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AN AID TO AGRICULTURAL DEW FORECASTING

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1. INTRODUCTION

Dew forecasting is a routine part of the National Weather Service agricultural program but to date little information has been published concerning practical dew forecasting schemes. One likely reason for this is the sparsity of reliable dew observations. Another reason must be the relatively minor emphasis given the dew forecasting program. But then, without verifying observations of any forecast element, quality control, with the ultimate goal of forecast improvement, is impracticable if not impossible.

This paper is an effort to improve the present "seat of the pants" method of dew forecasting. A set of semi-objective linear equations which estimate dew intensity, drying time, and starting time (number of hours of leaf wetness being implied) as functions of routinely observed and forecast variables is developed. No attempt is made to discuss the underlying theory of dew formation, because many agricultural meteorology publications cover this subject quite well.

2. DATA USED IN STUDY

A total of 594 cases of dew occurrence were collected from the dew weighing gage records at Weslaco Experiment Station, Texas (Lower Rio Grande Valley). Corresponding potential predictors were extracted from surface observation records at McAllen FSS, Texas (approximately 15 miles west of Weslaco).

The raw data were screened to eliminate cases where frontal passage occurred during the period of concern and cases that appeared to be of questionable accuracy. In addition, only cases where dew formation seemed to be relatively continuous from its starting time to its maximum intensity around sunrise were kept. This excluded many cases where cloud cover moved in and/or the winds increased during the night, causing the maximum intensity to occur well before sunrise with the drying time possibly occurring before sunrise. After the data screening, 291 cases remained for development of the forecast equations. This body of developmental data covers all months of the year and references dew on a grass surface.

3. METHOD USED TO DEVELOP FORECAST EQUATIONS

A stepwise screening regression computer program was employed in analyzing the relationships among the variables and determining the final regression equations. This method basically generates a series of linear regression equations in a stepwise manner in which each step adds a new independent variable to the equation, based on its relative predictive importance compared to the other variables. This process continues until all the independent variables are used. The final equation (step) selected for use is then based on the performance of three statistics; multiple

correlation coefficient (r), reduction of variance (r^2), and the standard error of estimate (SE). The mean absolute error (MAE) for the dependent data, which is the average of the absolute differences between the actual values of the dependent variable and the equations' estimates of them, is included. The best test of the reliability of the selected equation is, of course, how well it performs on independent data. It must be mentioned that any of the equations generated, at any step, can be used, depending on the degree of accuracy desired and the practicability of determining the predictor variables in real time. No attempt was made to infer why predictors were selected as they were since this is not always an easy task in multiple regression.

4. DEVELOPMENT AND VERIFICATION OF DEW INTENSITY FORECAST EQUATION

Dew intensity, extracted from the weighing gage charts, was the independent variable (predictand). These values and their subjectively determined categorical equivalents are listed in Table I.

TABLE I

Dew Intensity (DI) Weighing Gage	Duvdevani Dew Block (I) Equivalent	Suggested Forecast Term Equivalent
1 to 3	L1	Very Light
4 to 5	L2	Light
6 to 8	L3	Light
9 to 10	M1	Moderate
11 to 13	M2	Moderate
14 to 15	M3	Moderate to Heavy
16 to 18	H1	Heavy
19 to 20	H2	Heavy
21 or more	H3	Very Heavy

Independent variables (predictors) were chosen with respect to factors that have a possible correlation with nocturnal radiation intensity and factors that give a measure of how wet the surface soil is. A satisfactory method of deriving a quick measure of surface soil moisture was not readily available. Indexes, such as the Crop Moisture Index (2), are too involved to compute on a real time, daily basis. The hydrologic Antecedent Precipitation Index (3), although simple to compute daily, does not appear to be responsive enough to the rapidly fluctuating wetting and subsequent drying of the surface soil layer. Both indexes, and others, are more concerned with a relatively deep soil layer over a broad area.

A method by Poliakov (4) was found to be a suitable measure of surface soil moisture that seemed to be responsive to moisture fluctuations near the surface while being simple enough to calculate on a daily basis. Poliakov worked out an estimate of the percentage decrease of volumetric soil moisture within a 24-hour period as a function of initial soil humidity (ratio of moisture contained in a certain volume of soil to the weight of the same volume of dry soil) and mean daily temperature. He also accounted for precipitation by estimating that 1 mm of precipitation increased soil humidity

by 1 percent. Using his data as a basic guide, with a few subjective adjustments (one being increasing the effect of recent precipitation), a method was devised to objectively determine a surface soil moisture index (SMI). This SMI ranges in value from 50 (wet ground) to 10 (very dry ground). The computation of the SMI is given in the appendix.

The potential predictors of dew intensity (DI) were:

a. SMI
b. Forecast maximum temperature today (MX), °F
c. Forecast minimum temperature tonight (MN), °F
d. Forecast mean dew point 10PM to sunrise (DP), °F
e. Mean wind speed 10PM to sunrise (W), Kts
f. Mean opaque cloud cover 10PM to sunrise (C), tenths
g. 3PM temperature (T), °F
h. 3PM dew point (DP3), °F
i. 3PM wind speed (W3), Kts
j. 3PM cloud cover (C3), tenths

The potential predictors were chosen with the intent of applying the scheme during the late afternoon forecast period to predict DI for the following morning. Relative humidities were not included because they would be implied by temperature and dew point variables.

The first screening results indicated the first 6 predictors (a. thru f.) as the most important. A second run was made using only these 6 predictors (MX was replaced with T because of the high intercorrelation between the two and the immediate availability of T) with the following results:

<u>Step 1</u>, Enter "W"

$r=.5803$ $r^2=.337$ SE=5.44
DI=13.48 -.961W

<u>Step 2</u>, Enter "SMI"

$r=.7173$ $r^2=.514$ SE=4.66
DI=3.83 -.881W +.315SMI

<u>Step 3</u>, Enter "C"

$r=.7505$ $r^2=.563$ SE=4.43
DI=4.64 -.728W +.307SMI -.50C

<u>Step 4</u>, Enter "DP"

$r=.7827$ $r^2=.613$ SE=4.18
DI= -1.31 -.66W +.324SMI -.599C +.092DP

<u>Step 5</u>, Enter "MN"

$r=.8019$ $r^2=.643$ SE=4.02
DI=3.33 -.534W +.282SMI -.534C +.469DP -.438MN

<u>Step 6</u>, Enter "T"

$r=.8105$ $r^2=.657$ SE=3.95
DI=8.14 -.53W +.259SMI -.675C +.484DP -.325MN -.144T

MAE=2.4

The stepwise results show that most of the variance (56.3%) is explained by W, SMI and C (step 3), but there is still a significant reduction of variance by the addition of DP, MN and T. Therefore, the last equation (step 6) was chosen for verification on independent data. Verification was made on 71 cases from Weslaco and, to indicate applicability to other areas, 49 cases from Oklahoma City (dew measuring device at OKC employs electrical resistance changes as a measure of DI). Contingency Tables 2 and 3 show the results for Weslaco and OKC respectively:

TABLE 2

OBSERVED	FORECAST: None	Light	Moderate	Heavy	Total
None	12	11	1		24
Light		15	5		20
Moderate		3	17		20
Heavy			4	3	7
Total	12	29	27	3	71
% Correct	50	52	63	100	66
Bias	.5	1.45	1.35	.43	

MAE=2.7

The verification for Weslaco indicates a reasonably good overall percent correct (66%). The most significant fact, though, is how well the MAE of 2.7 corresponds to the MAE of 2.4 for the dependent data sample. This indicates that many of the categorical misses were "near misses", and this indeed was the case. The same was true for the OKC verification results.

TABLE 3

OBSERVED	FORECAST: None	Light	Moderate	Heavy	Total
None	15	9			24
Light		10	1		11
Moderate		2	4		6
Heavy			8		8
Total	15	21	13	0	49
% Correct	100	48	50	100	59
Bias	.63	1.91	2.17	0	

5. DEVELOPMENT OF DEW STARTING TIME EQUATION

The predictand (ST) was the number of hours after local standard time of sunset that dew deposit began. Potential predictors were the same as those used for dew intensity (SMI, T, MN, DP, W, C). It was decided that, because only cases within the same airmass were included in the dependent data, a high intercorrelation would exist between the selected predictors and any predictors chosen before 10PM. In addition, starting time is not currently a part of the agricultural forecast program but it was included since the data were available. The only additional predictor was the standard time of local sunset (SS) in hours and tenths, LST. The screening regression results were:

Step 1, Enter "SMI"

$r=.4467$ $r^2=.20$ SE=1.89hrs
ST= 6.74 -.103SMI

Step 2, Enter "W"

$r=.5441$ $r^2=.30$ SE=1.79hrs
ST= 5.08 -.093SMI +.264W

Step 3, Enter "SS"

$r=.6424$ $r^2=.41$ SE=1.64hrs
ST= 36.35 -.094SMI +.295W -1.67SS

Step 4, Enter "MN"

$r=.6642$ $r^2=.44$ SE=1.60hrs
ST=51.67 -.081SMI +.251W -2.68SS +.056MN

MAE 1.2 hrs

Introduction of additional predictors in subsequent steps increased the reduction of variance less than 1 percent, so the equation in step 4 is the final dew starting time equation. Because of limited data, no verification was performed on this equation. However, a MAE of 1.2 hrs for the dependent data sample was indicated.

6. DEVELOPMENT OF DEW DRYING TIME EQUATION

The predictand (DT) was the number of hours after standard time of local sunrise that dew totally evaporated. Potential predictors were:

a. Dew intensity (DI)
b. Standard time of local sunrise (SR)
c. Mean wind speed sunrise to 10AM (WW)
d. Temperature at 3AM (TT)
e. Mean cloud cover sunrise to 10AM (CC)
f. Forecast maximum temperature (TX)

(Units as indicated previously)

The screening regression results were:

Step 1, Enter "DI"

$r=.6570$ $r^2=.432$ SE=.81hrs
DT= 1.67 +.128DI

Step 2, Enter "SR"

$r=.7223$ $r^2=.522$ SE=.75hrs
DT= 5.09 +.135DI -.541SR

Step 3, Enter "WW"

$r=.7376$ $r^2=.544$ SE=.74hrs
DT= .566 +.126DI -.564SR -.045WW

Step 4, Enter "TT"

$r=.7429$ $r^2=.552$ SE=.73hrs
DT= 3.83 +.126DI -.384SR -.048WW +.011TT

Step 5, Enter "CC"

$r=.7430$ $r^2=.552$ SE=.73hrs
DT= 3.83 +.126DI -.385SR -.049WW +.011TT +.05CC

MAE= .5hrs

The addition of TX (step 6, not included) had no effect on the reduction of variance. Actually, the introduction of CC (step 5) also showed a very minor contribution to the estimate of DT. This seems strange at first, but apparently most of the dependent data cases, where cloudy skies existed after sunrise, also had significant cloud cover during the night and therefore little or no dew. Therefore, the step 4, or possibly even the step 3, equation is considered adequate. However, the inclusion of CC would, at least, add some delay in DT for those cases where cloud cover moves in after sunrise after significant dew deposit.

The DT equation was not verified on independent data, but the step 5 equation did indicate a MAE of 1/2 hour for the dependent data sample.

7. SUMMARY OF DEW FORECAST EQUATIONS AND THEIR APPLICATION

a. Dew Intensity (DI)

DI= 8.14 -.53W +.259SMI -.675C +.484DP -.325MN -.144T

Equation is applied at late afternoon forecast time. It can also be used for early morning forecast by replacing forecast predictors (such as W, DP, etc.) with observed data.

b. Dew Starting Time (ST)

$$ST = 51.67 - .081SMI + .251W - 2.68SS + .056MN$$

Equation is applied at late afternoon forecast time if desired.

c. Dew Drying Time (DT)

$$DT = 3.83 + .126DI - .385SR - .049WW + .011TT + .05CC$$

Equation is applied at both late afternoon and early morning forecast times.

Basic guidance for deriving the forecast predictors (e.g. W, C, etc.) are available from the NMC MOS forecast package. It is restated that any one of the equations in any step is a complete entity, and can be used as a forecast scheme. However, the more predictors used, given a significant increase in reduction of variance, the more accurate the forecast should be.

8. CONCLUSION

This paper has presented equations which forecast dew intensity, starting time and drying time. The limited developmental data makes these equations probably not as rigorous as needed for a sound agricultural forecast program, but they do supply the forecaster with a useful tool to aid in dew forecasting. Verification of the dew intensity equation on independent data does indicate reasonable skill for both the area of development (Weslaco, Texas) and a separate area (OKC).

What is really needed is a more widespread and reliable dew observation network. This would supply the broad data base needed for the development of a forecasting scheme similar to MOS, which has been proven to be effective and accurate. The present system does not supply feedback of verifying observations which is prerequisite to improving the forecasting of dew.

9. ACKNOWLEDGEMENTS

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APPENDIX

COMPUTATION OF SURFACE SOIL MOISTURE INDEX (SMI)

The SMI is a measure of how moist the surface soil is, which implies a measure of the soil's contribution to dew formation. It is a function of precipitation as an additive factor and mean daily temperature as a depletion factor (evaporation). Of course evaporation is also a function of wind, relative humidity and solar radiation, but inclusion of these would make daily computation of the SMI too involved.

The SMI ranges in value from 50 for wet ground to 10 for very dry ground. To initialize the SMI value, choose a day (sometime before real-time application is begun) where 1 inch or more precipitation occurred (or a period of heavy rains which left the ground wet) then assign a value of 50 on this day. Table 1 is then used to derive a new SMI for each succeeding day. Simply enter Table 1 with yesterday's SMI value (SMI-1) and the mean daily temperature (average of this morning's minimum and this afternoon's maximum) to get this afternoon's SMI. If precipitation occurs, use Table 2 to derive a new SMI based on the current SMI and the precipitation amount. For example, if yesterday's SMI was 35 and .6 inch of rain fell overnight with an overnight low of 55 and today's maximum being 85, the new SMI for this afternoon would be 43. Enter Table 2 with 35 and .6 to get 50, then enter Table 1 with 50 and 70 [(85+55)/2] to get 43. If the rain would have ended, say at 3PM, then Table 1 would have been used first which would have yielded a higher value for SMI (around 48).

For machine applications (as is currently available for Oklahoma City's agricultural program) linear equation approximations of the tables are:

Table 1: $SMI\text{-}2 = 10 + .79\ SMI\text{-}1 - .11T$

where; SMI-2 = final SMI value.
SMI-1 = initial SMI value.
T = Mean temperature (°F) (average of this morning's minimum and this afternoon's maximum)

Table 2: $SMI\text{-}2 = 6.5 + .83\ SMI\text{-}1 + 31.6P$

where; SMI-2 = final SMI value.
SMI-1 = initial SMI value (yesterday's value for overnight or morning precipitation, or SMI-2 from Table 1 for precipitation that ended during this afternoon).
P = Precipitation amount in inches and hundreths

TABLE 1

SMI-1

MEAN DAILY TEMP	50	45	40	35	30	25	20	15	10
30	49	44	39	35	30	25	20	15	10
40	47	43	37	34	29	25	20	15	10
50	45	41	36	33	28	24	20	15	10
60	43	39	36	32	28	24	19	15	10
70	43	38	35	32	28	23	19	14	10
80	41	37	35	31	27	22	18	13	10

Table 1: Final SMI values as a function of initial SMI values (SM-1) and mean daily temperature.

TABLE 2

SMI-1

PCPN AMOUNT (IN)	50	45	40	35	30	25	20	15	10
1.2	50	50	50	50	50	50	50	50	50
1.0	50	50	50	50	50	50	50	49	48
.8	50	50	50	50	50	49	47	45	44
.6	50	50	50	50	49	46	42	39	37
.4	50	50	50	48	44	39	35	32	30
.2	50	50	47	41	37	32	27	24	23
0	50	45	40	35	30	25	20	15	10

Table 2: Final SMI values as a function of initial SMI values (SMI-1) and precipitation amount.