Agricultural Water Management 103 (2012) 105–113

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

New approach in modeling spring wheat yielding based on dry periods

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ARTICLE INFO

Article history:
Received 7 January 2011
Accepted 28 October 2011
Available online 17 November 2011

Keywords:
MoDrY
Weather-yield model
Spring wheat
Dry periods
Vegetation period

ABSTRACT

The developed model MoDrY is designed for the estimation of the level of spring wheat yields on the basis of dry periods occurring during the particular periods between the phenological phases of the crop plant. A characteristic feature of this model, unlike most existing weather-yield models, is that the principle of its operation is based only on information on the occurrence of precipitation. In the study the authors used research material from 27 years and diurnal sums of atmospheric precipitation. Five measures were adopted to characterise the error of approximation: coefficient of correlation, mean relative error, RRMSE, EF, and CRM. The coefficient of correlation obtained was at the level of 0.91, and the mean relative error at the level of 9.79%. Validation was performed by means of the Cross Validation test (CV), version LOO. For the approximation and validation, the values of CRM and RRMSE indicated a very good fit of the model, also supported by the value of EF obtained for calibration. Additional result of developed MoDrY model is the information that could be helpful to assess the impact of rainless periods occurring during particular interphase periods on the spring wheat yielding.

1. Introduction

Cereals are of fundamental importance in feeding the world population. Wheat plays the leading role among the cereals, also under the conditions of Poland. Its growth and yielding are inseparably related with the weather conditions, and especially with the thermal and precipitation conditions. Studies conducted in Poland for years on the effect of weather factors on that crop plant indicate that it responds to air temperature strongly and in a varying manner, depending of the growth phase. In the first phase (from sowing to tillering) it is characterised by the least thermal requirements (thermal optimum at 6.0–8.0 °C). High temperatures have a negative effect on the plant in the period from shooting to heading (above 14.0 °C), and also in the phase of kernel filling (above 17.0 °C).

The yielding of wheat depends significantly on the water conditions (e.g. Brooks et al., 2001; Chen et al., 2010; Marletto et al., 2007; Qian et al., 2009a). Both an excess and a deficit of rainfall may result in reduced yield. Under the Polish conditions, precipitation is too high prior to and during the emergence phase, while during the period from tillering to heading – too low, which is not conducive to the obtainment of very high yields of wheat. According to Koźmiński and Michalska (2001), the potential reduction in spring wheat yields due to excessive rainfalls varies from about 10% in South-Eastern Poland do more than 15% in the western and northern parts of the country. In the West of Poland excessive rainfalls in March are of particular importance, while in the East – rainfalls in March and April.

The literature of the subject contains numerous studies concerned with wheat yielding under drought conditions (e.g. Chipanshi et al., 1999; Hlavinka et al., 2009; Mkhabela et al., 2010; Leilah and Al-Khateeb, 2005). Poland is situated in a climatic zone characterised by rainfalls that are basically sufficient for satisfactory production of cereals, without a need for irrigation as a factor necessary for their proper growth and development. Irrigation may only be required to supplement potential precipitation deficits relative to the water requirements of crops, depending on their development phase, soil conditions and weather conditions. As reported by Jasińska and Kotecki (2003), spring wheat has a high coefficient of transpiration, within the range of 450–500 $dm^3\ kg^{-1}$ of dry matter, and it has no specific morphological or anatomical features that would make it particularly resistant to drought. Studies indicate that the crop is specially sensitive to rainfall deficit from the 1st decade of May till the 2nd decade of June in the central and lower Vistula valley and in the eastern part of the Pomeranian Lake District, and from the 1st decade of May till the 1st decade of July in South-Eastern Poland and from the 1st decade of May till the end of June in the remaining parts of the country. This results in wheat yield reduction by 5–10% (Koźmiński and Michalska, 2001).

The effect of unfavourable climatic factors and weather phenomena on the growth and yielding of plants can be estimated using a variety of methods (e.g. Hlavinka et al., 2009). Depending

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doi:10.1016/j.agwat.2011.10.023

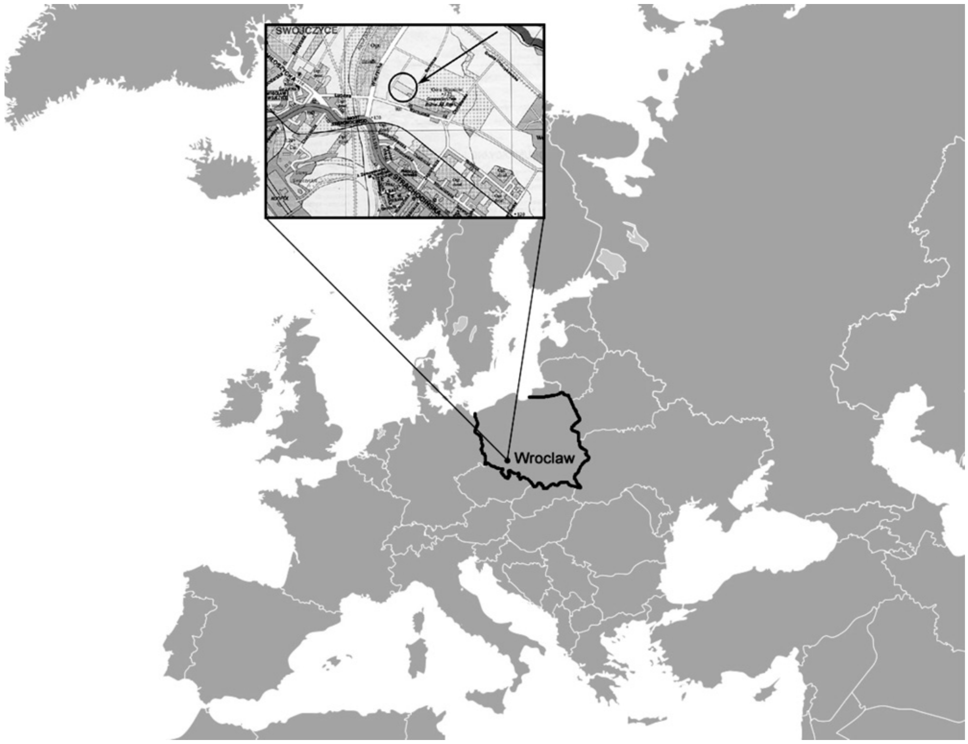

Fig. 1. Location of the Observatory of Agro- and Hydrometeorology in Wrocław, Poland.

on the objective of the estimation, one can distinguish statistical, deterministic, stochastic, dynamic, static or simulation methods. Statistical methods are frequently employed, among which one should enumerate correlation models, regression models, path analysis models, factor analysis or concentration analysis models. Such an approach was proposed by Qian et al. (2009b), Leilah and Al-Khateeb (2005), Kuchar (1989), and others. Another group is constituted by deterministic models. From the beginning of the 1990s, with the development of computer techniques there appeared many such models permitting the prediction of the growth and yielding of crops. Among those we can mention the more general models, e.g. CERES (Otter and Ritchie, 1985; Pecetti and Hollington, 1997), WOFOST (Boogaard et al., 1998), CROPSYST (Stockle et al., 2003). Other models were constructed for a specific purpose, e.g. the WheatPot model, proposed by Andarzian et al. (2008), permitting the simulation of wheat yields as a function of temperature and radiation or basing on satellite measurements (Bastiaanssen and Ali, 2003).

Mathematical models are usually based on very detailed meteorological data, there their application for larger areas is very difficult. Studies show that the best results in terms of predicted yield are obtained with the use of the diurnal values of selected meteorological elements, as all other values result in either overestimation or underestimation of the predicted yields. Since rainfall constitutes the primary factor determining the growth and development of plants, which is reflected in yield level and quality, it is the most frequently used input data in models of the weather-yield type. Another approach is the use of the number of rainless days as an element determining yield level (Szulczewski et al., 2010). Deterministic models based on mathematical equations permitting the estimation of plant growth rate and yield levels may be supplemented with data from satellite images, which permits monitoring of the growth and yielding of plants over large areas (e.g. Becker-Reshev et al., 2010; Duchemin et al., 2008; Mo et al., 2005; Moriondo et al., 2007; Clevers et al., 2002). Neural networks are also popular in the prediction of the level of yielding of crops, as exemplified in studies by e.g. Alvarez (2009) or Liu et al. (2005).

Models of plant growth and yielding are a very useful tool for the prediction of potential effects of climate changes and weather conditions changes on the growth and yielding of crops. Apart from that, such models permit also the solution of many practical problems and issues in agriculture. The most useful models are those that are characterised by a minimum number of easily available input data, due to which they can be used directly by the farmers like developed in that paper MoDrY model. In recent years increasing importance has the ability to determine yields on a regional scale. It is important to minimize the number of input data used in existing models according to different measurement methods applied in particular countries. Such an example is suggested by Therond et al. (2011). The developed MoDrY model is an alternative to the methods used there, because it requires even fewer input data than those used in this work.

2. Material and methods

The study reported herein was focused on the effect of dry periods on the yielding of spring wheat. Data on the occurrence of dry periods were used for the development of a weather-yield model based on a model proposed by the authors in an earlier work (Szulczewski et al., 2010). A characteristic feature of this model, unlike most existing weather-yield models, is that the principle of its operation is based only on information on the occurrence of precipitation.

2.1. Field experimentation

The study was conducted at the Agro- and Hydrometeorology Observatory of the University of Life and Environmental Sciences in Wrocław, Poland. Data concerning the yields of spring wheat covered the period of 1971–1997 (27 years). In parallel, measurements