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Research Article

EVALUATION OF YIELD OF SOYBEAN CROP USING AQUACROP MODEL FOR UJJAIN DISTRICT

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ABSTRACT

The objective of the study is to modify the crop properties on the basis of regional conditions and to evaluate produced biomass and crop yield production by the simulation model. The evapotranspiration of study area is calculated on daily basis using model which is based on Penman-Monteith equation. The average evapotranspiration of 13 years from 2000 to 2012 is found to be 2606.2mm/year. The specification of conservative crop parameters and tuning of non conservative crop parameters for model, the crop files were created on the basis of actual field conditions. The study concludes year wise yield production of Soybean by using model and actual available data of yield production of Ujjain district in Madhya Pradesh. The average yield of Soybean for 13 years calculated by the model is 1.052 ton/ha and data available from the department of land records Ujjain is 1.003 ton/ha which is very close to simulated data. And Nash-Sutcliff efficiency of simulated and actual data comes as 0.687 and root mean square error as 0.19 and coefficient of determination is found to be 0.773 which shows that model calculates satisfactory results and can be used for the departmental purpose for the calculation of yield production.

INTRODUCTION

In Global terms except Europe and Australia continent Soybean is cultivated across the continent in an approximate area of about 120 million ha. 90% of the total Soybean production in the world is contributed by USA, Brazil, Argentina, China, Paraguay and India (Kaphengst *et al*, 2011). In India the cultivation of Soybean was in practice in Himalayan States including North- Eastern Region from ancient time, when it was largely used as a pulse in Uttarakhand and Akhuni and a fermented food in NE-States (Qiu and Chang 2010). From 1970 the commercial cultivation of Soybean as an oilseed crop was began with an area approximately about 12000 ha. It is normally adopted as rain fed crop in the areas having an average rainfall of 750- 900 mm in the country. Five states of India contains area under Soybean cultivation more than 11.0 million ha the names of major states are Rajasthan, Karnataka, Madhya Pradesh, Telangana and Maharashtra (Dept. of Agriculture, India 2016). By the time the area from paddy, millets, and cotton has been converted to Soybean. From the total production Soybean of the country more than 90% comes from three states namely MP more than 53%, Maharashtra more than 30% and Rajasthan more than 9% (Chand, R. 2007).

A major crop of kharif season sown in Malwa region of Madhya Pradesh is Soybean. Ujjain district of Madhya Pradesh is at first position in the production of Soybean in Madhya Pradesh. However, Soybean yields in Malwa fluctuate from year to year; due primarily to variable growing season weather conditions. Thus, simulation model that calculates the impact of weather, water availability and local soil condition on Soybean yield prior to harvest are essential. Accurate information about crop yield makes it convenient by using available models like AquaCrop.

Introduction of AquaCrop model

AquaCrop is a model of simulation of crop which shows the relation between the plant and the soil (Raes *et al*. 2017). The plant gets and nutrients and water from its root zone (Long *et al*. 2006). The management of field and irrigation management are considered in the model since both affects the interaction. The model is connected by upper boundary conditions to the atmosphere which calculates carbon dioxide supplies, evapotranspiration and energy for growth of crop (Loomis *et al*. 1979). If the groundwater table of that location is at shallow depth water can move upward by capillary rise and participates in the system and if the ground water table is at lower depth the

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water can flows to the subsoil to reach it. AquaCrop uses less parameters and mostly intuitive input variables that can be calculated by simple methods (Steduto, *et al*. 2009). The calculation procedure is adjusted on basic and often complex biophysical processes for assurance of accurate simulation of the crop response in the plant-soil system.

The present study deals with the calibration of Simulation model (AquaCrop), which simulates Climatic parameters, crop parameters, soil parameters and field and irrigation management parameters to estimate produced biomass and dry yield production of herbaceous crops, for Ujjain district of Malwa region of Madhya Pradesh under variables climatic and rainfall scenarios for major kharif crop Soybean from year 2000 to 2012 with the field production data.

Study Area

Ujjain District of Madhya Pradesh is selected for the study located in the north-west part of Madhya Pradesh. It is also called a pilgrim city and the heart of Malwa Plateau. The surrounding districts Ujjain are Mandsaur and Shajapur district in the north, Indore and Dewas district in south by, Ratlam and Dhar in west and again by Dewas and Shajapur district in the east. The location of the district is situated between the latitude 22^0 50' and 23^0 46' North and between the meridians of longitude 75^0 08' and $76^0$16' East, and is belongs to the Survey of India Topo-Sheet No. 46M, 46N and 55A. Basically it is an agriculture-based district having diversified cropping pattern.

Climatic & Soil Information of Study Area

Rainfall and climate: The normal annual rainfall of Ujjain district is 912.5 mm. The Maximum rainfall is received by the Ujjain district by southwest monsoon during the period from June to November. About 92.1% of annual rainfall is received in monsoon season. The ground water is recharged by the surplus water of the south-west monsoon.

Temperature: The temperature of the region varies from maximum 46 ^oC in the month of June to minimum at 4^oC in month of January. Winter temperature varies from 10^oC to 25^oC and summer temperature varies from 25 ^oC to 40 ^oC.

Geomorphology: The location of district is on Malwa Plateau at a general elevation of 500 meter above mean sea level. The altitude varies between 450 m in the north to 558m in the south above mean sea level. The area is having broad undulations with no marked hill ranges.

Available Soils: Most common type of soil that is founded in whole are is black cotton soils with heavy to light texture. admixtures of clay in the form of alluvium and light textured silty 'Kankar' are present at course of major streams. By wrong forming practices and natural agents like water and wind Ujjain has problem of soil erosion.

Groundwater Quality: The variation in the quality of groundwater in Ujjain district is fresh to saline having EC value ranges from 707 to 3680 µs/cm at 25^0C. The range of Nitrate was found from 22 to 113 mg/l whereas fluoride was found in the range from 0.45 to 1.88 mg/l.

METHODOLOGY

The calculation scheme of AquaCrop: AquaCrop simulates final crop yield in four steps which runs in a series form at daily time step for simulation of:

Green canopy cover (CC): In AquaCrop model, development of foliage is termed as green canopy cover (CC) and not by Leaf Area Index (LAI). The green canopy cover (CC) is that fraction of the soil surface which is covered by the canopy.

$$CC = \frac{\text{soil surface covered by the green canopy}}{\text{unit ground surface area}} \quad \text{………[Eq. 1]}$$

The value of CC starts from zero at sowing when soil surface is 0 % covered by the canopy to a maximum value which can be 1 at mid-season when a full canopy cover is reached and of the soil surface is covered 100 % by the canopy.

Crop transpiration (Tr): Crop transpiration is determined by the multiplication of reference evapotranspiration (ETo) with the crop transpiration coefficient (Kc_{Tr}) in which the effect of water stress (Ks) and cold stress coefficient ($Ks_{Tr,x}$), which are 1 when stress does not induce stomatal closure is considered (Allen *et al*. 1998).

$$Tr = Ks\ (Ks_{Tr,x}\ Kc_{Tr}\ )ETo \quad \text{………[Eq. 2]}$$

The coefficient of crop transpiration (Kc_{Tr}) is proportional to the green canopy cover (CC):

$$Kc_{Tr} = Kc_{Tr,x}\ CC^* \quad \text{……… [Eq. 3]}$$

Where, $Kc_{Tr,x}$ is the crop coefficient for maximum crop transpiration, and CC* is the canopy cover adjusted for micro-advective effects.

Above-ground biomass (B): The basic equation in AquaCrop, states that biomass production (B) is proportional to the cumulative amount of water transpired (ΣTr). The evapotranspiration ET is separated from crop transpiration (Tr) and soil evaporation (E) and AquaCrop model does not takes consideration of confounding effect of the nonproductive consumption of water (E) (Ziyengere *et al*. 2011).

$$B = WP^* \sum\left(\frac{Tr_i}{ETo_i}\right) \quad \text{…………………………………[Eq.4]}$$

Where, WP* is the biomass water productivity normalized for climate (Vaux and Pruitt 1983).

Crop yield (Y): AquaCrop model does not differentiate between the type of biological products that are generated in the growing cycle (Abedinpour *et al*. 2012). The simulated dry above-ground biomass (B) contains stems, leaves, flowers, etc. Final crop yield (Y) is determined by the multiplication of B with a Harvest Index (HI), which is defined as the mass of the product harvested as a percentage of the total above-ground biomass (B) (Unkovich *et al*. 2010):

$$Y = HI\ B \quad \text{……………………………………………[Eq. 5]}$$

Water and temperature stresses during the growing cycle may affect HI from its reference value (HIo).

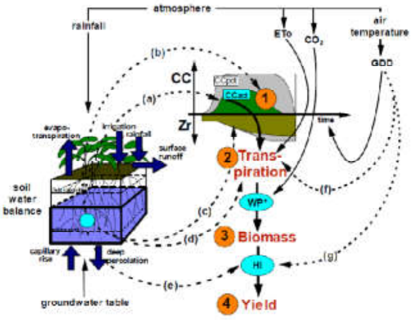


Figure 1 Diagrammatic representation of scheme of AquaCrop

Source: FAO, AquaCrop training handbook I. Understanding AquaCrop April 2017 (Raes *et al*. 2017)

The processes are classified in 4 steps by dotted arrows, The effect of stresses in represented as: Water stress by a to e and temperature stress by f to g.

- CC - green canopy cover;
- Zr -rooting depth;
- ETo- reference evapotranspiration
- WP*- normalized biomass water productivity;
- HI- harvest index; and
- GDD- growing degree day.

1. Slows canopy expansion,
2. Accelerates canopy senescence,
3. Decreases root deepening but only if severe,
4. Reduces stomatal opening and transpiration, and
5. Affects harvest index. Cold temperature stress
6. Reduces crop transpiration. Hot or cold temperature stress
7. Inhibits pollination and reduces HI.

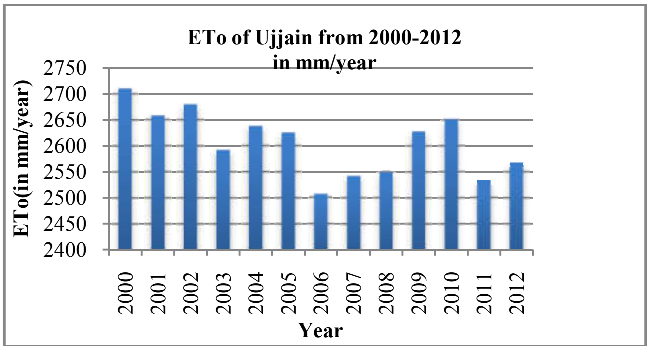
RESULTS AND DISCUSSIONS

Evapotranspiration from Cropped Area

The reference evapotranspiration has been computed with the help of AquaCrop 6.0 software developed by FAO using the climatic data which includes Maximum and Minimum Temperature, Relative Humidity, Wind Velocity and Solar Radiation (Araya *et al*. 2010). The reference evapotranspiration ET_0 has been evaluated for station falling in Ujjain district. The ET_0 evaluated for the study area is given in Table 1. The average reference evapotranspiration in Ujjain district is found as 2606.2mm/year. The variation of monthly ET_0 (mm/year) is given in Graph 2.

Table 1 Precipitation, Temperature and Reference Evapotranspiration (ET_0) at Ujjian

Sr. No.	Year	Precipitation (in mm/year)	Tmin (in ^{0}C)	Tmax (in ^{0}C)	GDD (in degree days /year)	ETo (in mm/year)
1	2000	658.7	19.3	33.3	6870.6	2710.4
2	2001	714.8	19.4	33.1	6895.3	2658
3	2002	755.3	20	33.5	6947.8	2679.8
4	2003	627.6	19.9	32.5	6932.5	2591.8
5	2004	597.2	19.8	32.9	6947.2	2637.5
6	2005	804.3	19.3	32.4	6802.1	2625.3
7	2006	732.2	20.1	32.5	6978.9	2507.1
8	2007	802.8	19.9	32.4	6931	2542.1
9	2008	961.1	19.6	32.2	6873.8	2549
10	2009	700.3	20.3	32.9	6987.2	2627.7
11	2010	843.3	20.3	32.8	6976.5	2650.4
12	2011	1468.8	19.2	31.7	6729.6	2533.1
13	2012	1091.4	19	31.7	6703	2568.1



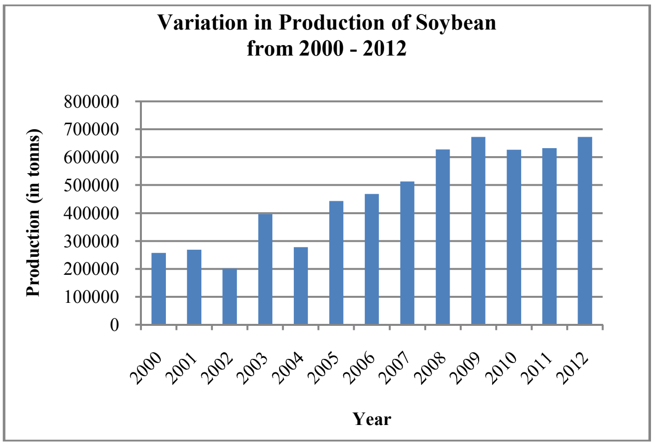
Graph 1 Yearly variation of ET_0 at Ujjain from year 2000 to 2012

Production of Soybean crop of Ujjain

As determined by the local agencies the total area sown under Soybean crop by the year 2000 to 2012 and respected accumulated production from the crop is used to calculate the actual yield production from the year 2000 to 2012 of Ujjain district of Madhya Pradesh. The values of the area sown by Soybean crop (in ha), corresponding production (in tons) and yield production (in tons/ha) calculated are shown in the table 2.

Table 2 Production of Soybean crop in Ujjain from 2000 to 2012

Sr. No.	Year	Area (in ha)	Production (tons)	Yield (tons/ha)
1	2000	421517	257547	0.611
2	2001	416685	268345	0.644
3	2002	414654	200693	0.484
4	2003	363977	396007	1.088
5	2004	400116	277280	0.693
6	2005	421674	443601	1.052
7	2006	430340	467780	1.087
8	2007	431720	513315	1.189
9	2008	443713	628298	1.416
10	2009	453838	673042	1.483
11	2010	451762	626825	1.388
12	2011	456653	632921	1.386
13	2012	458822	673092	1.467



Graph 2 Yearly variations in Production of Soybean crop in Ujjain from year 2000 to 2012

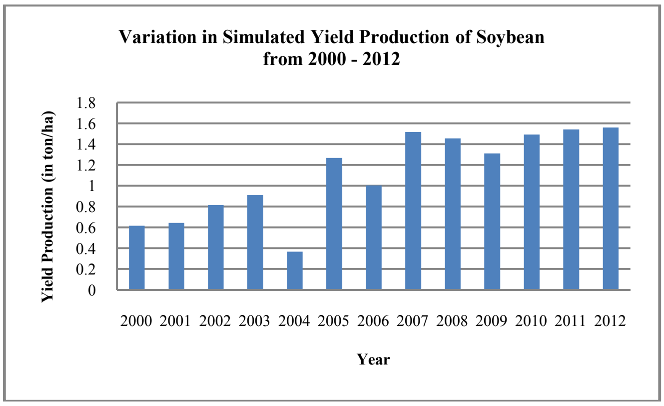
Graph 2 illustrates that there is so much variation observed in the total production corresponds to the area sown by the crop, which denotes that there are so many factors responsible for variation in the production of the study crop.

Simulated yield production by AquaCrop 6.0

As seen in the Graph 4 there is so much fluctuation in the production of the Soybean crop. So we expect the similar trend in simulated production by model. The simulation for the yield production of Soybean crop is done by using the required parameter like climatic parameters, crop parameters, soil parameters and field management parameters form year 2000 to 2012 and corresponding results are shown in the table 3 as follows:

Table 3 Simulated yield production of Soybean crop by AquaCrop for Ujjain from 2000 to 2012

Sr. No.	Year	Crop period	Simulated Yield Production (in ton/ha)
1	2	3	4
1	2000	1 july to 3 Oct	0.616
2	2001	1 july to 3 Oct	0.644
3	2002	1 july to 3 Oct	0.814
4	2003	1 july to 3 Oct	0.912
5	2004	1 july to 3 Oct	0.366
6	2005	1 july to 3 Oct	1.267
7	2006	1 july to 3 Oct	1.002
8	2007	1 july to 3 Oct	1.516
9	2008	1 july to 3 Oct	1.454
10	2009	1 july to 3 Oct	1.311
11	2010	1 july to 3 Oct	1.491
12	2011	1 july to 3 Oct	1.543
13	2012	1 july to 3 Oct	1.559



Graph 3 Yearly variations in simulated yield production of Soybean crop by AquaCrop for Ujjain from year 2000 to 2012

Comparison between simulated and actual yield production

The comparison can be done to see the effectiveness of model by using following methods of correlation.

1. Root mean square error
2. Nash-Sutcliff efficiency
3. Co-efficient of determination

Root mean square error: The performance of the selected model is analyzed by comparison between simulated results and the actual values. The root mean square error (RMSE) is used to determine the agreement between the observed and simulated yield production of crop (Willmott and Matsuura 2010).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Mi - Si)^2}$$

Where, Si and Mi are the simulated and actual values respectively and *n* is the number of observations. The unit of RMSE is the same as the parameters compared.

From the above equation the RMSE is calculated for the simulated and the observed results and its value is found to be 0.193, which is in the range of good collaboration between the simulated and observed results.

***The Nash-Sutcliffe model efficiency coefficient (E)*:** it is used to determine the proportion of variability in the observed values that is simulated by the model (McCuen *et al.*, 2006)

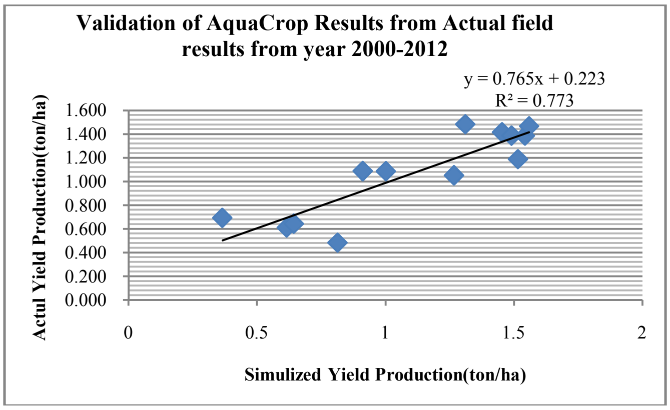
$$E = 1 - \frac{\sum_{i=1}^{n}(M_i - S_i)^2}{\sum_{i=1}^{n}(M_i - \bar{M})^2}$$

Where, $\bar{M}$ is the Observed mean.

1. An efficiency of 1 (E = 1) denotes to a perfect match of modeled results to the observed data.
2. An efficiency of 0 (E = 0) denotes that the model predictions are as accurate as the mean of the observed data,
3. Whereas, efficiency less than zero (E < 0) denotes that the observed mean is a better predictor than the model.

From the above equation the Nash-Sutcliff model efficiency coefficient (E) is calculated for the simulated and the observed results and its value is found to be 0.687, which is close to one so it can be said that the model is reliable for the simulation of the crop yield of the study crop i.e. Soybean in the Ujjain district region.

Co-efficient of determination

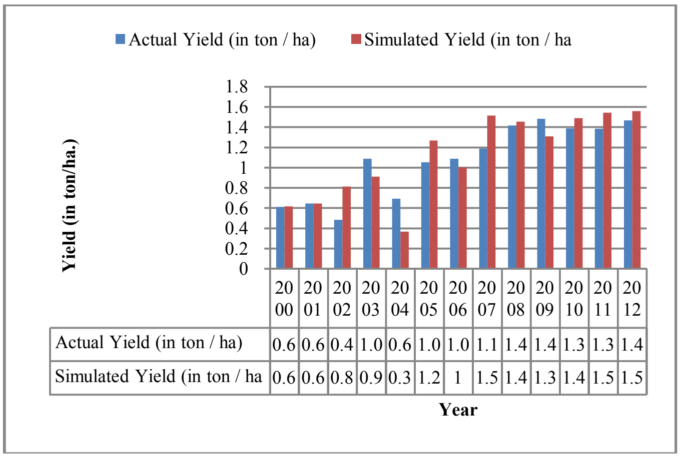


Graph 4 Graph showing the correlation between Actual yield production and Simulated yield production of Soybean crop for Ujjain from year 2000 to 2012

Table 5 Comparison between Actual to Simulated yearly yield production

Sr. No.	Year	Actual Yield (in ton/ha)	Simulated Yield (in ton/ha)
1	2000	0.611	0.616
2	2001	0.644	0.644
3	2002	0.484	0.814
4	2003	1.088	0.912
5	2004	0.693	0.366
6	2005	1.052	1.267
7	2006	1.087	1.002
8	2007	1.189	1.516
9	2008	1.416	1.454
10	2009	1.483	1.311
11	2010	1.388	1.491
12	2011	1.386	1.543
13	2012	1.467	1.559
Average		1.003	1.052

From the above graph and equation the coefficient of determination (R^2) is found to be 0.773 for the simulated and the observed results, which is close to one so from this coefficient it can also be said that the model gives good results for the simulation of the crop yield of the study crop i.e. Soybean in the Ujjain district region.



Graph 5 Comparison between Actual and Simulated Yield Production for Ujjain

SUMMARY AND CONCLUSION

The main crop of Ujjain district sown in kharif season is Soybean. Average Yearly yield production of Soybean 1.003 ton/ha. The above study carried out for the prediction of yearly yield production of Soybean crop of Ujjain district using AquaCrop 6.0. The input data used to predict yield includes climatic parameters (Precipitation, Maximum and minimum Temperature, wind velocity, sunshine hours and solar radiation), Crop parameters (root zone depth, growing days, crop period, canopy development) and field parameters. The evapotranspiration of study area is calculated on daily basis using model which is based on Penman-Montieth equation. The average evaporanspiration of 13 years from 2000 to 2012 is found to be 2606.2mm/year. The specification of conservative crop parameters is given by FAO and tuning of non conservative crop parameters for model the crop files was created on the basis of actual field conditions. The study concludes year wise yield production of Soybean by using model and actual available data of yield production of Ujjain which is summarized in Table 5.

The average yield of Soybean for 13 years calculated by the model is 1.052 ton/ha and data available from the department of land records Ujjain is 1.003 ton/ha which is very close to simulated data. And Nash-Sutcliff efficiency of simulated and actual data comes as 0.687 and root mean square error as 0.19 and coefficient of determination is found to be 0.773 which shows that model calculates satisfactory results and can be used for the departmental purpose for the calculation of yield production. The model also helps to calculate yield if any of the data is missing from the field.

References

Abedinpour, M., Sarangi, A., Rajput, T. B. S., Singh, M., Pathak, H., & Ahmad, T. (2012). Performance evaluation of AquaCrop model for maize crop in a semi-arid environment. *Agricultural Water Management*, 110, 55-66.

Allen, R. G., Pereira, L. S., Raes, D. & Smith, M. (1998). *Crop evapotranspiration: Guidelines for calculating crop water requirements.* Rome: FAO, Land and Water Division.

Araya, A., Habtu, S., Hadgu, K.M., Kebede, A., Dejene, T., (2010). Test of AquaCrop model in simulating biomass and yield of water deficient and irrigated barley (Hordeum vulgare). *Agricultural Water Management*, 97(11), 1838-1846.

Chand, R. (2007). *Agro-industries characterization and appraisal: soybeans in India*. Rome: Food and Agriculture Organization AGSF Working Document.

Kaphengst, T., El Benni, N., Evans, C., Finger, R., Herbert, S., Morse, S., & Stupak, N. (2011). Assessment of the economic performance of GM crops worldwide. Report to the European Commission. *Ecologic Institute*, Berlin.

Long, S.P., ZHU, X.G., Naidu, S.L., Ort, D.R., (2006). Can improvement in photosynthesis increase crop yields? *Plant, Cell & Environment*, 29(3), 315-330.

Loomis, R.S., Rabbinge, R., Ng, E., (1979). Explanatory Models in Crop Physiology. *Annual Review of Plant Physiology,* 30, 339-367.

McCuen, R. H., Knight, Z., & Cutter, A. G. (2006). Evaluation of the Nash–Sutcliffe efficiency index. *Journal of Hydrologic Engineering*, 11(6), 597-602.

Qiu, L.-J. & Chang, R.-J. (2010). 1. *The Origin and History of Soybean*. In: Singh, G. (ed.) the Soybean. Botany, Production and Uses. Oxford shire, U.K.: CAB International.

Raes, D., Steduto, P., Hsiao, T.C., and Fereres, E. (2017). *AquaCrop Reference manual (Version6.0)*, Rome: Food and Agriculture Organization.

Steduto, P., (1996). Water use efficiency: Sustainability of irrigated agriculture, (eds. 312). Kluwer: *Academic Publishers*, 193-209.

Steduto, P., Hsiao, T.C., Raes, D., Fereres, E., (2009). AquaCrop-The FAO crop model to simulate yield response to water: I. Concepts and underlying principles. *Agronomy Journal* 101(3), 426-437.

Steduto, P., Hsiao, T. C., Fereres, E., & Raes, D. (2012). *Crop yield response to water: FAO Irrigation and Drainage Paper 66*. Rome: Food and Agriculture Organization of the United Nations.

Unkovich, M., Baldock, J., Forbes, M., (2010). Variability in harvest index of grain crops and potential significance for carbon accounting: examples from Australian agriculture. *Advances in Agronomy*, 105, 173-219.

Vaux Jr, H. J. & Pruitt, W. O. (1983). Crop water production functions. *Advances in Irrigation*, 2 ,61-97.

Willmott, C. J., & Matsuura, K. (2005). Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research*, 30(1), 79-82.

Zinyengere, N., Mhizha, T., Mashonjowa, E., Chipindu, B., Geerts, S., Raes, D., (2011). Using seasonal climate forecasts to improve maize production decision support in Zimbabwe. *Agricultural and Forest Meteorology*, 151(12), 1792-1799.

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