

EVALUATION OF THE EPIC CROP GROWTH MODEL FROM LONG-TERM ROTATIONS

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ABSTRACT

The Erosion-Productivity Impact Calculator (EPIC) model was used to predict spring wheat (*Triticum aestivum*) yields from long-term (1960 to 1989) crop rotations at the Agriculture Canada Research Station at Melfort. These predictions were compared to actual yields using the paired *t* test and linear regression analysis. Simulated mean yields of wheat for the different rotations were generally similar to actual yields, when daily maximum and minimum temperatures and precipitation were input into the model. The fertilized continuous wheat rotation gave the highest yield when averaged over the 30-yr period. EPIC was also satisfactory in predicting yield when weather was generated from long-term climate data. However, regression analyses indicated no significant relationship between simulated (using actual and generated weather data) and actual annual yields over the 30-yr period. Therefore, EPIC predicts long-term average yields with sufficient accuracy, but is not recommended for yield prediction for individual years. It can be a valuable decision-making tool for identifying crop rotations and management practices that offer potential yield benefits over a long time period.

INTRODUCTION

Long-term agronomic field experiments are valuable for assessing the effects of different cropping systems, tillage, and fertilization practices on sustainable crop production under variable climatic conditions. The Rothamsted Classical Experiments, established almost 150 years ago, are the most renowned long-term studies (Jenkinson 1991). Experiments conducted over a long period of time are particularly useful for evaluating simulation models, which are rapidly becoming an important facet of agronomic research.

The Erosion-Productivity Impact Calculator (EPIC) model was developed in the early 1980s to estimate soil productivity as affected by erosion (Williams *et al.* 1983). However, the model is capable of many other types of analyses as well. EPIC is a detailed model of soil-crop-climate interactions. It consists of physically based submodels which simulate weather, hydrology, wind and water erosion, nutrient cycling, crop growth, soil temperature, tillage, and plant environmental control. Each submodel is linked sequentially and interactively with the other submodels.

Since soil productivity is expressed in terms of crop yield, the model must be capable of simulating yields with sufficient accuracy. The crop growth model simulates processes including leaf interception of solar radiation; conversion of intercepted energy to biomass; partitioning of biomass into roots, above-ground

biomass, and economic yield; root growth; water use; and nutrient uptake (Williams *et al.* 1989). Potential growth is simulated daily and constrained by the minimum of five stress factors (water, nitrogen (N), phosphorus (P), temperature, and aeration), which range from 0.0 (most severe) to 1.0. EPIC was shown to predict yields satisfactorily for six crops, including spring wheat, in various regions of the United States (Williams *et al.* 1989). However, local calibration of some crop parameters was required so that the model could predict yields of crops grown in various rotations in Texas (Steiner *et al.* 1987) and southern France (Cabelguenne *et al.* 1990) with reasonable accuracy.

Since the crop growth submodel has not been adequately tested under western Canadian climatic conditions, the EPIC model was used to compare predicted spring wheat yields to data collected during 1960 to 1989 from various long-term wheat rotations at Melfort, Saskatchewan.

MODEL DESCRIPTION

Data requirements. The EPIC model, which is written in FORTRAN, can be executed on mainframe or microcomputers. To run a simulation, four major sets of data are required (Williams *et al.* 1990). The first data set contains general information, such as latitude and longitude of the site location as well as topographical and hydrological properties of the site. The second data set comprises long-term monthly averages for climate variables including maximum and minimum temperatures, precipitation, wind speed, number of days of precipitation, and relative humidity. The third data set consists of physical and chemical characteristics of the soil profile for up to ten layers of variable thickness. These characteristics include bulk density, texture, organic nitrogen, organic carbon, pH, and calcium carbonate content. The final data set contains management information for each year of the crop rotation such as the crop(s) grown, planting and harvest dates, fertilizer applications, and tillage and harvest operations. Several crops can be included in a rotation, and the length of the rotation can be from one to ten years. The crop rotation can be run for any number of cycles up to hundreds of years.

A user-friendly interactive program facilitates data entry. In addition, crop and tillage/harvest parameters are supplied by the model. Parameters are listed for over thirty annual and perennial crops (such as the crop coefficient, k , for converting energy to biomass) and over fifty tillage/harvest operations. The EPIC model can be calibrated for local conditions by changing the values of these parameters. Although modifying existing parameters is straightforward, caution is advised since parameter values are fairly well established for most of the crops (Sharpley and Williams 1990).

The EPIC model requires daily weather data including precipitation, maximum and minimum temperatures, solar radiation, wind speed, and relative humidity. The daily weather variables can be input using actual values or simulated using the weather generator submodel. A combination of actual and generated weather data is possible as well. This allows for greater flexibility when data for particular weather variables are not available.

Crop growth model. A single crop growth model is used to simulate all crops considered in EPIC, with each crop having unique values for model parameters. Annual crops grow from planting date to harvest date, or until the accumulated heat units equal the potential heat units for the crop. Phenological development of the crop is based on daily heat unit accumulation.

Potential growth is determined by light interception. Intercepted photosynthetically active radiation (IPAR), in turn, is dependent on daily solar radiation and leaf area index (LAI). The daily potential increase in biomass (dB) is calculated by (Williams *et al.* 1989):

$$dB = k(IPAR)$$

where k is the crop coefficient for converting energy (IPAR) to biomass. For each long-term rotation, the crop growth model was run without modifying the k value.

The partitioning of biomass into plant parts is controlled by the accumulation of heat units (Figure 1). LAI development and senescence are controlled by heat units, maximum potential leaf area, and the fraction of the growing season when LAI starts declining. Economic crop yield (Y_e) is estimated by:

$$Y_e = (HI_m) (B_a)$$

where HI_m is the harvest index (unit grain/unit biomass), which increases nonlinearly from 0 at planting to HI_m at maturity, and B_a is the above-ground biomass.

LONG-TERM WHEAT ROTATIONS

The long-term wheat rotations at the Agriculture Canada Research Station at Melfort are listed in Table 1. The crop rotation was established such that each phase of the rotation would occur each year.

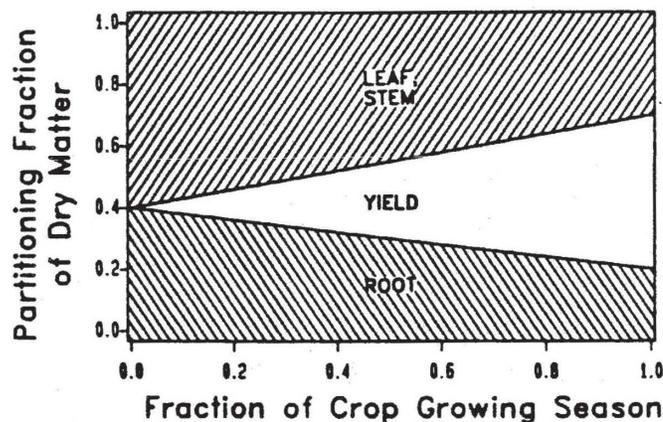


Figure 1. Partitioning of plant biomass (dry matter) through the growing season. The fraction of the growing season is determined by heat unit accumulation (Source: Steiner *et al.* 1987)

Table 1. Long-term wheat rotations and fertilizer treatments at the Agriculture Canada Research Station, Melfort, SK.

Rotation	Fertilizer treatment
Fallow-wheat (F-W)	N & P
Fallow-wheat-wheat (F-W-W)	N & P
Fallow-wheat-wheat (F-W-W)	None
Continuous wheat (W)	N & P
Continuous wheat (W)	None

Wheat was seeded at a rate of 100 kg ha⁻¹ (usually in mid-May) and swathed at the full-ripe stage (usually in early September) (Zentner *et al.* 1990). Yields were determined by threshing the grain from an area 3 m by 35 m using a conventional combine. From 1960 to 1971, N and P fertilizers were applied in accordance with the general recommendations for the region, regardless of amounts of soil available N and P. From 1972 to 1986, fertilizer was applied based on soil test levels and the recommendation criteria of the Saskatchewan Advisory Council on Soils. Constant rates of fertilizer were applied from 1987 to 1989.

Weeds were controlled by spraying as required. On summerfallow, weeds were controlled by tillage with an average of five operations with a heavy-duty cultivator. Stubble plots to be planted the following year received one tillage operation in late fall using a heavy-duty cultivator with mounted harrow.

RESULTS AND DISCUSSION

30-year average. EPIC predicts yields for a given set of climatic and agronomic conditions so that year-to-year variability in predicted yields is primarily a function of weather and climatic conditions (Figure 2). Crop yield estimates (30-yr average) from EPIC simulations were compared to actual data (Table 2) using the paired *t* test. When actual weather data (daily maximum and minimum temperatures and precipitation) were input into the model, no differences between mean simulated and actual yields were evident, with the exception of the unfertilized F-W-W rotation. For that rotation, the model underestimated yield by 0.5 t ha⁻¹. There was no consistent bias in model results. The standard errors of simulated yields were comparable to those of actual yields. Both actual and simulated results indicated that the fertilized continuous wheat rotation gave the highest yields when averaged over the 30-yr period.

When daily weather was generated from long-term climate data using the weather generator, simulated yields were similar to those estimated by the model using actual weather data. The only exception was an overestimation of yield for the fertilized continuous wheat rotation. Therefore, for locations where actual daily weather data is unavailable, the weather generator can be used with a reasonable

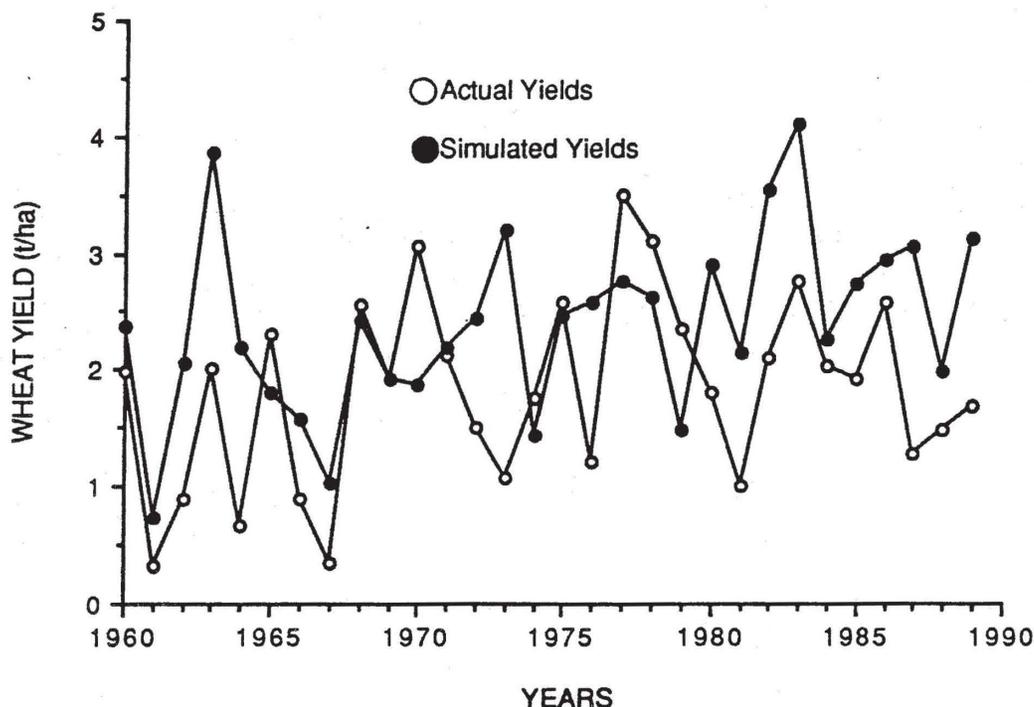


Figure 2. Actual and simulated yields for the fertilized continuous wheat rotation.

Table 2. Comparison of 30-yr means for actual and simulated wheat yields from long-term rotations (1960-1989), Agriculture Canada Research Station, Melfort, SK. (standard errors in parentheses). Phases sampled are underlined.

Crop rotation	Fertilizer treatment	Yield (30 yr avg) [†]	
		Actual	Simulated
		Actual weather	Generated weather
		t ha ⁻¹	
F- <u>W</u>	√	2.8 (0.2)	3.0 (0.1)
F- <u>W</u> -W	√	2.8 (0.2)	3.2 (0.2)
F- <u>W</u> - <u>W</u>	√	2.5 (0.2)	2.6 (0.1)
F- <u>W</u> -W		2.4 (0.2)	2.5 (0.1)
F- <u>W</u> - <u>W</u>		1.9 (0.2)	1.3 (0.1)*
<u>W</u>	√	1.8 (0.2)	2.4 (0.2)
<u>W</u>		1.3 (0.1)	1.2 (0.1)

[†] * - significant difference compared to actual yield at the 5% level according to the paired *t* test.

degree of confidence (Nicks *et al.* 1990).

Annual yields. Another method of describing model performance involved linear regression of simulated on actual annual yields (Figure 3). This involved testing for a significant relationship between simulated and actual annual yields by determining if the slope of the regression line was significantly different from zero (using the *t* test on parameter estimates of the equation for the regression line). Fertilized continuous wheat was the only rotation where the slope was significantly different from zero and the coefficient of determination (R^2) was significant ($P=0.05$). The general lack of relationship between simulated and actual yields indicates that the model fails to account for the year-to-year variability in yield. This is likely the result of the model being based on long-term average climate data and a very general description of crop growth, which, in turn, is based on a fixed energy conversion coefficient and biomass partitioning scheme (Williams *et al.* 1989). The lack of daily weather data for solar radiation, wind speed, and relative humidity for the period from 1960 to 1989 at Melfort would reduce model accuracy. Since there was a lack of correlation between simulated and actual yields for the rotations, prediction of yield for individual years is not recommended.

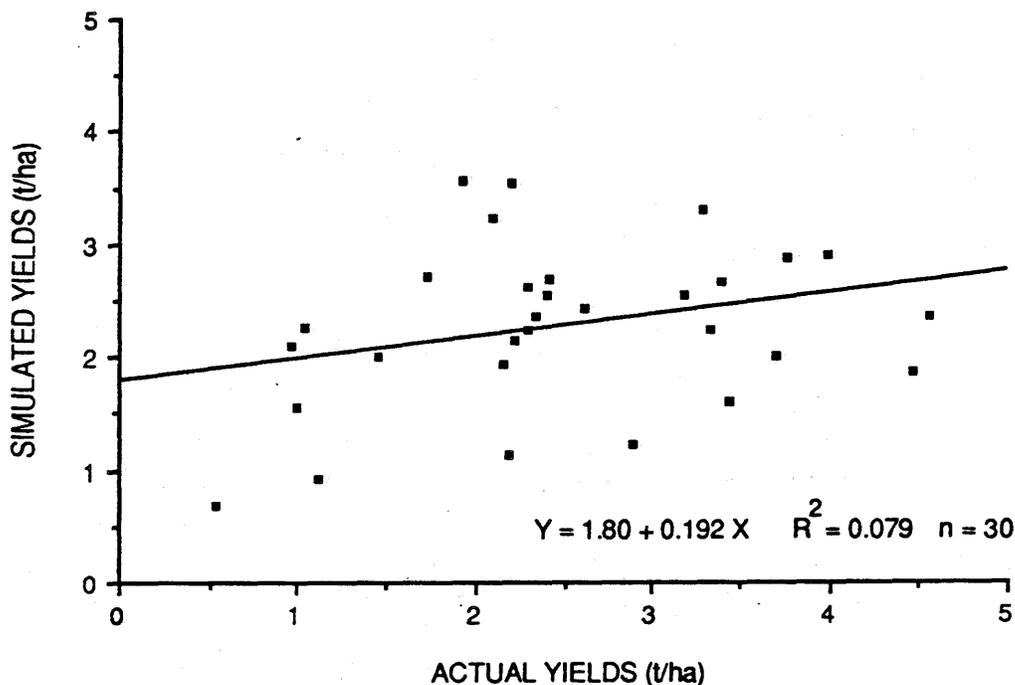


Figure 3. Regression of simulated on actual annual yields (1960 to 1989) for the fertilized F-W-W rotation. The slope of the line is not significantly different from zero.

CONCLUSIONS

EPIC gives a reasonable estimate of average wheat yields which facilitates long-term management decisions. The model has the potential to identify management factors, such as optimum sowing dates or fertilizer treatments, as well as crop rotations that may offer a potential yield benefit over a long period of time. EPIC, therefore, can be a valuable decision-making tool. The model can also be used to complement field experimentation in research programs, by identifying areas where knowledge is lacking and which require further research. Evaluation of the EPIC crop growth submodel is continuing, by comparing predicted and actual yields of different crops from long-term rotations. Furthermore, other submodels are being evaluated by examining a range of processes, including soil N dynamics.

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