SIMULATION MODELING OF GROWTH, DEVELOPMENT AND GRAIN YIELD OF WHEAT UNDER SEMI ARID CONDITIONS OF PAKISTAN

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The proposed study was undertaken to develop a simple mechanistic growth model, WHEATGROW, to simulate the growth, development and grain yield of wheat as affected by sowing date under semi arid conditions of Pakistan. Measurement of crop growth and environmental variables were made to establish the causes underlying the variation in crop yield associated with three sowing dates (10 Nov., 25 Nov., and 10 Dec.). Simulated grain yield output was 60 % in 10 November, 54 % in 25 November, 38 % in 10 December and total dry matter accumulation was 73 % higher in 10 November, 36 % in 25 November, 12 % in 10 December. Comparisons of simulated and measured quantities indicated satisfactory performance of the model, in reference to LAI, TDM, and grain yield in potential
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INTRODUCTION

There are many components of production technology which significantly affect grain yield of wheat in a region, for example sowing date, seeding rate, irrigation etc. Sowing date affects the growth and yield of wheat by affecting its environment. Early sowing always produces higher yields than late sowing mainly, due to longer duration of growth. Each day delay in sowing of wheat from 20th November onward in Punjab (Pakistan) decreases grain yield @ 36 kg ha^{-1} d^{-1} (Hussain *et al*., 1998).

Conventional methods of analysis in agronomic research usually produce results specific to the sites and seasons in which experiments are conducted. For example, yield formation in wheat and other crops is often described using yield components. Therefore, a very large number of agronomic and physiological studies have been based on this type of analysis. Thus a coherent framework for analyzing the process of yield is lacking. These old approaches of yield component analysis and growth analysis have failed to provide this framework (Monteith, 1981). Therefore, the results from such studies provide few insights into the causes of crop responses to agronomic treatments.

There is a need to quantify crop growth and development relative to the potential determined by the season and site to help agronomists in analyzing the causes of variation in yield. For example, phenological development of a cereal crop is dependent upon both temperature and photoperiod (Gallagher *et al*., 1983). Growth of wheat crop is primarily dependent upon the amount of intercepted radiation (Gallagher and Biscoe, 1978. To carry the analysis of yield formation beyond above mentioned quantitative and qualitative descriptions, predictive models of crop growth and yield are required.

Crop simulation models are important tools for agronomic management strategy evaluation, both under irrigated and rainfed conditions. The crop simulation modeling has been used in an attempt to bring ideas together (e.g. Weir *et al*., 1984). Recently many mechanistic simulations were reported about the growth, development and yield of wheat from sowing to maturity in response to a field environment (Porter *et al*., 1983; Otter-Nacke *et al*., 1986; Travis and Day, 1988; Rickman *et al*., 1996). These models simulate daily dry matter production as a function of radiation and temperature and water availability and nitrogen availability. Keeping in view the alone facts the present study was under taken and develop a crop growth model to evaluate the potential productivity of spring wheat under irrigated semi arid environment.

MATERIALS AND METHODS

The study was conducted at the Agronomic Research Area, University of Agriculture, Faisalabad, (31º.76, 75º.06́, and 184.4 m) during the year 2002-03. There were three replications having a plot size of 1.6m x 10m. The treatments were three sowing dates (10 Nov., 25 Nov. and 10 Dec.). All other practices such as hoeing, irrigation, weeding, etc. were kept uniform in both seasons for all the treatments.

The model consists of following parameterization:

The model was developed after Monteith (1977). The model simulated canopy growth, total dry matter and grain yield from input data collected during the season. The model was also used to assess the sowing date and seeding rate requirements of wheat.

Leaf growth

Leaf growth was considered in terms of leaf area index (LAI). The development of LAI can be described as a function of thermal time using three parameters.

i. **DE** -thermal duration from sowing to the start of linear increase of LAI.
ii. **PI** -thermal rate during the linear expansion of LAI. Increases in LAI up to maximum (LAI = 6) were calculated by defining a thermal time of LAI expansion.

iii. **DL**- thermal rate of LAI senescence. The rate of decline of LAI from maximum to Zero active area was taken as 0.004 per ºC days.

Total dry matter production

Total dry matter production (TDM) is the integral of crop growth rate (CGR) with time from emergence to maturity

$$\mathbf{TDM} = \int_{E}^{M} \mathbf{CGR.dt}$$

After calculation of TDM, the grain yield is simply the product of HI and TDM

Grain Yield = HI x TDM

A whole crop mechanistic simulation model (WHEATGROW) was developed and written in Java language (ver 1-4). Model simulates the growth, development and yield of wheat planted on different sowing dates (10 Nov; 25 Nov; 10 Dec) under adequate husbandry management. The primary objective of the model was to determine the potential grain yield of wheat and to develop strategies for optimizing the resources used under prevailing environmental conditions. The model simulates daily canopy development, fraction of intercepted radiation, cumulative intercepted PAR, crop growth rate and total dry matter production.

At maturity, an area of one square meter was harvested manually from each plot. Spikes were threshed manually and grains were separated and weighed. Then the grain yield was converted into kilograms per hectare. Measurements recorded each year include leaf area index, biomass accumulation, radiation interception, radiation use efficiency and grain yield. Data for each trait were analyzed in a randomized complete block design (RCBD) with split plot arrangement according to the procedure outlined by (Steel and Torrie, 1984).

Table 1. Comparison between observed and simulated TDM (g m^{-2}) and grain yield (Kg ha^{-1})

Sowing date	Total dry matter production (g m^{-2})		Grain yield (Kg ha^{-1})	
	Observed TDM	Simulated TDM	Observed grain yield	Simulated grain yield
10 Nov.	1173	2026	3183	5096
25 Nov.	1120	1523	2970	4565
10 Dec.	1184	1329	2995	4139
Mean	1159	1733	3049	4594

RESULTS AND DISCUSSION

Canopy development

Figure 1 presents the time course of observed and simulated canopy (LAI) development and its decay for different sowing dates during the seasons. The LAI development among different sowing dates was variable and it was underestimated specially during early growth among various planting dates. Simulated LAI during linear phase of growth was lower as compared with the observed values.

The pattern of simulated LAI values for the two seasons was quite close to measured values during the life cycle. When values of simulated and observed LAI development, upto maximum, were regressed, a highly close correlation was noted and the goodness of fit (R^2) ranging from 0.90 to 0.97 among different sowing dates during both the seasons, was significant (Fig. 3).

Dry matter production

The time course of simulated and observed total dry matter (TDM) accumulation among different sowing dates is shown in Fig. 2. In both Nov. sowings the model estimated production of TDM accurately, but it was underestimated in the Dec. sowing, especially in the later season growth. Total dry matter accumulation for 10 Nov., 25 Nov. and 10 Dec. reached 1173 gm^{-2}, 1120 mg^{-2} and 1184 mg^{-2} respectively (Table 1). Model estimates of TDM were very high as simulated TDM was higher as much as 50-62% than observed value indicating the potential of biomass productivity under the prevailing environmental conditions.

Grain yield

Table 1 presents the simulated and observed grain yield, indicating large differences between the two values. Data indicated a reduction of 55.5% to 60.1% in 10 Nov. 49.2% to 53.7% in 25 Nov. and 38.2% to 47.2% in 10 Dec. sowing from the potential productivity of wheat under the prevailing conditions. This was because the model was developed to produce potential production under adequate water and nutrients supplies. Thus, in this environment, the primary determinants of crop growth and yield are temperature and radiation. Early (10 Nov.) sowing showed its superiority over 25 Nov. or 10 Dec. sowing in producing higher yield at 5495 kg to 8544 kg ha^{-1} in the two seasons. These higher yields were primarily due to higher amount of intercepted PAR in the former than in the latter (Table.1.). The observed values may be an inadequate representation of the large variation normally associated with the field experiments. Nevertheless, it is clear that the model simulates growth and yield under well defined agronomic conditions ,and can be used in variable environments of the country where temperature and radiation receipts fluctuates considerably to determine the potential crop yield.

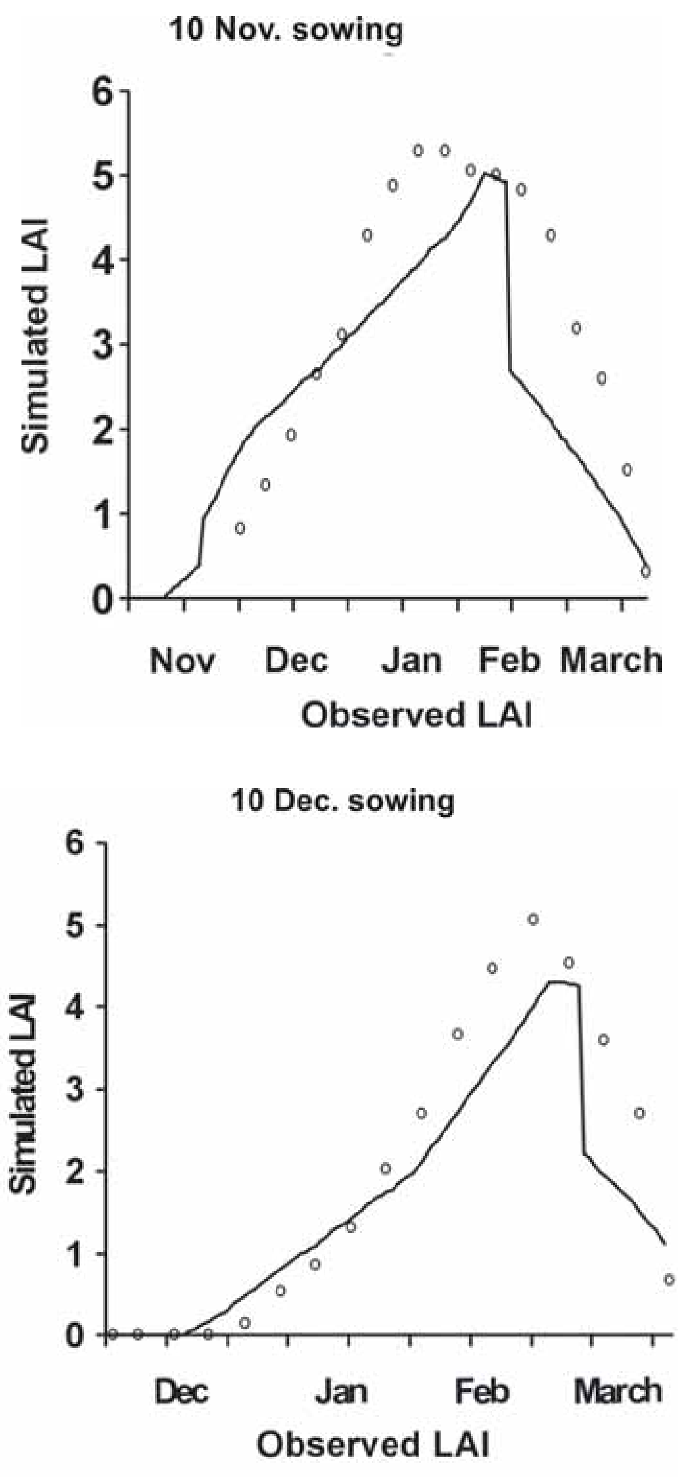


Fig 1. Changes in simulated (line) vs observed (circle) LAI with time

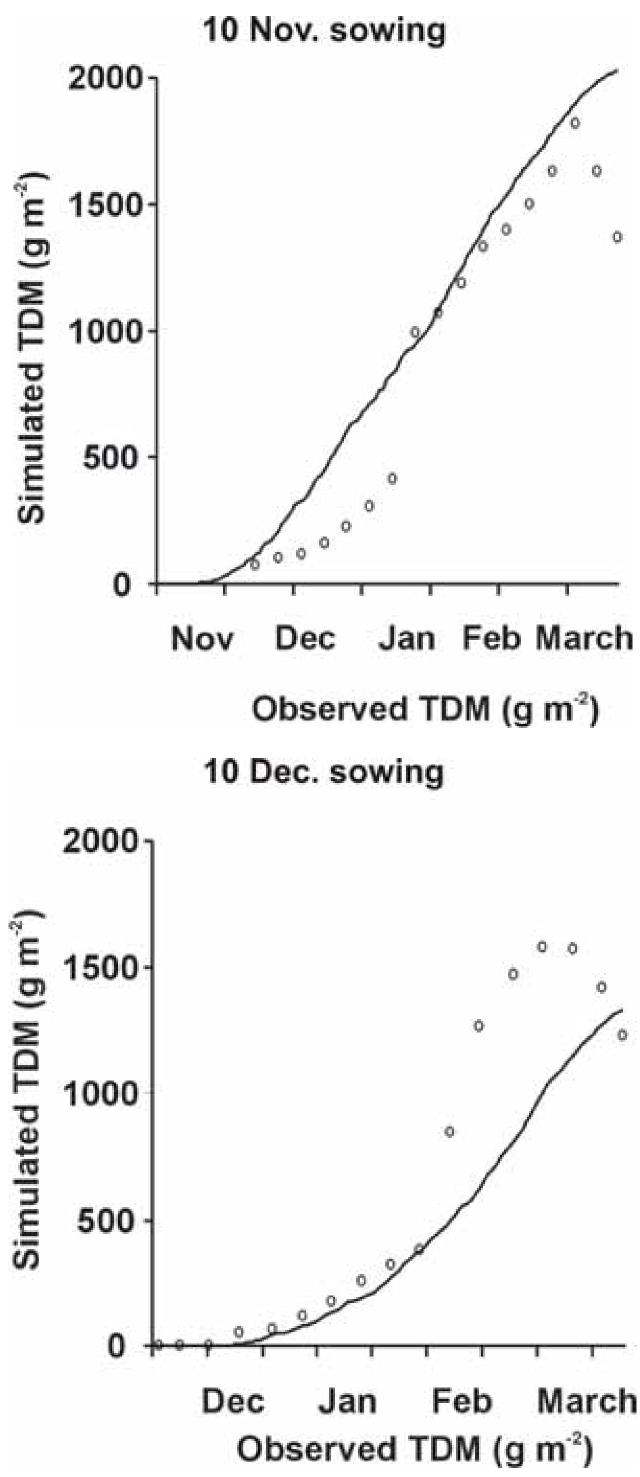
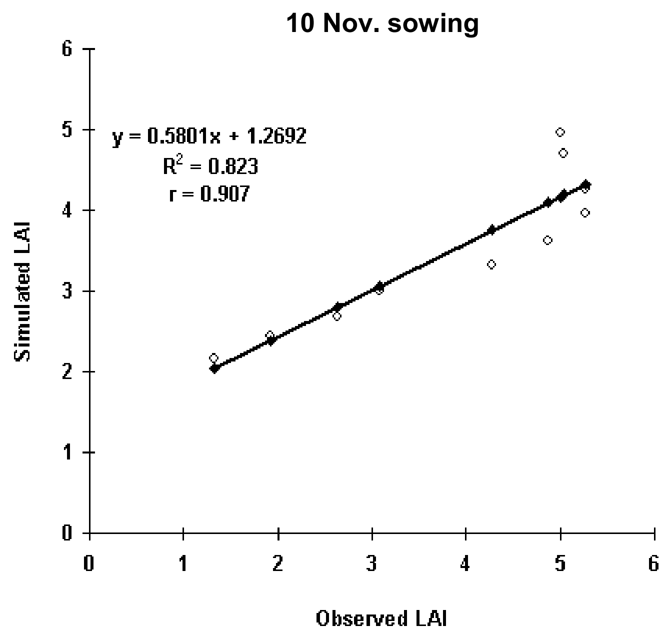


Fig. 2. Changes in simulated (line) vs observed (circle) TDM with time



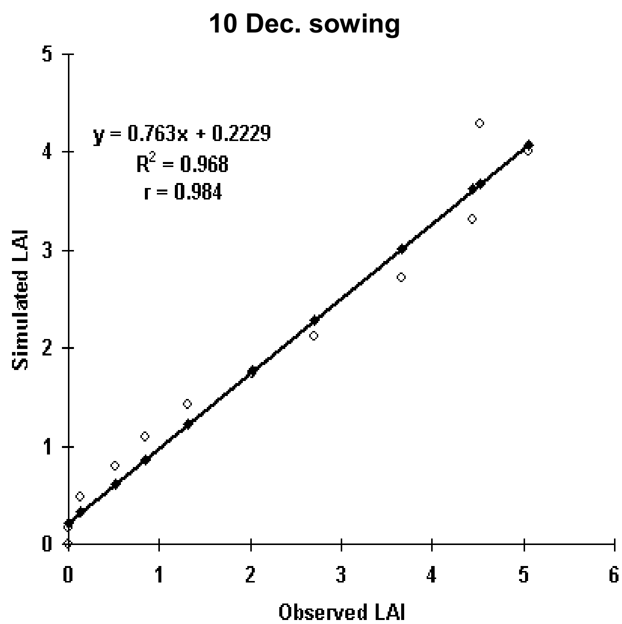


Fig. 3. Relationship between simulated (line) vs observed (circle) LAI

The model presented here is extremely simple, but it is based on sound physical and physiological processes. The model describes the growth and potential yield of wheat mechanistically under non-limiting conditions. However the model needs further developments in the field of nitrogen and drought effects under the hot semi arid areas.

CONCLUSION

Model shows that to achieve 6000–7000 kg ha^{-1} crop must intercept 600 MJ PAR from mid December to early March during the season with LAI of 4-6.

REFERENCES

Gallagher, J.N. and P.V. Biscoe. 1978. Radiation absorption growth and yield of cereals. J. Agric. Sci. Cambridge, 91: 47-60.

Gallagher, J.N., P.V. Biscoe and R.D. Jones. 1983. Environmental influence on the development, growth and yield of barley. In: Barley Production and Marketing. Agron. Soc. New Zealand. Special Publication No. 200. pp. 21-50.

Hussain, T. 1997. Comparative growth and yield performance of various wheat cultivars. M.Sc. Agri. Thesis, Univ. Agric., Faisalabad.

Monteith, J.L. 1977a. Climate and the efficiency of crop production in Britain. Philosophical Transactions of the Royal Society of London B281: 277-94.

Monteith, J.L. 1977b. Climate. Ecophysiology of Tropical Crops. Academic Press, pp 1-27.

Monteith, J.L. 1981. Does light limit crop production? In Johnson. C. B. (ed). Physiological Processes Limiting Plant Productivity. Butterworths, pp. 22-38.

Monteith, J.L. and J. Elston. 1983. Performance and productivity in the field. In Dale.

Otter-Nacke, S., D.C. Godwin and J.T. Ritchie. 1986. Testing and validating the CERES wheat model in diverse environments. PublicationYM-15-00407 JSC 20244. Earth Resource Application Div., LBJ Space Ctr., Houston, TX.

Proter, J.R., P.L. Bragg, J.H. Rayner, A.H. Weir and J.J. Landsberg. 1983. The AFRCWHEAT simulation model. Principles and progress. British Plant Growth Regulator Group. Monograph, 7, pp. 97-108. J.Agri. Camb., 102:371-382.

Steel, R.G.D. and J.H. Torrie. 1984. Principles and Procedures of Statistics, 2nd Ed. McGraw Hill Book Co., New York, USA.

Rickman, R.W., S.E. Waldman and B. Klepper. 1996. MOD Wht 3: A development- driven growth simulation. Agron. J., 88: 176-185.

Travis, K.Z. and W. Day. 1988. Modeling the timing of early development of winter wheat. Agricultural and Forest Meteorology, 44: 69-79.

Weir, A.H., P.L. Bragg, J.R. Porter and J.H. Rayner. 1984. A winter wheat crop simulation model without water or nutrient limitations. J. Agric. Sci. Camb., 102: 371-382.