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Performance Assessment of Aquacrop Model for Estimating Canopy Cover, Aboveground Biomass and Grain Yield of Winter Wheat in Saptari District: An Application to Irrigation Management

Lokendra Sodari[a], Jawed Alam[b], Keshaw Kumar Das[c]

[a, b] *Department of Agricultural Engineering, Purwanchal Campus, Institute of Engineering, Tribhuvan University, Nepal*
[c] *Department of Water Resources and Irrigation, Government of Nepal*
Corresponding Email: [a]lokendras@ioepc.edu.np, [b]ajawed@ioe.edu.np, [c]keshawdas77@gmail.com,

Abstract

In this study, we tested the ability of FAO developed Aquacrop model (V 6.1) to simulate canopy cover (CC), aboveground biomass (B) and grain yield (GY) for winter wheat under basin irrigation in Saptari district, the representative of eastern terai, Nepal. Here the simulation was performed at a daily time step, using thermal units, i.e., growing degree days (GDDs) during the cropping season in winter 2019/2020. Various crop parameters affecting CC, B and GY have been calibrated based on comparison between measurements and the results of the simulations. Other input parameters required by Aquacrop model were obtained from field measurements. Subsequently, the validation was done on four fields during the 2019/2020 cropping season. The experimental field varied on sowing dates, seeding rates, irrigation water. The average values of the Normalized Root Mean Square Error (NRMSE) between measured and simulated CC, B and GY were 14.49%, 13.78% and 9.11% for calibration fields and 13.58%, 13.97% and 4.07% for the validation fields, respectively. Likewise, the Mean Bias Error (MBE) between measured and simulated CC, B and GY were -2.69%, -9.30% and -3.42% for calibration fields and -7.95%, -7.07%, and -2.08% for validation fields, respectively. Additional statistical parameter Nash- Sutcliffe efficiency (NSE) also showed that the model gives good estimates of CC, B and GY.

After calibration and validation of the Aquacrop model, it was applied for irrigation scheduling over the two fields with contrasted sowing dates; similarly, run for different types of irrigation (Rainfed, 1-time irrigation and 2-time irrigation); also the model was run for contrasting sowing dates to see how the change in input-changes the output value. The scheduling provides the results like 358.4mm and 336.9mm irrigation water is required for grain yield of 4.741 t/ha and 3.875 t/ha respectively, with the same input parameters for the validation fields. The yield for the field where varying irrigation is 0 t/ha, 2.07 t/ha and 3.336 t/ha for rainfed, 1-time irrigation and 2-time irrigation respectively. The early sowing crop and late sowing crop gives 2.235 t/ha and 2.081 t/ha respectively. Consequently, this model can be considered as a potentially useful tool for irrigation management on an operational basis in terai, Nepal. It also concluded that early sowing is more beneficial than late sowing for obtaining adequate yield.

Keywords

Aquacrop Model, Calibration, GDD, Irrigation Scheduling, Model Validation

1. Introduction

Irrigation is a system of supplying (land) with water by means of artificial canals, ditches, etc, especially to promote the growth of food crops. Irrigation water requirement can be found on the basis of crop evapotranspiration rate. Evapotranspiration refers to the process by which water is transferred from the soil to the atmosphere by evaporation from the land and other surfaces and by transpiration from plants.

The agriculture contributes to about 34.7% to national Gross Domestic Product and provides part and full-time employment opportunities to 73.9% of its population[1, 2]. In Nepal, wheat crop was a minor cereal until early 2060s' and now it is the third most important staple food crop of Nepal. Wheat is grown in 791,573 ha with total production of 1,942,870 mt and the productivity is 2,454 Kg/ha. It occupies 23% of total cereal area and contributes 22.5% of the total cereal production in the country. Wheat is widely adapted with its coverage in all the three agro-climatic regions of the country, ranging from 60 to 4000 masl. Out of three Agro-climatic regions in Nepal, Terai shares 55.09% of wheat area and contributes 61.5% to total wheat production. Similarly, hill and mountain shares 37.57% and 7.3% of wheat area and contributes 33% and 5.5% to total wheat production, respectively[3].

Land and Water Division of Food and Agriculture Organization, FAO developed the Aquacrop model for addressing food security and to assess the effect of environment and management on crop production. The model is particularly suited to address conditions where water is a key limiting factor in crop production and also simulates yield response to water of herbaceous crops. When designing the model, an optimum balance between simplicity, accuracy and robustness was pursued. To be widely applicable AquaCrop uses only a relatively small number of explicit parameters and mostly-intuitive input-variables requiring simple methods for their determination. On the other hand, the calculation procedure is grounded on basic and often complex biophysical processes to guarantee an accurate simulation of the response of the crop in the plant-soil system.

Rice followed by wheat (rice-wheat System) is a dominant cropping system practiced in all low-lying areas with maximum population density (253.8 /km^2) and in many areas of low to mid hills in Nepal[4]. This system presently covers 0.52 million hectares out of 2.64 million hectares total cultivated land in the country[5]. Rice and wheat supply most of the daily caloric requirements of the majority of the people in the country. Despite the importance of rice and wheat in the national food security and the past efforts to increase their yields, the average yields of rice and wheat are low [6]. Low soil fertility, which too is declining, is claimed to be the main factor for the low production. Even there is no general consensus, there is growing concern among scientists that sustainability of rice-wheat system in the country is threatened. That is the reason why rice-wheat system is receiving growing attention of the concerned scientists and authorities and should receive top priority for future research and production planning for assuring the food security in the country[7].

Even though wheat is considered priority crop in the Agricultural Priority Plan of Nepal, the present rates of yield are lower than before. This may be due to lack of proper technique of cropping – when to sow, when and how much to irrigate, check of climatic parameters, evaluation of water productivity. After the use of Aquacrop model, we can achieve some solid evidence regarding irrigation management, recommendation can be made for making suitable planting date. We have not use many crop model for simulation in our country which creats the opportunity to do this research–collecting field data and simulating to get the proper result.

Also researches like [8] stated that for the grain yield r^2 values for the model's outputs under the single irrigation, double irrigation, triple irrigation and quadruple irrigation treatments found to be satisfactory results and also said that the minimum amounts of irrigation water required to achieve high Water Use Efficiency for winter wheat in wet, normal and dry years were 225, 150 and 150mm respectively. [9] stated in his paper that by considering the water scarcity in the region, application of deficit irrigation resulted in good and stable yields under low to moderate fertility and always resulted in better water productivity than fully irrigated crops.

Hence, such types of information can be referred from crop modelling techniques for making policies and strategy, how to deal with the rising food security problem in Nepal. By this specific crop modelling technique, we can achieve valid results by simulating the model using the input parameters, we can change the parameters type its values and refer result in short period of time and with less effort-for which in field it can take more funds, time and effort. Since, it is water driven model we can simulate and know the fact, how Canopy cover, Soil water content, biomass and grain yield are changed with variation in irrigation or water availability to the crops. After the model is calibrated and validated for the particular place, for that specific place it will be easier to demonstrate the various simulation, either that may be yield forecasting or studying the effect of climate change in yield production.

In this study, the objective is two-fold: (i) to calibrate and validate the FAO developed AquaCrop model to simulate canopy cover (CC), aboveground biomass (B) and grain yield (GY) for winter wheat at Saptari district; (ii) to apply the model for generating irrigation schedules in two different fields and compare their simulated yields; and (iii) to evaluate the results how the changes in input (irrigation and sowing date) varies the output. The study was focused to (i) Weather data collection from department of hydrology and metrology, field data collection for soil, canopy cover, biomass, yield (ii) Generation of crop file, irrigation file, soil file, field management file for different fields (iiii) Calibration and validation of the model (iv) Demonstrate the application of model in irrigation scheduling sector, variation in input causes-changes in output sectors.

2. Materials and Methods

2.1 Study Area

Saptari district is declared as super-zone of wheat crop by Government of Nepal. The experiment took place at 7 km southwest from Bhardaha (chowk in East-West highway) of Saptari District and is near to my work station. The field is located between latitude 26°31’39.87”N and longitude 86°51’30.07”E at an average elevation of 75.75m above from mean sea level. Experimental field of total area 0.17 hectares is divided into seven small fields each of size 24m x 10m. Three fields are selected for calibration fields and are symbolized as C1, C2 and C3 fields; similarly, V1, V2, V3 and V4 are the symbol of four fields used for validation. The experimental field has the surface irrigation facility. The main crop grown in this area is paddy where wheat comes second and main variety of wheat is Bijaya.

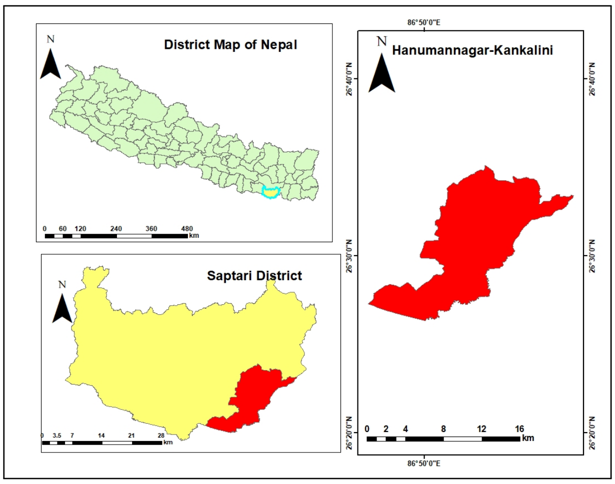

Figure 1: Site location of the study area

2.2 Field Experiments

AquaCrop model was calibrated using data from three fields and was validated on four ones, conducted during 2019/2020 cropping season; the calibration fields are denoted as C1-C3 and validation fields are V1-V4 in which the same variety (Bijaya) of wheat is cropped. According to Seed Quality Control Center, Ministry of Agriculture and Livestock Development-Bijaya variety of wheat was released in year 2011 in Nepal. In the seed catalog, it was stated that the yield will be 4.45 ton/ha which take 123 days for maturing whereas, the average height of the crop will be 98cm.

2.3 Data Description

For running Aquacrop model firstly, climatic data are required, which is for calculation of ETo done using Penman-Monteith method. To calculate ETo, ¬(i) air temperature, (ii) air humidity, (iii) radiation and (iv) wind speed data are required. However, daily rainfall, max temperature and minimum temperature only are available from DHM from Rajbiraj station. According to the Reference manual of Aquacrop model[10] the required vapour pressure will be estimated from Tmin, and the required solar radiation will be estimated from (Tmax – Tmin) difference. For the requirement of wind speed during creation of climatic files, the specified average wind speed value will be used and for CO_2 file, required for simulation of Aquacrop model where we used the default Manulua CO_2. The value of Rainfall, maximum temperature and minimum temperature of year 2019 and 2020 are shown in Figure 2.

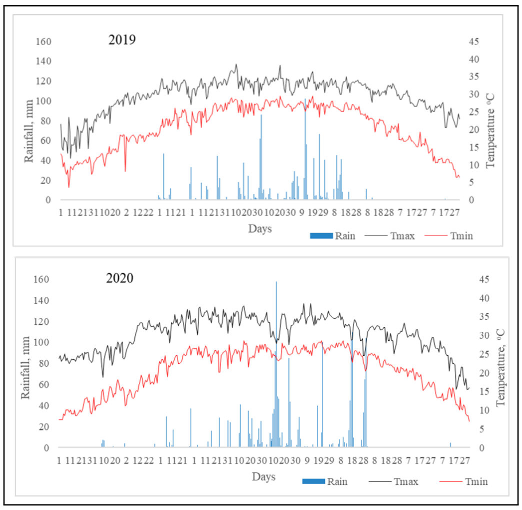

Figure 2: Rainfall, Maximum Temperature and Minimum Temperature of 2019 and 2020 at Rajbiraj Stationl

Table 1: Sowing date, Seeding rate, Planting density and Irrigation inputs in calibration and validation fields of Aquacrop model

field	sowing date	seeding rate (kgs/ha)	plant density (plants/m^2)	Irrigation water applied (dd-mm-yy) & (mm)			Irrigated water (mm)
				1st	2nd	3rd	
C1	23-Nov-19	176	281.6	16-dec-19 (21 DAS) 70	5-Feb-19 (75 DAS) 40		110
C2	30-Nov-19	176	281.6	19-dec-19 (20 DAS) 100	15-Feb-20 (75 DAS) 70		170
C3	7-Dec-19	150	240	27-dec-19 (21 DAS) 70	14-feb-20 (70 DAS) 70		140
V1	15-Dec-19	150	240	4-jan-20 (21 DAS) 70	22-feb-20 (70 DAS) 70		140
V2	23-Dec-19	150	240	12-jan-20 (21 DAS) 70			70
V3	27-Nov-19	150	240	17-dec-19 (21 DAS) 70	30-jan-20 (65 DAS) 80	1-mar-20 (95 DAS) 50	200
V4	4-Jan-20	176	281.6	15-feb-19 (43 DAS) 80			80

Soil samples were collected from the depth of 30 cm at various sites within the field. The textural analysis[11] showed that the upper 30 cm was characterized as a sandy clay loam horizon, according to the USDA classification (46.6% sand, 21.3% silt, 32.2% clay whereas, the organic matter content was found to be 1.01%. The textural and organic matter info were inserted to SPAW model[12] and soil saturation, field capacity, permanent wilting point and saturated hydraulic conductivity parameters were estimated. A representative bulk soil profile of the obtained soil's hydraulic properties is presented in Table 2. Same type of soil physical properties were considered in all experimental fields. Despite the fact that no soil samples were taken below the depth of 30 cm, a hypothesis was made that the soil structure and hydraulic properties remained the same until the depth of 100 cm. As the soil moisture was not measured at the beginning of season and knowing that the sowing of wheat in the field will be after paddy harvesting, a full flooding irrigation event, the farmers sowing when the soil moisture became suitable for ploughing and germination. Following this, the initial soil moisture used in AquaCrop model was between field capacity and wilting point. Therefore, the initial value of soil moisture was set to 50% of Total Available Water (TAW).

Table 2: Soil Physical Properties of the experimental fields

Soil texture	Sandy clay loam
Bulk density (g/cm3)	1.46
Field Capacity (%)	32.3
Permanent wilting point (%)	20.4
Saturation (%)	44.9
Saturated Hydraulic conductivity (mm/day)	116

Additionally, measurements of the canopy cover (CC) over each field were made using Canopeo application (canopea.apk) and the pictures of the crop are taken from Redmi Note 4 and Oppo. For more details about this technique and the software processing used for deriving CC, the reader can refer to [13]. About 8 times the canopy cover was recorded which will be compared with the simulated value after running the model. For management practices, no mulches are provided in the experimental fields, however a bund height of 25cm is taken in all the fields. Soil fertility was considered to non-limiting, which means crop does not suffer fertility stress. Further, perfect weed management practice was selected while running the model. Since, groundwater table was very below than the root zone depth, no shallow groundwater table is considered.

For simulation of the model, simulation period is linked with the crop growing cycle because we considered that the initial soil conditions-soil moisture was at 50% of the TAW, 25cm bund height was considered as it was measured in the field. No off-season data were required since the simulation period was linked to the cropping cycle. Total dry biomass from each field were weighed after the random sampling was carried by making five quadrates (i.e. area of 5 m^2= 2.5 m × 2 m). Firstly, the root was removed from the plant and it was oven dried at 62°C for 24 hours and then weighed. In the month of March, grain maturity was reached and final grain yield was measured. In each field, plant sampling was carried out in five quadrates (i.e. 5 m^2= 2.5 m × 2 m) selected randomly.

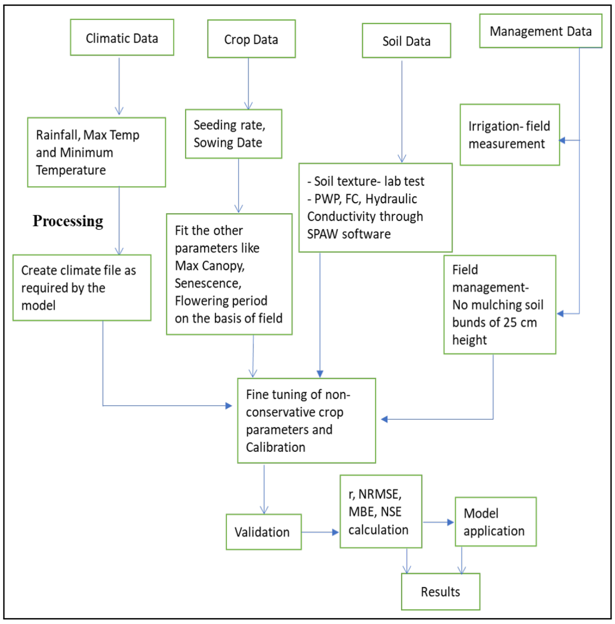

Figure 3: Flowdiagram of methodology

2.4 Modelling Approaches

The Aquacrop model[10] is basically a crop yield model that computes biomass and grain yield considering the actual transpiration (T_a,mm) which uses six input files for simulation: climate file (minimum and maximum temperature, ETo, rainfall and CO2), crop file (time to emergence, maximum canopy cover, start of senescence and maturity), soil file, management file, irrigation file and initial soil water conditions[14]. It separately computes Ta and Es using a daily time step. The soil evaporation coefficient is computed in AquaCrop using a deep modification of the Ritchie's two stages approach, including a skin layer modification. Stage I is determined by the available energy at the soil surface, thus not limited by the evaporable water available in the surface soil layer; Es is then at its potential rate and it is assumed that water evaporates from a thin soil surface layer with 0.04 m depth that directly contacts with the atmosphere. When water is evaporated from this thin surface layer, an upwards flux from the soil layer underneath occurs and evaporation is in stage II. At this stage, evaporation is limited by the soil water availability and the soil hydraulic properties determining the transfer of water from the underneath soil layer to the evaporative surface layer[15].

2.5 Model Paramaterization, Calibration and Validation

The AquaCrop model was calibrated on three fields (C1–C3) and then validated on three fields (V1–V4) during the 2019/2020 cropping season. Various parameters affecting CC, ETcact, TWC and GY were calibrated based on the comparison between measurements and the results of simulations. The estimation of CC in AquaCrop consists firstly of determining the initial canopy cover (CCo) which depends on the seed rate, the seed weight, the estimated germination rate, the plant density and the initial canopy size per seedling; this CCo is automatically estimated by the model. Afterwards, the canopy expansion rates were automatically estimated by the model after the determination of some phenological dates such as the dates after sowing, emergence, maximum canopy cover (CCx), senescence and maturity. It should be noted that the canopy growth coefficient (CGC), the canopy decline coefficient (CDC), the leaf expansion and the early senescence are considered as the most important parameters to calibrate the canopy cover (CC) [10]. So, these parameters are adjusted according to the observed previous values and field conditions. As heat units, expressed as growing degree-days (GDD) in the AquaCrop model, play an important role for the crop development, it is interesting to determine the cumulative growing degree day (CGDD) in each crop development stage. In AquaCrop model, the calculation of GDD is based on the base temperature (Tbase) and the upper temperature (Tupper). In the manual of the AquaCrop model [10], they used 0 and

26°C for Tbase and Tupper, respectively. In this study, we used the value 10 for Tbase and 33°C for and Tupper.

AquaCrop model contains several user-specific options for simulating irrigation, such as determining net irrigation requirement, generation of an irrigation schedule based upon irrigated and rainfed management strategies. The irrigation scheduling option also provides alternatives for different application methods [viz. sprinkler irrigation, surface irrigation (i.e. basin, furrow, and border) and drip irrigation]. The major difference between the application methods is the portion of the surface that is wetted during irrigation. In the present study, the experiment was conducted with surface irrigation and 100% wetted area option was selected. However, the provision for inputting the irrigation water application efficiency or uniformity is not available in AquaCrop model. But the application efficiency can be estimated outside the model to determine gross AquaCrop can be used to develop an irrigation schedule based upon either management allowed depletion (MAD) or a fixed time interval-based scheduling. The MAD of 50% was considered as initial condition in the model. The depletion level and depth of irrigation can be designated at different times throughout the simulated period to achieve management goals. An irrigation schedule was directly input into the model by specifying the date and depth of the irrigation for all fields. The field management file of AquaCrop contained the data of soil fertility, crop residue, and surface practices. No mulching practice during growing season was considered as there were no crop residues or mulches in the experimental field but soil bund of 25cm height is considered.

AquaCrop model was validated using data of 2019/2020 to predict grain yield and biomass under different water and seeding rates in the experiment. Calibrated AquaCrop model was simulated with the input data of the experiment during the same year to predict the canopy cover, biomass and grain yield. Further, these predicted values were compared with the observed values of the experiment and the model validation performance statistics were analyzed. Four Parameters were used for model evaluation: (i) the Pearson correlation coefficient, r[16] (ii) the normalized root mean square error, NRMSE (iii) the mean bias error, MBE[17], the Nash–Sutcliffe efficiency (NSE).

2.6 Model Application

After successive calibration and validation of the Aquacrop model, it is applied to determine the irrigation schedule-which find out the amount of irrigation water requirement throughout the lifecycle, for the crops with varying sowing dates. For this, the crop field V3 is used for early sowing and crop field V2 for late sowing. Irrigation scheduling file is created from irrigation management section of the model and it is set up that the irrigation will start when 100% of Total available water (TAW) is consumed by the crop. Before applying the AquaCrop model for irrigation management scenarios, it is more convenient to separate the effect of water and fertilization stresses on the crop response in terms of grain yield (GY) and biomass (B)[18]. For this objective, the model was run for fields in the same agricultural and environmental conditions but there is no fertilization stress. As stated, this study was performed during 2019/2020 cropping season on two fields (V3 and V2) that differ by their sowing dates (table 2). In the model the generation of irrigation schedules was selected at type of irrigation was selected as basin irrigation which will wet 100% surface of the field. During modeling set up for time and depth was selected as – the irrigation will start after 100% water is depleted from readily available moisture (RAW) and irrigation is provided till the soil moisture reaches its field capacity.

3. Results and Discussions

3.1 Calibration of the Model

Previous section mentioned that various parameters affecting CC, ETcact, TWC and GY have been calibrated. For Canopy cover, in addition of initial canopy cover CCo, canopy decline coefficient CDC, and canopy growth coefficient CGC, the values of CGDD in each crop development stages (Emergence, Maximum CC, Senescence and Maturity) were adjusted using the data collected from the fields C1, C2 and C3 during the cropping season (Figure 4).

Figure shows that the crop development stages are almost identical-C1 has relative higher CGDD which is due to sowing date where the air temperature is different to the base temperature. However, the values of CGDD in other phenological stages (from emergence to maturity) are similar.The averages values of CGDD in each phenological stages were used during the validation of Aquacrop model. The

Table 3: Main input parameters used for the calibration and validation of the Aquacrop model during 2019/2020 cropping

Parameters	Value						
	Calibration fields			Validation fields			
	C1	C2	C3	V1	V2	V3	V4
Conservative							
Base temperature (°C)	10	10	10	10	10	10	10
Upper temperature (°C)	30	30	30	30	30	30	30
Initial canopy cover, CCo (%)	4.22	4.22	3.6	3.6	3.6	3.6	4.22
Canopy cover per seeding (cm^2/plant)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Maximum coefficient for transpiration, KcTr,x	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Reference harvest index, HIo (%)	35	35	35	35	35	35	35
Normalized crop water productivity, WP* (g/m^2)	16	16	16	16	16	16	16
Non conservative							
Time from sowing to emergence (CGDD)	108	97	107	105	105	105	105
Time from sowing to maximum CC (CGDD)	481	473	486	486	486	486	486
Time from sowing to start senescence (CGDD)	849	830	837	825	825	825	825
Time from sowing to maturity (CGDD)	1237	1205	1224	1224	1224	1224	1224
Maximum canopy cover, CCx (%)	85	90	90	90	80	90	79
Canopy growth coefficient, CGC (%/GDD)	1.482	1.486	1.516	1.508	1.477	1.508	1.477
Canopy decline coefficient, CDC (%/GDD)	0.607	0.622	0.619	0.647	0.609	0.647	0.609
Maximum effective rooting depth, Z_x (m)	1	1	1	1	1	1	1
Minimum effective rooting depth, Z_r (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.3

other parameters (maximum canopy cover, CGC, CDC) which affects the CC have also been adjusted. Table 3 presents the conservative and fine-tuned non-conservative parameters for the local environment. Those values are in agreement with other studies which tested the Aquacrop model for winter wheat [18, 19, 20].

The comparison between the simulated and observed canopy cover (CC) for the three calibration fields is shown in figure 5 which shows that the Aquacrop model was able to simulate accurately the CC development, confirmed by the statistical parameters presented in Table 4. As stated previously, the field canopy cover was obtained after processing the picture obtained by the canopea application in mobile phone. The Pearson coefficient and NSE are close to 1 except for field C2 where some discrepancies have been observed between simulated and observed CC. This occurred due to some weeds present in the experimental field which increased the measured CC whereas the mode only simulates the wheat plants.

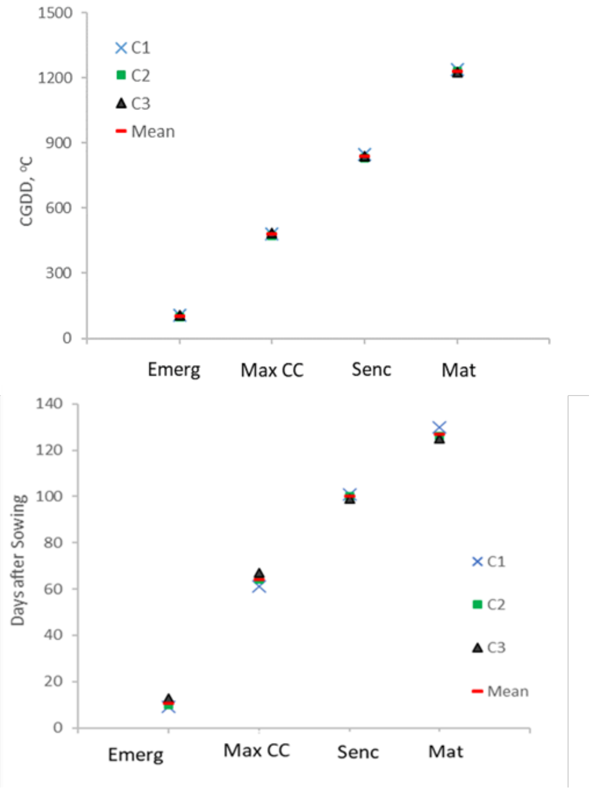

Figure 4: Four Phenological stages of crop in DAS and GDD

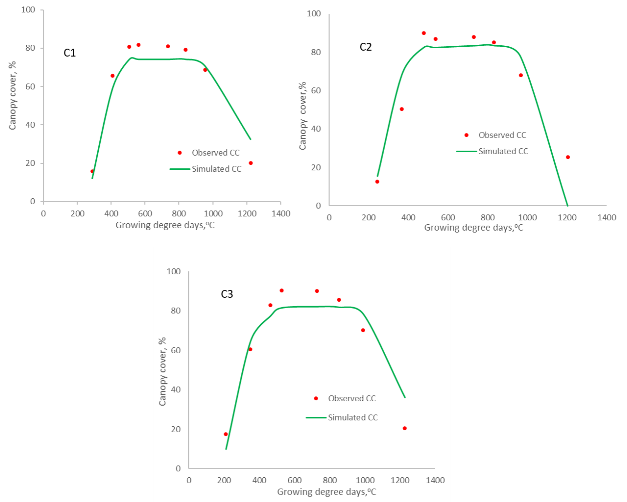

Figure 5: Observed (dot) and simulated (continuous line) Canopy Cover for three calibration fields during cropping season 2019/2020.

Aquacrop's simulation behavior of above-ground biomass is presented in figure 6. The statistics also shows that there is a good agreement between the observed and simulated dry biomass (see table 5). However, in C2 experimental field, the NRMSE and MBE are little more than others-measured biomass is high, this may be due to the insufficient dry of the biomass before weighing. In the model the aboveground biomass is derived from the crop transpiration using crop water productivity parameter, WP*, which is normalized for ETo and CO2[15]. The final aboveground biomass at harvest was predicted with good accuracy. The Aquacrop model was then assessed for the validation fields.

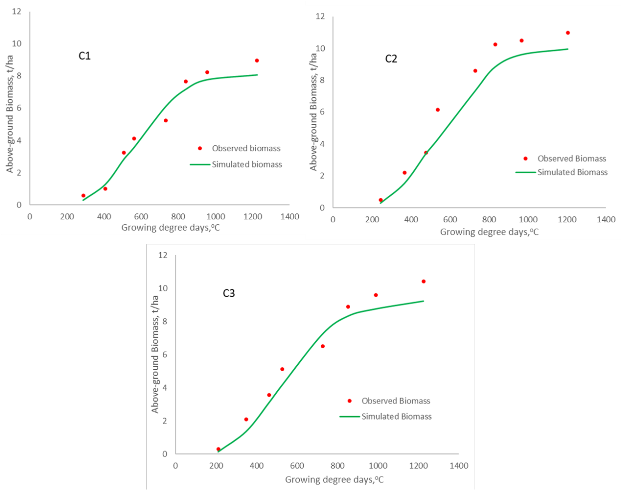

Figure 6: Observed (dot) and simulated (continuous line) Canopy Cover for four validation fields during cropping season 2019/2020.

3.2 Validation of the Model

Figure 7 illustrates the comparison between the measured and the simulated CC over the validation fields (V1-V4). This figure represents that Aquacrop model was able to simulate accurately CC. The r, MBE, RMSE and NSE between measured and simulated CC for all validation fields are relatively acceptable (table 4). However, there are some discrepancies observed at V3 and V4 fields, RMSE for all fields does not interpreted as very good, but is interpreted as good and moderate good. Overall, the obtained results for all the parameters in simulating canopy cover are satisfactory and are in agreement with other studies using same model with different crops, such as barley and corn, tomato and potato crops[21].

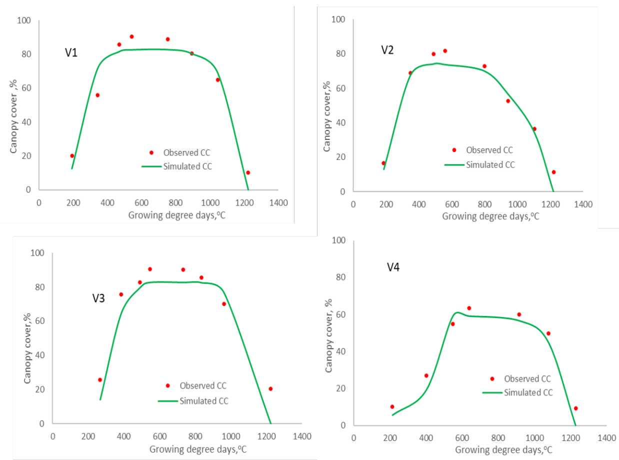

Figure 7: Observed (dot) and simulated (continuous line) Above ground Biomass for three calibration fields during cropping season 2019/2020.

The correspondence between the measured and simulated aboveground biomass values in GDD mode for all crop validation fields was found to be fair for the cropping season 2019/2020 (Figure 8), although it tended to underestimate the biomass after flowering stages. All the previously mentioned statistical parameter's -r, NRMSE, MBE and NSE, values are presented in table 4. In Aquacrop, dry biomass is directly determined by the green canopy – from the crop transpiration using the crop water productivity parameter, WP*.A possible reason for the underestimation of the simulated canopy cover (CC) and biomass in the validation fields is that the field plots were plowed and harrowed before sowing of the wheat, which brought out variation of the soil hydraulic properties during the initial growth stage [22]. Generally, the results of this experiment showed

Table 4: Statistical values between measured and simulated Canopy Cover and Aboveground Biomass of Calibration and Validation fields during cropping season 2019/2020

	Fields	n	Canopy Cover (CC)				Aboveground Biomass			
			r	NRMSE (%)	MBE (%)	NSE	r	NRMSE (%)	MBE (%)	NSE
Calibration fields	C1	8	0.97	11.21	-4.36	0.93	0.98	11.88	-5.07	0.96
	C2	8	0.92	19.15	-2.64	0.82	0.99	16.38	-13.94	0.92
	C3	8	0.95	13.11	-1.08	0.91	0.98	13.09	-8.89	0.95
Validation fields	V1	8	0.96	13.31	-3.32	0.92	0.99	13.19	-9.65	0.95
	V2	8	0.98	10.95	-7.09	0.95	0.97	15.08	-6.72	0.92
	V3	8	0.98	15.27	-10.79	0.85	0.98	14.33	-7.90	0.95
	V4	7	0.99	14.77	-10.60	0.93	0.98	13.28	-3.99	0.95

that the model adequately simulates the CC, B and GY; however, the model showed slight deviation hence we recommend verifying and refining the Canopy cover obtaining techniques. Further, We can see that, in the V2 and V4 field the canopy cover and biomass can not expand well, since they were late sowed and irrigation was provided less.

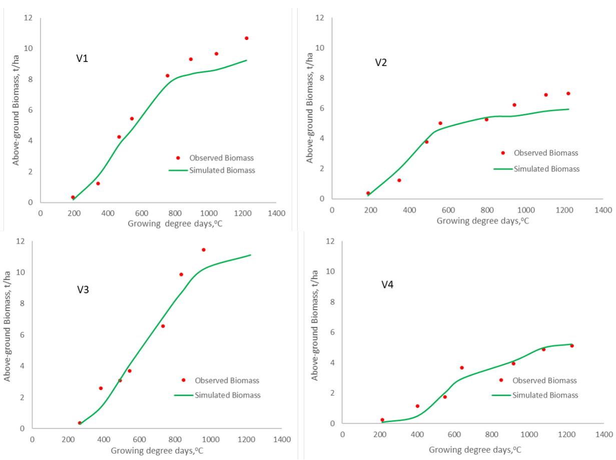

Figure 8: Observed (dot) and simulated (continuous line) Aboveground Biomass for four validation fields during cropping season 2019/2020.

Figure 9 displays the measured and simulated canopy cover and biomass values taken during the lifecycle of the crop for all the experimental fields. We can clearly see that the solid 1:1 line fits the observed and simulated values. That's why it has that much better statistical indicator. Figure shows that as compared to the canopy cover, the model has underestimated the aboveground biomass since most of the points are lying below the 1:1 line which may be due to insufficient drying of biomass before weighing.

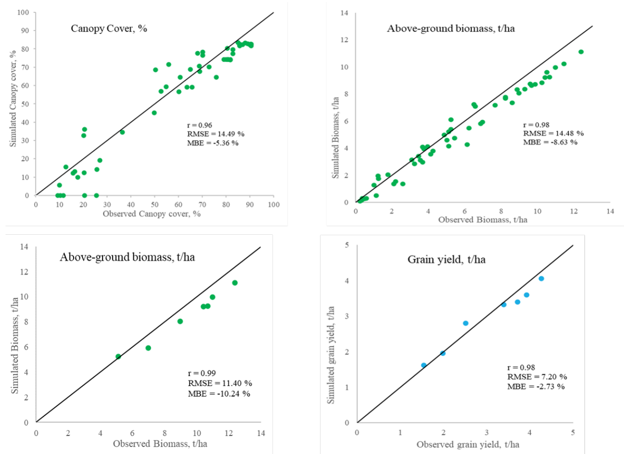

Figure 9: Measured and Simulated Canopy cover and Above-ground biomass at different times and Final B and GY of wheat growing season in all the experimental plots. The solid line is the 1:1 line.

The average values of the Normalized Root Mean Square Error (NRMSE) between measured and simulated CC, B and GY were 14.49%, 13.78% and 9.11% for calibration fields and 13.58%, 13.97% and 4.07% for the validation fields, respectively. Similarly,The average values of mean bias error (MBE) between measured and simulated CC, B and GY were -2.69%, -9.3% and -3.42% for the calibration fields and -7.95%, -7.07% and -2.08% for the validation fields respectively.

3.3 Model Application

We applied the validated model to find out the proper irrigation schedule and irrigation water requirement which gives the satisfactory grain yield. In the V3 field condition, which is the representation of early sowing crop, all the parameters for running the model was used in table 3. During the crop cycle, the ETo was found to be 426.8 mm which includes 1238.1 °C growing degree days. It resulted the irrigation water requirement of 358.4mm. The simulated dry biomass yield and gain yield by Aquacrop model is 13.313 t/ha 4.741 t/ha.

Similarly, using all the same parameters showed in table 3, the model was again run in V2 condition which displayed that the ETo is 413.8mm during the life cycle of 1236.6 °C growing days. The irrigation water requirement was found to be 336.9mm and the dry biomass and grain yield was simulated 10.822 t/ha and 3.867 t/ha respectively. Figure 10 displays the irrigation schedule how the model obtained those biomass and grain yield in both experimental fields V3 and V2, provided that the scheduling is also generated by the model.

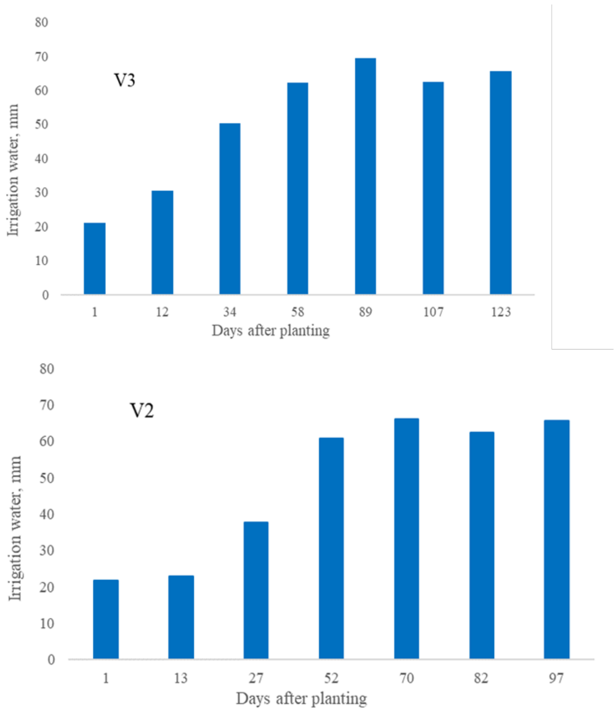

Figure 10: Irrigation schedules provided by the Aquacrop model for experimental fields V3 and V2

After the successful validation of the model, we performed to check, how irrigation water affects the grain yield, biomass yield and Evapotranspiration water productivity. The sowing date was take as 20-Dec-2020 and here the model was run for three different irrigation condition: (i) Rainfed irrigation (ii) One- time irrigation (15 DAS) and (iii) Two- time irrigation (21 DAS and 70 DAS). After this the model was run for each condition and following results are obtained: After the successful validation of the model, we performed to check, how sowing dates of wheat crop affects the grain yield, biomass yield and Evapotranspiration water productivity. Here the model was run for two different irrigation condition: (i) Early sowing (20-Nov-2020) and (ii) Late Sowing (2-January-2020). After this, the model was run for each condition and following results are obtained.

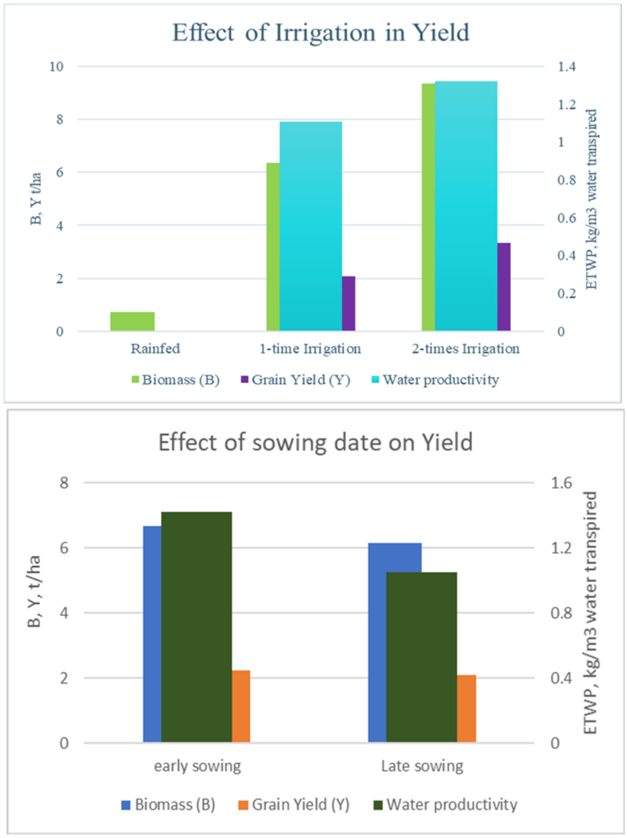

Figure 11: Effect of Input data (Irrigation; Sowing date) on Output data (Biomass, grain yield, ETWP

The ET water productivity was also found to be 1.40 kg yield per m^3 of water evapo-transpired in V3 field whereas only 1.11 kg yield per m^3 of water evapo-transpired was found in V2 field – which leads that the early sowing provide better result than late sowing. The 2-time irrigation showed the better output results regarding yield, biomass and ETWP than rainfed irrigation & 1-time irrigation. Also, the model showed that early sowing of the wheat crop results in higher yield and ETWP than late sowing of the crop.The water stress during the grain filling period in late sown (4-Jan 2020) wheat consequently reduced biomass and grain yield. [23] also obtained a decrease in trend in seed weight with a decrease in water supply levels from fully irrigated field (100% ETc) to moderately deficit irrigated field (50% ETc).

This decrease in seed weight was attributed to grain filling failure as a result of reduced water supply. Grain yield may be reduced due to shortening of the canopy cover duration resulting in short grain filling period[24] .

4. Conclusion and Recommendation

In this study, the first objective was to calibrate and validate Aquacrop model to estimate canopy cover (CC), aboveground biomass (B) and grain yield (GY) over wheat in Saptari district of Nepal. The second objective was to find out the irrigation schedule which will give the maximum yield within the available conditions (climate, crop, soil, management). From all the results obtained, the model simulates reasonably well CC, biomass and grain yield. Due to lack of funds, time and effort all the observation cannot be made directly on the field; after parameterization of crop, climate soil and management, this model faciliates for simulation and provides considerable results for crop planning, irrigation planning, field managemnet planning. Also, various checking of combination between input parameters leads to effective planning for minimizing input and increasing output which makes easier for policy making too.

After calibration and validation of the model for winter wheat, we used this model to generate irrigation schedules of the wheat for better irrigation management and good GY productivity. This was performed on two validation fields (V3 and V2) which differed by their sowing dates. As the model is run on the mode of generation of irrigation schedules when it simulates the grain yield data, it clearly showed that early sowing is more adequate than late one. Supporting the previous statement, the ET water productivity was also found to be 1.40 kg yield per m3 of water evapotranspired in V3 field whereas only 1.11 kg yield per m3 of water evapotranspired was found in V2 field. Further, we have simulated the model for checking- how variation in input data causes changes in output data. Firstly, three different type of Irrigation is supplied to the fields and output are recorded. Similarly, the model is run after changing the sowing date and those output are recorded. It is confirmed that model simulates well for those conditions. Obviously, the 2-time irrigation showed the better output results regarding yield, biomass and ETWP than rainfed irrigation and 1-time irrigation. Also, the model showed that early sowing of the wheat crop results in higher yield and ETWP than late sowing of the crop. Consequently, we can conclude that the Aquacrop model can be used as an operational tool for controlling irrigation water of the winter wheat in the Terai area. In addition, to standardize the conservative parameters developed in this study, further tests are recommended under different environmental and management conditions.

Finally, it should be noted that the test of the Aquacrop for irrigation scheduling is only based on simulations, so to confirm these conclusions, further validation studies under real conditions takaing more cropping season upto four years will be required. The observation should be made with more varying irrigation inputs, soil type and different climatic conditions. Aquacrop can not only applied for irrigation scheduling, it can be applied for managing deficit irrigation strategy where irrigation water is constraint, which can provide a scenario for decision making levels. It can also be applied for improving water productivity and for forecasting the yield having all the other input data. Another application of the Aquacrop model is checking the effect of climate change in simulated Aquacrop model with combination of climate model, which may be global climate model (GCM) or regional climate model (RCM).

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