Proc. Indian natn. Sci. Acad. **B51** No. 1 pp 117–122 (1985)

A Model to predict Wheat Emergence from Soil Temperature and Soil Moisture

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(Received 29 August 1984; after revision 22 December 1984)

The seedling emergence of 2 wheat varieties at various temperatures and soil moisture levels was evaluated. Mean emergence (over moistures and temperatures) was related to time through a Mitscherlich equation. A second degree logistic growth model was developed for predicting wheat emergence at a given time from temperature and soil moisture. An exponential model which provides a temperature-moisture schedule for achieving a desired emergence in a certain time was also developed. Validation of the logistic model has been confirmed from a good agreement found between the observed and predicted values of emergence under naturally varying temperature conditions.

Key Words: Logistic growth model, Varietal emergence difference in wheat, Sensitivity to temperature and moisture

Introduction

Due to increase in cropping intensity, sowing of wheat is done under considerably varying environmental conditions from October to early January. Wheat emergence and consequently crop stand is primarily affected by temperature and moisture (Hillel 1972, Lindstrom et al. 1976). Models capable of predicting wheat emergence under given temperature and moisture regimes will help in achieving the desired crop stand by manipulation of the seed rate or soil moisture content as temperature can be estimated from meteorological data. Lindstrom et al. (1976) model is of limited utility as it predicts time for 50% emergence only, neither higher nor lower emergence. we have followed a new approach in the development of models capable of predicting (*i*) emergence of wheat at a given time under different environmental conditions and (*ii*) optimum soil-water content for achieving desired crop stand in a given time under the prevailing temperature regime.

Materials and Methods

Theory

For computational convenience, the equally

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spaced temperature T (in °C) and soil moisture content θ (in %) were transformed into x and y as

$$x = (T - 10)/3 \text{ and } y = (\theta - 9)/2$$

Emergence ratio (defined as the emergence at any time as a fraction of the maximum attainable emergence, averaged over all temperature and moisture levels at t days after sowing, $\bar{p}_t$, was related to time t (in days after sowing) through a Mitscherlich equation written as:

$$\bar{p}_t = a - b \exp(-ct) \quad .. \quad (1)$$

where a, b and c are the unknown parameters of the equation. Following the approach of difference equations (Nair 1964) the equation was expressed linearly as:

$$D_t = a' + b' S_t \quad .. \quad (1.1)$$

where $D_t = (\bar{p}_{t+1} - \bar{p}_t)$, $S_t = (\bar{p}_{t+}\bar{p}_{t+1})$ and $a' = -2ab'$.

The coefficients a' and b' in (1.1) could be easily estimated, thus furnishing the estimate of a. The equation (1) could then be rewritten as :

$$Log(a - \bar{p}_t) = Log\ b - ct \quad .. \quad (1.2)$$

which was linear in Log $(a - \bar{p}_t)$ and t, from where the least squares estimates of b and c were evaluated. Equation (1) provides only an approximate estimate of the time (t_0) needed for achieving a desired emergence ratio $(\bar{p}_{t_o})$ as it ignores the influence of moisture and temperature on the emergence time.

Following Landsberg (1977) emergence ratio $(p_{x,y})$ at time t_o for temperature x and moisture y was expressed as second degree logistic growth model in x and y, viz.

$$p_{x,y} = k/\{1 + f\ exp\ (-g_1 x - g_2 y + g_{11} x^2 + g_{22} y^2 + g_{12} xy)\} \quad .. \quad (2)$$

representing geometrically a sigmoidal surface with a fall. The parameter k, which denotes the maximum attainable value of the dependent variable, equals 1.0 in the present case, the highest value of emergence ratio. Then the growth model (2) could be expressed as :

$$Log\ (1/p_{x,y} - 1) = Log\ f - g_1 x - g_2 y + g_{11} x^2 + g_{22} y^2 + g_{12} xy \quad .. \quad (2.1)$$

which represents the usual second degree multiple regression equation relating Log $(1/p_{x,y} - 1)$ with x and y. From (2.1) the parametric quantities f, g_1, g_2, g_{11}, g_{22} and g_{12} of the model (2) could be easily estimated. Equating $p_{x,y}$ in (2) to $\bar{p}_{t_o}$ and simplifying, a solution of y in terms of x was found to be

$$y = \{(g_2 - g_{12} x) - (l\ x^2 + mx + n)^{1/2}\}/2g_{22} \quad .. \quad (2.2)$$

Where,

$$l = g_{12}^2 - 4\ g_{11}\ g_{22},$$
$$m = 2\ (g_2\ g_{12} - 2\ g_1\ g_{22}),$$
$$n = g_2^2 + 4\ g_{22}\ \dot{p}_{t_o}, \text{ and}$$
$$\dot{p}_{t_o} = Log\ \{(1/p_{t_o} - 1)/f\}$$

Applying elementary algebra, it can be seen that the range of x in (2.2) providing real solutions for y is given by

$$x = \{-m \pm (m^2 - 4\ ln)^{1/2}\}/21 \quad .. \quad (2.3)$$

The equation (2.2) was used for computing various pairs of real values of moisture (y) and temperature (x) which would result in a predetermined emergence ratio $(\bar{p}_{t_o})$ after a given time (t_0). For facilitating the estimation of the corresponding values of moisture and temperature for the desired emergence, the above obtained values were further related through an exponential function (Draper & Smith 1968), given by

$$y = u\ exp\ (-vx + wx^2) \quad .. \quad (3)$$

The unknown parameters u, v and w of the model (3) were estimated from its parabolic expression (3.1) between Log y and x, viz.

$$Log\ y = Log\ u - vx + wx^2 \quad .. \quad (3.1)$$

This model provides a temperature-moisture schedule for achieving a crop stand of desired density in a certain time.

Goodness of each model fitted to two wheat varieties was evaluated by computing a measure ϕ defined as 1.0 minus the ratio

of the residual sum of squares to the corrected total sum of squares (Ware et al. 1982).

Experimental

A laboratory study was conducted to study the effect of 6 soil moisture and 6 constant temperature levels on emergence time of 2 wheat varieties. Surface silty clay loam (sand 21.5%, silt 45.4% and clay 32.8%) was air dried, sieved, and wetted in bulk to water contents ranging from 11 to 21%, in 2% increments. Seeds of two wheat varieties (Shailaza — a two gene dwarf and local — a tall variety) were planted at a depth of 4 cm in soil adjusted to different water contents and packed into 1 litre plastic containers. The containers were covered with polyethylene sheet with two small holes to allow adequate air exchange and were placed in a temperature controlled room. Temperature was changed between different sets within the range of 13 to 28°C with 3 degree increments and was maintained within $\pm$ 0.5°C. The required temperature was achieved in the insulated room by using room heaters connected in series with an adjustable thermostat. Air was circulated with a table fan, placed near the room heater, for maintaining uniformity in room temperature. 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 this model in the field. In this study 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 4 different sets of observations. Mean temperature of these 4 different sets of observations was 24.9, 22.0, 20.7 and 19.6°C. Soil moisture levels were same as those of first experiment.

Results and Discussion

Model 1

Estimates of the unknown parameters of this model for the two varieties are tabulated below:

Variety	a	b	c	ϕ value
Local	0·9485	2·1866	0·3489	0·998
Shailaza	0·8001	2·3732	0·3190	0·996

Average emergence for local wheat is consistently more than that for Shailaza (figure 1). Very high values of ϕ reveal a nice goodness of the fitted model. For local wheat, expected $\bar{p}_t$ was 0.758 at 7 DAS and 0.854 at 9 DAS. However, the expected $\bar{p}_t$ for Shailaza wheat was 0.546 at 7 DAS and 0.666 at 9 DAS.

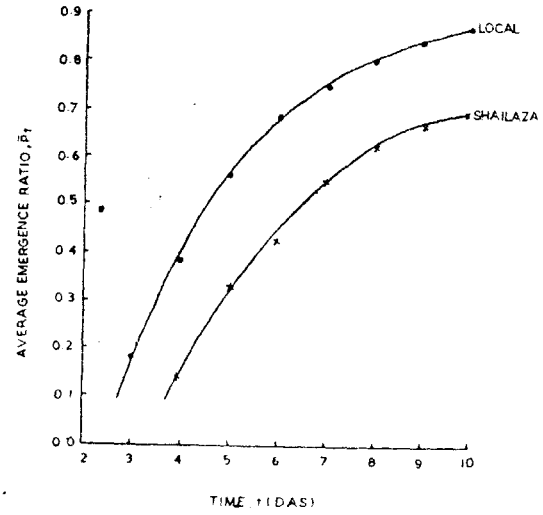

Figure 1 Average emergence of Local and Shailaza varieties of wheat in relation to time

Variety	f(x10⁶)	g_1	g_2	g_{11}	g_{22}	g_{12}	ϕ value
Local	2·2944	5·7179	4·3408	0·5704	0·3633	0·2904	0·923
Shailaza	0·4668	5·4177	2·6408	0·5884	0·1970	0·2019	0·878

Model 2

Fitting this model to both the varieties at $t = 9$ DAS yielded the above set of estimates of the parameters:

Fairly high values of ϕ, each computed at 36 data points, indicate goodness of fit of the model 2, which jointly relates emergence ratio to temperature and soil moisture after a known time.

A relative comparison of emergence ratio (observed and predicted) for both the varieties at 9 DAS conspicuously reveals that sigmoidal surface for the local variety is consistently higher than that for the Shailaza variety (figure 2), indicating thereby that the combined effect of temperature and moisture on local wheat is more pronounced than that on Shailaza. However, the sensitivity analysis based on computing values of partial derivatives of $p_{x,y}$ with respect to x and y revealed that except for 3 combinations of T and θ, viz. (13°C, 11%), (13°C, 13%) and (16°C, 11%), the values for Shailaza were higher than those for the local. This implies that barring a few low-levelled combinations of T and θ, Shailaza variety is more sensitive to changes in temperature and soil moisture than local wheat.

Model 3

Fitting this model for $t = 9$ DAS for both the varieties yielded the following set of estimates of the unknown parameters:

Variety	u	v	w	Expected emergence ratio ($\bar{p}_{t_0}$)	ϕ value
Local	19·5272	1·3409	0·1468	0·854	0·965
Shailaza	182·0056	2·5251	0·3001	0·666	0·915

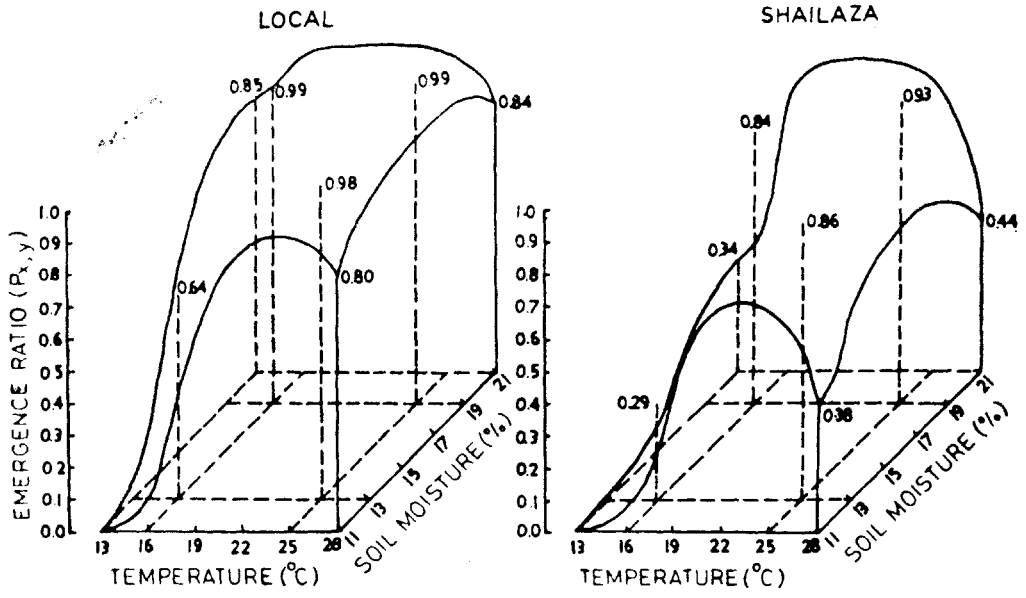

Figure 2 Representing interactive effect of temperature and soil moisture on emergence percentage of Local and Shailaza wheat at 9 DAS

Again, substantially high values of ϕ confirm goodness of fit of this model as well. The temperature-moisture schedule for both the varieties have been presented graphically (figure 3).

Finally, to assess applicability of the model 2 under varying temperature (field) conditions, estimated emergence was calculated for $t = 7$ and 9 DAS, using average of the variable temperature in the model. A fairly close proximity between observed and the corresponding predicted values (figure 4) indicates applicability of the model under varying temperature (field) conditions as well.

This model predicts that 91% emergence in local wheat can be achieved 7 days after sowing (data not included) when soil moisture content is 11% and temperature is 22°C. The same emergence can also be obtained in the same period by ensuring 17% moisture content when temperature is expected to be 16°C. Thus this model provides management practices for obtaining the desired crop stand under different situations. This model also predicts environmental conditions for ensuring early targetted emergence. For example 88% emergence of Shailaza wheat 9 days after sowing when soil moisture content is 21% and temperature is 25°C, could also be achieved in 7 days, according to this model, provided 15% soil moisture content and 25°C temperature is maintained. This model (Equation 2.3) also gives a critical temperature range within which the desired emergence can be obtained by maintaining certain level of soil moisture. This model predicts that 67% emergence of Shailaza wheat 9 days after sowing can be achieved only within the temperature range of 14.5 to 28.2°C. Outside this critical temperature range, the desired emergence cannot be achieved by manipulation of the soil moisture.

Development of crust after wheat sowing may adversely affect emergence and consequently utility of this model. Encrustation during wheat emergence period, however, is unlikely as soil drying is slow and probability of rains is low during this period. Another limitation of this model

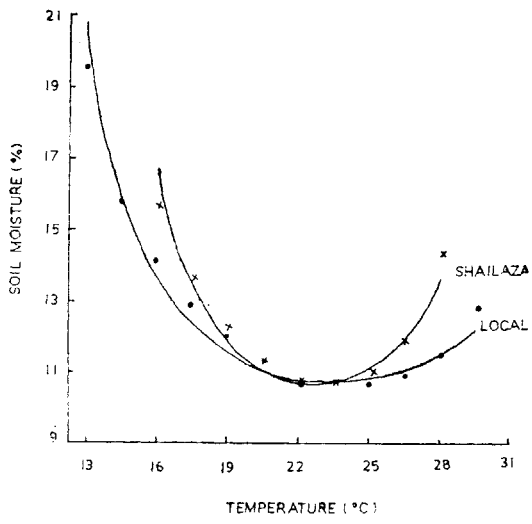

Figure 3 Temperature-moisture relationship for 85% emergence of Local and 66.6% emergence of Shailaza wheat at 9 DAS

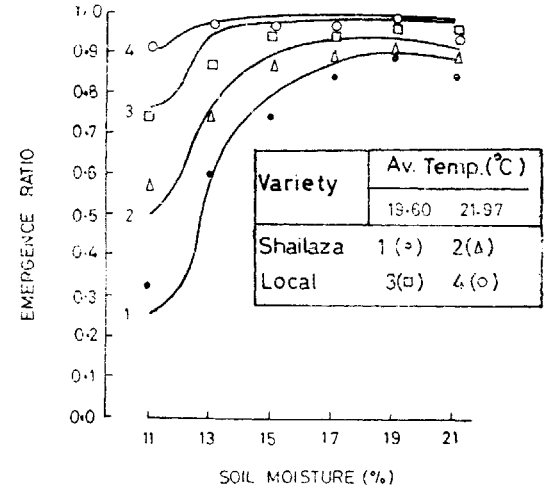

Figure 4 Observed and predicted emergence of Local and Shailaza varieties of wheat under variable temperature at 7 DAS

is that it does not apply equally well for the entire range of temperature and moisture tested, though the overall predictability of the model is fairly high. Predictability is relatively more at higher levels of moisture and temperature.

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