CROP SIMULATION MODELING THROUGH INFOCROP MODEL

Rani Saxena
Division of Agronomy, Rajasthan Agricultural Research Institute, Durgapura, Jaipur, India
E-mail: mathurrani@rediffmail.com

Environmental conditions of both atmosphere as well as soil have a detrimental effect on the growth and development of crop plants. Crop yield is influenced by several factors like weather, soil type and its nutrients status, management practices and other inputs available. Weather is one of the important components influencing agricultural production and productivity. There is no denying of the fact that weather and climate are important factor in determining our day-to-day and long term activities. As weather assumes significance in nearly every phase of agricultural activity from the preparatory tillage to harvesting and storage and by interfering with routine agricultural operation and plant protection measure, hence success or failure of farming is intimately related to the prevailing weather conditions. The extent of Influence of weather on crop growth mainly depends on the crop growth stage. The relationship between weather and crop production has been under stood through crop weather modeling and study on this aspect in a systematic manner started a century ago while in India it was initiated less than six decades ago. The understanding of the interactions between weather, soil, management practices etc using simulation modeling will help in impact, adaption and vulnerability studies in agriculture.

Weather Parameters:

a) Solar radiation:

Radiation is the energy that all matters impart at a temperature above the absolute zero. Sun is the ultimate source of energy required for all physical, biological and chemical processes occurring on the earth surface. Though there is uneven distribution of solar radiation on entire globe, but Sunshine is not a limiting factor anywhere in India. Even during the monsoon, excessive rain is responsible for negative effect on plant growth and not the sunshine. The total insolation (incoming solar radiation) within a given site is highly variable, changing with time, season and weather. The variation of the total insolation from location to location are enormous and the distribution of plants and animals response to this variation. But continued cloudiness during flowering is injurious to all plants. It also creates conditions favorable to the multiplication of pests and diseases. High humidity and warm temperatures are conducive to most plant diseases. The visible part of solar radiation affects the growth and development of all plants both directly or indirectly. Therefore light of correct intensity, duration and quality is necessary to normal plant development. Abnormal plant growth and disorders results from poor light availability. Light is indispensible to photosynthesis. Light plays role in distribution of photosynthates among different organs of plants. It affects the emergence, tillering, stability, strength and the size of leaves and the growth and development of roots. Solar radiation is very much important during the critical stages of plant growth. Solar radiations play a vital role in photosynthesis.

Temperature:

Temperature is defined as the measure of kinetic energy of the molecules. Hence it is therefore, intensity aspect of heat energy. Again sun is the major source of regulation of temperature of the earth. The growth and development rates of many crops are controlled by temperature Bannayan et al. 2004). There are many plant processes governed by the temperature.

(a) Whatever chemical or any substance applied or already present in soil, its solubility depends up on the temperature.

(b) All the physical, chemical and biological processes are regulated by the temperature within the plants.

(c) The enzymes and their functions are also regulated by the temperature.

(d) Temperature also affects the rate of reaction.

(e) The diffusion of different gases present in atmosphere or soil is also governed by the temperature.

Thus the atmospheric temperature is one of the most important climatic variables which affects the plant growth and development .The air temperature plays an important role in plant growth. The growing season in subtropical regions, where there is frost problem, is defined on the basis of air temperature. Each crop is known to have its own optimum, maximum and minimum temperature conditions called as cardinal temperatures.

1. The minimum temperatures below which no growth of plants
2. The optimum temperature at which maximum plant growth occurs.
3. The maximum temperature above which there in no plant growth.

Rainfall:

Solid or liquid form of atmospheric water is known as rain fall. Rainfall is one of the most important climatic factors. Water or moisture plays a vital role in the life of pants. It is a constituent part of protoplasm. Cells contain 80-90 % water and photosynthesis mainly requires water. Being universal solvent, it increases the chemical activity of the compound in the plant. Rain water increases soil moisture. Both, scanty as well as excess rain fall is harmful for plants. In case of scanty rainfall, there is water stressed condition. Water stress affects cell division, initiation of tissues and organ primordial and differentiation and expansion of cells. Shortage in water uptake and dehydration results in negative effect on most of the physiological processes. Water stress effects vary from stage to stage of crop plants. Not only stage but also age of plants behaves differently. Young seedlings of cereal plants can with stand a high degree of water stress in the first several days of their growth. As plants protoplasmic viscosity decreases, permeability and resistance to wilting increases. As a result flowering and fruiting are accelerated, shoots size decreases and that of roots increases, cuticle and cell wall are thickened.

In India, the windward side of the Western Ghats, the Khasi Hills and the Himalayas are the areas of very heavy rainfall. These areas act as a source region for many of the major river systems of the country, particularly the Himalayan ranges. On an average, the large part of the country receives annual rainfall less than 1000 mm. But, the average annual rainfall of 1050 mm is the highest in any part of the world. On the other hand, the north-western parts of India are the driest. Rajasthan receives even less than 500 mm of rain annually.
In case of excessive rainfall there is water logging problem and due to lack of oxygen supply, plants suffer. Because of immense importance of water, the knowledge of commencement and end of rainy season as well as duration of intermittent dry and wet spells is of paramount. Various agronomic operations like preparation of seed bed, fertilization, sowing, earthing, weeding, harvesting, threshing, drying can be planned on the basis of rainfall forecasting.

Wind:
Horizontal movement of air is defined as wind, while in vertical direction, it is known as current. Wind movement is basically governed by the pressure differences of a place. Wind movement is from higher pressure to lower pressure. Warm and dry winds cause greater losses through evaporation and results in water stress. Light winds blowing from colder parts will bring about a drop in temperature and create frosty conditions. Wind is another parameter which strongly affects the intake of carbon dioxide (Mavi 1984). The intake of carbon dioxide depends on its concentration in the atmosphere and its delivery to the leaf. When there is no wind or atmosphere is in stable condition then the carbon dioxide reaches the leaves by process of diffusion. In some cases there is no supply of carbon dioxide or its availability is restricted. In case of wind movement, the transportation of carbon dioxide to leaf is quite rapid. So it can be concluded that during calm condition, the rate of photosynthesis may be slow or less but it depends upon on other several conditions as well. As the speed of wind increase, a decrease in the rate of assimilation has been recorded. Different scientist has different views on maximum wind velocity upto which the rate of assimilation increases. High winds or squalls are experienced in association with cyclones, depressions and dust-storms and thunder-storms. High winds cause mechanical damage such as breaking or lodging to crops. For the protection to plants against damage because of winds, windbreaks are planted across the prevailing wind directions. They are recommended as a useful means to reduce the evapo-transpirative losses, soil erosion and frost damage by wind.

Terms used in modeling

Model: A model is a schematic representation of a system or a set of equations, which represents the behaviour of a system.
Simulation: Is the imitation of the operation of a real-world process or system over time. It is also defined as “Reproducing the essence of a system without reproducing the system itself”.

Calibration: the process of adjustments in model parameters to make the model to behave as per the defined system.

Validation: the comparison of predicted values of model with the results from experiments. There may be differences between experimental output and simulated output due stresses which were not considered during simulation. Validation is used as evaluation with emphasis on usefullness and relevance of the model.

Types of models

Depending upon the purpose, the models are classified into different groups or types.

1. Statistical models: These models represent the relationship between yield components and weather parameters. Statistical techniques are used to measure relationship.

2. Mechanistic models: These models explain not only the relationship between weather parameters and yield, but also the mechanism. These models are based on physical selection.

3. Deterministic models: In these models the input and output remains same. These models estimate the exact value of the yield. These models also have defined coefficients.

4. Stochastic models: these models calculate output at a given rate. A probability element is attached to each output. For each set of inputs different outputs are given along with probabilities.

5. Dynamic models: Time is included as a variable and output is a function of time. Both dependent and independent variables are having values which remain constant over a given period of time.

6. Static: In this model, time is not included as a variable. Dependent and independent variables having values remain constant over a given period of time.

7. Simulation models: These are a mathematical representation of a real world system. One of the important function of crop simulation models is to estimate agricultural production as a function of weather, soil conditions and crop management. In these models, one or more sets of differential equations are used and both rate and state variables over time are calculated.

Simulation models quantify the underlying processes and integrate the effect of weather, soil, insects and pests and management factors on crop growth, development and yield.

InfoCrop

The InfoCrop is a generic crop growth model that can simulate the effects of weather, soil, agronomic managements (including planting, nitrogen, residue and irrigation) and major pests on crop growth and yield (Aggarwal *et al.*, 2004). Different crop development and growth processes, which influence the yield, are considered in the model. InfoCrop is a simple user friendly and inputs for it are easily available. It performs well in tropical agro environments.

The key inputs and outputs used in InfoCrop model are shown in Fig. 1. InfoCrop requires weather data, edaphic data, varietal data, crop management data and insect and pest data. The output from the InfoCrop is like yield, total dry matter, crop duration, evapotranspiration, n uptake, green house gs emissions and soil C, N, and water dynamics.

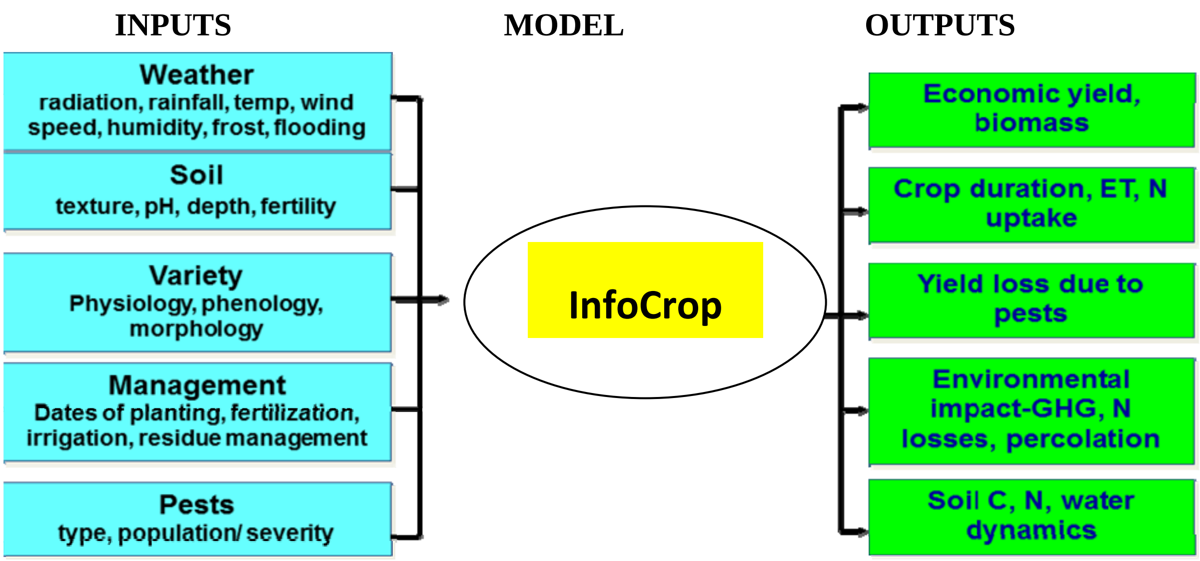

Figure 1. InfoCrop: Key inputs and outputs (Source: Aggarwal *et al*, 2004)

InfoCrop considers the processes like crop growth, crop pest interactions, soil water balance, soil nitrogen balance, soil organic carbon dynamics and emissions of green house gases (Fig. 2).

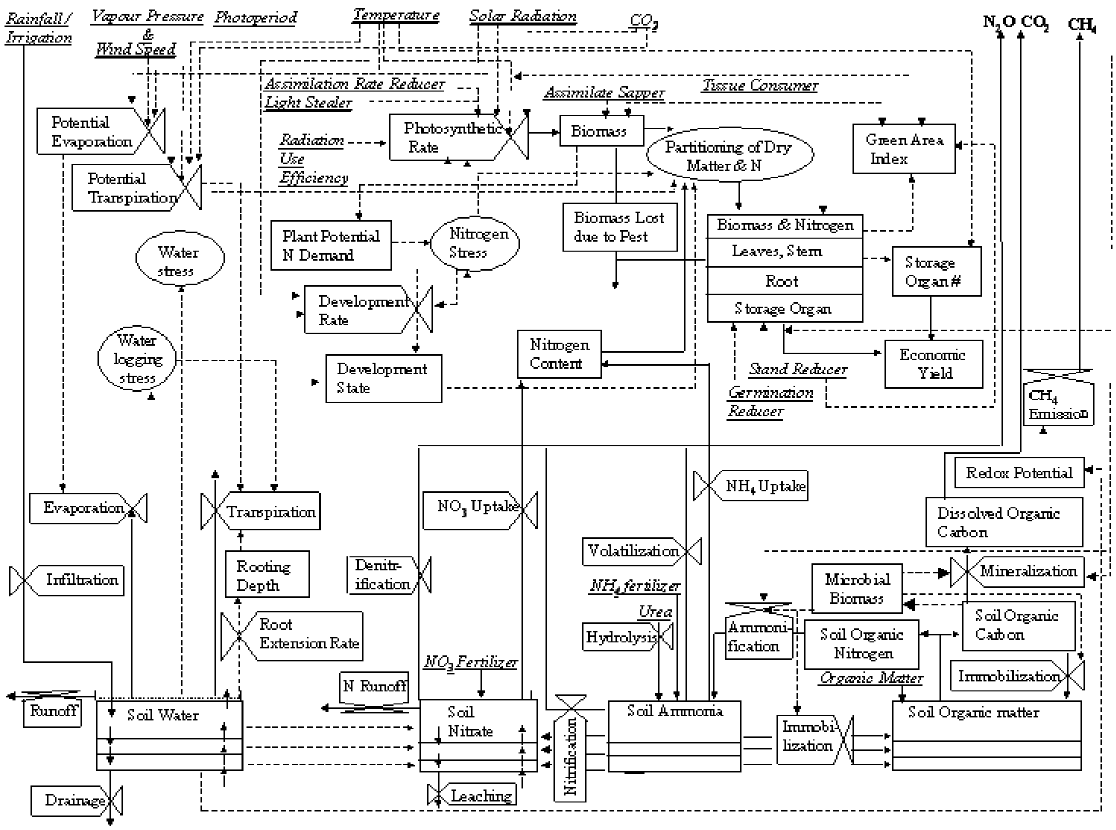

Figure 2. Relational diagram showing the variables and feedbacks among different processes in InfoCrop (Source: Aggarwal *et al.* , 20004).

The key modules of InfoCrop are weather, pest dynamics, soil water balance and soil N balance etc. (fig.3).

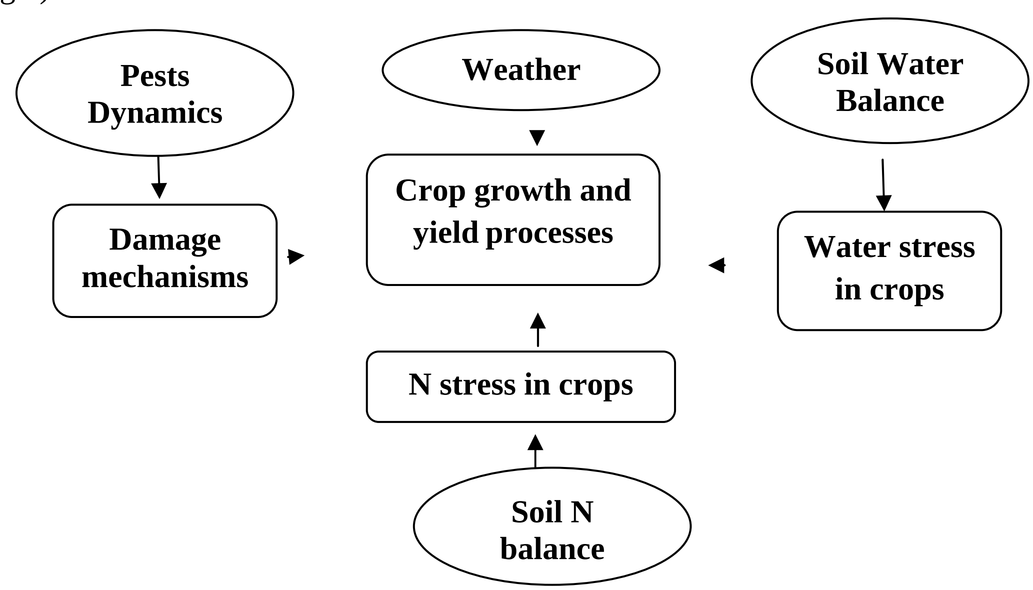

Figure 3. Key Modules of Infocrop model.

Minimum data set for InfoCrop:

1. Weather: The daily weather data on maximum air temperature (°C), minimum air temperature (°C), solar radiation (MJ m-2 day-1)/sun shine hours (h), wind speed and precipitation.
2. Site data: lat, long, altitude.
3. Soil data: soil layer thickness, field capacity, wilting point, hydraulic conductivity, sand, clay, bulk density, soil organic carbon, EC, PH
4. Cultivar coefficients: InfoCrop distinguishes varieties of a crop by their differences in phenology, growth and source- sink balance. In most cases, thermal times of three phenological phases, the sensitivity to photoperiod, early vigour (defined in the model as relative LAI growth rate during initial stages), index of storage organs formation (slope of the relation between SO and growth during SO formation stage), and the potential weight of the storage organs were sufficient to adequately characterize the varieties.
5. Plant data: seed rate, date of sowing, date of emergence, date of anthesis, date of physiological maturity, LAI, dry matter, grain number, grain weight etc.
6. Management data: date and amount of irrigation, date and amount of fertilizer, sowing depth, cultivar coefficients

Genetic coefficients/Varietal characteristics

InfoCrop distinguishes varieties of a crop by their differences in phenology, growth and source-sink balance (Table 1). Sensitivity analysis has shown that the major differences among popular cultivated varieties are generally in their phenological parameters. In most cases, thermal times of three phenological phases, the sensitivity to photoperiod, early vigour (defined in the model as relative LAI growth rate during initial stages), index of storage organs formation (slope of the relation between SO and growth during SO formation stage), and the potential weight of the storage organs alone were sufficient to adequately characterize the varieties.

Table 1: Varietal characteristics used in InfoCrop to distinguish varieties.

Genotypic constants	**Units**
Base temperature	^oC
Thermal time for-	
Germination	degree-days
Germination to anthesis (range)	degree-days
Anthesis to maturity (range)	degree-days
Relative growth rate of leaves during early stage (RGRPOT)	^oC/ d
Specific leaf area (SLA)	dm^2/mg
Radiation use efficiency (RUE) (range)	g/MJ/day
Extinction coefficient of leaf at flowering	ha leaf/ha soil

Potential boll weight	mg/boll
Root extension growth rate	mm day^{-1}
Sensitivity to flooding (between 1.0 –1.2)	Scale
Index of greenness of leaves (between $0.8^{-1}.2$)	Scale

Uses of crop weather models

- Crop system management: to evaluate optimum management production for cultural practice.
  1. Seed rate: Optimum seed rate can be found out with the help of these models.
  2. Irrigation: Optimum amount and time of application can be simulated.
  3. Fertilizer: Optimum amount of fertilizer and time of application of the fertilizer can be simulated.
- Yield gap analysis: Potential yield can be simulated using these models and the difference between potential yield and actual yield is the yield gap.
- Yield prediction and forecasting.
- Evaluation of climate change.
- Useful for solving various practical problems in agriculture.
- Are resource conserving tools.
- Can be used in precision farming studies.
- Are very effective tool for predicting possible impacts of climatic change on crop growth and yield.
- Helps in adaptation strategies, by which the negative impacts due to climate change can be minimized.

Simulation of temperature, CO_2 and rainfall using InfoCrop model.

In the model, the total crop growth period is divided into following three phases viz.

a) Sowing to seedling emergence.

b) Seedling emergence to anthesis.

c) The storage organ filling phases.

Aggarwal *et al* (2010) mentioned that in the InfoCrop model, change in temperature, CO_2, and rainfall are simulated as follows-

1. The overall crop growth and development of a crop is calculated by integrating the temperature-driven development rates i all the phases. There is linear reltionship between the rate of development and the daily mean temperature above base temperature up to the optimum temperature. Therefore, an increase in temperature generally accelerates phenology based on the threshold temperature of a loation and hence the crop duration is reduced.
2. Dry matter (DM) production is a function of radiation use efficiency (RUE), photosynthetically active radiation (PAR), total leaf area index (LAI) and specific light interception coefficient of cultivar.

3. In the initial stages of crop growth, leaf area formation is controlled by temperature. The senescence of leaves is also dependent on temperature.
4. Potential evapo-transpiration (PET) is influenced by temperature. The water stress is determined as the ratio of actual water uptake and potential transpiration. It accelerates phenological development, decreases gross photosynthesis, alters the allocation pattern of assimilates to different organs and accelerates the rate of senescence.
5. Whenever there is any deviation from threshold values of maximum and minimum temperature during a short period between anthesis and a few days afterwards, a part of the storage organ becomes sterile. This reduces the number of storage organs.
6. The influence of rainfall is operated in the model through soil water balance.

Climate Change Impact Assessment using InfoCrop model.

The impact of future climate change on grain yield of crops can be studied using InfoCrop simulation model. Scenarios derived from different Regional Climate Model and GCM can be used to depict the impact of climate change on crop production.

Adaptation and vulnerability analysis using InfoCrop model.

The following adaptation strategies can be followed to assess the adaptive capacity of crops to climate change.

a) The usage of short, medium and long duration variety
b) A change in sowing time which includes early and late sowing relative to timely sowing time.
c) A change in the seed rate.
d) A change in the irrigation and fertilizers.
e) Application of additional fertilizer

A combination of these can be put in the model to identify the most suitable adaptation combination. The combination, which gave the highest yield can be taken as the best suitable adaptation option. The net yield gain is expressed as the relative change from the mean current yield. The net vulnerability can be calculated by the following formula:

Vulnerability = Impact lose - Adaptation gain

Appendix: Abbreviations used in output of InfoCrop model.

NAME	**DEFINITION**	**Unit**
TIME	Time	Julian Day
DSTART	Days since start	Days
DAS	Days after sowing	Days
DS	Crop development stage	Scale
ANTHD	Days to anthesis	Days
GCROP	Mean crop growth rate	kg/ha/day
LAI	Leaf area index	

ZRT	Rooting depth	mm
TDM	Total dry matter	kg/ha
WLVG	Weight of green leaves	kg/ha
WSTEM	Weight of stems	kg/ha
WLVD	Weight of dead leaves	kg/ha
WSTD	Weight of dead stems	kg/ha
YIELD	Economic yield	kg/ha
GNO	No of grains/m^2	#/m2
WGRAIN	Weight of one grain	mg
LVFEED	Leaves eaten by insects	kg/ha
TSUCK	Cumulative dry matter sucked by insects	kg/ha
LALOSS	LAI Lost due to pests	
ANCR	Nitrogen in crop	kg/ha
ANLV	Nitrogen in leaves	kg/ha
ANLD	Nitrogen in dead leaves	kg/ha
ANST	Nitrogen in stems	kg/ha
ANSD	Nitrogen in dead stems	kg/ha
ANSO	Nitrogen in storage organs	kg/ha
NAPDAY	External nitrogen added	kg/ha
NAPADD	Cumulative external nitrogen added	kg/ha
NFIX	Nitrogen fixation	kg/ha
NFXSUM	Cumulative nitrogen fixation	kg/ha
SOILNT	Soil nitrogen	kg/ha
NLEACH	Nitrogen leached	kg/ha
NLECHT	Cumulative nitrogen leached	kg/ha
NLOSSD	Nitrogen lost	kg/ha
NLOSS	Cumulative nitrogen loss	kg/ha
SOCTOT	Soil organic carbon	%
NSTRES	Crop nitrogen stress index	0-1 scale
PTRANS	Potential transpiration	mm
PEVAP	Potential evaporation	mm
ATRANS	Crop transpiration	mm
AEVAP	Soil evaporation	mm
ETDAY	Evapotranspiration	mm
ETSUM	Cumulative evapotranspiration	mm
TATRAN	Cumulative transpiration	mm
TAEVAP	Cumulative soil evaporation	mm
WSTRES	Crop water stress index	0-1 scale
IRRIGS	Irrigation applied	mm

TIRRIG	Cumulative irrigation applied	mm
POND	Ponded water	mm
WCUM	Soil moisture	mm
DRAIN	Drainage	mm
TDRAIN	Cumulative drainage	mm
RNOFF	Runoff	mm
TRNOFF	Cumulative runoff	mm
N2OTOT	Emission of nitrous oxide	g/ha
N2OTOS	Cumulative emissions of nitrous oxide	g/ha
CHEMIT	Emission of methane	kg/ha
CH4SUM	Cumulative emission of methane	kg/ha
CO2EMS	CO2 emission	kg/ha
CO2SUM	Cumulative CO2 emission	kg/ha
GWP	Global warming potential of GHG emission	kg/ha carbon equivalents
GLOBWP	Cumulative global warming potential of GHG emission	kg/ha carbon equivalents
RAIN	Rainfall	mm
TRAIN	Cumulative rainfall	mm
DTR	Solar radiation	Mj/m^2
TMAX	Maximum temperature	C
TMIN	Minimum temperature	C
TPAV	Average temperature	C
WN	Wind speed	m/sec
VP	Vapour pressure	kPa
FROST	Frost day	day
FLOOD1	No of days of continuous flooding	days

REFERENCES

Aggarwal, P. K., Kalra, N., Chander, S. and Pathak, H., 2004. InfoCrop: A generic simulation model for annual crops in tropical environments. Indian Agricultural Research Institute, New Delhi, p-132.

Aggarwal, P.K., S Naresh Kumar, Himanshu Pathak, 2010. Impacts of climate change on growth and yield of rice and wheat in the Upper Ganga Basin . WWF report.

Bannayan M, Hoogenboom G, Crout N.M. J., 2004. Photothermal impact on maize performance: a simulation approach. Ecol Model 180(2&3):277–290.

Mavi, H. S., 1994. Introduction to Agrometeorology, Oxford and IBH publishing Co pvt ltd, New Delhi.