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# Calibration and validation of FAO: Aqua crop model for wheat in Vindhyan region

**Anup Kumar, AR Mishra, DM Denis, Pawan Jeet and Uday Singh**

## Abstract
This study was conducted for the calibration and validation of Aqua crop model (Version 4.0) for winter wheat (AAIW4) in Vindhyan region at Allahabad (Prayagraj) India. The experimental field was laid out in the research farm of Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (Prayagraj) during Rabi 2014-15 and 2015-16 in Randomized Complete Block Design (RCBD) with 4 treatments *viz*; $I_1$ (7 irrigation at iw/cpe=1.6, cpe = 37.5mm, 420 mm), $I_2$ (5 irrigation, iw/cpe=1.2, cpe=50mm, 300 mm), $I_3$ (3 irrigation, iw/cpe=0.8, cpe=75mm, 180 mm), $I_4$ (2 irrigation, iw/cpe=0.5, cpe=120mm, 120 mm) and with the soil texture properties as Sand, Silt and clay % was 60,14 and 26%. ETo was calculated using Cropwat 8.0, $ET_{crop}$ estimated for 2014-15 was 264 mm and for 2015-16 it was 238 mm. This model was calibrated using climatic and crop physiological data of 2014-15 whereas; its performance in simulating biomass and grain yield was validated using the data of 2015-16. The model was evaluated using NRMSE (Biomass 7.5 to 16.5, Yield 5.3 to 9.2), RMSE (Biomass 0.5 to 0.9, Yield 0.24 to 0.5), Pe (Biomass 7.2 to 13.7, Yield -3.4 to 5.2) and ME (Biomass 0.96 to 0.99, Yield 0.99 to 1). The correlation coefficient ($R^2$) for Biomass and Yield was obtained as 0.953 and 0.951 respectively.

**Keywords:** Vindhyan region, calibration, validation, biomass, grain yield

## Introduction
Increasing population has adversely increased water demand as agriculture is the world's second largest withdrawal sector of the available water and 1st largest consummator (Zammiet; *et.*2013) [1] of fresh water. Climate change is the upcoming dangerous reality because of starched and exploitive use of water resource. It requires proper allocation and use of the fresh water which has become one of the most alarming problems faced by water policy makers of the world (UN-GA; 2014) and one of the main reason of the water scarcity. It is expected that demand of freshwater use will be increased to14% for food by 2030 (FAO, 2012 report). Withdrawal of water for agricultural purpose accounts for about 75% of all usages in developing countries like India. Food and Agriculture Organization (FAO) has predicted a 14% net increase in use of water to meet the food demand by the year 2030 as compared to year 2000 (FAO, 2008). Low irrigation water use efficiency (Blum. A, 2005) [7] and optimum time for irrigation is being a major concern since so long and various concerning bodies and research institutions are working to rectify these heavy losses. In this context FAO has developed windows based software named: Aqua crop 4.0(Raes *et al*., 2009; Steduto *et al.*, 2009a) [8], a water driven crop simulating model which helps in irrigation planning and optimal use of resources for higher water productivity (Raes *et al*., 2009b) [8], mainly focused on simulating the attainable crop biomass and harvestable yield in response to the water available (Steduto *et al*., 2009) [9], more detailed description of the model was reported in RAES *et al.* (2009) [8], STEDUTO *et al*. (2009) [9].Crop growth models have been developing along with the progress of computer technology since the 1960s, which can provide the simulation of plant physiological processes and crop growth and development (Boote *et al.*, 2013) [12]. Calibration and performance evaluation for various crops has been done yet like for maize by Abedinpour *et al.* (2011) and for wheat by Singh *et al*. (2013) [13] in west Bengal. Wheat (*Triticum aestivum* L.) is one of the most important crop plants in world. Wheat is grown in India in an area of about 30 million hectares with a production of 93 million tons. The normal National productivity is about 2.98 tons/ha & production in 2015-16 is 93.82 million tons. This study was conducted in Vindhyan region, which is named after the Vindhyan Mountains, India. This region covers an exposed area of 60,000 km$^2$ and a concealed area of 1, 62,000 km$^2$ under the Indo-Gangetic Alluvium and Deccan Trap, Geographically; it starts from Sasaram, Bihar in the east to Dholpur, Rajasthan in the north. Most of the parts of Vindhyan region are rainfed and the productivity of crops is very low due to inadequacy of irrigation water. Farming round the year was not possible especially in summer season, because of unavailable

irrigation sources which is creating stress to agricultural production. Therefore it was observed that this region requires proper planning of water application to get optimum output with available resources which arouse the interest for the application of FAO Aqua Crop model. The Objective of this study was the calibration and validation of Aqua crop model (Version 4.0) for wheat in Vindhyan region at Allahabad (Prayagraj) India.

## Material and Methods

### Study Area

Experimental fields were laid out at research farm of Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (Prayagraj) for the 'Calibration and Validation of FAO Aqua crop model (Version 4.0) for Wheat crop (Variety used: AAIW4) in Vindhyan region' of India. The experimental field lies in at latitudes 25.45°N and longitude 81.84°E at an elevation of 98m above the mean sea level and stands at the confluence of Ganga and Yamuna River, in Vindhyan region.

The experiment was conducted in Rabi 2014-15 and 2015-16 in Randomized Complete Block Design (RCBD) with 4 treatments *viz*; $I_1$ (7 irrigation at iw/cpe=1.6, cpe = 37.5mm, 420 mm), $I_2$ (5 irrigation, iw/cpe=1.2, cpe=50mm, 300 mm), $I_3$ (3 irrigation, iw/cpe=0.8, cpe=75mm, 180 mm), $I_4$ (2 irrigation, iw/cpe=0.5, cpe=120mm, 120 mm) and 4 replications *viz*; R1, R2, R3, R4.The amount of water applied (IW) in each irrigation was 60 mm (depth) at each irrigation event. Crop physiological and other essential Data of Rabi 2015 was used to calibrate the model. Whereas, Rabi 2016 data was used to validate the calibrated model, whereas the daily climatic data was taken for the period of last 10 years i.e 2006-2016 (averaged). CropWat 8.0 was used to calculate the potential crop evapotranspiration (ETo) through Penman-Montieth method.

### Soil Parameters

Soil samples were collected from the experimental site at depth between 0-30 cm for the analysis of its physical and chemical properties such as textural class (soil texture), EC, pH, Organic matter, bulk density, etc along with moisture content at different DAS. Soil parameters were analyzed in the soil laboratory of Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad (Prayagraj). Table 1&2 below shows different physical and chemical Characteristics of the soil:

**Table 1:** Soil Characteristics

| Soil Depth (cm) | Soil Texture | | | Soil type | Field Capacity (%) | Permanent Wilting Point (%) | Bulk density (g $cm^{-3}$) | pH | Water Retaining Capacity (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Sand (%) | Silt (%) | Clay (%) | | | | | | |
| 0-30 | 60 | 14 | 26 | Sandy Loam | 22 | 10 | 1.64 | 7.38 | 54 |

**Table 2:** Chemical properties

| Soil Depth (cm) | Fe (mg $kg^{-1}$) | Cu (mg $kg^{-1}$) | Mn (mg $kg^{-1}$) | Zn (mg $kg^{-1}$) | N ($g/m^2$) | P ($g/m^2$) | K ($g/m^2$) | S ($g/m^2$) | Organic Matter (%) | Electrical Conductivity (ds $m^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0-30 | 5.57 | 2.77 | 4.39 | 0.72 | 25.21 | 1.42 | 16.12 | 0.75 | 0.36 | 0.35 |

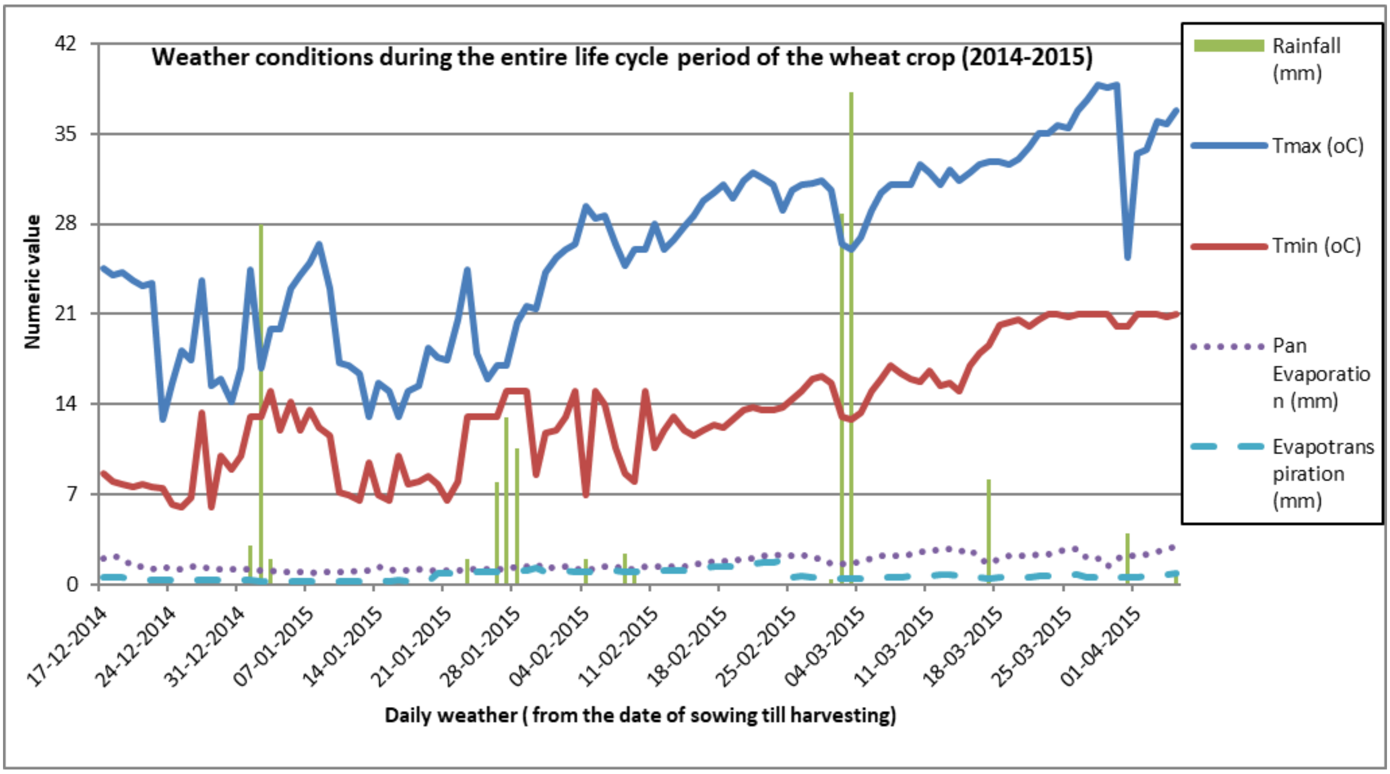


**Fig 1:** Climatic condition during the experimental period: Wheat (2014-15)

Total Rainfall received during the entire growth period of the wheat in Rabi 2014-15 was 157 mm, with effective rainfall of 117 mm and good rain was on $18^{th}$ (28 mm), $77^{th}$ (28.8mm) and $78^{th}$ (38.2 mm) day from the date of sowing. The Average daily maximum and minimum temperature recorded was 26.14 °C (range 12.8°C - 38.8 °C) and 13.40 °C (range 6 °C - 21°C), with total pan evaporation of 185.3 mm and effective daily average pan evaporation was 1.68 mm. Whereas ETo (reference evapotranspiration (mm/d)) was calculated using Cropwat 8.0, and Kc (crop coefficient) for each crop development stage (dimensionless) was adopted as 0.7, 0.93,1.15 and 0.25 i.e for the initial, development, mid and late stage respectively (FAO Irrigation and drainage paper 56). The ETo was calculated by using Cropwat 8.0 based on Penman-Monteith method (Allen *et al*., 1998) [15]. Total Crop Evapotranspiration ($ET_{crop}$) calculated was 264 mm.

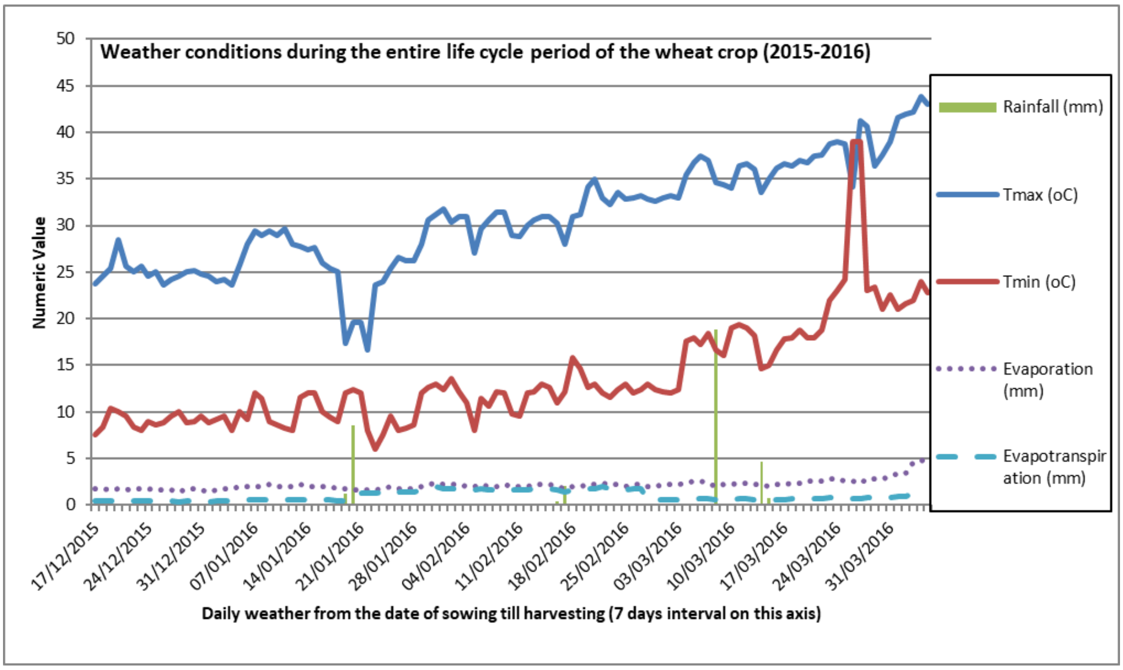


**Fig 2:** Climatic condition during the experimental period: Wheat (2015-16)

Total Rainfall received during the entire growth period of the wheat in Rabi 2015-16 was 31 mm, with effective rainfall of 2.5 mm and good rain was on $34^{th}$ (8.6 mm) and $84^{th}$ (18.8mm) day from the date of sowing. The Average daily maximum and minimum temperature recorded was 30.84°C(range 16.6 °C -43.8 °C) and 13.62 °C (range 7.5 °C - 24.2°C), with total pan evaporation of 241.8 mm and effective daily average pan evaporation was 4.31 mm. Whereas ETo (reference evapotranspiration (mm/d)) was calculated using Cropwat 8.0, and Kc (crop coefficient) for each crop development stage (dimensionless) was adopted as 0.7, 0.93,1.15 and 0.25 i.e for the initial, development, mid and late stage respectively (FAO Irrigation and drainage paper 56). The ETo was calculated by using Cropwat 8.0 based on Penman-Monteith method (Allen *et al*., 1998) [15]. Total Crop Evapotranspiration ($ET_{crop}$) calculated was 238 mm.

**Agronomic practices**

Agronomic practice for both years was almost the same. The date of sowing and harvesting were $17^{th}$ December and 5 April for both the year i.e. 2014-15 and 2015-16. The total number of plots were16, with an area of 6x6 $m^2$ each. Winter Wheat Crop of variety AAIW4 was taken for this experiment for both the years. DAP at the rate of 180 kg/hectare (65 kg/acre) was given as a basal dose application followed by 2 times Urea application at the rate of 225 kg/hectare (81.81 kg/acre), this two times fertilizer application was given on $25^{th}$ and $45^{th}$ day of CRI and Spike initiation stage during both the years. Weeds were controlled by hand weeding when it appeared. The seeds were manual broadcasted in a much précised manner to spread the seeds properly in each plot. The total life cycle of the crop in experimental fields was 110 days in 2014-15 and 111 days in 2015-16.

**Irrigation Practices**

Surface Irrigation method was used for watering the experimental fields. Irrigation scheduling was done with the 10 years weather data (from 2005 to 2015) collected from meteorological department of Sam Higginbottom Institute of Agriculture Technology and Sciences, Allahabad, UP. The daily crop water requirements were calculated by multiplying the reference evapotranspiration values with the Wheat crop coefficients at (0.7, 0.93, 1.15 and 0.25) initial, development, mid and final stage respectively,

$$Ir = ET_c = ET_o \times K_c$$

Where: Ir = irrigation water requirement (mm), ETc = crop water requirement (mm), ETo = reference crop evapotranspiration (mm), Kc = crop coefficient that varies by crop development stage (range 0.25 to 1.15). The reference evapotranspiration ETo was calculated using Cropwat 8.0. Values of crop coefficients Kc were selected according to the general recommendation of the FAO Irrigation and Drainage Paper no 24 by Doorenbos and Pruitt. Each plot was flooded with 60mm depth of water at every irrigation event. Irrigation in both the years was given according to the iw/cpe (Irrigation water per cumulative pan evaporation) ratio as per the treatments *viz;* I1 (iw/cpe=1.6, cpe = 37.5mm, total application 420 mm), I2 (iw/cpe=1.2, cpe=50mm, total application 300 mm), I3 (iw/cpe=0.8, cpe=75mm, total application 180 mm), I4 (iw/cpe=0.5, cpe=120mm, total application 120 mm).

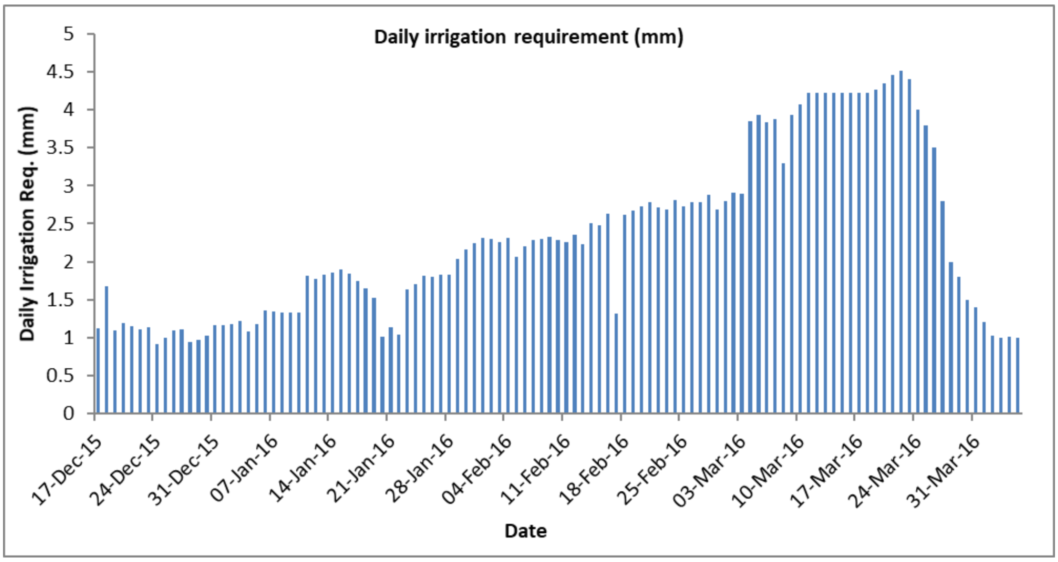


**Fig 3:** Daily crop water requirement for wheat during 2015-16

The daily irrigation requirement is depended on the daily evapotranspirative losses and effective rainfall. Highest irrigation requirement was 4.5 mm in the month of March, whereas the lowest was recorded as less than 1mm in the last week of the December.

**Measurement of Crop physiological parameters**

The crop parameters include the days from sowing to emergence, maximum canopy cover; start of senescence, and physiological maturity, as well as maximum effective rooting depth was obtained from the experimental plots by excavating pits at the root zone during maturity (destructive sampling). Leaf length, leaf width, number of leaf per plants, and number of branches per plants were measured at 10 days intervals throughout the season started from 28 days after planting. The dry above biomass were measured by destructive sampling. One sample per plot is taken from known quadrant of the experimental plots at an interval of 10 days during the season. The samples were oven dried at a temperature of $65^0$C for 48 hours and then weighed to determine their mass per area covered.

**Table 3:** Experimental Details.

| Year | 2014-2015 | 2015-2016 |
|---|---|---|
| Area of each plot | 6x6 $m^2$ | 6x6 $m^2$ |
| No. of plots | 16 | 16 |
| Row to row spacing | 20 cm | 20 cm |
| Date of Sowing | 17 December 2014 | 17 December 2015 |
| Crop and variety | Wheat, AAIW4 | Wheat, AAIW4 |
| Sowing method | Manual Broadcasting | Manual Broadcasting |
| Irrigation Method | Surface Irrigation | Surface Irrigation |
| Date of Harvesting | 5 April | 5 April |
| Depth of irrigation each time | 6 cm | 6cm |
| Crop Period | 110 days | 111 days |

**Model description**

Aqua Crop works from the biomass calculation which is based on the amount of transpired water. The structural equations of the model estimate biomass production directly from the crop transpiration via water use efficiency and the final yield based on the harvest index:

B = WP x $\Sigma$ TR

Y = BHI

Whereas,

| | | |
|---|---|---|
| WP | = | Water productivity (kg $m^{-2}$ $mm^{-1}$) |
| TR | = | Transpiration (mm) |
| B | = | Dry Biomass (kg) |
| Y | = | Yield or final production (kg) |

CC = 1.005 x [1 - exp (-0.6 LAI]. …... [HSIAO *et al* (2009)]

Whereas

| | | |
|---|---|---|
| HI | = | Harvest Index (%) |
| LAI | = | Leaf area index |
| CC | = | canopy cover |

**Model performance evaluation**

Model performance was evaluated by using the following statistical parameters: Prediction error (Pe), Root Mean Square Error (RMSE), Model efficiency (ME), Correlation coefficient ($R^2$). The statistical analyses of the Aqua Crop model calibrated for the Vindhyan region disclosed error acceptable for yield prediction of wheat grown under Rabi season.

**Root Mean Square Error (RMSE)**

Root mean square error (RMSE) was calculated according to Loague and Green (1991) [20] equation:

$$\text{RMSE}=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Sv-Ov)^2}$$

Where,

Ov = Observed value

Sv = Simulated value

N = number of observations

$\overline{Ov}$= Mean of Observed value

$\overline{Sv}$= Mean of Simulated value

M= Mean of Observed values

$$\text{NRMSE} = \frac{RMSE \times 100}{M}$$

**Prediction error (Pe)**

$$\text{Pe} = \frac{(Sv-Ov)}{Ov} \times 100$$

**Model Efficiency**

Coefficient of efficiency, E (Nash and Sutcliffe, 1970) is calculated using Equation below

$$ME = 1 - \frac{\sum_{i=1}^{N}(Ov - Sv)^2}{\sum_{i=1}^{N}(Ov - \overline{Ov})^2}$$

**Correlation coefficient ($R^2$)**

The correlation coefficient is an indicator of degree of closeness between observed values and model estimated values.

$$R^2 = \frac{(n\sum Ov \times Sv - \sum Ov \times \sum Sv)^2}{[n\sum Ov^2 - (\sum Ov)^2] - [n\sum Sv^2 - (\sum Sv)^2]}$$

**Result & Discussion**

It was found that the model has overestimated its output simulated values in almost every treatment result. The overestimation was in between the range of 0.10 to 0.50 tons/ha in case of biomass and 0.05 to 0.30 tons/ha in case of garin yield. The neccesary calibrated input was given to the model for better silumation accuray. The maximum biomass production was recoreded in T2 (5 irrigation, iw/cpe=1.2, cpe=50mm, 300 mm) as 6.6 tons/ha, whereas the lowest was in T4 (iw/cpe=0.5, cpe=120mm, total application 120 mm) as 4.9 tons/ha. Grain yield was recorded maximum in T2 (5 irrigation, iw/cpe=1.2, cpe=50mm, 300 mm) as 5.04 tons/ha and the lowest was in T1 (7 irrigation at iw/cpe=1.6, cpe = 37.5mm, 420 mm). Model simulation result also resembles the variation of biomass and grain yield production treatment wise.

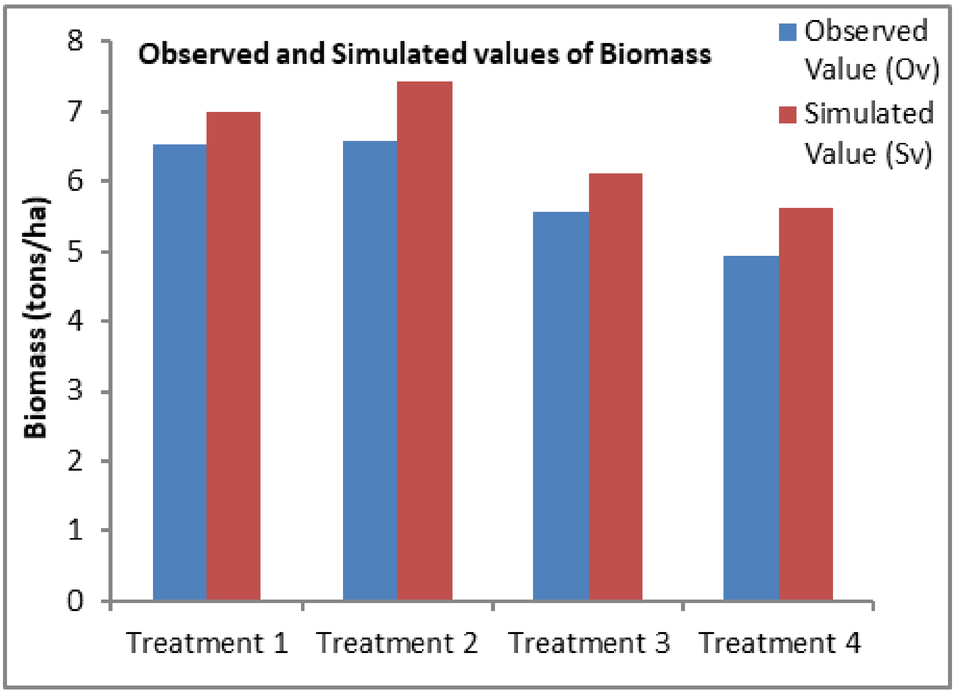


**Fig 4(a):** Treatment wise simulated biomass

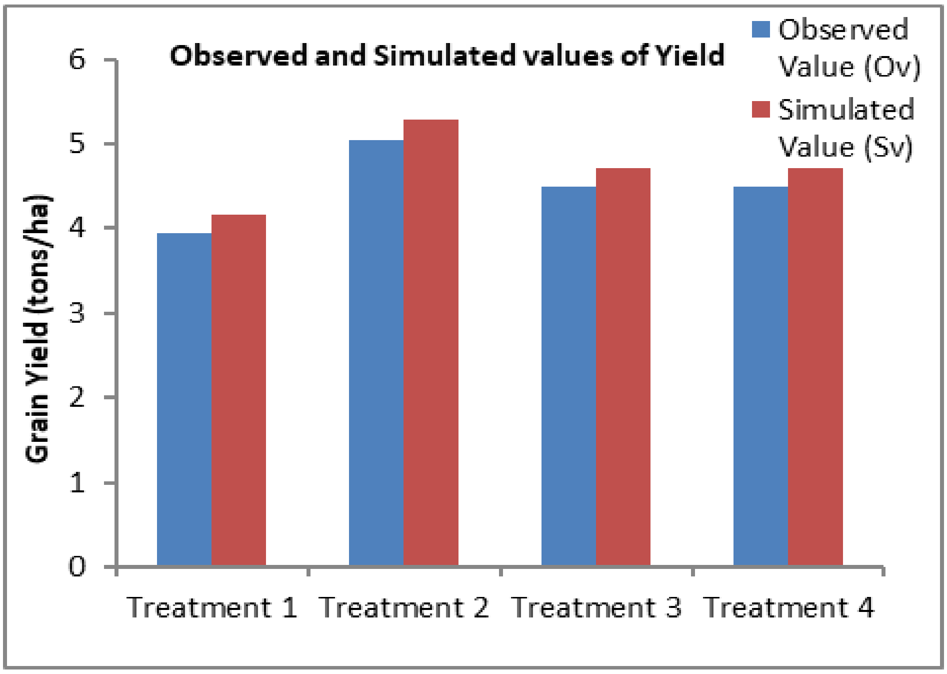


**Fig 4(b):** Treatment wise simulated Yield

**Performance of Aqua Crop in Simulating Dry Matter Yield of Wheat**

The model output after calibration was found in the good range as its $R^2$ value was 0.953 for biomass and 0.951 for grain yield. The lowest pridiction error for biomass simulation was found in T1 (7.20%) and the highest was in T4 (13.71%) whereas, for yield silumation lowest pridiction error was found in T4 (-3.41%) and highest in T3 (4.55%). NRMSE for biomass silumation was lowest in T1 (7.53%) and highest was in T4 (16.5%) whereas, in case of yield simulation lowest was in T3(5.30%) and highest was in T2 (9.24%). RMSE for biomass silumation was lowest in T1 (0.49) and highest was in T2 (0.91) whereas, in case of yield simulation lowest was in T3(0.24) and highest was in T2 (0.47). Model efficiency for the biomass was in the range of 0.96 to 0.99 and for yield it was 0.92 to 0.99.

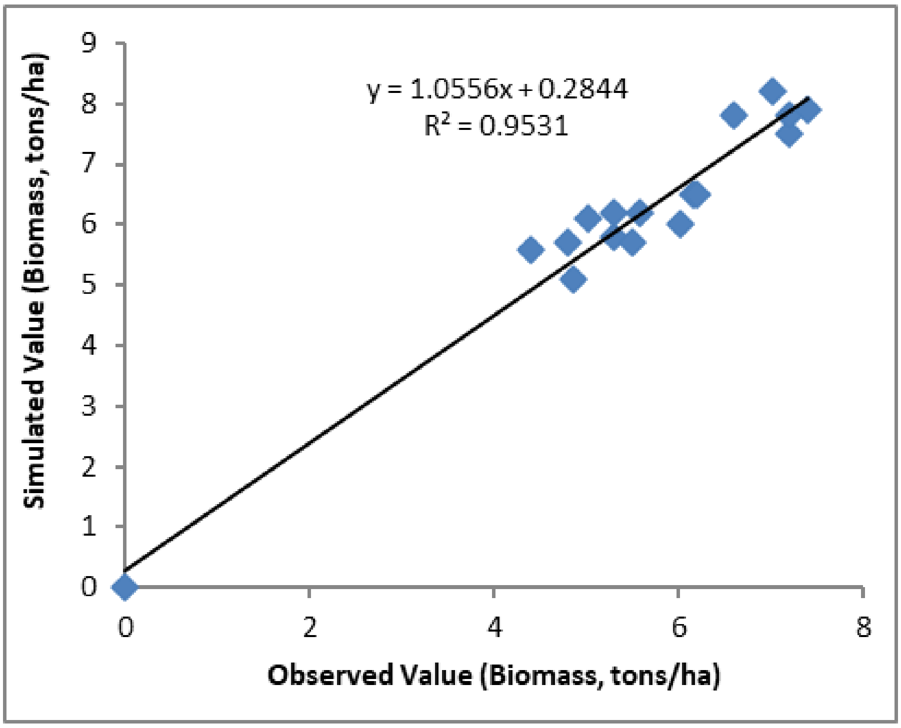


**Fig 5(a):** Validated Biomass (tons/ha)

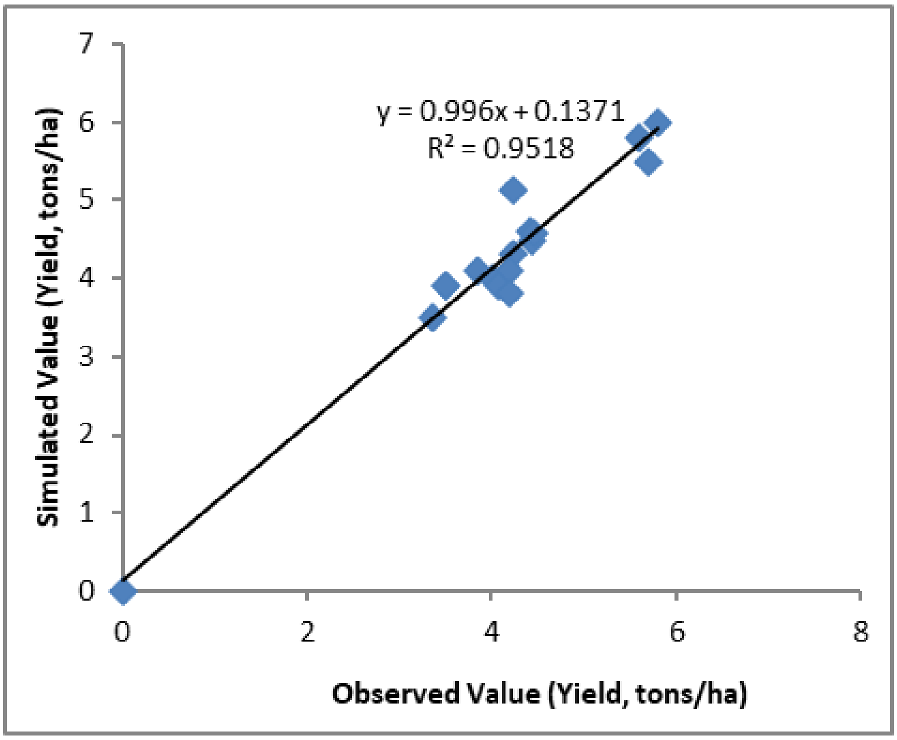


**Fig 5(b):** Validated Grain Yield (tons/ha)

Observed value of biomass and grain yield was validated with 16 plots production outputs which is also collectively corelated with the model simulation result. The corelation coefficient for both biomass and grain yield was 0.85 to 0.97 on individual plot basis with the specific treatments given to them.

**Table 4:** Model evaluation

| Treatments | Observed Value (Ov) | Simulated Value (Sv) | Pe (%) | NRMSE (%) | RMSE | ME | $R^2$ |
|---|---|---|---|---|---|---|---|
| **Biomass** | | | | | | | |
| T1 | 6.53 | 7 | 7.20 | 7.53 | 0.49 | 0.99 | 0.89 |
| T 2 | 6.58 | 7.43 | 12.89 | 13.2 | 0.91 | 0.97 | 0.90 |
| T 3 | 5.57 | 6.10 | 9.47 | 11.72 | 0.65 | 0.98 | 0.94 |
| T 4 | 4.94 | 5.62 | 13.71 | 16.5 | 0.81 | 0.96 | 0.90 |
| **Yield** | | | | | | | |
| T1 | 3.95 | 4.25 | 5.26 | 6.40 | 0.25 | 0.94 | 0.92 |
| T 2 | 5.04 | 5.37 | 4.71 | 9.24 | 0.47 | 0.99 | 0.95 |
| T 3 | 4.45 | 4.65 | 4.55 | 5.30 | 0.24 | 0.97 | 0.97 |
| T 4 | 3.96 | 3.83 | -3.41 | 5.95 | 0.24 | 0.92 | 0.85 |

## Conclusion

It was found that the wheat (variety: AAIW4) will have maximum biomass production of 6.58 tons/ha with 5 irrigation (T2) in this region. Whereas, the maximum grain yield of 5.04 t/ha is attainable in 5 irrigation (T2). Aqua crop (4.0) was found applicable after calibration in simulating biomass and grain yield in Vindhyan region as the correlation coefficient ($R^2$) for biomass (treatment wise) was in range 0.89 to 0.94 and for grain yield it was in range 0.85 to 0.97. More testing of this model is required under different conditions for the better simulation accuracy to provide a helpful decision support tool to agriculture advisers and practitioners in Vindhyan region.

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