



Use of WOFOST model in agriculture-A review

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ABSTRACT

To full fill the demands of increasing population for agricultural products, increases pressure on land, water, and other natural resources, to fulfils this demands and to take decision about agricultural product requires information about production, productivity of crop also for proper management and carried out intercultural operations need advanced information about crop phenology, pest and diseases presently it is possible to generate such advanced information through well validated crop growth simulation models such as CERES, WOFOST, SUCROS, and APSIM. These models provided such advanced information based on integrate the effects of different factors viz., increasing temperature, soil productivity, also consider changes in climatic on productivity. The present paper describes the review of research work done on crop simulation model as well as covers detailed information about WOFOST model.

Key words: Crop simulation model, WOFOST modelling.

Increasing demands of agricultural products, increases pressures on land, water, and other natural resources. To minimises such pressures required proper management and timely operations and this is only possible through advanced information about crop growth through, time of different crop phases, previously such information collected by conducting trials or field trial, but such trails conducted at particular points in time and space, making results site and season-specific, time consuming and expensive. Unless new data and research findings are put into formats that are relevant and easily accessible, they may not be used effectively (Jones *et al.*, 2003), but now crop simulation models are able to provide such information well in advance also gives an answer for “if then” type of question. According (Mote *et al.*, 2016) now a day’s various crop simulation models are used like DSSAT, WOFOST (World Food Study), WTGROWS, INFOCROP etc. These can also be used in decision making for farm operation viz., application of irrigation, fertilizers, etc. The use of models is very common in other disciplines, including the airplane industry, automobile industry, civil engineering chemical engineering etc. But use of models in agriculture and environmental sciences is not very common. Crop growth simulation models, properly validated against data have the potential for tactical and strategic decision making in agriculture. Such validated model can also take the information generated through site specific experiment and trial to other sites years (Mote and Kumar 2016). Several crop growth simulation models viz., CERES, WOFOST, SUCROS, InfoCrop and APSIM have been developed during

later period. These crop growth simulation models integrate the effects of different factors on productivity and have been used to determine the production potential, optimize crop management practices, to study the effect of climatic change and many others (Matthews and Stephens, 2002). Crop simulation model, which can deal with the interaction among weather, crop/variety, soils and management besides major pest. It has capacity to evaluate the production of major annual crops viz, rice, wheat, sorghum, millet, sugarcane, chickpea, pigeonpea, cotton, mustard, groundnut, potato and of course maize and has an inbuilt data base of Indian soils. It simulates daily dry matter production as a function of irradiance, maximum and minimum temperatures, water, nitrogen and biotic stress (Yadav *et al.*, 2018).

WOFOST model: WOFOST is a mechanistic model, it is widely used to simulate the effect of climate change on the growth, development and finally yield of many majors crops like wheat, rice, maize potato, barley, soybean, sugar beet etc. it give simulation results based upon eco-physiological processes, with a time step of one day. (Van Diepen *et al.* 1987., Wolf and Van Diepen 1995). WOFOST model able to simulate the phenological development from emergence to maturity on the basis of crop genetic properties and environmental conditions.

Input data required for WOFOST model

Weather data: Two types of weather file required namely WOFOST-format and in CABO-format in WOFOST model. The WOFOST format files contains information like time series of monthly averages of the relevant meteorological

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Table 1: Minimum input data required for WOFOST.

Input	Description
Station name	Station name for identification
Latitude	latitude
Longitude	Longitude
Altitude	altitude
Angstrom a	Constant for Angstrom A
Angstrom b	Constant for Angstrom B
Day	Julian day of year
Minimum temperature	Minimum temperature
Maximum temperature	Maximum temperature
Sun shine hours	Bright sunshine duration
Calculated radiation	Daily global radiation in
Wind speed	Daily wind speed at 10 m
Rainfall	Daily rainfall
Vapour pressure	Daily vapour pressure

parameters like daily temperature, sunshine hours, wind speed etc., There are no special rules for the names of the WOFOST-format weather files. In case of unavailability or larger variability or irrelevant daily weather data for several stations the monthly averages or climatological normal of weather variables may be very useful asset to simulate the crop characteristics, utilizing the WOFOST-format file. The files in CABO-format contain daily weather data for one station and one year (Boogaard *et al.*, 1998). In (Table 1) mention required of input for CABOW format file for calibration of WOFOST model.

Soil data: The soil file in WOFOST contains information about soil physical characteristics (Boogaard *et al.*, 1998). Detailed of required physical characteristics in WOFOST model are listed in Table 2.

Crop data: Crop data file include the information about crop phenology, assimilation and respiration characteristics, and partitioning of assimilates to plant organs (Boogaard *et al.* 1998).

Calibration of WOFOST model: Model calibration involves the modification of some model parameters such that data simulated by the error-free model fit the observed data. In many instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters. Non-compliance may arise from sampling errors as well as from incomplete knowledge of the system.

Table 2: Soil characteristics of Navsari used as input in WOFOST.

Parameters	Unit
Soil texture	—
Organic carbon	(%)
Field capacity	(cm ³ cm ⁻³)
Permanent wilting point	(cm ³ cm ⁻³)
Saturation moisture content	(cm ³ cm ⁻³)
Bulk density	(gcm ⁻³)

Alternatively, it may arise when the model is used in a situation that is markedly different from the one under which it was developed. Calibration of model involves adjusting certain model parameters or relationships to make the model work for any desired location. When using a crop model, one has to estimate the cultivar characteristics if they have not been previously determined.

Number of crop physiological parameters in WOFOST are defined as a function of development stage (DVS). DVS is a dimension less state variable 1. That for most annual crops is set to 0 at emergence, 1 at flowering and 2 at maturity (Boogaard *et al.* 1998). DVS changes with accumulated degree days between these phenological stages. Total degree-days required for completion of phenophases (from emergence to flowering and from flowering to physiological maturity) can be calculated based on the base temperature and average daily temperature. TSUM1 and TSUM2 are total degree days from emergence to flowering and from flowering to physiological maturity. Description of genetic coefficients need for calibration processes in WOFOST model given in Table 3.

Production levels in WOFOST model: To be able to deal with the ecological diversity of agriculture, three hierarchical levels of crop growth can be distinguished: potential growth limited growth and reduced growth. Each of these growth levels corresponds to a level of crop production: potential, limited and reduced production (Fig.1).

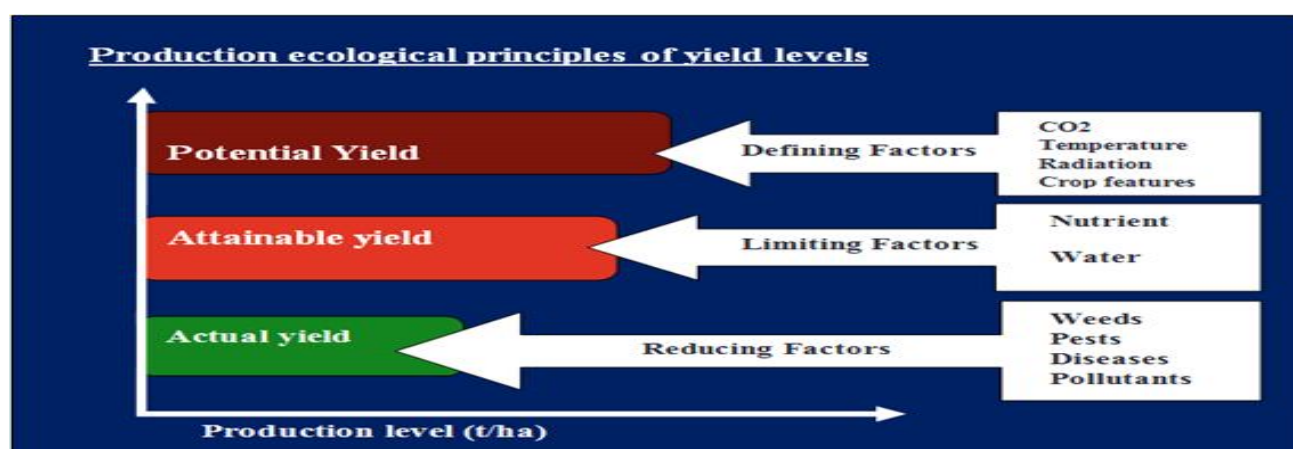
Reality rarely corresponds exactly to one of these growth/production levels, but it is useful to reduce specific cases to one of them, because this enables you to focus on the principal environmental constraints to crop production, such as light, temperature, water and the macro nutrients nitrogen (N), phosphorus (P) and potassium (K). Other factors can often be neglected because they do not influence the crop's growth rate (Rabbinge and De Wit, 1989., Penning de Vries *et al.* 1989).

The water-limited production level: The water limited production level takes into account the effect of periods of soil moisture deficit on crop growth, and the water limited yield represents the maximum yield that can be obtained under rainfed conditions. The yield limiting effect of drought depends on the soil moisture availability as determined by the amounts of rainfall and evapotranspiration, and their distribution over the growing season, by soil type, soil depth and groundwater influence. The difference between potential and water-limited production indicates the production increase that could be achieved by irrigation.

A special case of water-limited conditions is related to an excess of soil moisture, causing oxygen shortage for the plant roots. So oxygen limited production would be a more appropriate term. Its effect depends on soil properties and drainage measures and is difficult to quantify by modelling.

Table 3: Description and units of WOFOST parameters revised for calibration of model.

Coefficient	Description	Unit
TSUMI	temperature sum from emergence to anthesis	°C
TSUM2	temperature sum from anthesis to maturity	°C
LAIEM	leaf area at emergence	-
RGRLAI	maximum relative increase in LAI	-
CVL	Efficiency of conversion into leaves	kg ha ⁻¹
CVO	efficiency of conversion into storage organ	kg ha ⁻¹
CVR	efficiency of conversion into roots	kg ha ⁻¹
CVS	Efficiency of conversion into stem	kg ha ⁻¹
RML	Relative maintenance respiration rate of leaves	kg CH ₂ O kg ⁻¹ d ⁻¹
RMO	Relative maintenance respiration rate of storage organs	kg CH ₂ O kg ⁻¹ d ⁻¹
RMR	Relative maintenance respiration rate of roots	kg CH ₂ O kg ⁻¹ d ⁻¹
RMS	Relative maintenance respiration rate stems	kg CH ₂ O kg ⁻¹ d ⁻¹

**Fig 1:** Theoretical production levels (Van Ittersum and Rabbinge, 1997).

Temporal and spatial scale of the model: WOFOST is a one-dimensional simulation model, i.e. without reference to geographic scale. Its application to regions relies on the selection of representative points, followed by spatial aggregation or interpolation. Crop growth is simulated using daily weather data of many years and different parameters for each relevant soil type within a region. If required for a particular study, calculated values, e.g. yields, biomasses produced or water use, can be averaged over the simulated years or aggregated over soil types (Boogaard *et al.* 1998).

Development of WOFOST model: WOFOST originated in the framework of interdisciplinary studies on world food security and on the potential world food production by the Center for World Food Studies (CWFS) in cooperation with the Wageningen Agricultural University, Department of Theoretical Production Ecology (WAU-TPE) and the DLO-Center for Agro-biological Research and Soil Fertility (AB-DLO), Wageningen, the Netherlands. The development of WOFOST has been connected to the need for its application in various studies. Although most of these studies did not have the specific purpose to develop the model as such, efforts were made to maintain parts of the software

developed as options in the subsequent model versions (Boogaard *et al.* 1998)

General characteristics: In WOFOST, crop growth is simulated on the basis of eco-physiological processes. The major processes are phenological development, light interception, CO₂-assimilation, transpiration, respiration, partitioning of assimilates to the various organs, and dry matter formation. This is illustrated in Fig. 2. Potential and water-limited growth is simulated dynamically, with a time step of one day. Nutrient-limited production is calculated statically, on the basis of soil characteristics and the water-limited production. The core of the WOFOST's crop growth sub model has been taken from the SUCROS model (Spitters *et al.* 1989., Van Laar *et al.* 1992). The principles of WOFOST's water module are described in Van Keulen and Wolf (1986). Nutrient limited production is calculated according to the principles of the QUEFTS model (Janssen *et al.* 1990). In the following sections, an outline of the main calculation procedures used in WOFOST is provided.

Assimilation and respiration: The daily gross CO₂ assimilation rate of a crop is calculated from the absorbed radiation (I_a), and the photosynthesis-light response curve

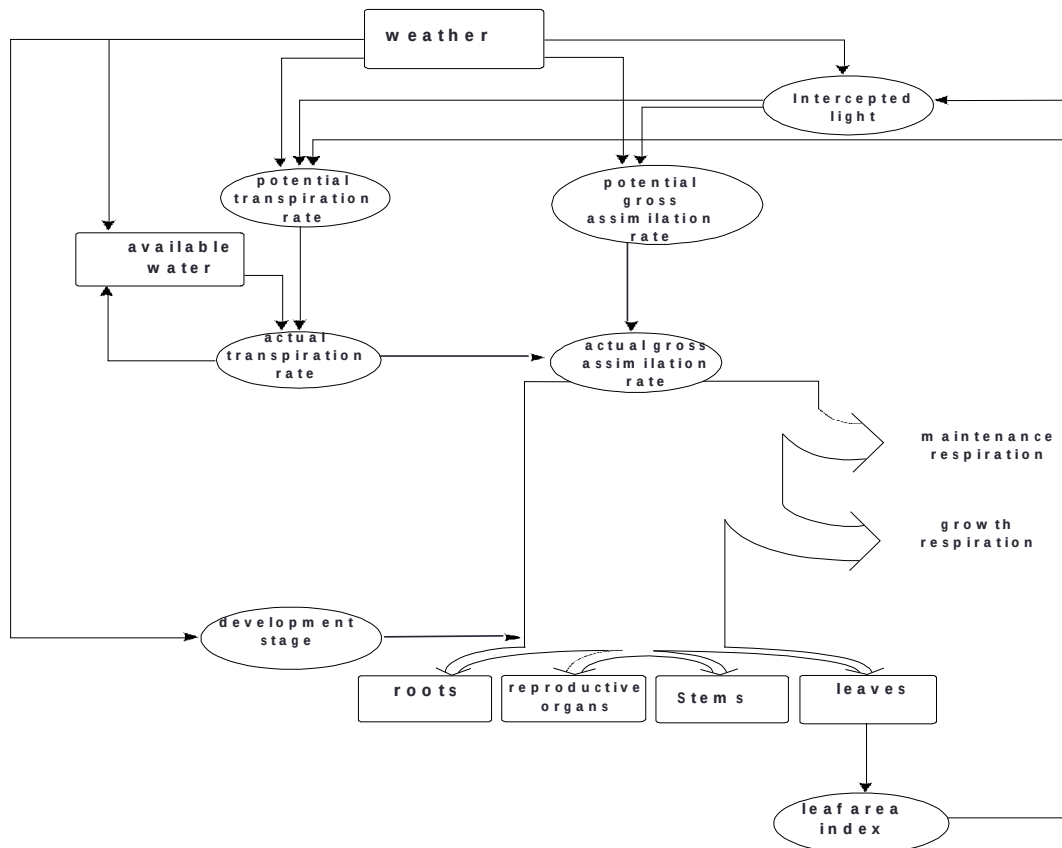


Fig 2: Simplified general structure of a dynamic, explanatory crop growth model (Kropf *et al.*, 1993).

of individual leaves. This response is dependent on temperature and leaf age. The absorbed radiation is calculated from the total incoming radiation and the leaf area. Because photosynthesis responds to light intensity in a non-linear way, variation in radiation level has been taken into account.

Phenological development: The order and the rate of appearance of vegetative and reproductive organs characterize phenological development of a crop. The order of appearance is a crop characteristic, which is independent of external conditions. The rate of appearance can vary strongly, notably under the influence of temperature and photoperiod (day-length) (Van Keulen and Van Diepen, 1990). In WOFOST phenology is described by the dimensionless state variable development stage (DVS). For most annual crops, DVS is set to 0 at seedling emergence, 1 at flowering and 2 at maturity. To calculate the time between sowing and emergence of a crop, WOFOST uses an additional set of thermal time variables.

Transpiration: Transpiration is the loss of water from a crop to the atmosphere. Water loss is caused by diffusion of water vapour from the open stomata to the atmosphere. The stomata need to be open to exchange gasses (CO_2 and O_2) with the

atmosphere. To avoid desiccation, a crop must compensate for transpiration losses, by water uptake from the soil. In WOFOST, an optimum soil moisture range for plant growth is determined as function of the evaporative demand of the atmosphere (reference potential transpiration of a fixed canopy), the crop group and total soil water retention capacity. Within that range, the transpiration losses are fully compensated. Outside the optimum range, the soil can either be too dry or too wet. Both conditions lead to reduce water uptake by the roots, in a dry soil due to water shortage, in a wet soil due to oxygen shortage.

Water balance of the soil: The moisture content in the root zone follows from the daily calculation of the water balance. In WOFOST three different soil water sub models are distinguished. The first and most simple soil water balance applies to the potential production situation. Assuming a continuously moist soil, the crop water requirements are quantified as the sum of crop transpiration and evaporation from the shaded soil under the canopy.

Nutrients : WOFOST can calculate nutrient-limited production under non-fertilized soils and the amount of plant nutrients needed to attain potential and water-limited production levels. Only the three macro nutrients, N, P and

K are accounted for. The calculations are performed according to the QUEFTS model (Quantitative Evaluation of the Fertility of Tropical Soils) (Janssen *et al.* 1990), which has been integrated in WOFOST. How elements of QUEFTS work in WOFOST and what kinds of data are required can be found in (Keulen and Wolf 1986).

Use of WOFOST models in Agriculture

Applications of WOFOST: Over the last twenty-five years, the successive WOFOST versions and their derivatives have been used in many studies. WOFOST has been applied as a tool for the analysis of:

- a) Yield risk and inter-annual yield variability;
- b) Yield variability over soil types, or over a range of agro-hydrological conditions;
- c) Differences among cultivars;
- d) Relative importance of growth determining factors;
- e) Sowing strategies;
- f) Effects of climate change;
- g) Critical periods for use of agricultural machinery.

The model has also been used for predictive purposes, in quantitative land evaluation, such as:

- a) Regional assessments of crop yield potential in the form of maximum yield levels;
- b) Estimation of maximum benefits from irrigation or from fertilizer use
- c) Detection of adverse growing conditions by simulation-monitoring the agricultural season
- d) Regional yield forecasts.

Case studies: The WOFOST model has been developed mainly for European conditions and it has been used to simulate the production of the chief annual crops in Europe (Supit *et al.*, 2010, 2012). Although it has also been used for regional land evaluation, yield potential simulation, risk analysis, and yield forecasting studies in Europe, Africa, and China (Hengsdijk *et al.* 2005., Boogaard *et al.* 2013., Lu and Fan, 2013)

Compared with the statistical analysis on spectral characteristics, the crop growth model WOFOST, which uses relevant environment and crop parameters, has the advantages of mechanism and time-scale simulation. The model can dynamically describe the fundamental processes of crop growth, such as photosynthesis, respiration, transpiration and biomass partitioning (Ma *et al.*, 2013). Moreover, the assimilation of multiperiod spectral indices into WOFOST model can not only improve the simulation precision of growth parameters, but also obtain input parameters in real time (Macdonald and Hall, 1980., Ren, *et al.*, 2011., Wu *et al.*, 2012., Zhao *et al.*, 2013).

The WOFOST model, widely used for the description of crop growth, was improved by incorporating stress factors with overall consideration for the changes in physiological status under heavy metal stress (Jin *et al.*,

2015). WOFOST model has been used to simulate dry matter of all parts of rice (Wu *et al.*, 2013) and dry weight of rice root (Liu *et al.*, 2015) under heavy metal stress. In this study, the WOFOST model was improved by incorporating stress factors, which can describe the fundamental processes of crop growth under heavy metal stress. Heavy metals can reduce both photosynthesis and the dry biomass of plants (Rahman *et al.* 2007., Das *et al.* 1997., Dias *et al.* 2012., Krupa *et al.*, 1999., Monteiro *et al.*, 2009).

By using WOFOST model can obtaining precise information regarding the levels of heavy metal stress in crops is vital for food security, agricultural production, and ecological protection. In this study, we can realized the dynamic simulation of crop growth parameters in experiment fields that are exposes to varying levels of soil heavy metals concentration, intending to monitor the stress-induced changes of growth parameters on time scale (Liu *et al.*, 2015). WOFOST can simulate daily crop growth (two or more days can also be selected for the simulation step) and compute the yield at the end of the growing season (Cheng *et al.*, 2016).

By using WOFOST model can check a sensitivity analysis of the responses of crops to the chosen production adaptation options under regional climate change and also estimates projections of crop production for different sowing dates and cultivars for a major economic and agricultural province. The WOFOST results indicate that adjusting the sowing dates and cultivars could mitigate the influences of climate change. The yield gains are projects from the choosing sowing date and cultivars (Tao *et al.* 2016).

Limitations of WOFOST: It should be stressed again that WOFOST is a model, hence a simplification of reality. The user always has to be cautious when drawing conclusions from the simulation results. Keep in mind that the quality of the model results cannot surpass the quality of the input data. A model merely elucidates the consequences of the user's opinions and data (Driessen, 1986).

In the validation process, crop growth as observed in reality can be compared with the simulation results. This provides an impression of the adequacy of WOFOST's predictions. When differences occur, you may need to adapt values of model-parameters (calibration). Then, the model should again be checked, against an independent set of observations. A problem in this respect is that there are an enormous number of parameters while only a few can be validated at a time. One should also realize that although calibration may improve the model results for a specific purpose, it can diminish its general applicability.

A weakness of WOFOST and all other crop growth simulation models is that some parameters are fixed whereas in practice they are known to vary, for example those concerning the relation between development stage and partitioning (Passioura, 1996)

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