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Determination of yield response character function for Broccoli: A case study for Ayodhya region using FAO aqua crop model

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Abstract
Water is fast becoming an economically scarce resource in many areas of the world, especially in arid and semi-arid regions of the world including the Mediterranean. Water is a 'bulky' resource. This means that its economic value per unit weight or volume tends to be relatively low. Therefore, its conveyance entails a high cost per unit of volume and is often not economically viable over long distances unless a high marginal value can be obtained. The FAO Aqua Crop model, version 6.0 was used to simulate the above ground biomass, grain yield, canopy cover and Evapotranspiration. First of all, Aqua Crop model was run with default agronomic parameters and then validate for the agronomic parameters was conducted. These model was validated using field data of year 2022-23, model showed good agreement while validating the ETo and ETp with the regression correlation coefficient ranging from R^2=0.406 respectively.

Keywords: AquaCrop model, yield response, evapotranspiration

Introduction
Economic price of water in agriculture is tons decrease than that during different sectors, which include manufacturing. Growing bodily scarcity of water on the only hand, and shortage of economically on hand water because of growing value of manufacturing and deliver of the useful resource at the different, had preoccupied researchers with growing productiveness of water use in agriculture with a purpose to get most manufacturing or price from each unit of water used. Water is rapid turning into an economically scarce useful resource in lots of regions of the world, mainly in arid and semi-arid areas of the world .which include the Mediterranean. Water is a `bulky' useful resource. This method that its financial price in keeping with unit weight or extent has a tendency to be highly low. Therefore, its conveyance involves an excessive value in keeping with unit of extent and is regularly now no longer economically feasible over lengthy distances until a excessive marginal price may be obtained. The charges of abstraction, garage and any conveyance have a tendency to be excessive relative to the low financial price this is located on using a further unit of water. This can create values for water which might be region specific. A similarly function of water is that the amount of deliver cannot be effortlessly specified; it's far decided with the aid of using diverse techniques: the waft of water; evaporation from the floor; and percolation into the floor. In the case of floor water, deliver is decided in large part with the aid of using the climate. Consequently, the amount furnished is variable and may be unreliable. This can prevent sure makes use of of water (e.g. the improvement of water-established industries) and have an effect on the price of water in a few makes use of (e.g. irrigation). The pleasant of water (i.e. the character and concentrations of pollutants) can exclude sure makes use of (e.g. drinking-water for family use), however don't have any effect on other. Water used for irrigation may be pumped from reserves of groundwater, or abstracted from rivers or our bodies of saved floor water. It is carried out to vegetation with the aid of using flooding, through channels, as a sprig or drips from nozzles. Crops additionally achieve water from precipitation. Water infiltrates into the soil, evaporates, or runs off as floor water. Of the water that infiltrates the soil, a few is taken up with the aid of using plants (and later misplaced thru transpiration) and a few percolates greater deeply,

recharging groundwater. This water may be polluted with agrochemicals (fertilizers, herbicides and pesticides), with salts leached from the soil and with effluent from animal waste. However, pollutants may be attenuated because the water movements thru the floor with the aid of using techniques that consist of sorption, ion exchange, filtration, precipitation and biodegradation. Aquifers also can be reassets of pollutants. Pollutants may be launched into groundwater from wallet of contaminants or herbal materials (e.g. reassets of fluoride) inside the aquifer. When river stages are low and groundwater stages are high, groundwater can recharge the stages of floor water, which creates a two-manner linkage among sources of floor and groundwater. (E.g. hydroelectric energy generation).

Agriculture is the biggest water withdrawal area main toward the situations of absolute water shortage and destiny water conflicts - but the sector relies upon on agriculture. Among all sectors of water users, agriculture has the biggest potential to make contributions to included water assets control via stepped forward agricultural practices and methods. Overall, dealing with the call for for agricultural water use we have to awareness on enhancing water use performance and agricultural productiveness at every level. The agriculture area is frequently criticized for excessive wastage and inefficient use of water on the factor of consumption (i.e. at farm level) advocated with the aid of using sponsored low costs for water use or low electricity price lists for pumping. It is frequently claimed that the costs made for irrigation water, fail to sign the shortage of the useful resource to farmers. This scenario can also additionally persist due to entrenched interests, political troubles related to fee reform, realistic problems in measuring and tracking water use, and social norms, e.g. notion of water as a unfastened properly and get admission to water as a primary right (Rosegrant, Cai and Cline, 2002). These low costs could have an unfavourable effect at the effectiveness of irrigation structures and water use. They bring about bad renovation and consequent inefficient operation of current irrigation structures, confined potential for upgrades or funding in new infrastructure, and waste of water on the farm level. Furthermore it's far claimed that the subsidies supplied for irrigation water have a tendency to favour the rich and thereby exacerbate inequalities in useful resource get admission to and wealth distribution in rural areas.

Research's Methodology

Input data requirement of AquaCrop model

The operation of the AquaCrop model requires input data consisting of climatic parameters, soil parameters, crop parameters, field and irrigation management data. However, the model includes a complete set of input parameters that can be selected and adjusted for different soil and crop types.

Climatic parameters

The climatic input data required are daily maximum and minimum air temperatures (^{0}C), Sunshine hours, rainfall (mm) of the year 2022-23. These data's were collected from automatic weather station of ANDUAT.

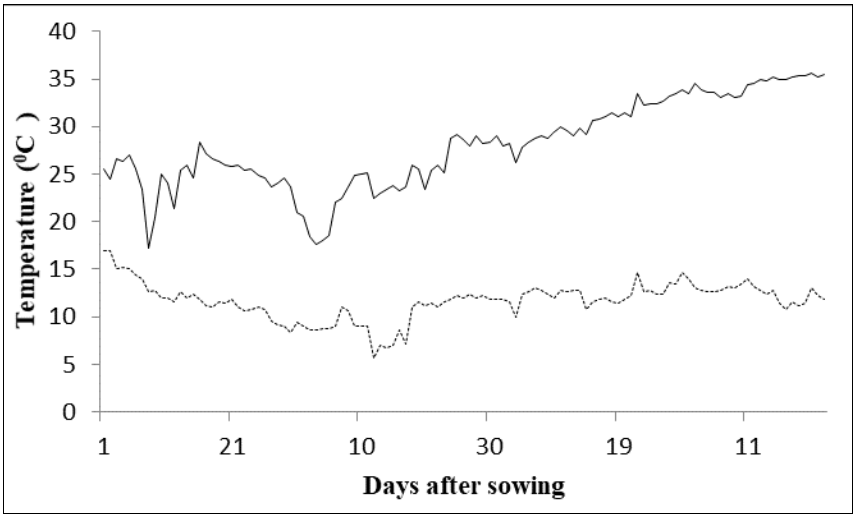


Fig 1: Calculated Climatic Parameters between (Tmax and Tmin)

Soil parameters

Before conducting the experiment soil samples were collected randomly from various places of experimental plot at a depth of 20 cm. Both mechanical and chemical analysis of soil was done before the conduct of the experiment to ascertain the initial conditions of the soil. The results are as follow.

Table 1: Physical & chemical properties of the soil from experimental field of ANDUAT

Determination	Soil depth (0-20 cm)
Sand (%)	60
Silt (%)	14
Clay (%)	26
Soil texture	Sandy loam
Field capacity (%)	22
Permanent wilting point (%)	10
Bulk density (g cm^{-3})	1.64
Electrical conductivity (ds m^{-1})	7.6
Ph	0.38
Organic matter (%)	0.36

Crop parameters
AquaCrop uses a relatively small number of plant parameters that describe the plant's characteristics. Two types of parameters are generally relevant for plant use: conservative parameters and cultivar-specific parameters. Conservative plant parameters do not vary significantly with time, management practices, or geographic location. In the simulation of broccoli growth in this study, the conservative parameters are assumed to be the same as those listed in the AquaCrop file. Cultivar-specific or less conservative parameters are influenced by climate, field management, or soil profile conditions. To run the model, variety-specific and management-dependent parameters were recorded in the field, including planting density, time to emergence, time to flowering, duration of the flowering stage, time to onset of canopy senescence, time to maturity, efficacy of rooting depth, time to reach maximum rooting depth and maximum canopy cover.

Model description
In this study, we estimate evapotranspiration, crop indices, and yield responses using the AquaCrop model version 6.0, developed by the Food and Agriculture Organization of the United Nations, Rome, Italy.

AquaCrop Model
AquaCrop, a new version of CROPWAT, is a Windows-based software program that simulates crop biomass and yield responses to different levels of water availability. Its applications include rainwater irrigation as well as supplemental, deficit and full irrigation. It is based on a water-powered growth machine that uses biomass-water productivity (or biomass-water use efficiency) as the main growth parameter. The model runs at daily time steps using either calendar or thermal time. It considers three levels of water stress response (Canopy expansion rate, stomatal closure, accelerated senescence), root zone salt formation and fertility conditions. AquaCrop is a tool for predicting crop yields under different water management conditions (Including rainfed vs. supplemental irrigation, deficit vs. full irrigation) under current and future climate change conditions, and for considering different management strategies under current and future climate change conditions.

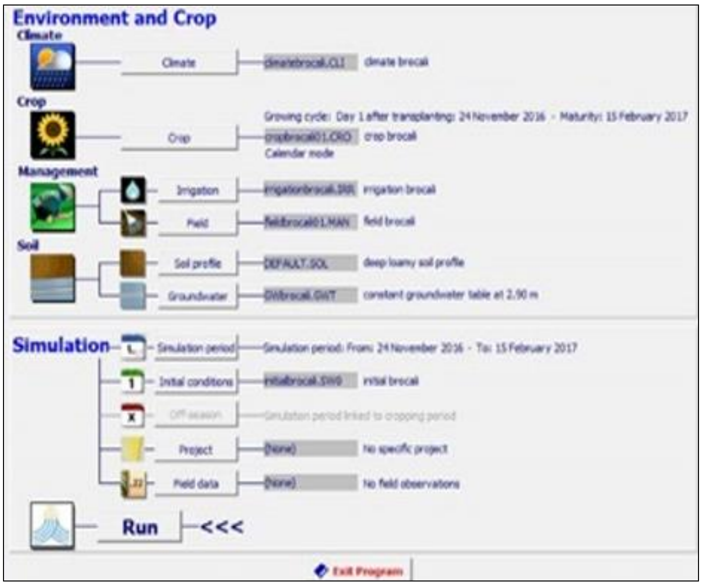


Fig 2: crop and environment

Yield Response Function
Because of the complex nature of crop responses to water scarcity, empirical production functions have come to be adopted as the most practical way to assess crop yield response to water. Among the empirical functional approaches, FAO Irrigation and Drainage Paper No. 33 Doorenbos and Kassam (1979) was an important source for determining yield response to water for field, vegetable and tree crops using the following equation:

$$(Y_x - Y_a)/Y_x = k_y(ET_x - ET_a)/ET_x \qquad \text{- eqn. 3.1}$$

Where:
Y_x and Y_a are the maximum and actual yield
ET_x and ET_a are the maximum and actual evapotranspiration
K_y is the proportionality factor between relative yield decline and relative reduction in evapotranspiration.
AquaCrop (i) splits ET into soil evaporation (Es) and plant transpiration (Tr), (ii) obtains biomass (B) from the product of water productivity (WP) and cumulative plant transpiration, (iii) developed from Eq. 3.1.) expresses final yield (Y) as the product of B and harvest index (HI), (iv) normalizes Tr by reference evapotranspiration (ETo), and (v) calculates crop water consumption, growth, and production in daily time steps rather than hourly. The separation of Y into B and HI, as well as final ET and Y, allows us to distinguish the fundamental functional relationship between the environment and biomass (B) from the relationship between the environment and harvest index (HI). These relationships are fundamentally different in practice, and using them avoids the confounding effects of water stress on B and HI. The modifications described resulted in the following equation at the core of the AquaCrop cultivation engine.

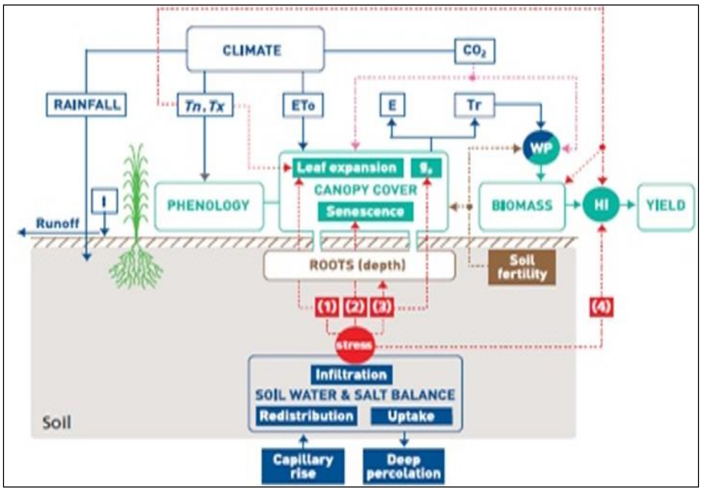
$$B = WP * \Sigma Tr \qquad \text{- eqn. 3.2}$$

Where:WP = water productivity parameter (Kg of biomass per mm of cumulated water Transpired (Tr) over the time period in which the biomass is produced).

Harvest Index (HI)
Harvest index describes the plant's ability to allocate (assimilate) biomass to the reproductive organs formed. It is therefore an

important trait for plant breeding. The relationship with biomass and grain yield follows a multiplicative yield component model, where grain yield is the product of crop index and biomass yield. This project proposes a visualization technique that aims to provide insight into the relationship between harvest index, biomass yield and grain yield. Unlike yield component analysis methods, which provide information on the influence of crop index and biomass yield on grain yield, the graph allows us to focus on the crop index and make inferences about the pattern of its relationship with biomass and grain yield for different groups such as varietal or environmental habitat pulls.:

$$HI = \frac{GrainYield}{BiomasYield}$$



Results and Discussions

Model Simulation Results

AquaCrop model was simulated using default input parameters with the climatic data of the year 2022-23 to determine "Yield Response factor" and "Harvest Index" for Broccoli.

The performance evaluations of the simulated model are as given below:

Table 2: Biomassand Water productivity before calibration

Parameters	Model output parameters	Actual output parameters
Grain yield	4.116 ton/ha	13.105 ton/ha
Biomass yield	4.843 ton/ha	15.421ton/ha

Calibration results

AquaCrop model was calibrated using experimental data set of 2022-23 to predict maximum evapotranspiration, under surface irrigation. The result shown in figures (3) that simulate the R^2= 0.406 for maximum evapotranspiration.

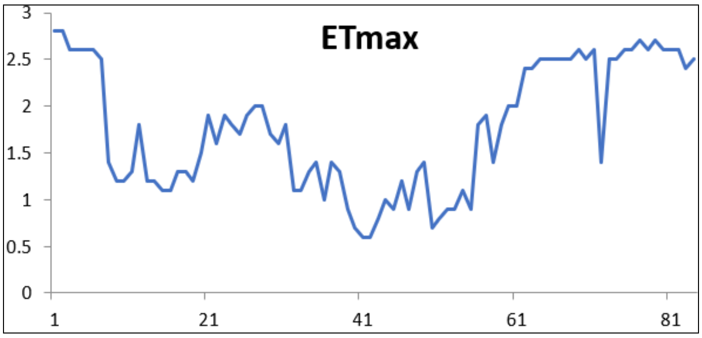


Fig 3: Maximum Evapotranspiration of the year 2022-23

Table 3: AquaCrop model calibrated parameters for broccoli simulation for 2022-23.

Parameter	Calibrated value
Number of plants per hectare	26,6667/ha
Time to reach maximum canopy cover	70 days
Initial canopy cover	1.5%
Maximum canopy cover	85%
Time to start senescence	62 days
Time to reach flowering	34 days
Length of flowering stage	9 days
Time from sowing to emergence	9 days
Time from sowing to reach maturity	84 days
Minimum effective rooting depth	0.3m
Maximum effective rooting depth	1.5m
Time from sowing to maximum root depth	40 days
Building up of harvest index	18 days
Reference harvest index	80%

Simulation of canopy cover

It was observed from Fig. 4 that under surface irrigation the calibration results for level of irrigations were in the range of (R^2 = 0.406). These results were similar to that of Heng et al., who showed in an experiment that AquaCrop model can simulate canopy cover of corn in treatments of optimum irrigation better than the treatments of water stress, Garcia-vila et al., (2009) and Ghanbbari et al., (2013) showed similar results to this research on canopy cover of cotton respectively.

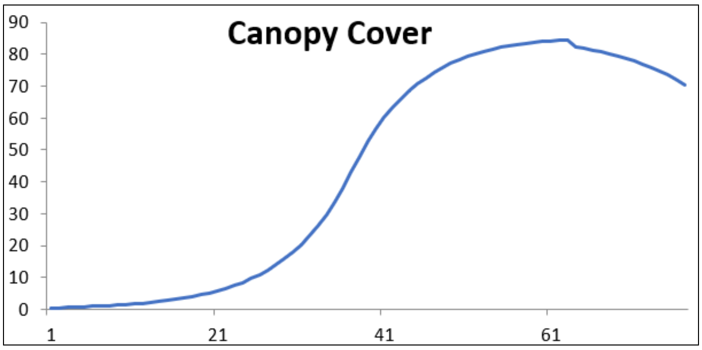


Fig 4: Simulated canopy cover for Broccoli growth from the calibrated model.

Simulation of biomass

Model simulated ground biomass under surface irrigation levels are shown in Fig 5. It was observed from the figures that the model predictions for the ground biomass were very close to the R^2 = 1.

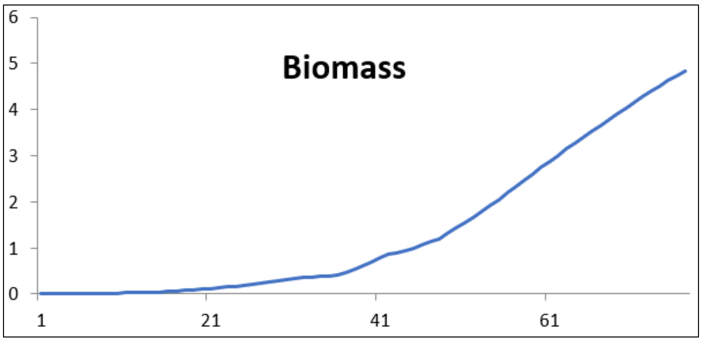


Fig 5: Simulated biomass for Broccoli growth from the calibrated model.

Simulation of grain yield

The results of model performance pertaining to grain yield is shown in Fig 6, the model was calibrated for grain yield with $R^2$of 0.406

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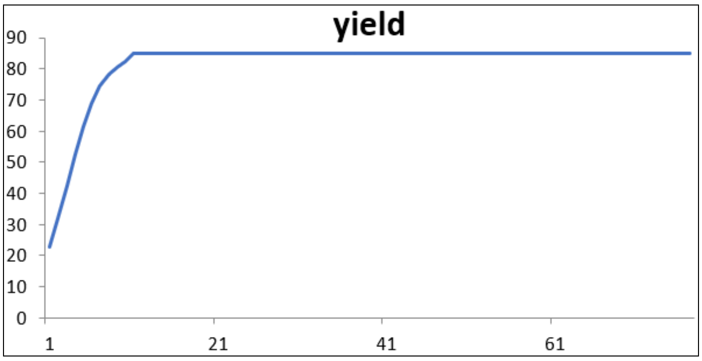

Fig 6: Simulated grain yield for Broccoli growth from the calibrated model.

Simulation of Yield response factor

The yield response factor (Ky) captures the essence of the complex linkages between production and water use by a crop, where many biological, physical and chemical processes are involved. The relationship has shown a remarkable validity and allowed a workable procedure to quantify the effects of water deficits on yield. The simulation of yield response factor of broccoli is 1.46

$$\left(1-\frac{Ya}{Yx}\right) = Ky\left(1-\frac{ETa}{ETx}\right)$$

Where, Yx and Ya are the maximum and actual yields, ETx and ETa are the maximum and actual evapotranspiration, and Ky is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses. Equation is a water production function and can be applied to all agricultural crops.

Simulation of crop coefficient (Kc)

Crop coefficients are properties of crop used in predicting evapotranspiration (ET). The most basic crop coefficient, K_c, is simply the ratio of ET observed for the crop studied over that observed for the well calibrated reference crop under the same conditions. The model was calibrated R2 = 0.5997

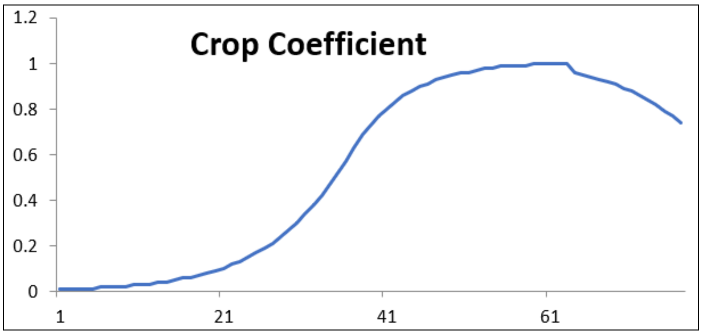

Fig 7: Simulated crop coefficient for broccoli from the calibrated model

Simulation of Harvest Index (HI)

THE partition of biomass into yield part (y) is simulated by means of harvest index (HI). For Broccoli crop, data on different species indicate there is a linear increase with time in the ratio of Broccoli crop biomass to total above ground biomass, from the time not too long after pollination and fruit set not until maturity or near maturity. HI is the ratio at maturity or harvest time. In aqua crop, this ratio at earlier stages is also referred to as HI for simplicity. HI is set to increase from zero at flowering, first at over a short lag phase, when the increase start slowly but accelerate with time. The harvest index of broccoli is 80%.

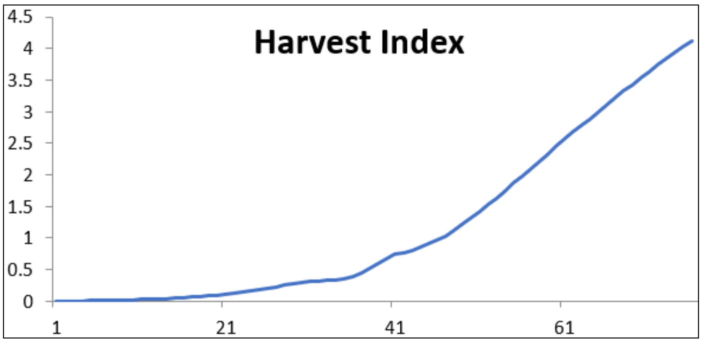

Fig 8: Calculated Harvest Index

Validation results

ETo was calculated for the 2022-23 years and it was exported to the AquaCrop model. From the field experiment of year 2022-23 Evapotranspiration parameter were used in the validation steps for AquaCrop. ETp was taken from the weather station ANDUAT.

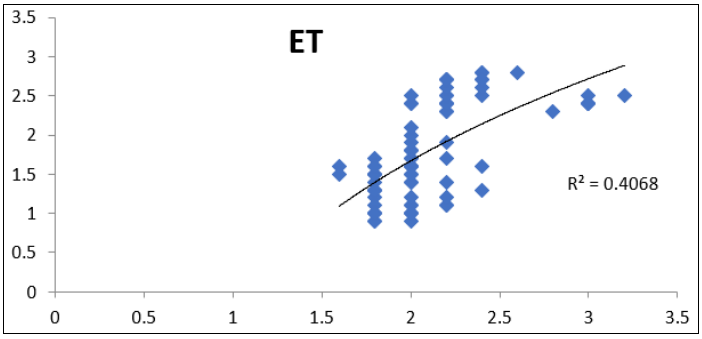

Fig 9: Validations between ET_0 and ETp

Summary and Conclusion

The present study entitles "Determination of Yield Response Character Function for Broccoli". A case study for Ayodhya region using FAO AquaCrop model". For this study, a field experiment was carried out in the research farm of ANDUAT in the Rabi season of 2022-23, Broccolivariety F1 Calabrese broccoli was sown. Soil and crop data were collected from the field experiments and climatic data was from Automatic weather station of ANDUAT.

The FAO AquaCrop model, version 6.0 was used to simulate the above ground biomass, grain yield, canopy cover and Evapotranspiration. First of all, AquaCrop model was run with default agronomic parameters and then validate for the agronomic parameters was conducted. These model was validated using field data of year 2022-23, model showed good agreement while validating the ETo and ETp with the regression correlation coefficient ranging from R^2=0.406 respectively.

Conclusion

1. It can be concluded that the water driven FAO AquaCrop model could be used to predict the broccoli yield with acceptable accuracy surface irrigation and situations in Ayodhya region.
2. The recommendations for timely sowing of Broccoli that is in the first fifteen days of November, optimum level surface irrigation to be applied can be given on the basis of the present study.

3. It was found that surface irrigation was the best irrigation with maximum yield and is being recommended for Ayodhya region.
4. Without conducting the actual experiment we can access the growth and yield of Broccoli by the use of FAO AquaCrop model and irrigation schedules can also be generated.

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