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A Dynamic Model to Predict Wheat Emergence from Soil Moisture and Temperature

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An interactive, dynamic, logistic growth model was developed for predicting wheat emergence from soil temperature and soil moisture. This model also predicts the time required for achieving any desired level of emergence at a given combination of temperature and moisture. Validation of the model under naturally varying temperature conditions is evident from a good agreement found between the observed and the corresponding predicted values of emergence.

Key Words: **Dynamic logistic growth model, Sensitivity to temperature, moisture and time**

Introduction

Wheat emergence and consequently crop stand is primarily affected by temperature and moisture (Hillel 1972, Lindstrom et al. 1976). A desired stand of wheat crop can be ensured by the manipulation of soil moisture or seed rate provided emergence under a given moisture and temperature regime could be predicted. The Lindstrom et al.'s (1976) model is of limited utility as it predicts time for 50% emergence only. Model of Sethi et al. (1985) though overcomes this limitation, but the approach followed is a bit complicated and the predicted time for the desired emergence is imprecise. Moreover, both are virtually static models as time has not been considered a model parameter. This study was undertaken to overcome these drawbacks and to explicitly introduce time as an independent variable.

Materials and Methods

Development of the Model

An attempt has been made to incorporate the effect of time in the model of Sethi et al. (1985), resulting in the interactive, dynamic, logistic growth model:

$$p = [1 + a\ exp(b_1 t + b_2 T + b_3 \theta + b_{22} T^2 + b_{33} \theta^2 + b_{12} tT + b_{13} t\theta + b_{23} T\theta + b_{123} tT\theta)]^{-1} \quad \ldots(1)$$

where p stands for emergence ratio (defined as the emergence at any time as a fraction of the maximum attainable emergence) after time t (in DAS) when the soil temperature is T (in °C) and soil moisture is θ (in %). The quantities a, b_1, b_2, b_3, b_{22}, b_{33}, b_{12}, b_{13}, b_{23} and b_{123} are the unknown parameters of the model (1). The second degree terms in the model signify the curvilinear response of emergence to T and θ, whereas the product terms reflect the interactive effects of time, temperature and moisture on wheat emergence.

Under logarithmic transformation of q/p ($q = 1 - p$), the model (1) reduces to the usual curvilinear form, from which its parameters can be easily estimated (Draper & Smith 1981). Following Snedecor and Cochran (1980), the relative significance of each effect in the model was evaluated for two wheat varieties. In order to allow estimation at border line cases, the quantity p was taken to be $p \pm 0.001$ according as $p = 0$ and $p = 1$, respectively. A measure ϕ was computed as 1.0 minus the ratio of residual sum of squares to the corrected total sum of squares. Closeness of ϕ to

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unity was taken to signify the goodness of fit of the dynamic growth model (Ware et al. 1982).

The model (1) could also be written as

$$t_p = (f - g)/h \quad \ldots (2)$$

where $f = ln\ (q/ap)$,

$g = b_2T + b_3\theta + b_{22}T^2 + b_{33}\theta^2 + b_{23}T\theta$,

$h = b_1 + b_{12}T + b_{13}\theta + b_{123}T\theta$, and

t_p = time (days) to an emergence ratio p.

From (2), it is possible to evaluate the time t_p required to achieve a desired emergence ratio p under a given combination of temperature and moisture.

Development of models in relation to soil matric potential is generally preferred (Lindstrom et al. 1976). Soil water content, however, has been used in this model and in the model of Sethi et al. (1985), as measurement of soil water potential is difficult under many situations. Use of soil moisture content, however, has not lowered the utility of this work as the approach followed for the development of model remains the same even when soil matric potential is used. Moreover, soil water content in this model can be easily replaced by soil matric potential, provided the relationship between soil water content and soil matric potential is available.

Experimental

A laboratory study was conducted to investigate the effect of six soil moisture contents ranging from 11 to 21% in 2% increments, and six constant temperature levels in the range of 13 to 28°C with 3°C increments. The experimental temperature range was within the basal (4.4°C) temperature (Nuttonson 1956) and the maximum (35°C) temperature (Peterson 1965) for wheat. Seeds of two wheat varieties (Shailaza and local) were planted at a depth of 4 cm in soil adjusted to different water contents and packed into 1 litre plastic containers. Each set was replicated three times. Seedling emergence was recorded daily up to 10 days after sowing.

In the second phase of the study, emergence time under naturally varying temperature conditions was observed for evaluating the predictability of the proposed model in the field. In this study the containers were removed to a well ventilated laboratory. Variation in temperature was achieved by sowing the seeds on four different dates—at an interval of 10 days. A thermograph was placed in the laboratory for recording temperature variations. Temperature varied from 22 to 27°C, 18 to 27°C, 19 to 24°C and 17 to 22°C during the four different sets of observations. Mean temperatures of these sets were 24.9, 22.0, 20.7 and 19.6°C. Soil moisture levels were the same as those of the first experiment. The other experimental details were as reported earlier (Sethi et al. 1985).

Results and Discussion

Parameters of the model for both wheat varieties were estimated from the data (288 observations for local and 252 observations for Shailaza variety) from first phase of the study. The maximum contribution (24.8% in local and 28.7% in Shailaza) to variability to wheat emergence was due to temperature's quadratic effect (table 1) followed by its linear effect (15.4% in local and 14.0% in Shailaza). Thus, temperature was found to play predominant role in producing variability in wheat emergence. Among the interactive effects, $t \times T \times \theta$ was the most significant one. The relative contributions of the different effects to the variability in wheat emergence explainable by the dynamic model were found to be closely associated for the two varieties (r = 0.97, significant at 1% probability level). Hence, the pattern of the relative significance of the various effects exhibited a tendency to remain unchanged due to varietal differences.

From the fitted model we can predict wheat emergence after a known time under given temperature and moisture conditions (table 2). But the

Table 1 *Estimates of the parameters of the dynamic logistic growth model and the relative contributions of the various effects to the variability in emergence for two varieties of wheat*

Parameter	Local		Shailaza	
	Estimate	Relative contribution to variability (%)	Estimate	Relative contribution to variability (%)
a	2.6829×10^{19}	7.4**	8.9414×10^{12}	7.4**
b_1	3.2103	3.2+	2.9136	2.9
b_2	−2.1912	15.4**	−1.5353	14.0**
b_3	−1.0529	2.8+	0.0836	0.1
b_{22}	0.0715	24.8**	0.0603	28.7**
b_{33}	0.0877	13.5**	0.0505	10.7**
b_{12}	−0.1990	3.9*	−0.1940	5.4**
b_{13}	−0.3546	10.0**	−0.2993	9.3**
b_{23}	−0.0972	8.7**	−0.1010	10.3**
b_{123}	0.0166	10.3**	0.0152	11.2**
Predictability measure (ϕ)	0.893		0.856	

\+ Significant at 10% probability level
* Significant at 5% probability level
** Significant at 1% probability level

Table 2 *Emergence (%) of two wheat varieties at different times under various temperatures and moistures as predicted from the dynamic logistic growth model*

Temperature (°C)	Moisture (%)	Local				Shailaza			
		Time (DAS)				Time (DAS)			
		4	6	8	10	4	6	8	10
16	13	1.2 (0)*	10.5 (27.5)	52.6 (87.5)	91.3 (97.5)	0.3 (0)	2.2 (2.5)	12.5 (42.5)	47.3 (67.5)
	17	4.4 (0)	47.1 (65.0)	94.5 (100.0)	99.7 (100.0)	0.9 (0)	8.5 (27.5)	47.9 (75.0)	90.1 (90.0)
	19	3.0 (0)	46.1 (70.0)	95.9 (100.0)	99.8 (100.0)	0.8 (0)	9.4 (25.0)	56.1 (77.5)	94.0 (95.0)
22	13	40.5 (57.5)	84.0 (90.0)	97.6 (92.0)	99.7 (95.0)	8.4 (2.5)	35.8 (50.0)	77.1 (77.5)	95.3 (92.5)
	17	84.2 (85.0)	97.4 (97.5)	99.6 (100.0)	99.9 (100.0)	38.9 (42.5)	74.4 (77.5)	93.0 (92.5)	98.4 (97.5)
	19	83.9 (82.5)	97.2 (97.5)	99.6 (100.0)	99.9 (100.0)	47.8 (62.5)	78.4 (92.5)	93.5 (97.5)	98.3 (97.5)
25	13	42.3 (82.5)	83.7 (92.5)	97.3 (97.5)	99.6 (97.5)	8.4 (10.0)	35.2 (67.5)	76.3 (82.5)	95.0 (85.0)
	17	89.3 (87.5)	97.3 (97.5)	99.3 (100.0)	99.8 (100.0)	50.7 (37.5)	76.1 (80.0)	90.8 (92.5)	96.8 (92.5)
	19	90.7 (92.5)	97.0 (97.5)	99.1 (100.0)	99.7 (100.0)	65.3 (47.5)	80.8 (92.5)	90.5 (97.5)	95.5 (97.5)

* Values within parenthesis denote the corresponding observed emergence

reliability of predictions is not the same at the different data points. The model has a tendency to underestimate wheat emergence at low moistures and temperatures on intermediate time intervals. However, the agreement between observed and the corresponding predicted values of final emergence for both the varieties is fairly good. Moreover, the overall predictability of the model is high enough; the ϕ values being 0.893 for local and 0.856 for Shailaza. The model is, thus, capable of precisely providing guidelines for the management practices to attain a desired crop stand under different environmental conditions. For instance, an emergence of 75% of Shailaza wheat shall expectedly occur in 9 days when the temperature is 16°C and soil moisture is 17%. The same emergence may also be obtained in the same time by maintaining 13% moisture if the temperature is likely to be 19°C.

The predicted emergence of local wheat was found to be consistently more than that of Shailaza wheat at each combination of t, T and θ (table 2). Thus, the joint effect of time, temperature and moisture on the emergence of local variety of wheat is more pronounced than that on the emergence of Shailaza.

Partial derivative of emergence with respect to temperature/moisture/time for Shailaza was, in general, numerically larger than that for local. This indicates that Shailaza variety, on the whole, is more sensitive to changes in temperature, moisture and time than the local variety.

Under naturally varying temperature conditions, the compatibility between observed and the corresponding predicted values of emergence is satisfactory (figure 1), thereby implying that the dynamic growth model may hold good under field conditions too.

Lindstrom et al.'s (1976) model is capable of predicting time required for achieving 50% emergence at various combinations of soil temperature and moisture. Our model has an advantage over this model as it can do the same job for any desired emergence. For example, an emergence of 80% of local wheat under a temperature of 19°C and a moisture content of 11% shall expectedly take place in 9 days. The same emergence may be attained just in 7 days provided the temperature is 16°C and moisture is maintained at 17% (figure 2). Hence another utility of our model lies in that it enables to predict environmental conditions for early targetted emergence of a desired extent.

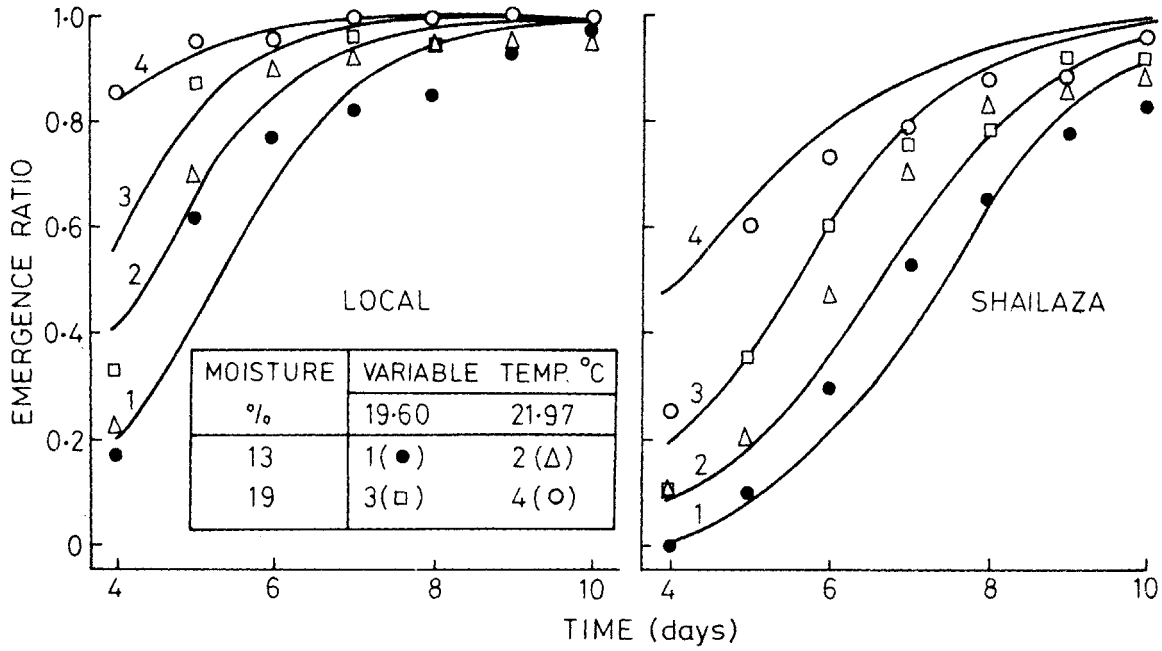

Figure 1 Observed (symbol) and predicted (line) emergence of local and Shailaza varieties of wheat at different times under variable temperature

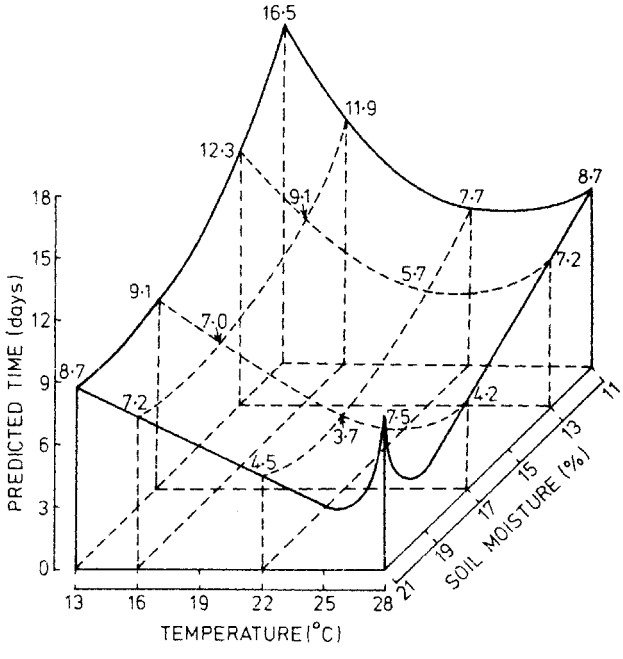

Figure 2 Predicted time for 80% emergence of local wheat under different temperatures and moistures.

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