the precipitation minus potential evapotranspiration. The sign of the coefficients for these variables indicates that more moisture is associated with higher yields.

Cumulative precipitation appears in the models for all APU's. The cumulative precipitation from September prior to planting through April is squared after subtracting the average. This variable has a negative coefficient indicating that too much or too little precipitation during those eight months, which affects soil moisture at planting in April and May, is associated with decreased yield. The western APU also has the linear term of the cumulative precipitation from September through April. This reflects the fact that this APU climatically has less moisture than the other two APU's, and the impact of deficit precipitation is more pronounced, i.e., yields are lower, than with precipitation greater than normal. The western APU model also has a variable for May which indicates yield increases are associated with more precipitation than potential evapotranspiration.

The first trend (TREND1) for the spring wheat models was significant for all APU's and is defined as year minus 1954 from 1955 until 1966. It is one prior to 1955 and 12 after 1966. An additional trend (referred to as TREND3)

included in the central and eastern APU's is 1 until 1974, then it is year minus 1972. The changes in the contribution of trend to the yield as estimated from the full season models from 1948 to 1979 are the following: 12.4 quintals/hectare for central APU; 12.5 quintals/hectare for eastern APU; and 7.5 quintals/hectare for western APU. Graphs of the fit of the full season models are shown in Figures 6-8.

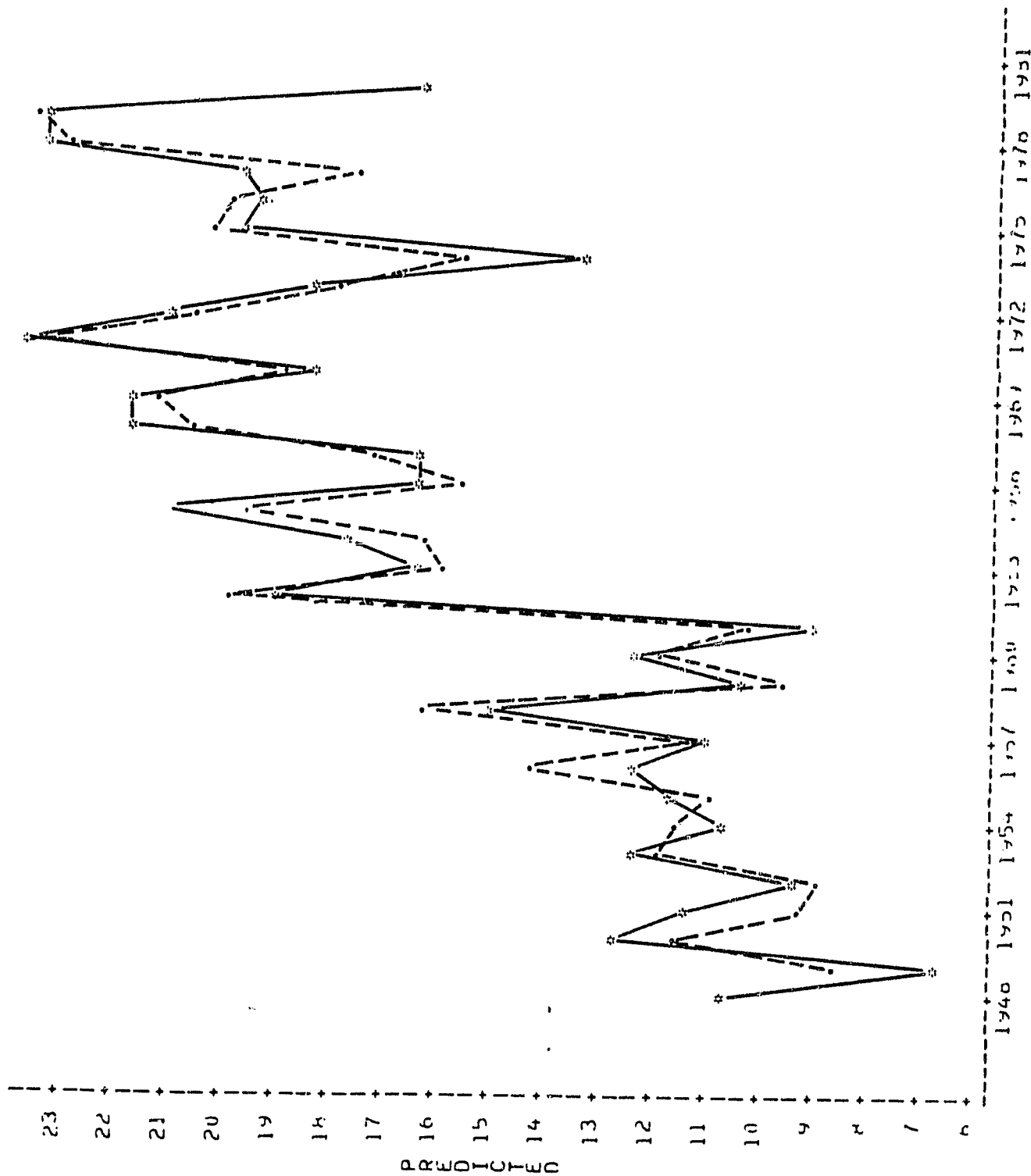
Comparison with Crop Reporting District (CRD) Models

Barley

The trend used in the CRD barley models had two linear components, one from 1931 until 1961 and the second from 1961 through 1978. Five of the nine CRDs had an additional quadratic trends from 1961-1978: west central, central, and the three southern CRDs. The APU barley models have two linear trends which by design are exactly the same as the linear trends for the CRD models. No quadratic trends were included in any of the APU models. None of the APU models have May or March truncations. All except two of the CRDs have models for May truncations, and four have a March truncation. Two of the eastern and one of the western CRDs have August truncations whereas only the central APU had an August truncation. The explained variance (R^2) for the full season model is very similar, perhaps slightly higher (.91 - .94) for the APU models; CRD models ranged from .80 to .94. There is quite a bit of difference in the meteorological variables selected as predictors. The July variables did not seem to improve the R^2 as much with the CRD models as with the APU models and August truncations are included for the CRD models.

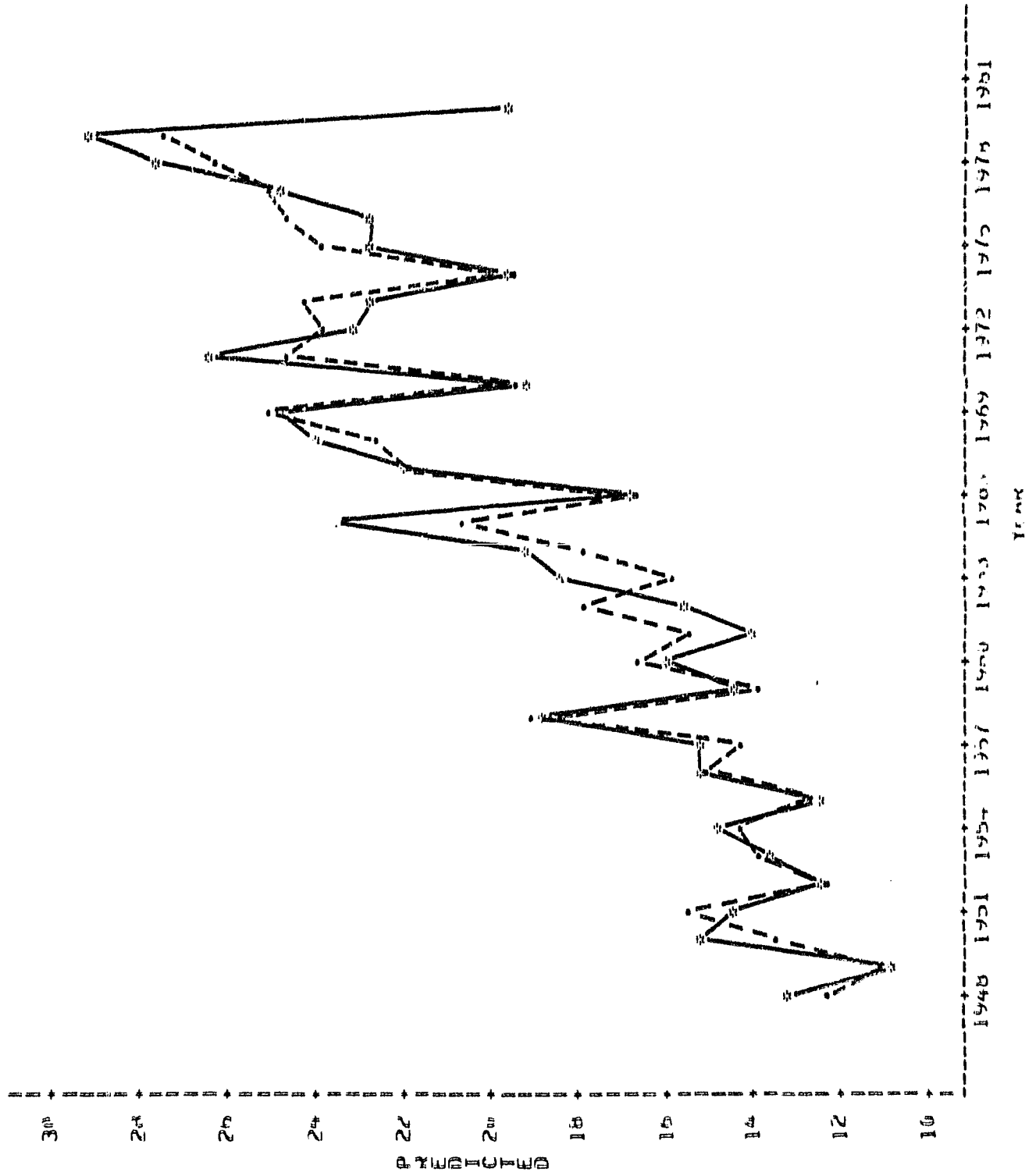
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FIGURE 3 NORTH DAKOTA BARLEY CENTRAL APJ 19
PLOT OF YIELD x YEAR SYMBOL USED *
PLOT OF YHAT x YEAR SYMBOL USED .



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FIGURE 4 NORTH DAKOTA BARLEY EASTERN APU 20
PLOT OF YIELD x YEAR SYMBOL USED *
PLOT OF YHAT x YEAR SYMBOL USED .



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FIGURE 5 NORTH DAKOTA BARLEY WESTERN APU 21

PLOT OF YIELD x YEAR *
PLOT OF YHAT YEAR
SYMBOL USED *
SYMBOL USED :

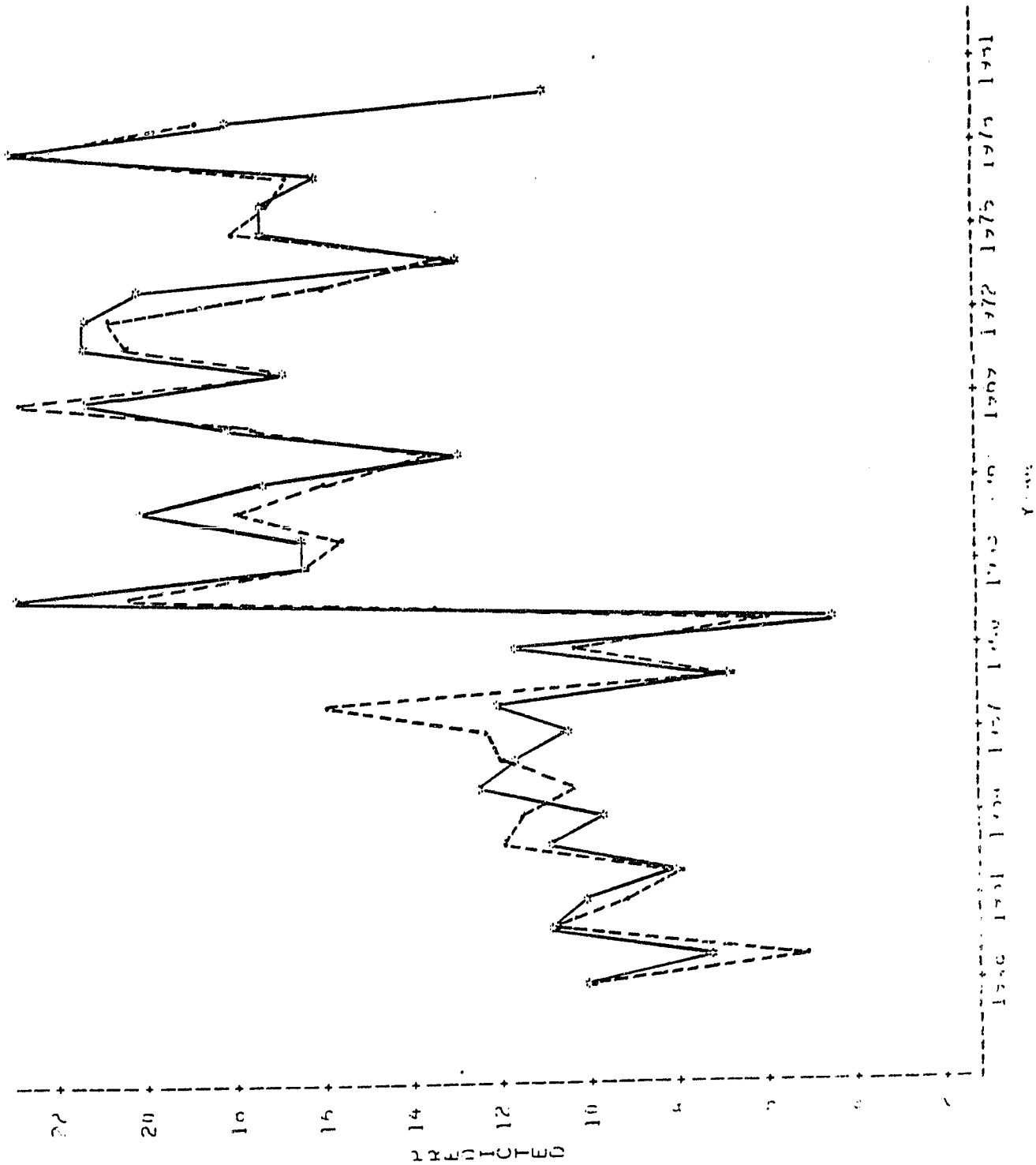
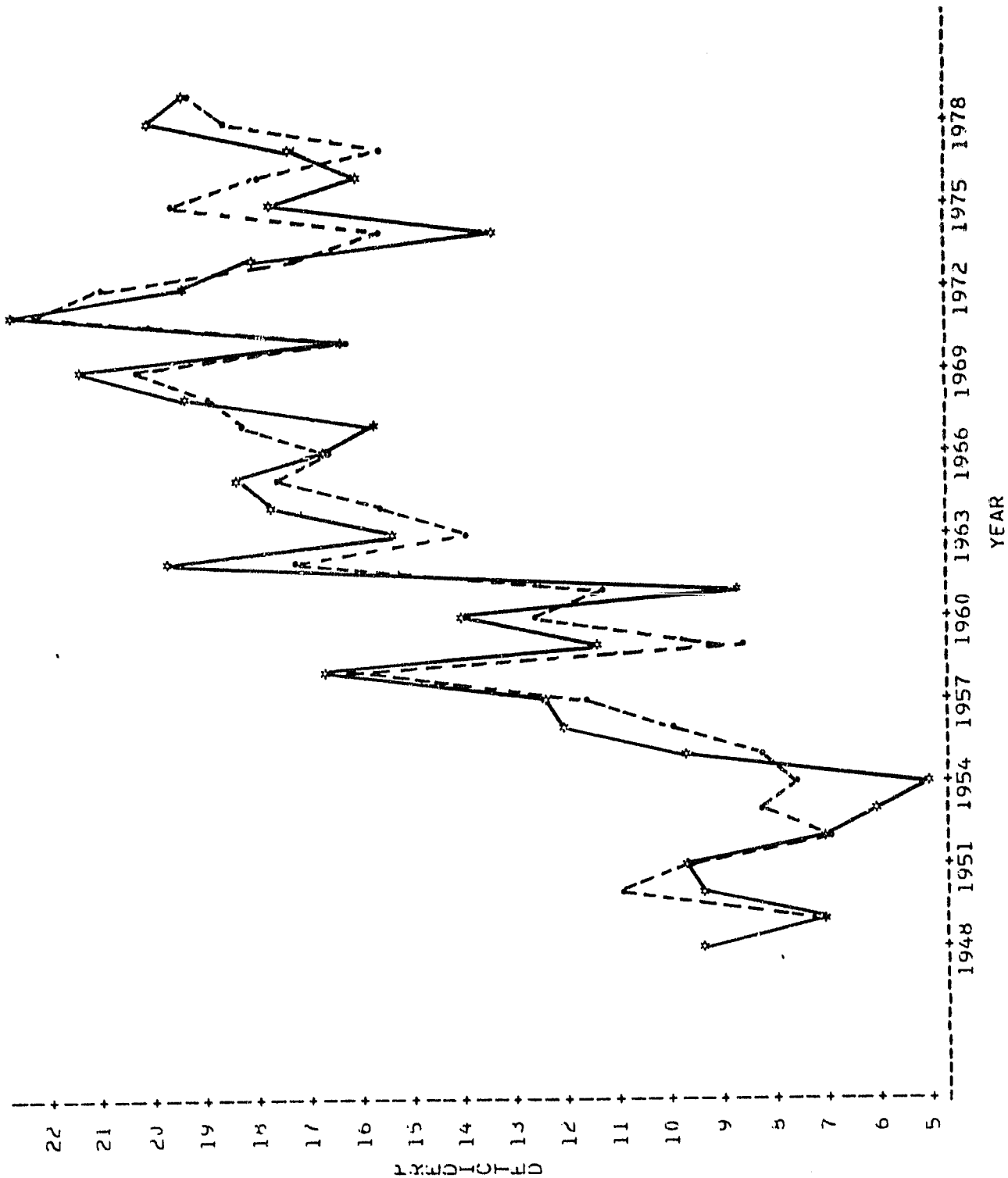


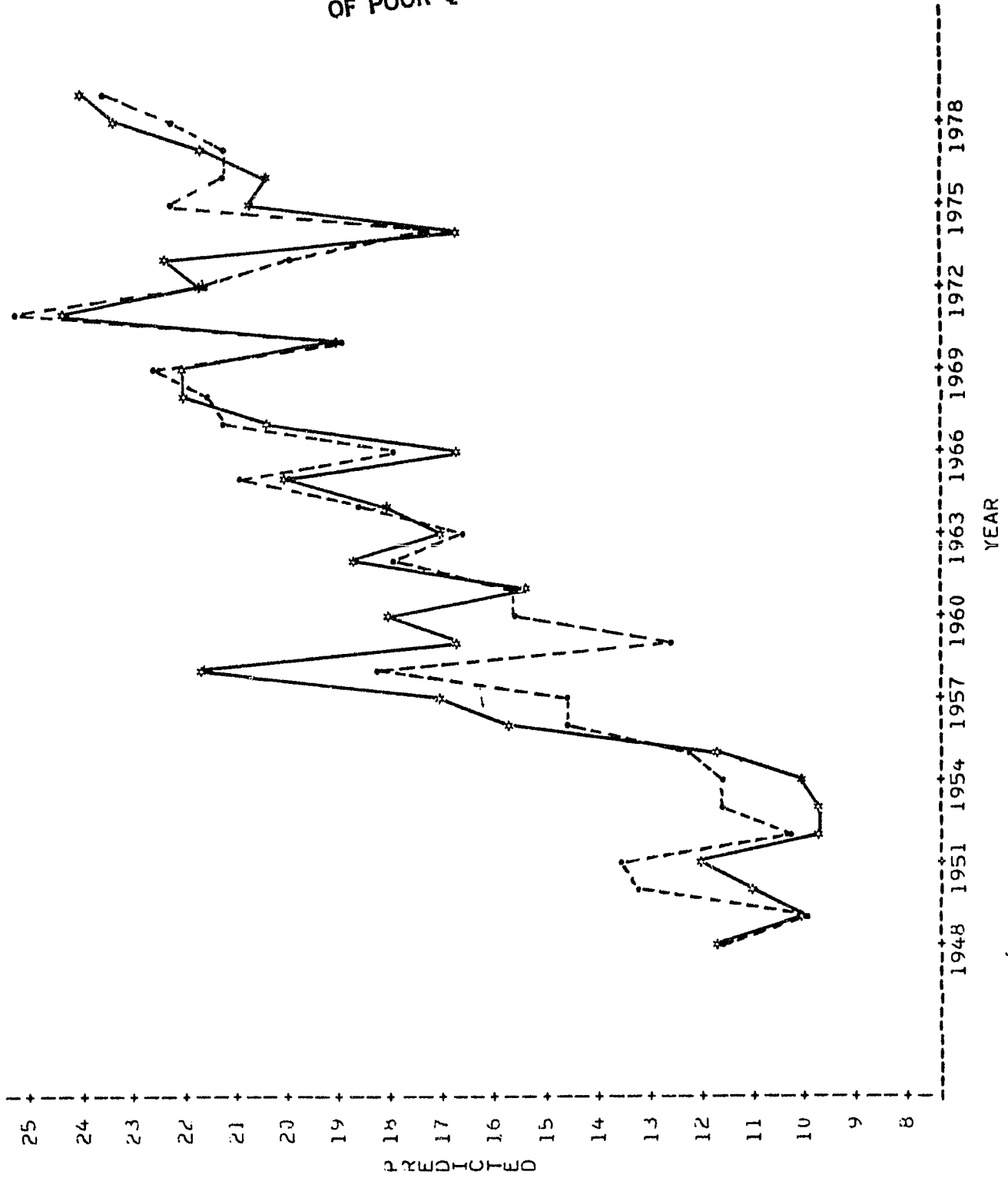
Figure 6. NORTH DAKOTA SPRING WHEAT CENTRAL APU 19
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Figure 7. NORTH DAKOTA SPRING WHEAT EASTERN APU 20

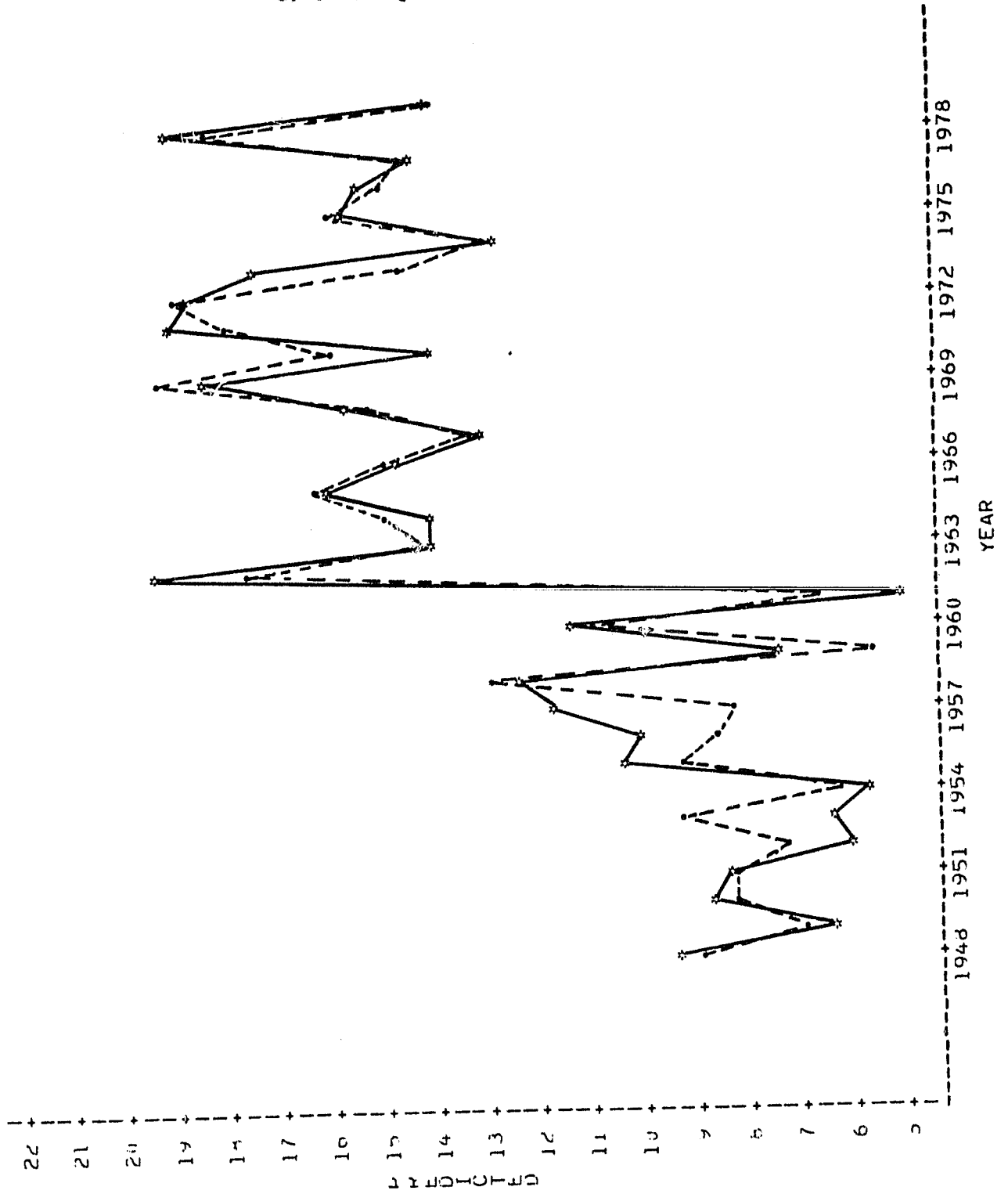
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PLOT OF YHAT*YEAR SYMBOL USED IS .



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Figure 8. NORTH DAKOTA SPRING WHEAT WESTERN APU 21

PLOT OF YIELD*YEAR SYMBOL USED IS *
PLOT OF Y4AT*YEAR SYMBOL USED IS .



Spring Wheat

CRD models included one trend or, in the southeast CRD, two trends. The trends which were examined for APU's were designed to be the same as in the CRD models. The first (TREND1) is linear from 1955 until 1966. The second (TREND2) was linear from 1966 until 1973 and constant before and after that period. The southeast was the only CRD which included the second trend. An additional (TREND3) which was considered but not selected by any of the CRD models was constant prior to 1973 and linear after that. This trend was selected for the eastern and central APU models. All CRDs except the three western and the south central had an August truncation. The explained variance R^2 in yield for the final truncation model, ranged from .85 to .88 for the CRDs, except south central which was .77. The explained variances for APU final truncation models were the following: .89 central APU; .89 eastern APU; and .92 western. These were quite compatible with the CRD results. Although July appeared to be an important month in the APU models, two CRDs (central east and south central) do not even have July truncations and the July truncation does not improve the R^2 appreciably for the southwest CRD. Temperature variables are common for July, the month of heading, for both types of models. Only the three western CRDs and south central CRD have May truncations, correspondingly only the western APU model has a May truncation.

SUMMARY

The models for APUs should provide yield estimates that allow for evaluation of the improvement over CRD models. The models are defined in this paper and a general comparison is made with the CRD models. A testing procedure will be necessary to evaluate the improvement by using APU instead of CRD models.

This study provides the first attempt to develop agrophysical unit models, i.e. models for areas larger than CRDs that are assumed to have similar physical characteristics. These candidate models will be evaluated and compared with the CRD models at the state level. This is a task in the YMD project. Procedures for comparing the yield indications at the state level already exist.

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APPENDIX

VARIABLE DEFINITIONS FOR NORTH DAKOTA EARLY AND SPRING WHEAT

- TREND1 - 1 IF YR<1955 OR YR=1954 IF YR<1950 OR 12 IF YR<1973 (SP WHEAT)
- TREND3 - 1<1973 OR YEAR=1972 IF YEAR>1972 (SP WHEAT)
- TREND1 - YR=1930 IF YR<1951 OR 31 IF YR>1950 (BARLEY)
- TREND2 - 1 IF YR<1951 OR YR=1950 IF YR>1950 (BARLEY)
- CP4 - CUMULATIVE PRECIPITATION FOR APRIL
- DSQ4 - SUMMER CUM DEFICIT DEVIATION FOR APRIL
- DEF5 - SCP-PET FOR MAY
- XDD5 - TEMPERATURE DEVIATION FOR MAY
- DEF6 - TEMPERATURE DEVIATION FOR JUNE
- XDD6 - TEMPERATURE DEVIATION FOR JUNE
- ETHAT5 - CLIMATICALLY APPROPRIATE POTENTIAL EVAPOTRANSPIRATION FOR JUNE
- FIP5 - EIPET FOR JUNE
- DEF7 - TEMPERATURE DEVIATION FOR JULY
- XDD7 - TEMP DEVIATION FOR JULY
- ETHAT7 - CLIMATICALLY APPROPRIATE POTENTIAL EVAPOTRANSPIRATION FOR JULY

NORTH DAKOTA BARLEY CENTRAL APU 19

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MODEL: TREND F RATIO 29.21
 DEP VAR: YIELD PROB>F 0.0001
 R-SQUARE 0.6760

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 -1.068372 4.401951 -0.2427 0.8100
 TREND1 1 0.507354 0.166335 3.0502 0.0050
 TREND2 1 0.399985 0.103774 3.8457 0.0006

MODEL: APRIL F RATIO 32.07
 DEP VAR: YIELD PROB>F 0.0001
 R-SQUARE 0.7809

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 -0.0000405362 3.698368 -0.0000 1.0000
 TREND1 1 0.490358 0.139375 3.5197 0.0016
 TREND2 1 0.501902 0.091490 5.4859 0.0001
 DSQ4 1 -0.000746905 0.002077573 -3.5951 0.0013

MODEL: JUNE F RATIO 30.77
 DEP VAR: YIELD PROB>F 0.0001
 R-SQUARE 0.8256

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 -9.604923 5.013965 -1.9156 0.0665
 TREND1 1 0.500404 0.126768 3.9475 0.0005
 TREND2 1 0.478392 0.083672 5.7175 0.0001
 DSQ4 1 -0.000495788 0.0002124409 -2.3338 0.0276
 ETP6 1 10.244010 3.967065 2.5823 0.0158

MODEL: JULY F RATIO 66.94
 DEP VAR: YIELD PROB>F 0.0001
 R-SQUARE 0.9436

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 7.075284 4.359200 1.6231 0.1176
 TREND1 1 0.511309 0.077420 6.6044 0.0001
 TREND2 1 0.503610 0.051982 9.6882 0.0001
 DSQ4 1 -0.000295259 0.0001320788 -2.2355 0.0349
 ETP6 1 12.884531 2.384465 5.4035 0.0001
 ETHAT7 1 -0.175684 0.042329 -4.1504 0.0004
 DEF7 1 0.033686 0.009859557 3.4165 0.0023

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NORTH DAKOTA BARLEY CENTRAL APU 19

OBS	YEAR	YIELD	TREND1	TREND2	DSQ4	ETP6	ETHAT7	DEF7	YHAT
1	1948	10.81118	18	1	835.40	0.33965	100.860	-36.36	8.5898
2	1949	11.63285	19	1	836.62	0.81221	199.849	-40.98	11.6240
3	1950	11.36535	20	1	955.01	0.98342	91.271	-76.21	19.2026
4	1951	11.40777	21	1	2693.94	0.85820	96.313	-88.13	9.0577
5	1952	11.24963	22	1	1017.32	0.00000	96.313	-92.13	11.8990
6	1953	11.07693	23	1	620.01	0.00000	106.937	-84.75	11.7995
7	1954	11.37110	24	1	436.94	0.86586	101.832	-53.70	11.9219
8	1955	11.95602	25	1	894.20	0.89793	191.775	-55.27	14.3070
9	1956	11.10225	26	1	403.88	0.91257	119.995	-65.45	11.1795
10	1957	11.37250	27	1	745.12	0.91572	102.257	-42.45	11.6130
11	1958	11.46300	28	1	4510.85	0.89930	105.923	-90.31	19.1464
12	1959	11.13966	29	1	734.72	0.54696	198.337	-105.30	12.0224
13	1960	11.01638	30	1	274.43	0.92107	198.337	-66.48	11.1928
14	1961	11.40345	31	1	320.43	0.95107	90.923	-103.90	12.2644
15	1962	11.81403	31	1	994.20	0.00000	90.923	-63.31	10.2546
16	1963	11.40345	31	1	320.43	0.90187	104.910	-85.92	15.2356
17	1964	11.02601	31	1	320.43	0.95850	196.313	-91.79	16.7414
18	1965	11.58315	31	1	320.43	0.88062	104.323	-69.43	15.2356
19	1966	11.09132	31	1	123.69	0.00000	197.323	-102.51	17.5630
20	1967	11.40601	31	1	324.69	0.00000	104.323	-67.43	17.2100
21	1968	11.58315	31	1	629.33	0.00000	95.808	-58.74	20.6280
22	1969	11.40601	31	1	171.53	0.91600	95.808	-66.61	18.4348
23	1970	11.30879	31	1	171.07	0.00000	108.416	-60.76	21.3602
24	1971	11.30879	31	1	2714.07	0.79632	108.416	-61.45	20.6770
25	1972	11.30879	31	1	1842.78	0.70028	89.257	-61.45	20.6770
26	1973	11.30879	31	1	1942.78	0.87557	89.257	-61.45	20.6770
27	1974	11.30879	31	1	259.72	0.00000	96.980	-86.88	15.0180
28	1975	11.30879	31	1	195.78	0.85301	109.980	-99.88	15.0180
29	1976	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
30	1977	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
31	1978	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
32	1979	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
33	1980	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
34	1981	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
35	1982	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955
36	1983	11.30879	31	1	195.78	0.85301	101.366	-122.06	19.3955

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MODEL: TREND
DEP VAR: YIELD

VARIABLE	DF	PARAMETER ESTIMATE	SSE DFE MSE	STANDARD ERROR	F RATIO	PROB>F	R-SQUARE
INTERCEPT	1	5.164359	156.519529	3.176578	1.6321	0.1135	0.0001
TREND1	1	0.358749	5.397229	0.122042	2.9396	0.0064	0.0001
TREND2	1	0.557328		0.083553	5.6763	0.0001	0.0001

MODEL: APRIL
DEP VAR: YIELD

VARIABLE	DF	PARAMETER ESTIMATE	SSE DFE MSE	STANDARD ERROR	F RATIO	PROB>F	R-SQUARE
INTERCEPT	1	6.934125	115.163134	2.841197	2.4406	0.0212	0.0001
TREND1	1	0.315441	27	0.107398	8.1672	0.0068	0.0001
TREND2	1	0.629123	4.148553	0.075725	-3.1119	0.0042	0.0001
DS94	1	-0.0003691	0.000156068	0.000156068			

MODEL: JUNE
DEP VAR: YIELD

VARIABLE	DF	PARAMETER ESTIMATE	SSE DFE MSE	STANDARD ERROR	F RATIO	PROB>F	R-SQUARE
INTERCEPT	1	17.479094	87.009668	4.308307	4.0571	0.0004	0.0001
TREND1	1	0.344003	27	0.095707	3.6361	0.0012	0.0001
TREND2	1	0.624165	3.222558	0.056732	9.3253	0.0001	0.0001
DS94	1	-0.00031122	0.0001042477	0.0001042477	-2.9844	0.0060	0.0001
ETHAT6	1	-0.111516	0.0037109	0.0037109	-3.0078	0.0056	0.0001

MODEL: JULY
DEP VAR: YIELD

VARIABLE	DF	PARAMETER ESTIMATE	SSE DFE MSE	STANDARD ERROR	F RATIO	PROB>F	R-SQUARE
INTERCEPT	1	16.425581	40.120484	3.272237	5.0217	0.0001	0.0001
TREND1	1	0.361151	26	0.072553	4.9755	0.0001	0.0001
TREND2	1	0.626453	1.850785	0.059727	12.3496	0.0001	0.0001
DS94	1	-0.000227292	0.000109223	0.000109223	-5.6427	0.0001	0.0001
ETHAT6	1	-0.111516	0.0037109	0.0037109	-3.0078	0.0056	0.0001
XDD7	1	-0.0003691	0.000156068	0.000156068			

NORTH DAKOTA BARLEY WESTERN APU 21

MODEL:	TREND	SSE	OFF	MSF	390.966110	F RATIO	14.98
DEP VAR:	YIELD	PARAMETER	ESTIMATE	STANDARD	ERROR	PROB>F	0.0001
VARIABLE	DF	ESTIMATE	ERROR	PROB>ITI		P-SQUARE	0.5061
INTERCEPT	1	-0.604502	5.020944	0.9049			
TREND1	1	0.459529	0.192503	0.0240			
TREND2	1	0.336344	0.132053	2.5470			

MODEL:	JUNE	SSE	OFF	MSF	200.761443	F RATIO	27.58
DEP VAR:	YIELD	PARAMETER	ESTIMATE	STANDARD	ERROR	PROB>F	0.0001
VARIABLE	DF	ESTIMATE	ERROR	PROB>ITI		K-SQUARE	0.7472
INTERCEPT	1	-13.390789	4.426755	0.0053			
TREND1	1	0.326193	0.141454	0.0108			
TREND2	1	0.330114	0.096357	0.0019			
ETP6	1	17.310511	3.364381	0.0001			

MODEL:	JULY	SSE	OFF	MSF	73.956241	F RATIO	50.68
DEP VAR:	YIELD	PARAMETER	ESTIMATE	STANDARD	ERROR	PROB>F	0.0001
VARIABLE	DF	ESTIMATE	ERROR	PROB>ITI		K-SQUARE	0.9069
INTERCEPT	1	2.055687	5.273589	0.6999			
TREND1	1	0.442914	0.089562	0.0001			
TREND2	1	0.358115	0.061201	0.0001			
ETP6	1	15.701157	2.131770	0.0001			
DEF7	1	0.058543	0.013535	0.0002			
ETHAT7	1	-0.109524	0.050775	-2.1476			

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OBS	YEAR	YIELD	TRENDI	TREND2	ETP6	DEF7	ETHAT7	YHAT
1	1948	10.0883	18	1	0.84536	-45.33	100.105	10.0530
2	1949	17.0956	19	1	0.61661	-73.17	102.144	15.0351
3	1950	10.6805	20	1	0.94994	-88.47	101.461	19.9819
4	1951	10.0171	21	1	0.23415	-81.53	98.068	19.2899
5	1952	18.0359	22	1	0.71556	-81.44	96.541	8.0533
6	1953	19.6514	23	1	1.00000	-96.73	97.559	11.4963
7	1954	19.7209	24	1	1.00000	-95.73	106.229	11.4963
8	1955	12.5589	25	1	0.84762	-83.56	106.984	11.2505
9	1956	11.6224	26	1	0.64264	-34.56	92.372	11.8091
10	1957	11.0484	27	1	1.00000	-91.16	117.914	12.4205
11	1958	11.8873	28	1	0.87435	-42.60	87.916	16.0061
12	1959	11.6542	29	1	0.54856	-12.63	109.810	16.7850
13	1960	11.6356	30	1	0.86384	-116.83	109.696	16.3973
14	1961	22.9648	31	1	0.42913	-19.63	107.914	19.1366
15	1962	14.9648	31	2	0.95718	-72.43	102.434	20.5813
16	1963	26.4648	31	3	0.99494	-94.43	106.741	20.5438
17	1964	16.2762	31	4	1.00000	-74.43	106.741	15.6972
18	1965	16.1790	31	5	0.96180	-62.64	109.515	18.0930
19	1966	17.1790	31	6	0.70906	-75.93	97.529	15.4866
20	1967	12.1693	31	7	0.81806	-115.83	99.086	13.4866
21	1968	18.1414	31	8	1.00000	-103.04	97.529	13.5779
22	1969	18.1133	31	9	1.00000	-73.08	95.227	17.7208
23	1970	16.1836	31	10	0.84880	-85.08	106.447	17.3012
24	1971	21.3243	31	11	1.00000	-85.91	90.408	20.9566
25	1972	21.1259	31	12	0.91150	-61.55	87.408	16.0835
26	1973	19.8789	31	13	0.78574	-101.45	98.068	13.2404
27	1974	12.6090	31	14	1.00000	-109.64	119.810	13.9331
28	1975	17.1066	31	15	1.00000	-117.23	103.675	17.2138
29	1976	17.0923	31	16	0.87582	-114.93	104.186	16.8564
30	1977	15.8613	31	17	0.73560	-87.93	104.186	16.8564
31	1978	22.6923	31	18	0.97910	-73.44	102.654	18.7284
32	1979	17.8074	31	19	0.72608	-66.83	102.654	18.7284
33	1980	10. . . .	31	20
34	1981	31	21
35	1982	31	22
36	1983	31	23

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YEAR	TREND1	TREND3	DS04	XDD6	XDD7	ETHAT7	YIELD	YHAT	RES
1948	1	1	835.40	-0.6531	0.2594	100.860	9.3395	7.2812	0.2449
1949	1	1	846.62	-0.1469	0.0594	199.849	7.0363	10.9544	-1.5028
1950	1	1	955.01	-0.4531	-0.6406	91.2713	9.4517	19.5875	-0.0686
1951	1	1	2693.94	-0.7531	-0.5406	96.813	9.0627	7.0152	0.3872
1952	1	1	1017.82	-0.2531	-0.6406	96.372	5.9588	8.7370	-2.7781
1953	1	1	0.00	-0.5531	0.4594	101.937	4.9585	7.2651	-2.3307
1954	1	1	36.00	-0.4669	1.4594	106.975	9.0585	8.1187	1.0390
1955	2	3	894.20	-2.4531	-2.2594	199.795	12.0585	10.3282	0.6343
1956	4	4	403.88	-2.5531	0.406	189.257	11.6714	11.1577	0.3489
1957	5	5	4610.85	-1.0531	0.594	105.923	14.0493	12.5442	2.5048
1958	7	7	734.24	-2.4669	0.2406	108.333	11.493	12.5442	0.5048
1959	8	8	2794.72	-0.4669	-0.7406	198.767	18.621	17.2733	-2.2389
1960	8	8	789.43	0.2469	0.2594	90.923	15.5125	11.7273	2.2555
1961	10	10	320.20	-0.5531	0.594	104.910	17.368	13.9373	0.6170
1962	11	11	320.58	-0.4669	-0.6406	106.313	18.3028	15.1065	-1.2881
1963	11	11	5201.14	-0.1469	0.7594	196.453	16.8215	17.6519	0.6170
1964	11	11	320.34	-0.8531	0.406	108.323	19.3726	18.4845	0.7886
1965	11	11	1364.85	-0.3469	-0.8406	95.804	19.2724	20.3203	1.0253
1966	11	11	146.33	-2.0469	0.1406	105.475	12.6048	16.2978	0.7623
1967	11	11	171.09	0.0469	0.1406	89.757	12.9033	17.7767	0.6170
1968	11	11	2740.69	0.2469	0.5406	96.818	17.2905	15.2077	-1.6236
1969	11	11	1942.78	0.0469	0.0594	109.980	17.3370	15.9773	1.8559
1970	11	11	298.11	0.1469	0.0594	109.980	17.3370	15.9773	1.8559
1971	11	11	198.78	0.1469	0.0594	101.366	17.0277	17.5247	-1.8559
1972	11	11	303.78	0.0469	0.0594	101.366	17.0277	17.5247	-1.8559
1973	11	11	3732.75	0.0469	0.0594	101.366	17.0277	17.5247	-1.8559
1974	11	11	1607.75	-0.1531	0.0594	101.366	17.0277	17.5247	-1.8559
1975	11	11							
1976	11	11							
1977	11	11							
1978	11	11							
1979	11	11							

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NORTH DAKOTA SPRING WHEAT EASTERN APU 20

MODEL: TREND F RATIO 42.32
 DEP VAR: YIELD DFE 0.0001
 MSE 0.7448

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 11.038124 0.429293 13.3103 0.0001
 TREND1 1 0.733749 0.098759 7.9360 0.0001
 TREND3 1 0.323413 0.300299 1.0936 0.2831

MODEL: APRIL F RATIO 36.07
 DEP VAR: YIELD DFE 0.0001
 MSE 0.7944

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 11.270228 0.784544 14.7458 0.0001
 TREND1 1 0.795246 0.090315 8.8052 0.0001
 TREND3 1 0.453153 0.278450 1.6274 0.1149
 DSO4 1 -0.00032472 0.000124504 -2.5999 0.0147

MODEL: JUNE F RATIO 29.18
 DEP VAR: YIELD DFE 0.0001
 MSE 0.8121

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 11.379142 0.773165 14.7175 0.0001
 TREND1 1 0.807850 0.088274 9.1516 0.0001
 TREND3 1 0.461471 0.271125 1.7021 0.1002
 DSO4 1 -0.00029208 0.0001231788 -2.3712 0.0251
 XDD6 1 -0.430986 0.270097 -1.5957 0.1222

MODEL: JULY F RATIO 35.13
 DEP VAR: YIELD DFE 0.0001
 MSE 0.8940

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>ITI
 INTERCEPT 1 -6287.04 2047.108 -3.0712 0.0051
 TREND1 1 0.762966 0.069959 10.9058 0.0001
 TREND3 1 0.737518 0.222407 3.3165 0.0028
 DSO4 1 -0.000269422 0.0000994995 -2.7102 0.0120
 XDD5 1 -0.399653 0.211054 -1.8937 0.0699
 XDD7 1 -322.461052 104.557482 -3.0841 0.0049
 ETHAT7 1 62.148680 20.200296 -3.0766 0.0050

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YEAR	TREND1	TREND3	DSQ4	XDD6	XDD7	ETHAT7	YIELD	YHAT	RES
1943	1	1	1229.4	-0.7469	0.2719	102.735	1.7255	1.6244	0.1011
1944	1	1	193.8	-0.3531	0.2719	102.735	1.9448	1.1168	1.1735
1945	1	1	347.0	-0.2469	-0.5281	97.563	1.1208	1.1368	-0.2593
1946	1	1	65.0	-0.5469	0.2719	109.147	1.9488	1.0463	-0.1715
1947	1	1	33.0	-0.1469	0.4281	100.172	1.6073	1.0580	-0.9739
1948	1	1	291.5	-0.5469	0.4719	103.569	1.9210	1.1725	-0.8079
1949	1	1	844.3	-0.0469	1.9281	112.410	1.6940	1.1259	-0.5656
1950	1	1	101.8	-0.5469	1.1719	112.611	1.5308	1.1456	-0.9386
1951	2	3	1758.6	-0.6469	-1.9281	112.382	1.9125	1.1817	0.3566
1952	3	4	149.8	-0.3531	0.5719	104.290	1.6873	1.1448	0.3197
1953	4	5	98.8	-0.0469	0.5719	104.290	1.7453	1.1577	0.1977
1954	5	6	347.8	-0.4669	0.5719	109.153	1.8950	1.1550	0.3117
1955	6	7	1854.8	-0.9531	0.4281	93.886	1.0850	1.1559	0.0989
1956	7	8	347.8	-0.2531	0.4281	93.886	1.4253	1.1871	0.4689
1957	8	9	964.9	-0.6469	1.0719	108.415	1.8466	1.1660	0.3367
1958	9	10	1300.4	-0.5469	0.3719	108.415	1.0925	1.1812	0.5077
1959	1	1	799.9	-0.2531	0.3719	108.415	1.6574	1.1805	0.8952
1960	1	1	240.9	-0.9469	0.7281	97.563	1.3967	1.2122	0.4527
1961	1	1	122.3	-0.2531	0.7281	97.563	1.5408	1.2292	0.5477
1962	1	1	300.4	-0.9469	0.7281	97.563	1.3967	1.2292	0.2587
1963	1	1	799.9	-0.4669	0.2719	97.922	1.9617	1.2292	0.5875
1964	1	1	129.5	-0.2531	0.2719	97.922	1.4461	1.2292	0.2499
1965	1	1	475.4	-0.1531	0.2719	97.922	1.4461	1.2292	0.9989
1966	1	1	1300.3	-0.5531	0.4281	99.410	1.6642	1.2292	0.1885
1967	1	1	1586.0	-0.0469	0.4281	99.410	1.4669	1.2292	0.3905
1968	1	1	531.9	-0.5531	0.4719	112.090	1.7706	1.2292	0.5580
1969	1	1	4632.5	-0.0469	0.9719	112.569	1.6329	1.2292	0.1905
1970	1	1	31.9	-0.5531	0.5719	103.290	1.3295	1.2292	0.5513
1971	1	1	491.5	-0.7531	0.4719	103.290	1.6329	1.2292	0.8332
1972	1	1	347.3	-0.0531	0.2719	102.735	1.3490	1.2292	0.4320
1973	1	1	517.6	-0.2469	0.2719	102.735	1.3490	1.2292	0.8590
1974	1	1	347.3	-0.0469	0.2719	102.735	1.3490	1.2292	0.3404

NORTH DAKOTA SPRING WHEAT WESTERN APU 21

MODEL: TREND SSE 203.891653 F RATIO 56.23
 DEP VAR: YIELD DFE 30 PROB>F 0.0001
 MSE 6.796388 R-SQUARE 0.5521

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>|T|
 INTERCEPT 1 7.104585 0.867354 8.1912 0.0001
 TREND1 1 0.731606 0.097565 7.4986 0.0001

MODEL: APRIL SSE 175.049397 F RATIO 21.91
 DEP VAR: YIELD DFE 25 PROB>F 0.0001
 MSE 6.251764 R-SQUARE 0.7013

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>|T|
 INTERCEPT 1 3.322984 1.947507 1.7065 0.0990
 TREND1 1 0.647338 0.105244 6.1508 0.0001
 CP4 1 0.029568 0.013774 2.1466 0.0406
 USQ4 1 -0.0015575 0.000208287 -0.7450 0.4525

MODEL: MAY SSE 105.230415 F RATIO 23.76
 DEP VAR: YIELD DFE 25 PROB>F 0.0001
 MSE 4.047324 R-SQUARE 0.8204

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>|T|
 INTERCEPT 1 3.037801 1.687983 1.7997 0.0835
 TREND1 1 0.652802 0.084770 7.7009 0.0001
 CP4 1 0.039064 0.011528 3.3594 0.0024
 USQ4 1 -0.000548538 0.0001928312 -2.8447 0.0086
 DEFS 1 0.038111 0.013595 2.7827 0.0099
 XDD5 1 1.098873 0.272561 4.0302 0.0004

MODEL: JUNE SSE 88.616588 F RATIO 23.39
 DEP VAR: YIELD DFE 25 PROB>F 0.0001
 MSE 3.544575 R-SQUARE 0.8488

VARIABLE DF PARAMETER ESTIMATE STANDARD ERROR T RATIO PROB>|T|
 INTERCEPT 1 4.021534 1.643747 2.4466 0.0218
 TREND1 1 0.642444 0.079476 8.0835 0.0001
 CP4 1 0.036093 0.010369 3.2906 0.0030
 USQ4 1 -0.000406554 0.0001919924 -2.1181 0.0443
 DEFS 1 0.036329 0.012345 2.8286 0.0091
 XDD5 1 0.967387 0.252297 3.6881 0.0011
 DEFS 1 0.023880 0.011931 2.1649 0.0401

NORTH DAKOTA SPRING WHEAT WESTERN APU 21

MODEL:	JULY	SSE	47.566303	F RATIO	32.55
DFP VAR:	YIELD	DFE	23	PROB>F	0.0001
		MSE	2.068100	R-SQUARE	0.9188
VARIABLE	DF	PARAMETER ESTIMATE	STANDARD ERROR	T RATIO	PROB> T
INTERCEPT	1	6.997863	1.616037	4.3303	0.0002
TIME01	1	0.084311	0.061573	1.3839	0.0001
CP4	1	0.028964	0.008559	3.3839	0.0026
USQ4	1	-0.002909	0.000155	-1.8734	0.0738
DEF5	1	0.027157	0.010370	2.6198	0.0153
XDD5	1	0.065296	0.223512	0.2926	0.0068
DEF6	1	0.027845	0.008530	3.2643	0.0034
XDD7	1	-0.461521	0.231920	-1.9900	0.0386
DEF7	1	0.029206	0.013337	2.2403	0.0350

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NORTH DAKOTA SPRING WHEAT WESTERN APU 21

YEAR	TREND	CP4	DSW4	DEF5	XDD5	DEF6	XDD7	DEF7	YIELD	YHAT	RES
1949	1	149	68.1	-43.310	7344	-35.028	0.125	-45.33	9.2279	0.348	1931
1950	1	127	915.0	-41.419	0.8344	-64.319	-0.275	-73.13	6.4740	0.3258	0.17118
1951	1	146	126.0	-49.816	-1.4656	-35.949	-0.525	-88.47	8.3155	7.81578	-0.41922
1952	1	139	333.1	-63.147	0.0344	-44.138	-0.825	-81.53	5.3585	8.4587	-0.14321
1953	1	133	495.1	-34.896	-1.7656	21.532	-0.675	-81.44	6.4663	9.2905	-2.81251
1954	1	158	528.0	-27.178	1.8344	-19.591	-1.075	-95.73	5.2626	6.3347	-0.92578
1955	1	116	170.1	-22.139	0.0344	-67.409	-1.525	-83.56	10.6657	9.3347	0.04034
1956	2	142	1242.1	-74.550	0.2344	-14.999	-2.225	-91.60	11.4223	6.3108	3.4910
1957	4	140	150.0	-16.841	-1.3344	-27.243	-0.775	-49.63	12.2423	8.2627	-0.72578
1958	5	100	3277.6	-1.148	0.0344	-27.965	0.375	-122.64	1.3347	11.9174	0.25195
1959	5	166	3277.6	-38.483	-0.9656	-96.329	-2.225	-116.83	11.0273	11.6472	0.65839
1960	7	100	45.0	-60.523	-0.3656	-32.227	-1.175	-19.69	19.0734	17.6892	-1.6195
1961	8	144	76.0	-15.495	-0.4344	51.907	-1.225	-72.43	14.9484	15.2271	0.2167
1962	8	154	1540.0	-44.188	1.4656	-33.782	-1.175	-94.63	13.9484	14.0284	0.1825
1963	8	114	555.0	-32.812	-0.4344	-32.227	-1.225	-72.43	16.7520	15.2592	0.2072
1964	10	120	217.0	-22.239	-0.3656	-17.591	-0.325	-115.93	14.0115	14.4446	0.4331
1965	11	152	217.0	-16.898	-2.2656	-45.591	-0.625	-103.84	13.5413	13.4886	0.3614
1966	12	171	33.1	-45.810	0.0344	17.098	-1.075	-26.73	18.4135	19.3548	0.9423
1967	12	153	348.1	-18.813	-0.5656	-60.628	-2.025	-73.08	14.9228	15.9500	0.8318
1968	12	148	945.0	-29.514	0.0344	-54.299	-2.625	-85.91	18.5306	17.0613	0.9728
1969	12	250	502.0	-21.473	-1.0656	-43.919	-2.775	-109.45	17.3954	19.0713	0.4566
1970	12	155	4064.1	-28.784	0.0656	-85.919	-2.775	-109.45	14.3579	14.7194	0.5560
1971	12	203	2093.1	-53.812	-2.0656	-11.595	-1.775	-114.64	15.3557	16.1561	0.5684
1972	12	197	885.0	-42.879	0.8344	-27.446	-0.575	-117.23	14.3420	13.1048	0.2372
1973	12	190	4522.0	-42.102	0.9344	-38.907	-0.825	-114.64	14.3557	15.1641	0.4566
1974	12	259	10353.0	-28.164	-1.3344	-66.160	-0.375	-73.48	15.3420	14.1048	0.2372
1975	12	184	715.0	-29.239	-2.3056	-66.990	-0.825	-76.66	14.9730	13.4044	0.5686
1976	12	259	10353.0	-29.239	-2.3056	-66.990	-0.825	-76.66	14.9730	13.4044	0.5686
1977	12	184	715.0	-29.239	-2.3056	-66.990	-0.825	-76.66	14.9730	13.4044	0.5686
1978	12	259	10353.0	-29.239	-2.3056	-66.990	-0.825	-76.66	14.9730	13.4044	0.5686
1979	12	184	715.0	-29.239	-2.3056	-66.990	-0.825	-76.66	14.9730	13.4044	0.5686