Evaluation of Five Thermal Time Models for Modelling Spring Wheat Phenological Development on the Canadian Prairies

Manasah S. Mkhabela[1]*, Guy Ash[2], Mike Grenier[2] and Paul R. Bullock[1]

[1]Department of Soil Science, University of Manitoba, Winnipeg, MB, R3T 2N2

[2]Canadian Wheat Board, 423 Main Street, P.O. Box 816, Station Main, Winnipeg, MB, R3C 2P5

ABSTRACT

The impact of temperature on crop development rate (CDR) is often assessed using the thermal time concept. The purpose of this study was to compare and contrast five thermal time models i.e., NDGDD, GDD_0, GDD_5, BF and MBF for the purpose of identifying the best model for simulating spring wheat phenology in western Canada. Crop and weather data collected from several sites across western Canada from 2003 through 2006 and from 2009 through 2011 were utilised.

Results showed that accumulated GDD/daily growth rates calculated using the different models correlated well with spring wheat phenological stages with R^2 ranging from 0.91 to 0.94 and p<0.001. However, when the developed regression models were used to predict time (calendar days) **from planting to anthesis** for cultivar AC Barrie, both the BF and MBF models performed poorly compared to the GDD-based models. Overall, the predicted time (calendar days) **from planting to anthesis** by the NDGDD, GDD_0, GDD_5, BF and MBF models were 64, 64, 63, 65 and 65 days, respectively; while the observed time was 60 days. The RMSE value for the NDGDD, GDD_0 and GDD_5 models was 5 days, while that for the BF was 6 days, and that for the MBF was 7 days. These findings suggest that the NDGDD model, which WeatherFarm.com has adopted and deployed for modelling spring wheat phenology in western Canada, is a good model. Nonetheless, the model has to be constantly validated and updated as new wheat varieties come into production and the impact of climate change/variability becomes apparent.

*Corresponding author:
Manasah Mkhabela
Email: Manasah.Mkhabela@ad.umanitoba.ca

INTRODUCTION

Understanding and accurately predicting crop development (phenology) is fundamental to many aspects of crop production including optimising crop management practices such as fungicides, herbicides, pesticides and fertiliser applications. The thermal time concept is commonly used to assess crop development rate (CDR) as impacted by temperature (heat). There are various thermal time models used to estimate crop phenological development, each with strengths and weaknesses. The most frequently used thermal time models include the growing degree-days (GDD), which relates CDR linearly to temperature and the beta function (BF), which relates CDR to temperature nonlinearly. The objective of this study was to compare and contrast five (5) different thermal time models for the purpose of identifying the best model for simulating spring wheat phenology in western Canada.

MATERIALS AND METHODS

Crop and weather data collected from plot experiments (Figure 1) during 2009 through 2011 growing seasons from Carman, Regina, Melita, Hamiota, Swift Current, Melfort and Saskatoon were used in the analysis. Five (5) thermal time models i.e., NDGDD (developed and used in North Dakota), GDD_0 (base temperature zero), GDD_5 (base temperature 5), Beta Function (BF) and weighted Modified Beta Function (MBF) were tested for their ability to predict phonological stages (from seeding to anthesis) of three (3) commonly grown spring wheat cultivars (i.e., AC Barrie, AC Intrepid and BW874).

The analysis involved correlating crop growth stage (phenology) for each variety at each site with accumulated GDD/daily growth rate (calculated using the five different thermal time models) from planting to anthesis. All sites within each year were combined and finally all years were combined to derive representative regression equations for each variety and the three varieties combined.

The ability of each model to predict time (calendar days) from planting to anthesis was tested using wheat phenology data collected in 2011 and data collected from five (5) experimental sites (i.e., Carman, Winnipeg, Melfort, Regina and Swift Current) from 2003 through 2006 giving a total of twenty (20) site-years of data. The overall predicted time (number of days) from seeding to anthesis was compared to the observed time using a student ***t*-test** at 5% probability level.

Figure 1: Plot experiments at different wheat growth stages and weather recording instruments.

RESULTS AND DISCUSSION

Figure 2 shows the linear relationship between wheat growth stage (planting to anthesis) for all cultivars, sites and years combined and accumulated GDD/daily growth rates calculated using the five different thermal time models. The relationship was highly significant with p<0.01 and R^2 ranging from 0.91 to 0.94, indicating that the models explained from 91% to 94% of the variability in wheat phenological development. All five models were equally good in explaining the variability as indicated by the almost similar R^2 values.

Figure 3 shows the linear relationship between predicted and observed time (calendar days) **from planting to anthesis** for cultivar AC Barrie. For all the models, the correlation is high with R^2 ranging from 0.77 to 0.83 and p<0.01, indicating that the models explained from 77% to 83% of the variability. All the models except for the BF and MBF performed well in predicting the time **from planting to anthesis** for the cultivar AC Barrie. When averaged across all site-years, the predicted number of calendar days from planting to anthesis by the NDGDD, GDD_0, GDD_5, the BF and MBF models was 64, 64, 63, 65 and 65, respectively; while the observed number of calendar days was 60. A student *t-test* showed that the values (calendar days from planting to anthesis) predicted by the NDGDD, GDD_0 and GDD_5 were statistically similar (p>0.05) to the observed value. However, the values predicted by the BF and MBF models were significantly higher (p<0.05) than the observed value. The root mean square error (RMSE) value for the NDGDD, GDD_0 and GDD_5 was 5 while that for the BF was 6 and that for the MBF was 7. The MAE values followed a similar trend as the RMSE values but were slightly lower.

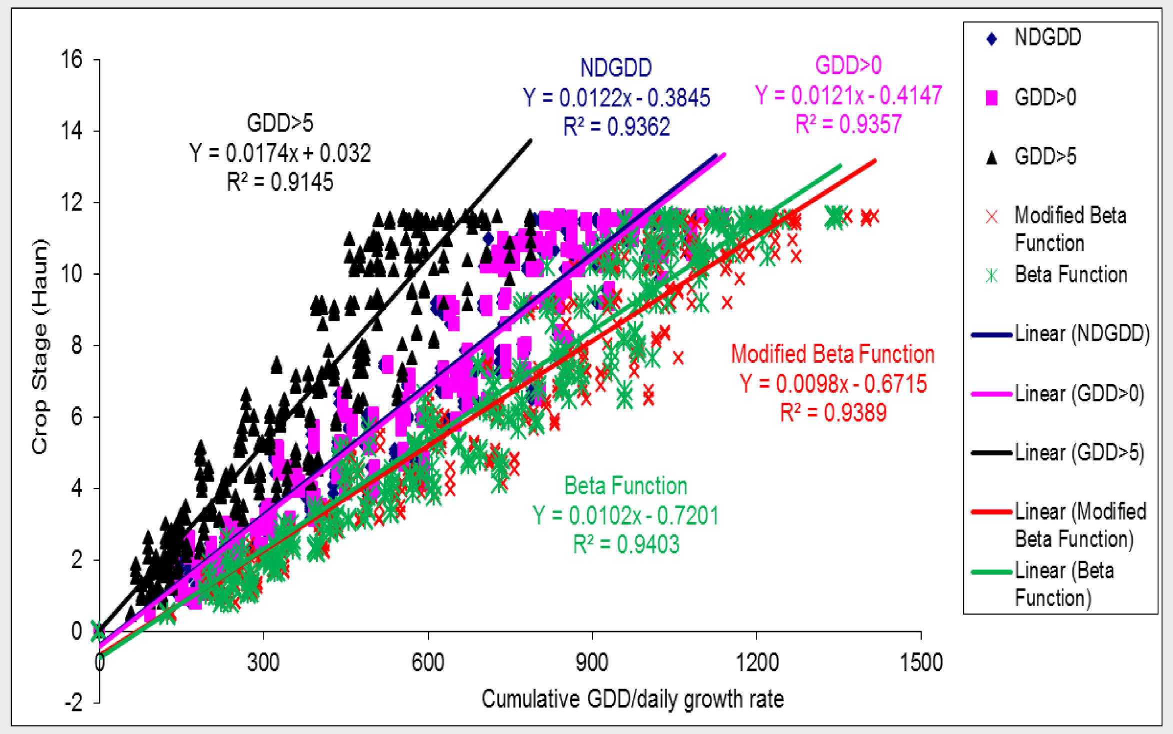

Figure 2: Linear relationship between wheat growth stage (planting to anthesis) and cumulative GDD/growth rate calculated using the different methods for all three cultivars and all years combined. Note; cumulative daily growth rate values for both the BF and MBF models were multiplied by 100 so that they can be plotted on the same graph with the other models.

CONCLUSION

Based on this analysis, the NDGDD model can be used as a predictive tool for estimating spring wheat phenological development in western Canada. Accordingly, WeatherFarm.com has adopted and deployed the NDGDD model for estimating spring wheat phenology across western Canada. However, the model must be tested, validated and updated as new spring wheat varieties are released into production and the effects of climate change/variability become apparent.

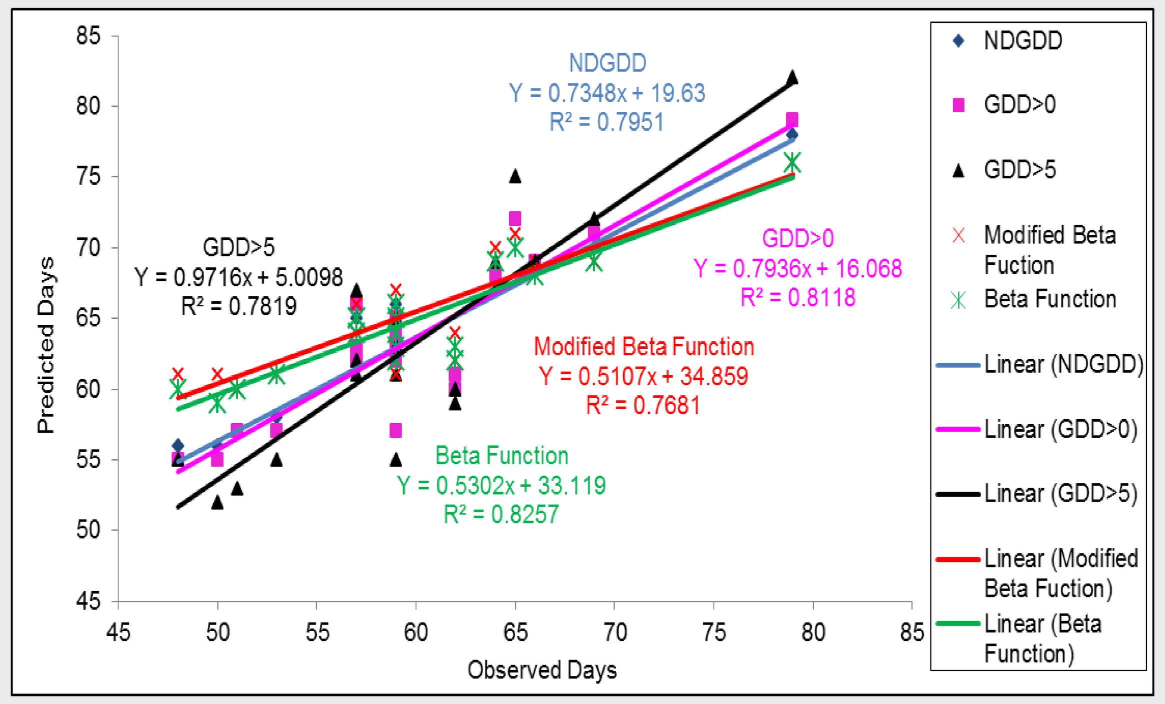

Figure 3: Linear relationship between predicted and observed time (calendar days) from planting to anthesis for all the thermal models.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Canadian Wheat Board (CWB) together with the Pest Management Centre of Agriculture and Agri-Food Canada (AAFC).