Modeling rice seedling emergence and growth under tillage and residue management in a rice–wheat system on a Vertisol in Central India

ARTICLE · JANUARY 2004

Monoranjan Mohanty
ICAR-Indian Institute of Soil Science

Available online at www.sciencedirect.com
SCIENCE DIRECT®
Soil & Tillage Research 76 (2004) 167–174
Soil & Tillage Research
www.elsevier.com/locate/still

Modeling rice seedling emergence and growth under tillage and residue management in a rice–wheat system on a Vertisol in Central India

M. Mohanty*, D.K. Painuli

Indian Institute of Soil Science, Indian Council of Agricultural Research, Nabi Bagh, Berasia Road, Bhopal 462038, MP, India

Received 3 April 2002; received in revised form 30 September 2003; accepted 9 October 2003

Abstract

Tillage and residue management practices are known to affect seedling emergence and growth. However, information on direct seeded rice (*Oryza sativa* L.) in rice–wheat (*Triticum* spp.) cropping system is lacking. Thus a study was undertaken under different tillage (conventional and zero tillage) and residue (residue-retained and removed) management options on rice seedling emergence and growth in rice–wheat system on a Vertisol of Central India. Seedling emergence was greater in residue removed plots compared to residue-retained one. Prediction of rice seedling emergence with the France and Thornley [Mathematical Models in Agriculture and Related Sciences, Butterworths, London, 1984] model and growth by the Logistic and Gompertz model, and Monomolecular model were also attempted. Emergence indicators showed that seedling emergence of rice was favored more by conventional tillage than zero tillage in wheat. Of the three models tested, the Gompertz model gave the best fit. The effect of tillage and residue of wheat on the estimated parameters of the models were also studied.

Keywords: Emergence; Growth; Tillage; Rice; Model; Vertisol

1. Introduction

Tillage is practiced for various advantages including controlling weeds, break crusts (improve water entry), increase surface roughness (assist water storage) and prepare a seedbed. The type of tillage depends upon the soil type and the climate of the area. Tillage practices affect mechanical characteristics of the seedbed considerably and thus the crop emergence. As reported by Leslie (1965) crop emergence is commonly a major problem in Vertisols due to inadequate soil moisture and poor structure of the seedbed. Press wheels can in some cases, greatly improve emergence (Smith et al., 1984). Maintenance of crop residue on soil surface through zero tillage has been shown to benefit some Vertisols due to improved soil physical properties in northeastern Australia (Freebairn et al., 1986a,b; Sallaway et al., 1990). Radford and Nielsen (1983) have reported that stubble retention may improve seedling emergence in Vertisols, however others (Thomas et al., 1990) have reported that zero and reduced tillage with stubble retention decreased seedling emergence.

* Corresponding author. Tel.: +91-755-2734221; fax: +91-755-2733310.
E-mail address: mmohanty@iiss.mp.nic.in (M. Mohanty).

0167-1987/$ – see front matter
doi:10.1016/j.still.2003.10.001

Gan et al. (1992) reported that plants that emerge early contribute more to crop yield than those that emerge later. Thus, desirable crop yields are achieved by providing seeds with an environment that encourages early germination and emergence. Several authors have emphasized the importance of analyzing the stand establishment process and have shown that the main factors affecting germination, seedling emergence and plant establishment are associated with the mechanical characteristics of the seedbed (Jensen, 1971; Blacklow, 1972; Schneider and Gupta, 1985). The mechanical characteristics of seedbeds are influenced by tillage practices. Tillage influences bulk density, penetration resistance, aggregate mean weight diameter and surface roughness (Carman, 1996) and is practiced to induce a congenial environment for crop establishment. Chastain et al. (1994) reported that high levels of residue cover reduced emergence rate of wheat probably by reducing seed soil contact. Swan et al. (1996) reported that removing excessive plant residue from the seed row increased the germination and emergence rate of maize.

There is little information on emergence of rice seedlings under different tillage and crop residue systems. This may be because rice is mostly transplanted. Some recent reports suggest that direct seeding of rice can increase the productivity of rice–wheat systems on a Vertisol (Painuli, 2000) and that residue should be retained in situ to maintain soil organic matter. The objective of the study reported here was to determine the emergence and growth of dry-seeded rice in a rice–wheat system on a Vertisol under different tillage and wheat residue management. Prediction of the emergence and growth of seedlings by suitable growth models was also attempted.

2. Materials and methods

2.1. Site and soil

The field experiment was conducted during the wet season of the year 2001 at the experimental farm of the Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India, located at 485 m above mean sea level. The soil had not had a rice crop in the last few decades but had been under soybean (*Glycine max* L. Merr.) based cropping systems. The soil is an Entic Chromusterts with 520 g kg^{-1} clay, 300 g kg^{-1} silt, 180 g kg^{-1} and soil pH was 7.8 and CEC was 49 cmol (p+) kg^{-1}, and organic carbon was 4.6 g kg^{-1} in the surface 0–15 cm layer. The drainage rate of the profile is 5 mm per day during the *kharif* season.

2.2. Tillage and residue levels

The sequence of treatment imposition is given in Table 1. In the year 2000, direct seeded rice was sown in conventionally tilled dry soil (one pass of a disc harrow followed by two passes of a duck foot cultivator) and at harvest, rice residue of 30 cm height (approximately, 5000 kg ha^{-1}) was retained in residue-retained plots and removed from other plots for the succeeding wheat crop. Conventional (one pass of a disc harrow followed by two passes of a duck foot cultivator) and zero tillage (sowing by Pantnagar zero till seed drill in the untilled soil) were the two tillage treatments imposed in wheat. In the second year for rice, wheat residue of 45 cm height (approximately 4500 kg ha^{-1}) was retained in residue-retained plots; residue was removed from the non-residue-retained plots. In year 2001, the soil was conventionally tilled and the rice was seeded with a seed drill at 100 kg ha^{-1}. The

Table 1
Sequence of treatment imposition

Rice, 2000	Wheat, 2000–2001	Abbreviation	Rice, 2001
Rice sown directly and residue-retained at harvest	Wheat sown under conventional tillage and residue (5000 kg ha^{-1}) retained	R_r, CT	Rice under conventional tillage imposed over R_r, CT
Rice sown directly and residue-retained at harvest	Wheat sown under zero tillage and residue (4500 kg ha^{-1}) retained	R_r, ZT	Rice under conventional tillage imposed over R_r, ZT
Rice sown directly and residue removed at harvest	Wheat sown under conventional tillage and residue (5000 kg ha^{-1}) removed	R_0, CT	Rice under conventional tillage imposed over R_0, CT
Rice sown directly and residue removed at harvest	Wheat sown under zero tillage and residue (5000 kg ha^{-1}) removed	R_0, ZT	Rice under conventional tillage R_0, ZT

residual effect of tillage and residue treatments in wheat on rice seedling emergence was studied.

The data were analyzed using the standard procedure for a split plot design (Cochran and Cox, 1957) to compare treatment means. Analysis of variance (ANOVA) technique was used to test the treatment effects. Treatment means were compared using least significant difference (LSD) procedure at the 5% level of significance.

2.3. Plant observations

Seedling emergence was determined by daily counting the number of newly emerged seedlings in 1 m length of row, with three replications. Two methods were used to analyze emergence. In the first method, speed of emergence (Tessier, 1988), mean emergence date (MED), emergence rate index (ERI) and relative emergence (RE) (Bilbro and Wanjura, 1982) were calculated directly from the emergence count as follows:

$$\mathrm{SOE} = \frac{N_1 + N_2 + \cdots + N_n}{t_1 + t_2 + \cdots + t_n} \tag{1}$$

$$\mathrm{MED} = \frac{N_1 t_1 + N_2 t_2 + \cdots + N_n t_n}{t_1 + t_2 + \cdots + t_n} \tag{2}$$

$$\mathrm{ERI} = \frac{N_1 + N_2 + \cdots + N_n}{\mathrm{MED}} \tag{3}$$

where $N_1, N_2, \ldots, N_n$ are the number of newly emerged seedlings in time $t_1, t_2, \ldots, t_n$ since the start of seedling emergence, respectively.

In the second method, the RE data was fitted using non-linear regression procedures to the Logistic growth model of the following form (France and Thornley, 1984):

$$\mathrm{RE} = \frac{1}{1 + \exp(a + bt)} \tag{4}$$

In the equation, a is the constant of integration and b the emergence rate constant and t the time since sowing. The Logistic growth model has been used successfully to assess the effect of environmental conditions on seed germination (Schimpf et al., 1977). The Logistic growth model has a point of inflection, at which the rate of emergence reaches a maximum and this occurs at a time when $\mathrm{RE} = 0.5M$ where M is a parameter describing the maximum number of seedlings that eventually emerged (France and Thornley, 1984). The time at which the point of inflection occurs also called the median emergence time ($T_{0.5}$), is given by

$$T_{0.5} = \frac{a}{b} \tag{5}$$

The maximum emergence rate (MER) is given by

$$\mathrm{MER} = \tfrac{1}{4}(Mb) \tag{6}$$

2.4. Modeling growth of rice seedlings

In the absence of a general theoretical equation to describe seedling growth, three empirical curvilinear growth functions historically used for analyzing dry matter accumulation versus time (namely the Logistic, Gompertz and Monomolecular equations) were examined for applicability. A common property of these models is that the length (L) approaches a constant (L_f) as time approaches infinity. In fact the seedling temporarily stops increasing in height and increases its number of leaves just after emergence (2–3-leaf stage). It was assumed that temperature and soil water potential remained unchanged over the study period.

2.5. Parameter estimation

On the basis of experimental data related to growth of shoots in different tillage and residue management practices at a constant temperature, a non-linear regression fitting procedure was used to estimate the parameters of the three functions given below.

2.5.1. The logistic model

This is a symmetrical logistic function with an inflection point:

$$L(t) = \frac{L_0 L_f}{L_0 + [L_f - L_0]\exp(-\Gamma_0 t)} \tag{7}$$

where $L(t)$ is the length in mm of shoot at any time, L_0 the length at the onset of growth ($t = 0$), Γ_0 the relative growth rate at time 0 (per day).

Assuming that $L_0 = 1$ mm just after germination, the above equation can be written as

$$L(t) = \frac{L_f}{1 + [L_f - 1]\exp(-\Gamma_0 t)} \tag{8}$$

Thus, only two parameters L_f and Γ_0 were to be estimated.

2.5.2. The Gompertz model

This is an asymmetrical function with an inflection point; in this case RGR (relative growth rate) defined by Γ, decreases exponentially with time:

$$L(t) = L_{\rm f}\exp[\{-\ln(L_{\rm f})\}\{\exp(-K_{\rm g}t)\}] \quad (9)$$

where $K_{\rm g}$ is the relative growth rate

Only two parameters $L_{\rm f}$ and $K_{\rm g}$ were to be estimated.

2.5.3. The Monomolecular model

The mathematical function is an increasing one without any inflection point:

$$L(t) = L_{\rm f}[1 - \exp(-K_{\rm m}t)] \quad (10)$$

where the $K_{\rm m}$ (per day) is a proportionality coefficient to Γ and the equation implies that $L_0 = 0$ when $t = 0$. Two parameters $L_{\rm f}$ and $K_{\rm m}$ were to be estimated.

2.6. Model evaluation

Seedling emergence rate and growth were the variables on which the model predictions were compared with the observed values. Only one model was used for emergence whereas three models were used for growth of seedlings. The statistical criteria used to compare the predicted (P_i) and observed (O_i) values for growth models were Eqs. (11)–(13) as suggested by Smith et al. (1996).

- Modeling efficiency (EF):

$$\text{EF} = 1 - \frac{\sum_{i=1}^{i=n}(P_i - O_i)^2}{\sum_{i=1}^{i=n}(O_i - \bar{O})^2} \quad (11)$$

- Root mean square error (RMSE):

$$\text{RMSE} = \frac{100}{\bar{O}}\sqrt{\frac{\sum_{i=1}^{i=n}(P_i - O_i)^2}{n}} \quad (12)$$

- The coefficient of residual mass (CRM):

$$\text{CRM} = \frac{\sum_{i=1}^{i=n}O_i - \sum_{i=1}^{i=n}P_i}{\sum_{i=1}^{i=n}O_i} \quad (13)$$

In the above equations, n is the number of times heights of the seedlings were observed and $\bar{O}$ the mean observed values.

3. Results and discussion

3.1. Rice seedling emergence under different tillage and residue management

At any given time percent emergence was less in ZT and $R_{\rm r}$ plots than in the CT and R_0 plots, respectively (Fig. 1) A lower ultimate emergence under ZT than under CT may be because larger aggregates caused seedling entrapment (Durr and Jean-Noel, 2000) as well as poorer seed–soil contact. This, as reported by some researchers (Schneider and Gupta, 1985; Hayhoe et al., 1993) could introduce increased variability in

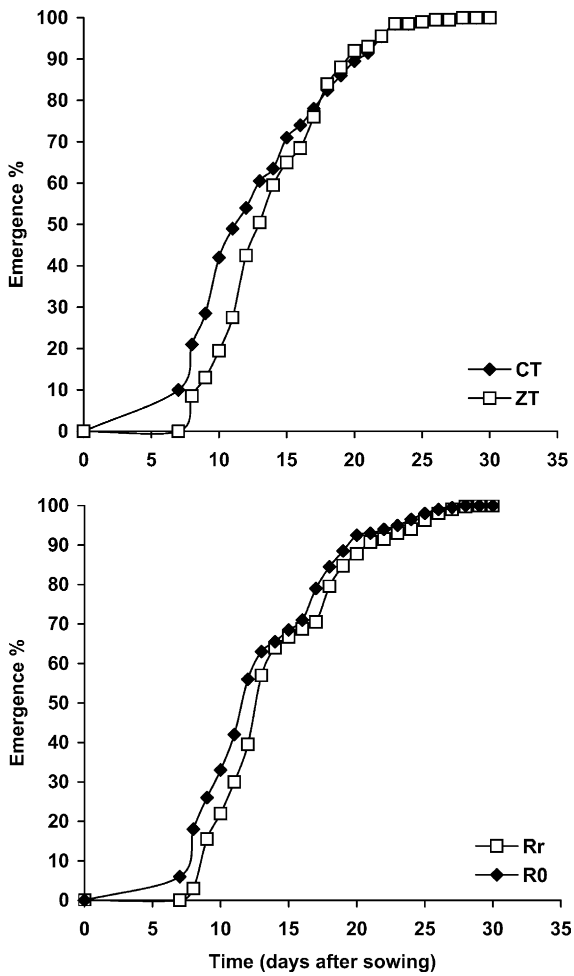

Fig. 1. Emergence of rice seedlings as affected by tillage in wheat (CT and ZT) and residue management in rice and wheat (R_0 and $R_{\rm r}$).

the rate of emergence as well as in the final stand establishment.

3.2. Final emergence percent, maximum and ultimate emergence and 50% emergence versus tillage and residue management

After 25 days, no difference in final emergence percentage was observed among the various treatments but the time required to reach maximum or ultimate emergence as well as 50% emergence ($T_{0.5}$), varied. Emergence indicators (SOE, MED, ERI, MER and $T_{0.5}$) showed that seedling emergence of rice was favored by CT when compared with ZT in wheat (Table 2). R_0 increased rice seedling emergence compared with the R_r treatments.

3.3. Estimation of seedling emergence parameters

Fitting of the RE data of each treatment to the Logistic model (Fig. 2) showed that the parameters *a* and *b* were different for all the treatments (Table 2). The values of the median emergence date predicted by the Logistic model were in close agreement with the time required for 50% emergence calculated directly from interpolation of the raw emergence data.

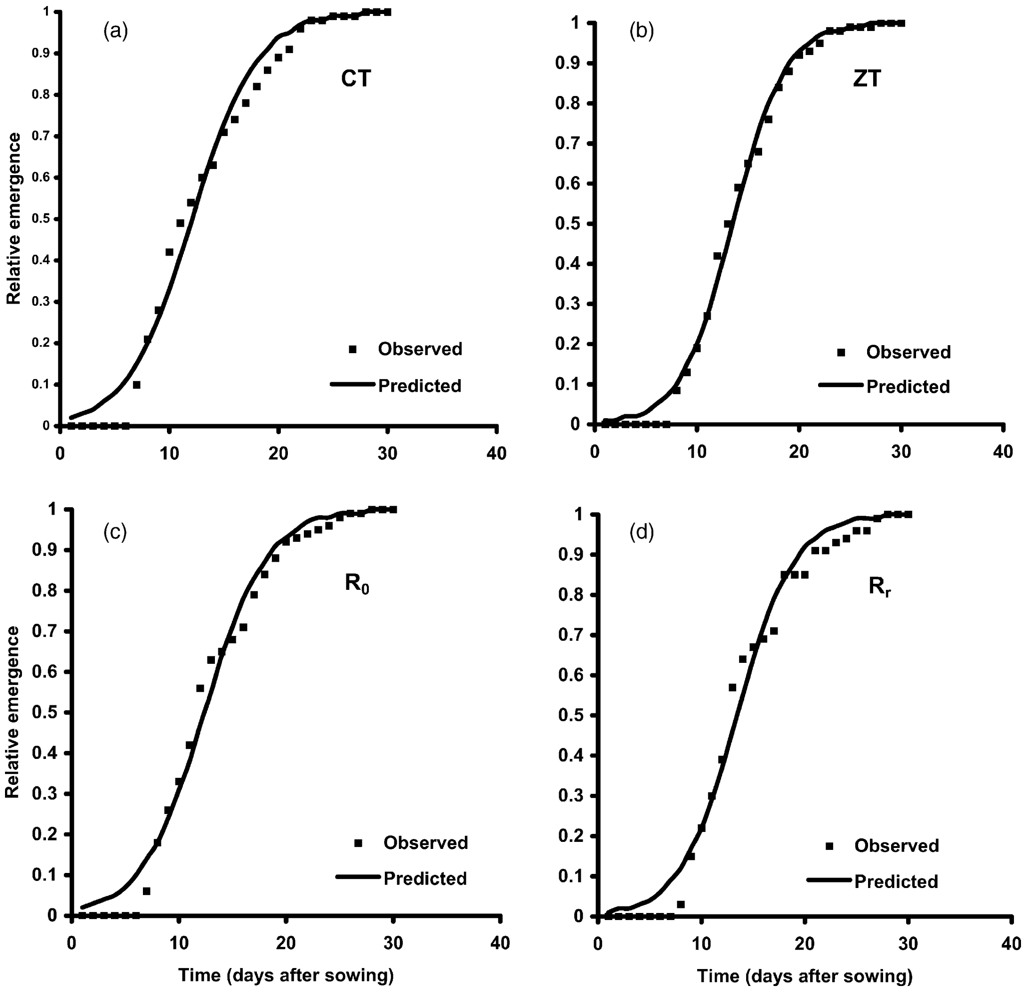

Fig. 2. Observed versus predicted values for the RE of rice in CT, ZT, R_0 and R_r treatments as predicted by Logistic growth model.

Table 2
Emergence indicators of rice seedlings (Tessier, 1988; Bilbro and Wanjura, 1982) and empirical constants *a*, *b* and coefficient of determinations (R^2) for emergence of rice seedlings as estimated from Logistic model (France and Thornley, 1984) under different tillage and residue management

Treatments	Emergence indicator[a]					Empirical constants		
	SOE	MED	ERI	MER	$T_{0.5}$	a	b	R^2
CT	0.48	6.08	36.69	18.36	12.19	4.00	0.33	0.98*
ZT	0.30	4.61	33.21	15.95	13.49	5.56	0.41	0.99*
LSD ($P = 0.05$)	0.08	1.11	1.55	1.78	NS	0.25	NS[b]	
R_r	0.32	5.98	34.84	13.96	13.30	5.25	0.39	0.98*
R_0	0.43	4.70	35.06	20.35	12.48	4.32	0.35	0.98*
LSD ($P = 0.05$)	NS	NS	NS	2.55	NS	NS	NS	

[a] SOE: speed of emergence (plants per day); MED: mean emergence date (days); ERI: emergence rate index (per day); MER: maximum emergence rate (plants per day); $T_{0.5}$: median emergence time (days).
[b] Non-significant.
* Significant at 5% level.

3.4. Shoot growth responses to tillage and residue of wheat

Fig. 3 shows the sensitivity of rice shoot elongation to residual effects of tillage and effects of wheat residue management practices. Shoot length of rice seedlings was significantly smaller in ZT compared with CT at 15 days after emergence and remained so until 35 days. The growth of rice seedlings under R_r was less compared with that in the R_0 conditions, but the difference was not significant. Alsaadawi et al. (1998) reported allelopathic effect of wheat residues on rice seedling growth. The extent to which this might have affected the rice seedling growth in this study is unknown. The differences in shoot lengths between the tillage treatments were pronounced in the early stages, whereas the differences in between the residue treatments was evident only in the later stages.

3.5. Estimation of seedling growth parameters

We compared three empirical growth functions to select the best model. Overall results (Table 3) showed that

1. Curve fitting generally gave efficiency >0.90 in all three cases.
2. Among the three models, the Gompertz and the Monomolecular models gave quite satisfactory results as the predicted values from the model and the observed values from the experiment were close (EF 0.98 in most of the cases and RMSE < 7.0,). The Logistic model was not further considered because of the higher RMSE values (>13 in all cases).
3. Between the Gompertz and the Monomolecular models, the predicted changes in growth of rice seedlings with time were slightly greater than the observed values in the Monomolecular model

Table 3
Values of statistical criteria for growth models on all treatments

Models	EF	RMSE	CRM
CT			
Logistic	0.93	14.08	0.043
Gompertz	0.98	5.92	0.016
Monomolecular	0.93	5.70	−0.0007
ZT			
Logistic	0.94	14.41	0.036
Gompertz	0.98	6.35	0.018
Monomolecular	0.93	5.63	−0.004
R_r			
Logistic	0.94	13.94	0.037
Gompertz	0.98	5.90	0.013
Monomolecular	0.98	5.89	−0.003
R_0			
Logistic	0.93	14.87	0.040
Gompertz	0.98	7.00	0.016
Monomolecular	0.99	5.83	−0.0007

Table 4
Empirical constants; final length (L_f), proportional (K_m) or attenuated coefficient (K_g) of the tillage and residue relationships for shoots for Eqs. (8)–(10)

Treatments	Logistic		Gompertz		Monomolecular	
	L_f	Γ_0	L_f	K_g	L_f	K_m
CT	72.20	0.337	79.10	0.143	125.59	0.030
ZT	61.62	0.316	68.50	0.133	120.44	0.024
LSD ($P = 0.05$)	1.25	NS[a]	3.33	NS	1.65	NS
R_r	63.93	0.323	70.68	0.137	117.52	0.027
R_0	67.53	0.326	75.20	0.135	132.45	0.024
LSD ($P = 0.05$)	2.22	NS	2.63	NS	4.55	NS

[a] Non-significant.

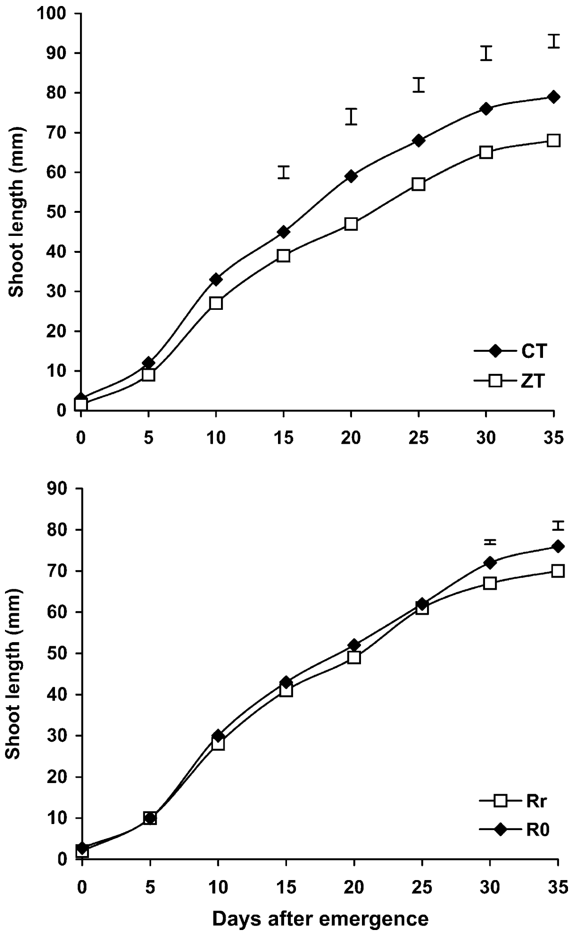

Fig. 3. Shoot length of rice seedlings as affected by tillage and residue of wheat (vertical bar represents LSD at 5%).

(CRM having negative values in all cases) though it fitted well with the shape of the experimental data for rice. So, this showed a slight over prediction in the case of the Monomolecular model. However, Bouaziz and Bruckler (1989) reported the non-applicability of this model in the case of growth of wheat in the laboratory, as the shape of experimental data curve did not fit with the function.

4. The Gompertz model was considered to fit best of the three models.

3.6. Estimated parameters under different tillage and residue management

All estimated parameters corresponding to different tillage and residue treatments were analyzed independently of each other. Tillage and residue had different effects on Gompertz parameters L_f and K_g and Logistic parameters L_f and Γ_0 and Monomolecular parameters L_f and K_m (Table 4). The L_f decreased significantly with ZT and R_r treatments compared with the CT and R_0 treatments. L_f varied from approximately 61 to 132 mm across all treatments and models. The parameters Γ_0, K_g and K_m were least affected by tillage and residue treatments and they showed nothing but the relative growth rates for every model.

4. Conclusions

From the standpoint of seedling emergence, a good seedbed must provide physical conditions conducive to maximize emergence and speed of emergence. An empirical approach that takes into consideration the growth of rice seedling has been proposed. Curve fittings according to the Gompertz, Logistic and Monomolecular models gave satisfactory results. Among the models, the Gompertz model proved to be the best one.

Acknowledgements

The fund provided by National Agricultural Technology project (PSR 31) for this study is duly acknowledged.

References

Alsaadawi, I.S., Zwain, K.H.Y., Shahata, H.A., 1998. Allelopathic inhibition growth of rice by wheat residues. Allelopathy J. 5, 163–169.

Bilbro, J.D., Wanjura, D.F., 1982. Soil crust and cotton emergence relationship. Trans. ASAE 25, 1485–1488.

Blacklow, W.M., 1972. Influence of temperature on germination and elongation of the radicle and shoot of corn (*Zea mays* L.). Crop Sci. 12, 647–650.

Bouaziz, A., Bruckler, L., 1989. Modeling wheat seedling growth and emergence: seedling growth affected by soil water potential. Soil Sci. Soc. Am. J. 53, 1832–1838.

Carman, K., 1996. Effect of different tillage systems on soil properties and wheat yield in middle Anatolia. Soil Till. Res. 40 (3–4), 204–207.

Chastain, T.G., Ward, K.J., Wysocki, D.J., 1994. Stand establishment responses of soft white winter wheat to seedbed residue and seed size. Crop Sci. 35, 213–218.

Cochran, W.G., Cox, G.M., 1957. Experimental Designs. Wiley, New York, USA.

Durr, C., Jean-Noel, A., 2000. Emergence of seedling of sugar beet (*Beta vulgaris* L.) as affected by size, roughness and position of aggregates in the seedbed. Plant Soil 219, 211–220.

France, J., Thornley, J.H.M., 1984. Mathematical Models in Agriculture and Related Sciences. Butterworths, London.

Freebairn, D.M., Wockner, G.H., Silburn, D.M., 1986a. Effect of catchment management on runoff, water quality and yield potential from Vertisols. Agric. Water Manage. 12, 1–19.

Freebairn, D.M., Ward, L.D., Clarke, A.L., Smith, G.D., 1986b. Research and development of reduced tillage systems for Vertisols in Queensland, Australia. Soil Till. Res. 8, 211–229.

Gan, Y., Stobe, E.H., Moes, J., 1992. Relative date of wheat seedling emergence and its impact on grain yield. Crop Sci. 32, 1275–1281.

Hayhoe, H.N., Dwyer, L.M., Balchin, D., Culley, J.L.B., 1993. Tillage effect on corn emergence rates. Soil Till. Res. 26, 45–53.

Jensen, R.D., 1971. Effect of soil water tension on the emergence and growth of cotton seedling. Agron. J. 63, 766–768.

Leslie, J.K., 1965. Factors responsible for failure in the establishment of summer grasses of the black earths of the Darling Downs, Queensland. J. Agric. Anim. Sci. 22, 17–38.

Painuli, D.K. (Ed.), 2000. Annual Report 1997–1999. All India Coordinated Research Project on Soil Physical Constraints and their Amelioration for Sustainable Crop Production. Indian Institute of Soil Science, Bhopal, India, p. 133.

Radford, B.J., Nielsen, R.G., 1983. Extension of crop sowing times during dry weather by means of stubble mulching and water injection. Aust. J. Agric. Anim. Husb. 23, 302–308.

Sallaway, M.M., Yule, D.F., Mayer, D., Burger, P.W., 1990. Effect of surface management on the hydrology of a Vertisol in semi-arid Australia. Soil Till. Res. 15, 227–245.

Schimpf, D.J., Flint, S.D., Palmblad, I.G., 1977. Representation of germination curves with the logistic function. Ann. Bot. 41, 1357–1360.

Schneider, E.C., Gupta, S.C., 1985. Predicting corn emergence from soil temperature, matric potential and aggregate size distribution. Soil Sci. Soc. Am. J. 49, 415–422.

Smith, G.D., Yule, D.F., Coughlan, K.J., 1984. Soil physical factors in crop production on Vertisols in Queensland, Australia. In: Proceedings of the International Workshop on Soils, Townville, Queensland, Australia, September 1983. Australian Centre for International Agricultural Research, pp. 12–16, 87–104.

Smith, J., Smith, P., Addiscott, T., 1996. Quantitative methods to evaluate and compare soil organic matter models. In: Powlson, D.S., et al. (Eds.), Evaluation of Soil Organic Matter Models. Springer-Verlag, Berlin, pp. 181–199.

Swan, J.B., Kaspar, T.C., Erbach, D.C., Tisdall, T.M., 1996. Seed row residue management for corn establishment in the northern US corn belt. Soil Till. Res. 40, 55–72.

Tessier, S., 1988. Zero till furrow opener geometry effect on wheat emergence and seed zone properties. Ph.D. Dissertation. Washington State University, Pullman.

Thomas, G.A., Standley, J., Webb, A.A., Blight, G.W., Hunter, H.M., 1990. Tillage and crop residue management affect Vertisols properties and grain sorghum growth over seven years in semiarid subtropics. 1. Crop residue and soil water during fallow periods. Soil Till. Res. 17, 179–181.