U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

TDL OFFICE NOTE 78-9

SPECIALIZED AGRICULTURAL FORECAST GUIDANCE FOR MICHIGAN AND INDIANA

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May 1978

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1. INTRODUCTION

The Techniques Development Laboratory (TDL) has developed a guidance forecast package for 46 agricultural stations in Indiana and Michigan (see Figure 1). For the 19 stations in Indiana, the guidance consists of forecasts of maximum (max) and minimum (min) air temperatures, and max and min soil temperatures 4 inches under both bare and grassy soil surfaces for projections out to 132 hours. Also included in Indiana's package are min relative humidity and probability of precipitation amount (PoPA) forecasts out to 84 hours. For the 27 stations in Michigan, the guidance consists of max and min air temperatures out to 132 hours and PoPA forecasts out to 84 hours. The complete agricultural guidance forecast package is valid during the growing season of April through October.

2. METHOD

All the prediction equations were developed with use of the Model Output Statistics (MOS) technique (Glahn and Lowry, 1972). This technique consists of determining statistical relationships between local weather observations (predictands) and the output of numerical models (predictors). A forward selection procedure was used to derive multiple linear regression equations to forecast temperature and humidity while an application of regression known as Regression Estimation of Event Probabilities (Miller, 1964) was used to develop equations to forecast PoPA.

We used output from the six-layer Primitive Equation (PE) model (Shuman and Hovermale, 1968) to derive all of the agricultural prediction equations. Some of the PE fields were space-smoothed over five, nine, or 25 model grid points in order to reduce the amount of small scale noise inherent in the numerical output. The PE forecasts were then interpolated from grid-points to the location of each of the stations. The variables available to the regression program as potential predictors of air and soil temperature, relative humidity and PoPA included 1000-, 850-, and 500-mb temperatures; 1000-, 850-, 700-, and 500-mb heights; boundary layer, 850-, and 500-mb winds; boundary layer, 850-, and 700-mb vertical velocities; 1000-850 mb, 1000-700 mb, and 1000-500 mb thicknesses; several low and middle level mean relative humidities; surface pressure; boundary layer potential temperature; precipitation amount; precipitable water; and boundary layer moisture divergence. We also screened several trigonometric functions of the day of the year, the maximum possible number of hours of sunshine per day, and the daily insolation at the top of the atmosphere.

The predictands for max air temperature, max and min bare-ground and grassy-ground soil temperatures, and min relative humidity are valid for 24-h periods ending at approximately 7 AM local time. In contrast, the min air temperature predictands are valid for periods from late afternoon until 7 AM local time the next morning. Predictands for the PoPA equations are the occurrences of greater than or equal to .01, .10, .25, .50, and 1.00 inches of precipitation in 24-h periods ending at 7 AM local time.

3. EQUATION CHARACTERISTICS

A. Max/Min Temperature

Single station max and min air temperature equations were developed for the 19 agricultural stations in Indiana and the 27 stations in Michigan. The equations were limited to 10 predictors with each predictor being required to reduce the variance at least one-tenth of one percent. For equations with projections of 84 hours and less, the developmental sample consisted of observations taken in October of 1972 and April to October of 1973-75. Beyond 84 hours we were limited to data from October of 1975 and April to October of 1976.

The average number of predictors in the max air temperature equations ranges from eight for the 12-36 h projection to 10 for most of the projections beyond 60 hours. The majority of the air temperature equations contain the maximum limit of 10 predictors. Table 1 lists the developmental mean reductions of variance and standard errors of estimate for these equations.

The screening regression program selected the 1000-850 mb thickness as the best predictor for max air temperature. The corresponding best predictor for min air temperature was the 850-mb temperature. The cosine of the day of the year, 500-mb height and temperature, 1000-500 mb and 1000-700 mb thicknesses, boundary layer and mean relative humidities, number of hours of sunshine, and daily insolation were also important predictors of max/min air temperature.

B. Max/Min Bare-Ground and Grassy-Ground Soil Temperatures

We developed separate max and min bare-ground and grassy-ground soil temperature prediction equations for each of the 19 agricultural stations in Indiana. These equations were also limited to 10 predictors with each predictor being required to reduce the variance at least one-tenth of one percent. The developmental sample for these equations was the same as for the air temperature equations. A sample 60-84 h max bare-ground soil temperature equation is given in Table 2.

Most bare-ground soil temperature equations contain between seven and nine predictors. The grassy-ground equations have slightly fewer predictors, averaging six or seven. Table 1 lists the developmental mean reductions of variance and standard errors for these equations.

The most important predictors of soil temperature were the 850-1000 mb, 700-1000 mb, and 500-1000 mb thicknesses, cosine of the day of the year, number of hours of sunshine, 500-mb height, and boundary layer and mean relative humidities.

C. Relative Humidity

We developed single station min relative humidity equations for the 19 agricultural stations in Indiana for projections out to 84 hours using data from October of 1972 and April to October of 1973-75. These equations also had a 10 predictor limit with each predictor required to reduce the variance at least one-tenth of one percent.

All the minimum relative humidity equations contain the maximum limit of 10 predictors. Table 1 also lists the developmental mean reductions of variance and standard errors for these equations.

The screening regression program selected the boundary layer and mean relative humidities as the best predictors of min relative humidity. The number of hours of sunshine, daily insolation, low level humidity, surface pressure, and precipitation amount were also important predictors.

D. Probability of Precipitation Amount

PoPA equations were developed for both Michigan and Indiana for projections out to 84 hours. Five seasons of data (1972-76) were used to develop the 12-36 h equations, while four seasons (1973-76) were used to develop the 36-60 h and 60-84 h equations.

Before deriving the equations we combined the data for each state to obtain a larger developmental data base. This technique is often used when the data from one station will not support the development of a stable equation, and it is especially useful for the prediction of rare events such as heavy precipitation.

For each state we derived the equations for all categories for a given projection simultaneously. Thus, the resulting equations for a particular projection will contain the same predictors. Of course, the coefficients of these predictors usually will differ for each equation. By deriving the equations in this manner, we minimize the chances of inconsistent forecast probabilities between categories. An example of an inconsistent forecast is one in which the probability of the greater than or equal to .25 inch category is higher than the probability of the greater than or equal to .01 inch category.

Twelve-term equations were developed in all cases. We have found that 12 terms is about the optimum number of predictors to use in forecasting PoPA (Zurndorfer and Bermowitz, 1976). Table 3 lists the developmental mean reductions of variance for each set of PoPA equations.

The most important predictors for forecasting PoPA were found to be the PE model forecasts of precipitation amount, surface to 490-mb mean relative humidity, and boundary layer moisture divergence.

4. MESSAGES AND SCHEDULES

Agricultural weather guidance for Indiana and Michigan are transmitted daily to the Central Region on the overlay circuit at approximately 0900 GMT. The guidance is divided into two new teletype bulletins: AXUS50 for Indiana and AXUS51 for Michigan. Sample portions of both bulletins are shown in Figure 2. Table 4 lists the station abbreviations used in these bulletins.

Values of air and soil temperature guidance in these messages are rounded to the nearest whole degree Fahrenheit. Values of relative humidity are in percent. The PoPA guidance is in tens of percent with the numbers from left to right in the teletype bulletin being the probability of greater than or equal to .01, .10, .25, and 1.00 inches of precipitation.

The max air temperature, max/min soil temperature, min relative humidity, and PoPA forecasts are all valid for 24-h periods ending at approximately 7 AM local time. Min air temperature forecasts are valid from late afternoon until 7 AM the next morning.

Dates and times given at the beginning of each bulletin should be used to identify the valid time period for each of the forecasts. Min air and soil temperature and PoPA forecasts are listed under the date and time corresponding to the end of the period for which they are valid. Max air and min relative humidity forecasts are listed at the midpoint of their valid period.

5. OPERATIONAL CONSIDERATIONS

All the agricultural forecast equations have been developed from output of the six-layer PE model and its barotropic extension. The equations, however, are being applied to output of the seven-layer PE model (National Weather Service, 1978) and the barotropic mesh extension. As a result, the equations may not fully account for the characteristic differences between the old and new versions of these models. Bermowitz and Zurndorfer (1978) have discussed an example where PoPA equations derived from one atmospheric model were being applied to another model.

The air and soil temperature and relative humidity equations with projections of 84 hours and less were tested on one growing season (April-October, 1976) of independent data. The forecasts from these equations were compared with forecasts based on persistence and climatology. The results of these tests are given in Table 5.

The MOS air temperature guidance for both Michigan and Indiana was better than either the forecasts based on persistence or climatology. Also, the bare-ground soil temperature guidance for Indiana was generally better than forecasts of persistence or climatic estimates. In contrast, the grassy-ground soil temperature guidance was generally worse than forecasts based on persistence but better than forecasts based on climatology. The guidance for relative humidity was consistently better than forecasts of persistence or climatic estimates.

Although these results show that forecasts of persistence are generally better than the raw MOS grassy-ground soil temperature guidance out to 84 hours, a forecaster using this guidance should be able to significantly improve his forecast by also considering stored soil heat, soil moisture, and past error trends in the raw MOS guidance. To substantiate this idea, we conducted a test in which we added the mean error for the past three 12-36 h forecasts to the raw MOS guidance. For example, if the past three MOS 12-36 h max grassy-ground soil temperature forecasts averaged 5°F too low, we added 5°F to all the max grassy-ground guidance generated that day. This modification significantly improved the mean absolute errors for most soil temperature forecasts out to 84 hours, especially for the 12-36 h projection where the average improvement ranged from about 0.4°F for the max bare-ground soil temperature guidance to about 0.9°F for the min grassy-ground soil temperature guidance. The verification statistics for these modified forecasts are also listed in Table 5. The modification also improved the relative humidity forecasts out to 60 hours slightly. However, similar modifications made to the air temperature forecasts tended to degrade the forecasts.

6. ACKNOWLEDGMENTS

We would like to thank Mr. Ceel Van Den Brink, Michigan State University and Dr. Fred Nurnberger, Michigan Department of Agriculture Weather Service for their help in obtaining observed data for Michigan. We are also grateful to Mr. Warren Bruns and Mr. Ken Scheeringa, Environmental Studies Service Center, West Lafayette for their help in obtaining agricultural weather observations in Indiana. Further thanks are extended to Mr. Fred Marshall of TDL for his computer programming support.

We would also like to acknowledge the overall support and guidance provided by Mr. Harold Scott, Agricultural Weather Services Branch, Office of Meteorology and Oceanography.

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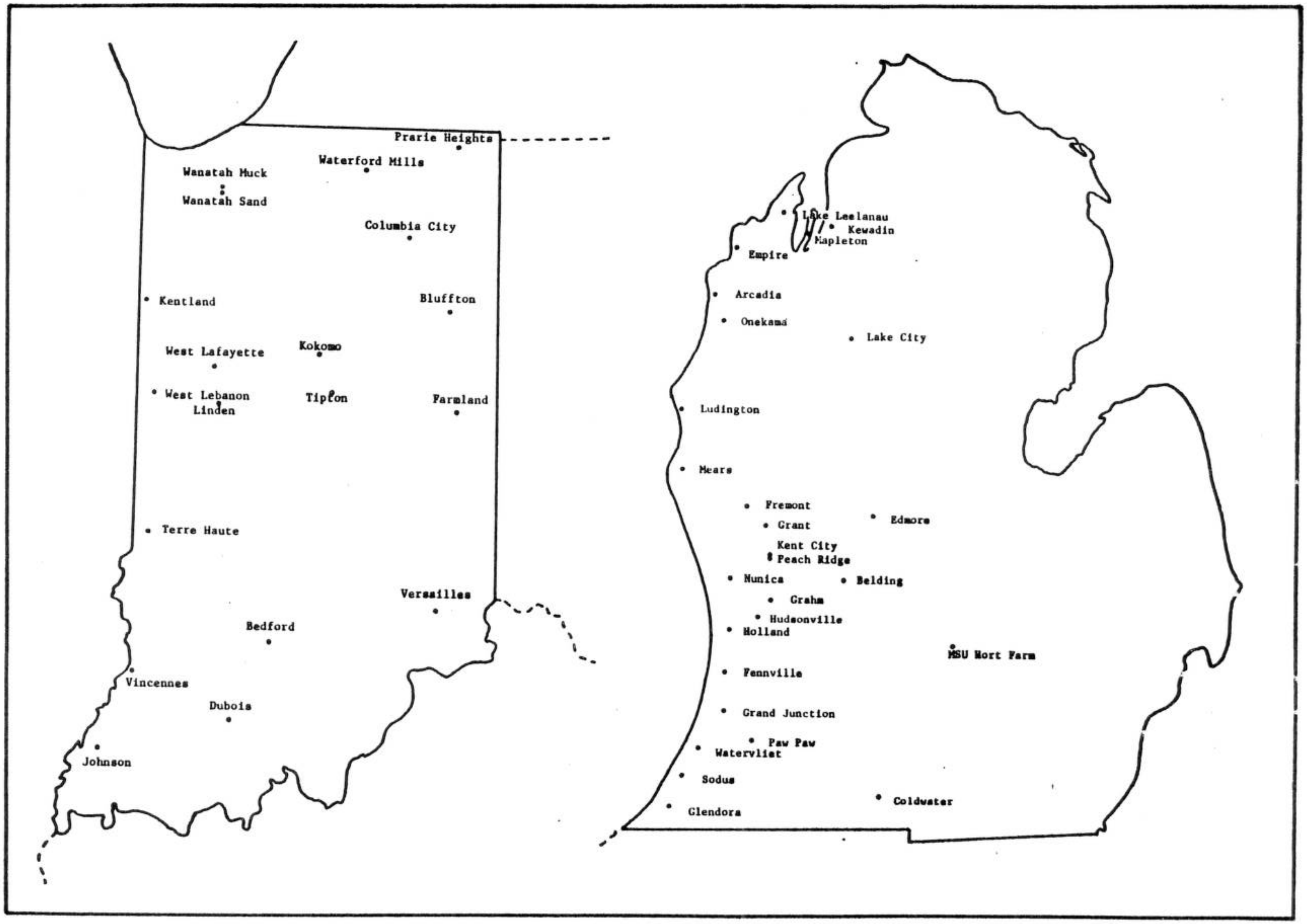

Figure 1. The 19 agricultural stations in Indiana and 27 agricultural stations in Michigan for which specialized weather guidance is available.

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AXUS50 KWBC 150000
 AG WEATHER GUIDANCE /MOS/  4/15/78  0000 GMT    INDIANA
             DATE  16    16   17    17   18    18  19  19  20  20
              GMT  00    12   00    12   00    12  00  12  00  12

BDFD AIR    MX/MN  58    37   61    48   64    52  70  43  67  41
     BARE   MX/MN  57    45   57    48   56    49  58  49  63  48
     GRASS  MX/MN  55    49   54    49   54    50  59  52  57  52
     RH     MN     42         47         58
     POPA/24-HR/     32100      76531      75320

BLFN AIR    MX/MN  50    29   52    40   52    43  63  42  60  37
     BARE   MX/MN  53    40   53    43   53    45  57  46  57  47
     GRASS  MX/MN  49    45   51    45   51    47  58  50  55  51
     RH     MN     42         48         64
     POPA/24-HR/     10000      43211      64321




AXUS51 KWBC 150000
 AG WEATHER GUIDANCE /MOS/  4/15/78  0000 GMT    MICHIGAN
             DATE  16    16   17    17   18    18  19  19  20  20
              GMT  00    12   00    12   00    12  00  12  00  12

LELA AIR    MX/MN  43    26   47    27   53    33  58  36  57  36
     POPA/24-HR/     10000      21100      54310

WADN AIR    MX/MN  43    27   45    28   52    37  58  38  55  38
     POPA/24-HR/     10000      21100      54310
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Figure 2. Sample portions of the AXUS50 and AXUS51 bulletins.

Table 1. Developmental reductions of variance (RV) and standard errors (SE) for the air and soil temperature and relative humidity equations. Please note that the min air temperature equations are valid from late afternoon until approximately 7 AM local time the next morning. All the standard errors for the temperature equations are given in ^{o}F, while those for relative humidity are in percent.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT) 12 - 36		36 - 60		60 - 84		84 - 108		108 - 132	
	RV	SE	RV	SE	RV	SE	RV	SE	RV	SE
INDIANA										
Max Air Temp	.920	4.13	.894	4.76	.853	5.64	.839	6.01	.761	7.55
Min Air Temp	.884	4.47	.848	5.17	.783	6.13	.743	7.06	.660	8.22
Max Bare-Ground Temp	.914	4.37	.905	4.62	.895	4.90	.905	4.73	.889	5.16
Min Bare-Ground Temp	.926	3.22	.924	3.29	.909	3.61	.916	3.55	.898	3.92
Max Grassy-Ground Temp	.935	3.02	.933	3.08	.930	3.15	.945	2.84	.937	3.07
Min Grassy Ground Temp	.938	2.67	.937	2.70	.932	2.82	.945	2.54	.940	2.71
Min Relative Humidity	.483	13.7	.388	14.9	.276	16.3				
MICHIGAN										
Max Air Temp	.904	4.12	.874	4.69	.818	5.61	.765	6.50	.676	7.66
Min Air Temp	.860	4.56	.811	5.29	.731	6.27	.661	6.91	.564	7.81

Table 2. Sample equation for the 60-84 h maximum 4-inch bare-ground soil temperature at Farmland, Indiana.

Predictor	Units	Smoothing (Points)	Forecast Projection (Hours)	Cumulative Reduction Of Variance	Coefficient
Regression Constant	--	--	--	--	-128.800000
1. PE 850-1000 mb Thickness	m	9	60	.6979	-0.053420
2. Cosine of the Day of Year	--	--	--	.8453	-39.200000
3. Hours of Sunshine	--	--	--	.8841	-8.429000
4. PE 500-mb Height	m	9	84	.8948	0.006409
5. PE Mean Relative Humidity	%	9	84	.8995	-0.073470
6. PE 500-mb Height	m	5	48	.9027	0.022890
7. PE Boundary Layer Potential Temp.	^{o}K	9	84	.9050	0.273500
8. PE 850-1000 mb Thickness	m	5	48	.9066	0.090850
9. PE Precipitation Amount	m	5	48	.9077	-171.900000

Multiple Correlation Coefficient .9528
Standard Error of Estimate 4.7065

Table 3. Developmental reductions of variance for the PoPA equations.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT) 12 - 36	36 - 60	60 - 84
INDIANA			
Probability of $\geq$ .01 inches	.368	.266	.150
Probability of $\geq$ .10 inches	.315	.228	.131
Probability of $\geq$ .25 inches	.253	.186	.113
Probability of $\geq$ .50 inches	.165	.124	.077
Probability of $\geq$ 1.00 inches	.070	.055	.035
MICHIGAN			
Probability of $\geq$ .01 inches	.323	.224	.136
Probability of $\geq$ .10 inches	.294	.182	.109
Probability of $\geq$ .25 inches	.249	.143	.091
Probability of $\geq$ .50 inches	.170	.098	.060
Probability of $\geq$ 1.00 inches	.081	.050	.029

Table 4. The four-letter abbreviations used for agricultural stations in Indiana and Michigan.

Michigan		Indiana	
LELA	Lake Leelanau	PRHI	Prarie Heights
WADN	Kewadin	WMIL	Waterford Mills
MAPL	Mapleton	WSAN	Wanatah Sand
EMPR	Empire	WMUK	Wanatah Muck
BULA	Arcadia (Beulah)	CLMB	Columbia City
BEAR	Onekama (Bear Lake)	ENTL	Kentland
LKCT	Lake City	BLFN	Bluffton
LUDI	Ludington	OKMO	Kokomo
MEAR	Mears	WLAF	West Lafayette
FREM	Fremont	WLEB	West Lebanon
GRAN	Grant	LIND	Linden
EDMR	Edmore	TIPT	Tipton
ENTC	Kent City	FARM	Farmland
NUNI	Nunica	TERE	Terre Haute
PEAC	Peach Ridge	VERS	Versailles
BELD	Belding	BDFD	Bedford
GRAM	Grahm	VINC	Vincennes
HOLL	Holland	DUBS	Dubois
HUDS	Hudsonville	JOHN	Johnson
FENN	Fennville		
GJCT	Grand Junction		
PAWP	Paw Paw		
VLET	Watervliet		
SODU	Sodus		
GLEN	Glendora		
COLD	Coldwater		
MSUH	MSU Hort. Farm		

Table 5. Mean absolute errors for the air and soil temperature and relative humidity MOS prediction equations when tested on one growing season of independent data (April-October, 1976). Mean absolute errors for persistence, climatology, and a modified forecast based on the mean error of the past three 12-36 h forecasts (Mod.) are also included. Please note that the min air temperature equations are valid from late afternoon until approximately 7 AM local time the next morning. All the errors for temperature equations are in ^{o}F, while those for relative humidity are in percent.

Type of Equation	Approximate Forecast Projection (hours from 0000 GMT) 12 - 36				36 - 60				60 - 84			
	MOS	Pers.	Clim.	Mod.	MOS	Pers.	Clim.	Mod.	MOS	Pers.	Clim.	Mod.
INDIANA												
Max Air Temp	3.34	5.55	6.86	3.33	3.73	7.22	6.86	3.85	4.42	7.66	6.86	4.66
Min Air Temp	3.56	6.40	7.16	3.86	4.09	8.55	7.16	4.39	4.84	9.01	7.16	5.12
Max Bare-Ground Temp	3.58	3.76	5.57	3.20	3.89	4.92	5.57	3.77	4.20	5.59	5.57	4.29
Min Bare-Ground Temp	2.70	2.51	4.19	2.23	2.71	3.73	4.19	2.49	2.86	4.34	4.19	2.89
Max Grassy-Ground Temp	2.78	2.01	3.58	1.96	2.90	2.61	3.58	2.25	2.96	2.94	3.58	2.47
Min Grassy-Ground Temp	2.48	1.61	3.25	1.57	2.45	2.31	3.25	1.76	2.44	2.74	3.25	1.97
Min Relative Humidity	11.6	13.8	16.9	10.2	11.5	17.9	16.9	11.3	12.8	19.2	16.9	13.2
MICHIGAN												
Max Air Temp	3.14	5.99	7.22	3.37	3.70	8.07	7.22	3.98	4.42	8.30	7.22	4.80
Min Air Temp	3.88	6.38	7.17	4.00	4.37	8.48	7.17	4.61	5.25	8.77	7.17	5.45