Simulating Genotype x Environment x Management Interactions for Wheat Using APSIM: Model Evaluation and Application

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Abstract

Rainfed farming systems in Pakistan are suffering from low productivity. Rainfall and temperature variability, exacerbated by climate change have caused significant crop losses. Implemented in the framework of Agricultural Production Systems Simulator (APSIM), the current study evaluated the impact of long term climate change on yield of wheat at three locations of Pothwar. Specifically, APSIM was employed to assess the impact of Genotype x Environment x Management interactions (G x E x M) to manage the productivity of select wheat genotypes recommended for the region. Model simulated yield under different scenarios were evaluated against actual data. The APSIM- G x E x M modules displayed good accuracy of model. The validation skill score R^2 throughout exceeded 0.95 (RMSE: 4.41 days) for phenological development, 0.87 (RMSE: 3.84 t ha^{-1}) for drymatter and 0.85 (RMSE: 0.44 t ha^{-1}) for grain yield. The results revealed the significance of phenology for accurate estimation of the duration of growing season and crop yield under changing climate, when used within the dynamic cropping systems model. Results highlight the role of simulation models as complementary tool to field experiments, to monitor and quantify G x E x M interactions and that of APSIM, in particular, as decision support tool to design innovative and sustainable farming systems under wide range of climatic conditions.

Methods

ENVIRONMENTS

- Three experimental sites of rainfed ecosystem were Islamabad (33°40'N, 73°10'E, 508 m a.s.l.), Chakwal (32°56'N, 72°52'E, 513 m a.s.l.), and Talagang (32°55'N, 72°25'E, 458 m a.s.l.) (Fig. 1).

MANAGEMENTS

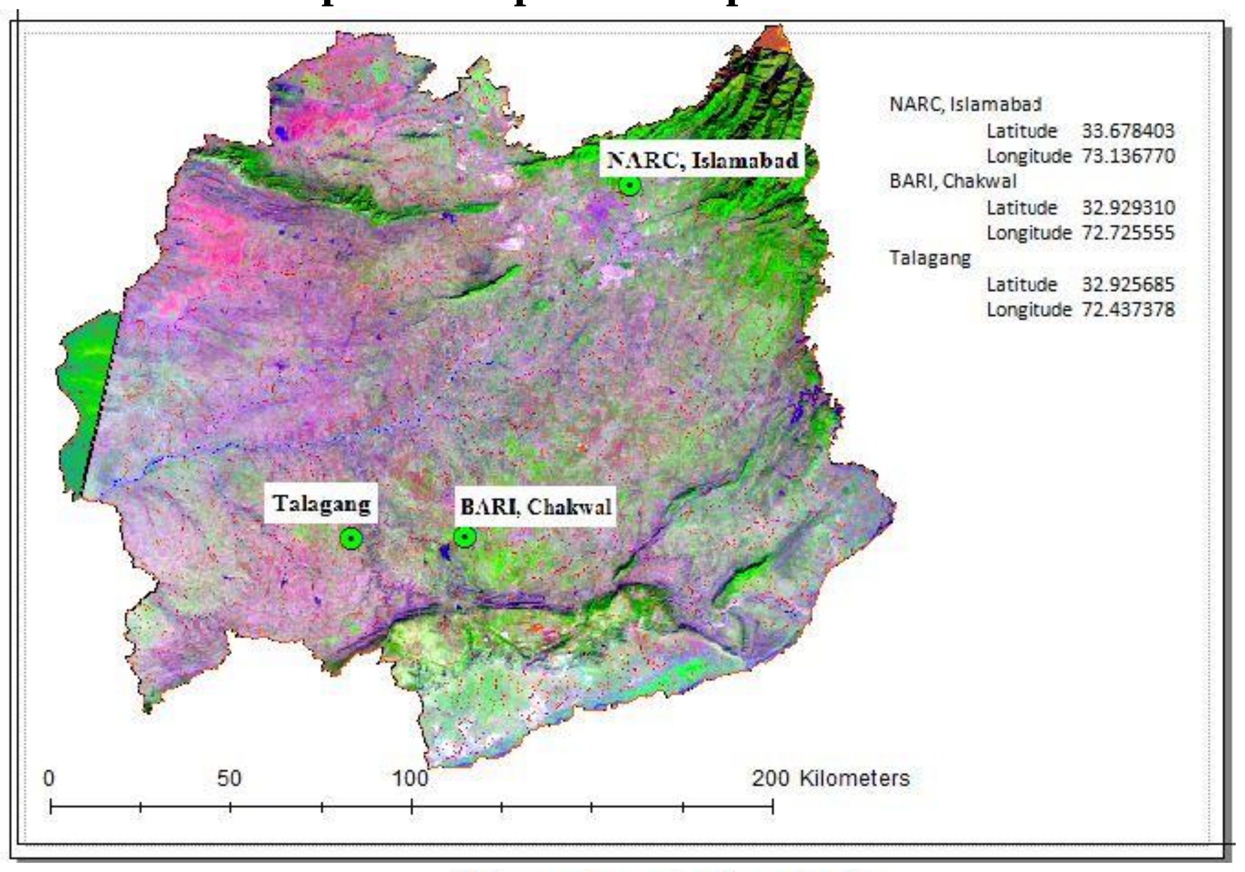
- Five varying sowing dates (Early sown = SD1, (sowing between 15 - 20 October), SD2 (sowing between 25 - 30 October), SD3 (sowing between 5 – 10 November), Optimum sowing time (SD4) = sowing between 15 – 20 November) and Late sown = SD5 (sowing between 01 - 10 December)) were used as managements .

GENOTYPES

- Wheat (*Triticum aestivum* L.) genotypes *viz*; Chakwal-50, Wafaq-2001, Tatara, NARC-2009, Sehar-2006, SKD-1 and F-Sarhad of diverse origin were planted in a randomized complete block design replicated four times under five varying sowing dates as managements.

APSIM-Wheat (Agricultural Production System Simulator)

- Agricultural Production Systems Simulator (APSIM) is a software tool that enables sub-models (or modules) to be linked to simulate agricultural systems (McCown et al., 1996; Keating et al., 2003).
- APSIM has various modules grouped and categorized as Plant, Environment and Management. It simulates the mechanistic growth of crops, key soil processes, and range of management options considering cropping systems perspective.
- APSIM-Wheat module simulates the growth and development of a wheat crop in a daily time-step on an area basis (per square meter, not single plant).
- The wheat growth and development responds to weather (radiation, temperature), soil water and soil nitrogen, and management practices.
- APSIM-Wheat module consists of eleven phasing development determined by the accumulation of thermal time and other factors like vernalisation, photoperiod and N from emergence to terminal spikelet (Chen et al. 2010).
- The length of each phase is linked to fixed thermal time mentioned as tt_<phase_name> in wheat.xml.
- Detailed descriptions of APSIM structure, its crop and soil modules can be found in Keating et al. (2003) or at the APSIM **website: http://www.apsim.info/apsim/.**



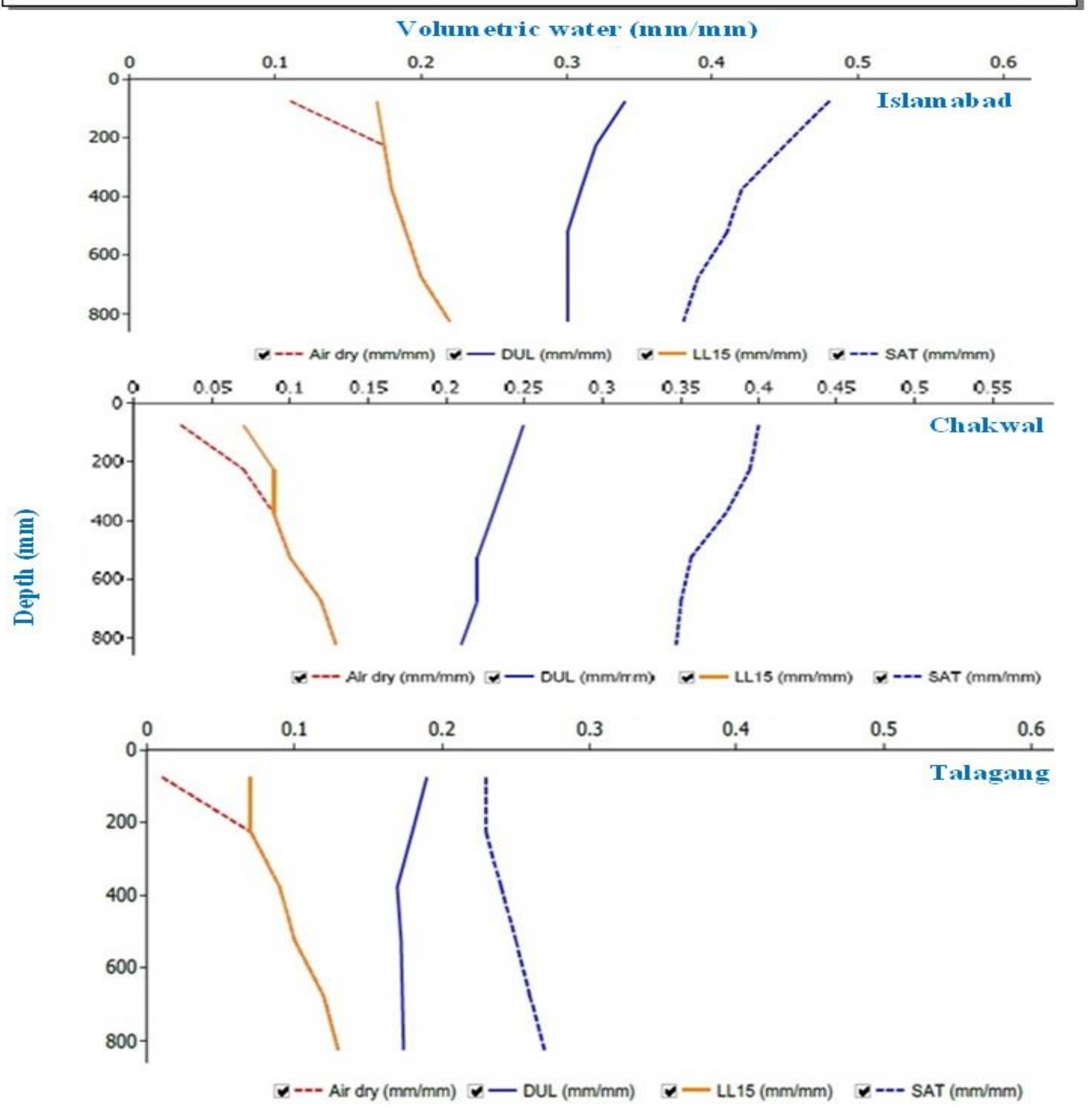


Fig. 2. Soil moisture holding characteristics used in the simulation. The terms SAT, DUL and LL15 are the soil water contents at saturation, drained upper limit, and 15 bar suction, respectively, while air dry refers to the driest profile moisture contents under evaporative drying.

Model Evaluation

- The growth and development module of APSIM-Wheat uses sets of different coefficients (Vern_sens, photop_sens, startgf_to_mat, grains_per_gram_stem, Potential_grain_fi lling_rate and Phyllochron) which define the phenology, crop growth and yield in time domain
- The APSIM-Wheat was calibrated for Chakwal-50, Wafaq-2001, Tatara, NARC-2009, Sehar-2006, SKD-1 and F-Sarhad with data obtained from 2000-2011 cropping year.
- For calibration the cultivar coefficients were obtained step by step firstly for phenological development and then for grain developmental parameters. The manual trial and error method was used to determine genetic coefficients as concluded by Godwin and Singh (1998).
- The values were adjusted to have minimum RMSE (Root mean square error) between simulated and observed data. The anthesis, physiological maturity date and yield were used to evaluate model performance. The coefficients of determination (R^2), d-index and RMSE were used to check the agreement between observed and simulated values.

Results

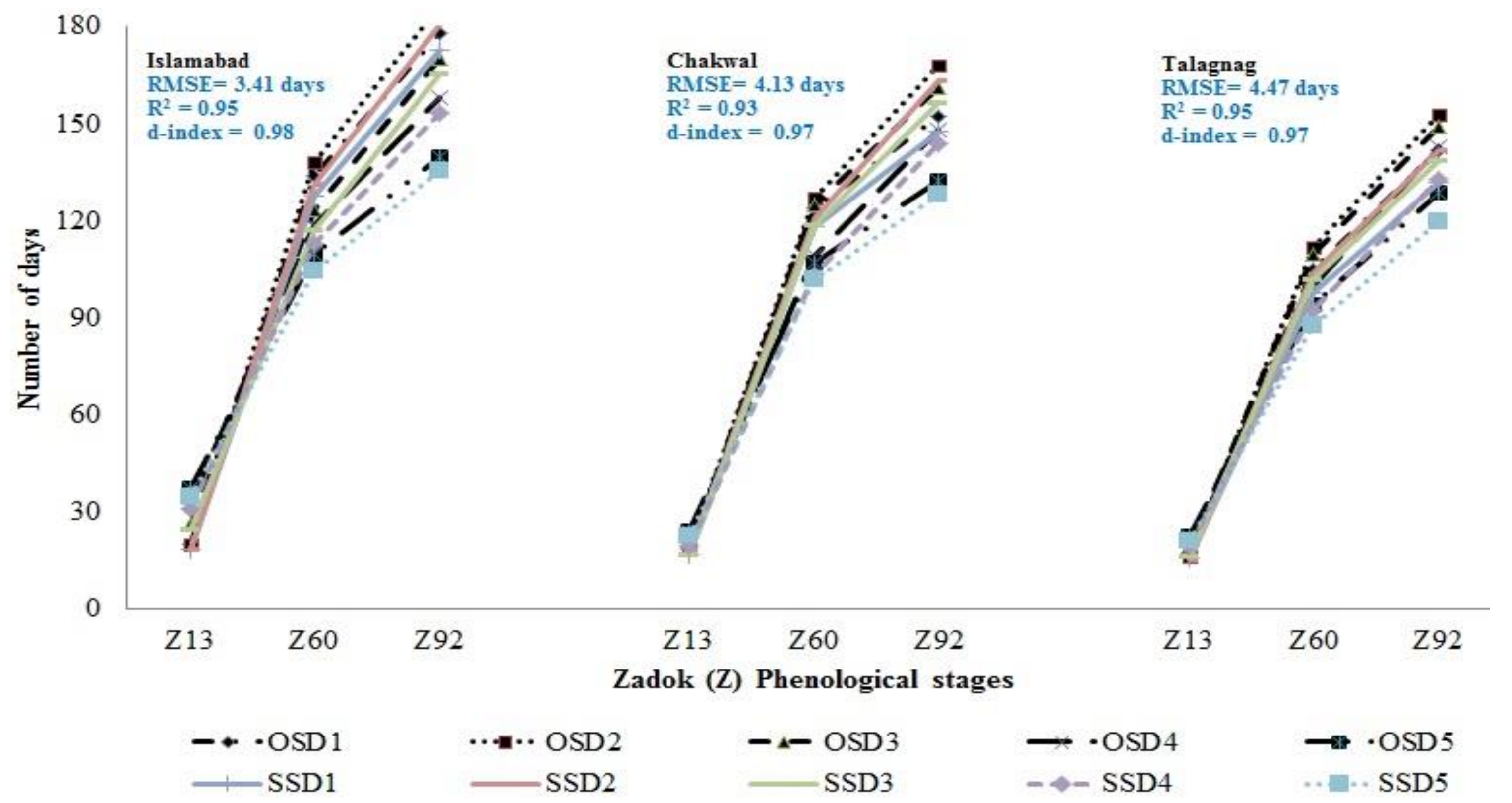


Fig. 3. Observed and simulated phenological development of wheat combined over environments and genotypes (Where OSD and SSD are Observed and Simulated Sowing date respectively)

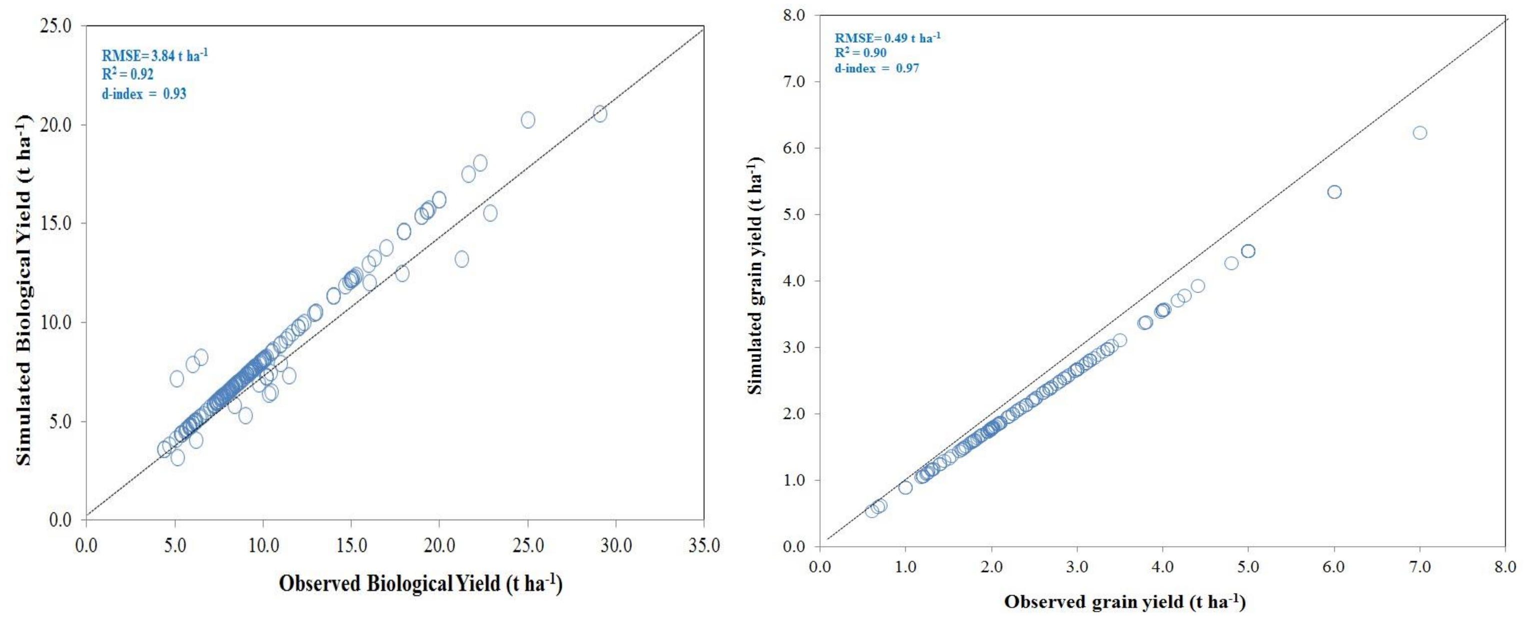


Fig. 4. Observed and simulated biological and grain yield (t ha^{-1}) of wheat combined over environments and genotypes

Table 1. Average maximum yield increase due to GxExM as an adaptation strategies

Optimum adaptation strategy	Yield Increase (t ha^{-1})
Genotype	2.8
Crop development	1.5
Crop Growth	0.3
Environment	3.8
Management	1.3
Genotype combined with management	3
Genotype combined with environment	3.3
GxExM	3.7

Conclusion

Changes in crop management provided an average yield increase of 1.3 t ha^{-1} while environment and genotype modifications resulted to 3.8 and 2.8 t ha^{-1} respectively. Meanwhile simulated GxM, GxE and GxExM depicted 3,3.3 and 3.7 t ha^{-1} yield increase respectively. The APSIM provided good estimates of phenology, biomass and yield, with a root mean square error (RMSE) ranging between 3%, 10% and 20%.

References

- **Keating B.A., Carberry P.S., Hammer G.L., Probert M.E., Robertson M.J., Holzworth D., Huth N.I., Hargreaves J.N.G., Meinke H., Hochman Z., McLean G., Verburg K., Snow V., Dimes J.P., Silburn M., Wang E., Brown S., Bristow K.L., Asseng S., Chapman S., McCown R.L., Freebairn D.M., Smith C.J. (2003) An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18:267-288. DOI: http://dx.doi.org/10.1016/S1161-0301(02)00108-9.**
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