AUTOMATION OF THE DSSAT CROP GROWTH SIMULATION MODEL

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ABSTRACT:

Crop Simulation Models (CSM) simulate the growth, development, and yield of crops using various inputs such as soil water, carbon and nitrogen processes, and management practices. DSSAT (Decision Support System for Agrotechnology Transfer) is a software program that comprises dynamic crop growth simulation models for over 42 crops. It incorporates modules for crop, soil, and weather to simulate long-term outcomes of crop management strategies. DSSAT-CSM requires various data for model operation. This includes data on the site where the model is to be operated, on the daily weather during the growth cycle, on the characteristics of the soil at the beginning of the growing cycle or crop sequence, and on the management of the crop. Acquisition of the data and providing the data to the DSSAT model is tedious and time-consuming as each individual value has to be manually entered. Additionally, crop simulation models can only be run for specific points and not for entire locations. Sometimes site-specific data especially weather data cannot be obtained. The output thus produced is difficult to analyze spatially at a large scale. The main purpose of this paper is to take the required dataset directly from spatial data. This is done by dividing locations into grids and taking the data from each grid. Python scripts are then used to convert this data into crop model format which is then run through DSSAT on an individual basis. The output thus obtained is be entered back into their respective grids as spatial data.

1. INTRODUCTION

Agriculture is the backbone of every country. Especially in India the agriculture sector occupies a vital position with the vast per cent of the population depending on agriculture as a means of living. It has a prime role in the Indian economy, although the share of agriculture in the national income has come down, it still has a substantial share in the GDP. India is the second largest producer of rice, wheat, sugarcane, cotton, and groundnuts. Despite these facts, it is considered to be highly inefficient, wasteful, and incapable of solving the hunger and malnutrition problems. It is estimated that as much as one-fifth of the total agricultural output is lost due to inefficiencies in harvesting, transport, and storage.

Hence there is a requirement for a system by which we can predict the growth and yield of crops in any environment. So far this has been done by on-site experimentation which is a very tedious and time-consuming process. Therefore, crop simulation models were introduced. These models help to simulate the growth of yield on computers with the requirement of minimal input.

Information needs for agricultural decision making at all levels are increasing rapidly due to increased demands for agricultural products and increased pressures on land, water, and other natural resources. The generation of new data through traditional agronomic research methods and its publication are not sufficient to meet these increasing needs. Traditional agronomic experiments are 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.

1.1 Overview of DSSAT

The decision support system for agrotechnology transfer (DSSAT) incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes. It has one Soil module, a Crop Template module which can simulate different crops by defining species input files, an interface to add individual crop models if they have the same design and interface, a Weather module, and a module for dealing with competition for light and water among the soil, plants, and atmosphere. It is also designed for incorporation into various application packages, ranging from those that help researchers adapt and test the CSM to those that operate the DSSAT/CSM to simulate production over time and space for different purposes.

CSM models allow one to predict the behaviour of the system for given conditions. After one is confident that the models simulate the real world adequately, computer experiments can be performed hundreds or even thousands of times for given environments to determine how to best manage or control the system.
DSSAT was developed to operationalize this approach and make it available for global applications. The DSSAT helps decision-makers by reducing the time and human resources required for analysing complex alternative decisions. It also provides a framework for scientific cooperation through

research to integrate new knowledge and apply it to research questions.

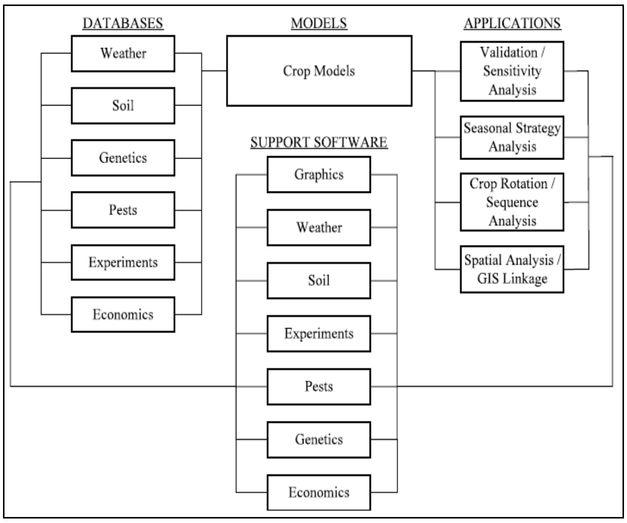

Figure 1. Database, Application, and Support Software

The DSSAT/CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The DSSAT/CSM incorporates models of all crops within one set of code allowing all crops to utilize the same soil model components. This design feature greatly simplifies the simulation of crop rotations since soil processes operate continuously, and different crops are planted, managed, and harvested according to cropping system information provided as inputs to the model. Each module has six operational steps, (run initialization, season initialization, rate calculations, integration, daily output, and summary output).

1.2 Objectives

The aim of this work is to develop a simple and efficient program to predict the growth and yield of crops. This is done by using weather and soil data and processing that data using the DSSAT crop simulation model. This model will help estimate the time duration that specific growth stages are attained, biomass of crop components (*e.g*., leaves, stems, roots and harvestable products) as they change over time, and similarly, changes in soil moisture and nutrient status.

This will be done by taking the required data from spatial maps instead of being manually entered for each point. This process is then repeated for all the points on the map by the usage of a Python script. The processed output is put back into a postgres database and then sent back to the shape file for usage by scientists, researches etc.

1.3 Related Work

1. **J.W. Jones, *et.al.*, (2003)** describe in detail the DSSAT crop simulation model. The authors have described the design of the model as well as the primary scientific components. They also describe the data requirements and the methods used for model evaluation. They are the original authors of the DSSAT program. Thehe input as well as the output data has been described in detail. This paper will help in gaining a basic understanding of the crop simulation model.
2. **Ruchi Sood, (2013)** developed a user interface for running a stripped-down DSSAT crop model. A GUI system has been developed that will provide users with an avenue to input large volumes of climate scenario, soil and weather data. It will optimize the available computer resources to run parallel multiple instances of the DSSAT crop model over a very large number of grids for up to global scale; and display the outputs. The graphical user interface was developed using Visual Basic. This document describes different types of files that are used in the DSSAT model and in interface. It then describes the process in detail.
3. **N. B. Pickering *et al.*, (1994)** defined a software package that is designed to assist users in preparing daily weather data for use with simulation models. The software is able to import or export daily weather files with any column format and convert that data into desirable units. The data is checked and flagged for possible errors on import. It also contains methods for stochastically generating sequences of daily weather data.
4. **Philip K. Thornton, *et.al.*, (1995)** described a software program which was written to perform simple analyses of simulation experiments. The major purpose of their paper is to develop a software program that allows the user to investigate the stability and profitability of software sequences. The program calculates summary statistics for model output variable which are presented to the user in tabular and graphical formats.
5. **Arjan J. Gijsman**, ***et.al.*, (2007)** have developed a soil database which was used to convert soil profiles into a format that can be used as an input data to some commonly used computer models such as DSSAT. This database can be used to estimate some of the parameters based on comparison with soil profiles of other soils from the same region. The authors conclude with conclude with recommendations for further work to improve the database for biophysical modelling applications.
6. **K.J. Boote, *et.al.*, (2017)** describe the new developments made in DSSAT including re-evaluated parameterization for response to CO2 and temperature, phosphorous module and additional crop models and the incorporation of IXIM-Maize (Lizaso’s model) to DSSAT.
7. **J. W. White, *et.al.*, (2005)** in their paper describe a procedure for assessing how models respond to temperature. The results from this procedure can be employed with multiple models. This procedure when applied to the CSM-CERES models were able to identify differences in temperature adaptations in two crops. The authors assess several responses to avoid interactions of

duration of life cycle with growth. The procedure will require adjustments for specific situations but provides a foundation for assessing modelled responses to temperature.

8. **Philip K.Thornton, *et.al.*, (1995)** developed a software to perform simple analyses of such simulation experiments. The major purpose of the software is to allow the user to investigate the stability and profitability of crop sequences. The program calculates summary statistics for model output variables; these are presented to the user in tabular and graphical forms. This program also allows to calculate net monetary returns or gross margins taking into account price and cost variability. The analysis performed by the authors constitute a first step in investigating the sustainability of a particular cropping sequence for a specified length of time.

9. **Nguyen V. Long, *et.al., (2017)*** identified spatial yield variability within the high-yielding maize dataset and tried to understand the impacts of planting data on yield variability while exploring the effect of management practices on maize yield-planting data relationship and utilized the yield-planting data dataset for relationship with maize producing regions.

10. **Kazeem O. Rauff**, ***et.al.*, (2015)** reviewed some of the crop growth models that have been successfully developed and used over time. The applications of crop growth models in agricultural meteorology, the role that climate changes play in these models and few of the successfully used crop models in agro-meteorology are also discussed in detail in this paper.

11. **R.P. Singh, *et.al.*, (1995)** assessed the relative strengths and weaknesses of India's public and private maize seed industries and examines future options for maize seed industry policies. They observed that Seed production in the public sector and especially in the private sector appears to be reasonably efficient, judging by the level of reported seed production costs. However, seed certification procedures are sometimes ineffective, and a significant proportion of the maize seed produced in India escapes rigorous quality controls. They also observed that growth in sales of proprietary hybrids produced by private companies has been much more rapid than growth in sales of public OPVs and hybrids, indicating that private companies deliver seed to farmers more effectively than public agencies and that government involvement in seed production and distribution seems destined to decrease, with responsibility for those functions gradually shifting to the private sector.

2. METHODOLOGY

2.1 Creation of Spatial Database

A spatial database is created in PostgreSQL with the required extensions. Shapefile containing soil data is imported to the database by using PostGIS.

sand_per double precision	silt_per double precision	clay_per double precision	texture character varying (30)	ph double precision
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
47.5	15	37.5	CLAY	8
40.2	13.75	44.25	CLAY	8.34
40.2	13.75	44.25	CLAY	8.34
40.2	13.75	44.25	CLAY	8.34
40.2	13.75	44.25	CLAY	8.34
47.5	15	37.5	CLAY	8

Figure 2. Soil Data

The same is done with a shapefile containing the weather data for the whole region.

t2m_max numeric	t2m_min numeric	allsky_sfc numeric	t2m numeric
27.53000000000	25.93000000000	18.78000000000	26.66000000000
29.41000000000	23.88000000000	16.12000000000	25.89000000000
28.25000000000	20.23000000000	16.12000000000	23.37000000000
29.09000000000	20.19000000000	16.34000000000	23.71000000000
30.65000000000	21.10000000000	16.34000000000	25.05000000000
31.56000000000	22.49000000000	16.07000000000	26.05000000000
30.62000000000	23.10000000000	16.07000000000	25.94000000000
28.34000000000	23.59000000000	15.26000000000	25.54000000000
26.84000000000	24.46000000000	15.26000000000	25.61000000000
26.22000000000	25.27000000000	18.68000000000	25.83000000000
27.95000000000	25.07000000000	18.78000000000	26.24000000000
29.37000000000	22.21000000000	16.12000000000	24.87000000000

Figure 3. Weather Data

2.2 Reading Data from Database

The data in the database is extracted using the python programming language. Psycopg2 is a database adapter which is used to extract the data from the postgres database into the python code.

The required data is queried and fetched from the database by the usage of a cursor created by psycopg2 module and then stored in a list.

2.3 Writing the Soil data

The soil file is opened using the python code and the data is written to the soil file in the format required by DSSAT.

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```
*Soils: Piracicaba, SP. Brazil

*BRPI020002  ESALQ      C      150 TERRA ROXA (IRRIGATED)
@SITE        COUNTRY         LAT     LONG SCS FAMILY
 Piracicaba  Brazil       -22.430 -47.250 Typic Eutrudox
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
     R  0.14   9.1  0.20  83.0  1.00  0.96 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    20     A 0.280 0.349 0.530 1.000  0.39  1.23  1.47  65.0  15.0   0.0 0.120   5.0   -99  10.8   -99
    40    AA 0.284 0.345 0.530 1.000  0.63  1.13  1.11  65.0  17.0   0.0 0.100   5.5   -99   9.2   -99
   120    AB 0.280 0.311 0.530 0.900  1.21  1.08  0.90  62.0  16.0   0.0 0.090   5.5   -99   9.0   -99
   150     B 0.280 0.311 0.530 0.100  1.21  1.08  0.90  62.0  16.0   0.0 0.090   5.5   -99   9.0   -99
```

Figure 4. Soil data in DSSAT format

2.4 Writing the Weather Data

For the weather data, the weatherid from the weather database is first checked if to be matching with the weatherid from the soil database. This will ensure that only the weather data relevant to the current grid in the loop will be taken into the weather file. This will also ensure that the weather data of all the days of a specific year will only be taken into the weather file.

```
*WEATHER DATA : Piracicaba, SP. india

@ INSI      LAT     LONG  ELEV   TAV   AMP REFHT WNDHT
  BRPI  -22.430  -47.250   580  21.6   7.2 -99.0   2.0
@DATE  SRAD  TMAX  TMIN  RAIN
02001  11.3  28.2  19.6  21.6
02002  23.1  29.9  18.7   0.2
02003  27.0  31.6  19.5   0.0
02004  24.5  31.7  19.4   0.0
02005  22.5  31.7  19.6   0.0
02006  22.9  31.8  19.7  11.9
02007   9.6  25.3  20.6   9.9
02008  18.4  29.8  18.5  29.2
02009  11.9  27.7  18.0  16.0
02010  16.9  28.1  18.9   2.2
02011   9.5  25.7  19.5   0.0
02012  12.6  27.7  19.2  33.2
02013   7.4  25.1  19.0  28.1
02014  14.8  26.9  20.3   5.5
02015  11.2  26.6  20.1   2.2
02016  14.9  24.1  16.5   0.0
02017  28.8  27.4  13.7   0.0
02018  19.9  26.9  16.5   0.0
02019  15.2  25.3  16.7   2.7
02020  13.8  28.3  19.0   2.0
02021  24.0  31.8  19.8   0.1
02022  18.6  32.3  19.8   1.0
02023  19.6  29.1  19.5   2.4
02024  21.7  32.0  19.9   0.0
02025  14.3  31.0  19.7  12.0
02026  24.2  32.0  19.4   9.8
02027  18.5  32.3  19.9  20.5
02028  20.6  31.1  19.9  49.8
02029  17.2  30.3  20.4  14.7
02030  19.1  31.3  21.2   0.0
```

Figure 5. Weather data in DSSAT format

2.5 Inputting Management Data

The management data is entered into the input file along with the cultivar names which will be reflected in the cultivar input file. This data comprises the treatments, cultivars and field data along with the initial conditions, planting details, irrigation and water management, fertilizer, simulation controls and automatic management data.

```
*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    MZ 02060   -99   -99     1     1   -99  5100   1.5   -99   100    15 rainfed
@C  ICBL  SH2O  SNH4  SNO3
 1    20   .25    .4   3.9
 1    40   .25    .4   3.9
 1   120   .26    .4   3.9
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 2    MZ 02060   -99   -99     1     1   -99  5800   1.5   -99   100    15 irrigated
@C  ICBL  SH2O  SNH4  SNO3
 2    20   .26    .4   3.9
 2    40   .26    .4   3.9
 2   120   .25    .4   3.9

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
 1 02072 02078     7     5     S     R    80    45     5   -99   -99   -99   -99     0

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1    .9    30    50   100 GS000 IR001    10 -99
@I IDATE  IROP IRVAL
 1 02075 IR004     7
 1 02079 IR004     7
 1 02089 IR004     7
 1 02091 IR004    13
 1 02095 IR004    13
 1 02097 IR004    13
 1 02099 IR004     7
 1 02101 IR004    13
 1 02103 IR004     7
 1 02105 IR004    13
 1 02107 IR004     7
 1 02109 IR004    13
```

Figure 6. Management data in DSSAT format

2.6 Cultivar data:

The cultivar names along with their data is entered into the cultivar file. This includes the ecotype name, Thermal time from seedling emergence to the end of the juvenile phase, Extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photo period at which development proceeds at a maximum rate, Thermal time from silking to physiological maturity, Maximum possible number of kernels per plant, Kernel filling rate during the linear grain filling stage and under optimum conditions and Phylochron interval.

```
! Added by RRSC-S
RS0001 Aravali Makaa-1     . IB0001 305  0     920   750  6.3   32
RS0002 Bajuara Makka       . IB0001 215  1.38  648   806  8.53  38.7
RS0003 Bio-9637            . IB0001 305  0     980   850  5.3   30
RS0004 C15                 . IB0001 312  0.66  630   700  6.8   51.97
RS0005 C6                  . IB0001 260  0.6   630   700  6.8   45
RS0006 CO6                 . IB0001 450  2     580   600  16.5  50
RS0007 COHM (5)            . IB0001 330  0.52  860   769  8.5   38.8
RS0008 Grija               . IB0001 206  1.88  653.8 842  8.58  39.4
RS0009 KH-9451             . IB0001 200  1.905 660.4 933  8.5   38
RS0010 Local               . IB0001 218  1.19  617.4 740  8.5   38.9
RS0011 P3301               . IB0001 390  0.5   470   470  11.5  75
RS0012 P3501               . IB0001 110  0.5   890   490  11.5  75
RS0013 PHM5                . IB0001 120  0.5   760   450  11.5  75
RS0014 PMZ-4               . IB0001 210  1.92  660.4 941  8.55  39.6
RS0015 POLO                . IB0001 193  2     643   829  15.5  38
RS0016 Pratap Makaa-3      . IB0001 285  0     980   800  5.9   26
RS0017 Pratap QPM-1        . IB0001 300  0     980   850  6.3   36
RS0018 RCM 76              . IB0001 225  0.7   500   850  6     50
```

Figure 7. Cultivar data in DSSAT format

2.7 Editing Ecotype File

The ecotype file is edited to match the cultivar data, namely the code for the ecotype, the base temperature, temperature at which the maximum development rate occurs for vegetative and reproductive states, the growing degree days, radiation and the canopy light efficiency.

```
*MAIZE ECOTYPE COEFFICIENTS: MZCER047 MODEL
!
! COEFF   DEFINITIONS
! =====   ===========
! ECO#    Code for the ecotype to which a cultivar belongs (see *.cul
!         file)
! ECONAME Name of the ecotype, which is referenced from *.CUL file
! TBASE   Base temperature below which no development occurs, C
! TOPT    Temperature at which maximum development rate occurs during vegetative stages, C
! ROPT    Temperature at which maximum development rate occurs for reproductive stages, C
! P20     Daylength below which daylength does not affect development rate, hours
! DJTI    Minimum days from end of juvenile stage to tassel initiation if the cultivar
!                is not photoperiod sensitive, days
! GDDE    Growing degree days per cm seed depth required for emergence, GDD/cm
! DSGFT   GDD from silking to effective grain filling period, C
! RUE     Radiation use efficiency, g plant dry matter/MJ PAR
! KCAN    Canopy light extinction coefficient for daily PAR.
! TSEN    Critical temperature below which leaf damage occurs (default 6°C)
! CDAY    Number of cold days parameter (default 15.0 )
@ECO#  ECONAME.........  TBASE  TOPT ROPT   P20  DJTI  GDDE  DSGFT  RUE   KCAN  TSEN  CDAY
!                            1     2    3     4     5     6     7     8      9    10    11
IB0001 GENERIC MIDWEST1    10.0 34.0  34.0  12.5   4.0   6.0   170.  4.2   0.85
IB0002 GENERIC MIDWEST2    10.0 34.0  34.0  12.5   4.0   6.0   170.  4.5   0.85
IB0003 GENERIC MIDWEST3    10.0 34.0  34.0  12.5   4.0   6.0   170.  2.0   0.85
IB0004 +5% RUE MIDWEST1    10.0 34.0  34.0  12.5   4.0   6.0   170.  4.4   0.85
DFAULT DEFAULT             10.0 34.0  34.0  12.5   4.0   6.0   170.  4.2   0.85
```

Figure 8. Ecotype data in DSSAT format

2.8 Species File

The species file is edited and the temperature effects, photosynthesis parameters, stress response, seed growth parameters and the initial conditions for emergence are entered.

```
*MAIZE SPECIES COEFFICIENTS: MZCER047 MODEL

*TEMPERATURE EFFECTS
!       TBASE TOP1  TOP2  TMAX
  PRFTC  6.2  16.5  33.0  44.0
!  RGFIL  5.5  16.0  29.0  37.0
  RGFIL  5.5  16.0  27.0  35.0

*PHOTOSYNTHESIS PARAMETERS
  PARSR   0.50      !Conversion of solar radiation to PAR
  CO2X     0   220   280   330   400   490   570   750   990  9999
  CO2Y  0.00  0.85  0.95  1.00  1.02  1.04  1.05  1.06  1.07  1.08

*STRESS RESPONSE
  FSLFW   0.050
  FSLFN   0.050
  FSLFP   0.050

*SEED GROWTH PARAMETERS
  SDSZ   .2750
  RSGR     0.1
  RSGRT    5.0
  CARBOT   7.0
  DSGT    21.0
  DGET   150.0
  SWCG    0.02

*EMERGENCE INITIAL CONDITIONS
  STMWTE  0.20      !Stem weight at emergence, g/plant
  RTWTE   0.20      !Root weight at emergence, g/plant
  LFWTE   0.20      !Leaf weight at emergence, g/plant
  SEEDRVE 0.20      !Carbohydrate reserve in seed at emergence, g/plant
  LEAFNOE 1.0       !Leaf number at emergence, #/plant
  PLAE    1.0       !Leaf area at emergence, cm2/plant
```

Figure 9. Species data in DSSAT format

3. CONCLUSIONS

With the successful completion of this project researches will be able to run the model in a loop incorporating the weather, soil data present in spatial data (either grid or csv) into postgres format. The python script written convers this data from each unique ID into model required format. DSSAT model can then be imitated to run in loop for each grid simultaneously producing the model output for each grid. Which can then be converted into postgres/spatial data of output parameters. Therefore, uncertainty in crop production associated with weather variability and the associated economic risks that farmers face under such climate variability can be addressed. They can also study the potential impacts of climate change on agricultural production. The results of this project can also be used in studying the potential use of climate forecasts for improving management of different cropping systems, and the value and risks associated with the use of this information. This output can be used by educators, growers, and policy and decision makers for a wide range of applications at different spatial and temporal scales. This includes regional assessments of the impact of climate variability and climate change, on-farm and precision management, water use, greenhouse gas emissions, gene-based modelling and breeding selection, and long-term sustainability through the soil organic carbon and nitrogen balances.

FUTURE SCOPE OF STUDY

This can be used by researchers, educators, growers, and policy and decision makers for a wide range of applications at different spatial and temporal scales. This includes regional assessments of the impact of climate variability and climate change, on-farm and precision management, water use, greenhouse gas emissions,
sustainability through the soil organic carbon and nitrogen balances.

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REFERENCES

G. Hoogenboom, C.H. Porter, V. Shelia, K.J. Boote, U. Singh, J.W. White, L.A. Hunt, R. Ogoshi, J.I. Lizaso, J. Koo, S. Asseng, A. Singels, L.P. Moreno, and J.W. Jones, 2017, Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.7 (https://DSSAT.net), DSSAT Foundation, Gainesville, Florida, USA.

J.W. Jones, G. Hoogenboom, C.H. Porter, K.J. Boote, W.D. Batchelor, L.A. Hunt, P.W. Wilkens, U. Singh, A.J. Gijsman, and J.T. Ritchie, 2003, DSSAT Cropping System Model, European Journal of Agronomy, 18:235-265.

Ruchi Sood, 2013, An interface for running crop models over gridded land surfaces, CCAFS Technical Report, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark.

N.B. Pickering, J.W.Hansen, J.W.Jones, C.M.Wells, V.K.Chan and D.C.Godwin, 1994, WeatherMan: A Utility for managing and generating daily weather data, Agronomy Journal, Vol 86.

Philip K.Thornton, Gerrit Hoogenboom, Paul W. Wilkens and Walter T.Bown, 1995, Agronomy Journal, Vol, 87.

Arjan J. Gijsman, Philip K. Thornton, Gerrit Hoogenboom, 2007, Using the WISE database to parameterize soil inputs for crop simulation models Computers and Electronics in Agriculture 56: 85–100.

K.J. Boote, 2017, New Developments in DSSAT Crop Modeling: Testing and Adding Crops, Presentation at STICS Workshop La Rochelle, France.

J. W. White, G. Hoogenboom, and L. A. Hunt, 2005, A Structured Procedure for Assessing How Crop Models Respond to Temperature, Agron. J. 97:426, American Society of Agronomy.

Philip K.Thornton, Gerrit Hoogenboom, 1994, A Computer Program to Analyze Single-Season Crop Model Outputs, Agron. J. 86:860-868.

Philip K. Thornton, Gerrit Hoogenboom, Paul W. Wilkens, and Walter T. Bowen, 1995, A Computer Program to Analyze Multiple-Season Crop Model Outputs, Agron. J. 87:131-136.

Nguyen V. Long, Yared Assefa, Rai Schwalbert, and Ignacio A. Ciampitti, 2017, Maize Yield and Planting Data Relationship: A Synthesis- Analysis for US High-Yielding Field Research Data, Frontiers in Plant Science, 29312377

Singh, R.P., S. Pal, and M. Morris. 1995. Maize Research and Development and Seed Production in India: Contributions of the Public and Private Sectors. CIMMYT Economics Working Paper 95-03. Mexico, D.F.: CIMMYT.

Rauff, K.O. and Bello, R. (2015) A Review of Crop Growth Simulation Models as Tools for Agricultural Meteorology. Agricultural Sciences, 6, 1098-1105