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Maize Yield Modelling in Pyuthan district for Assessing Yield Gap

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Abstract

Maize is the second major cereal crop in Nepal, which is staple food for hills people. The major objective of this research is to simulate maize yield using a model and assess the yield gaps and the constraints that limit the potential yield of Maize in Pyuthan district, Nepal. Farmers' survey was carried out to understand the actual field management practices in the region. Farmers' survey showed that they sow maize after enough rainfall and used very low dose of fertilizer. The regional soil physical properties were determined from the analysis of raw data from Nepal Agricultural Research Council by using Pedo-transfer function. Yield gap and its constraints were assessed with calibrated AquaCrop model by simulation with 100% of national recommended fertilizer dose and full irrigation with 32-years of historical climatic data. The main constraint for monsoon season crop is found as fertilizer. Farmer can increase crop yield by nearly 120% by using 100% of national recommended fertilizer dose.

Keywords

AquaCrop, maize, yield constraints, yield gap

1. Introduction

Agriculture is the major economic sector in Nepal that plays an important role for improving the national economic. As per the Ministry of Agriculture and Livestock Development (MoALD) the agriculture sectors contribute 27% in Gross domestic product (GDP) as well as it also creates employment opportunities to around 65% of the population. The major cereal crops in Nepal are Paddy, Maize, Wheat, Millet, Buckwheat and Barley[1]. The Andean area of Central America is the origin of maize (Zea Mays L.). Grown for grain and fodder, it is one of the most significant grains for consumption by humans and animals alike. In Nepal, maize is a traditional crop that is grown on sloping Bari (upland) in both the mid- and high-hills for food, feed, and fodder. It is cultivated under rain water during the summer (April-August) as a single crop or relayed with millet later in the season[2]. Maize is second major cereal crop in Nepal in terms of area (979,776 Ha) and productivity (2.99 ton per ha) after rice[1]. Maize is staple food for hills people. About 70% maize cultivation area is in the Hills. It occupies around 34% of total cultivated cereal crops and contributes 30% as a total edible food in Nepal[3].

In Nepal Maize cultivation is strated from March to May depending on the amount of rainfall distribution[3]. Maize is generally grown under rain-fed condition in Nepal. Most commonly, it is grown in subtropical to cool temperate areas. Depending on the climate and duration of the crop, it requires 500-600 mm crop water, there should be enough water at the time of the crop establishment period for higher yield. Insufficient of water at the period of grain filling may results in lower grain weight. However, at the period of maturity and harvesting, rainfall has negative impact on grain quality.[3]. Crop yield is the quantity of agricultural products produced on a specific cultivated land. Yield of individual crops are normally measure in kg/ha (or ton/ha). The term "yield gaps" refers to the differences between farmers' actual yields and theoretical yield levels.[4]. To ensure the food security, constraints for crop production is necessary to determine. Crop yield can be influenced by different factors. The factors that influence the crop yield are divided in three basic class known as technological (agricultural practices, managerial decision, etc.), biological (diseases, insects, pests, weeds) and environmental (climatic condition, soil fertility, topography, water quality, etc[5]. The specific objectives of this research are: i) to develop a crop yield model for Pyuthan, ii) to identify yield gap, iii) to characterize constraints for crop yield.

2. Crop Models

Crop models are such models that were developed to uses for different purposes. Mainly, crop models interpret experimental results and work as agronomic research tools for research knowledge synthesis. Crop modeling is a formal way to present mathematical algorithms that represent quantitative knowledge about how a crop grows in interaction with its environment[6].

Most of the popular crop model are DSSAT [7], APSIM[8], CropSyst [9], models from Wageningen [10] and EPIC[11]. Many crop models are developed in a modular structure along with crop modules which linked different crops to soil water soil nitrogen and carbon modules. They (a crop module linked with soil modules) have been extensively tested by field experiments and used in various applications.

Unlike other crop models (i.e., light driven or carbon driven), AquaCrop model [12][13][6] is water driven model, which is simple, robust and accurate [6]. This model has been widely applied in precision agriculture practices such as crop monitoring, intelligent irrigation management and yield prediction before harvest[14].

2.1 AquaCrop model

AquaCrop model was developed by FAO to assess management and environment effect on production of crop to address food security. When designing it, an optimum balance between robustness, accuracy and simplicity was pursued. To be widely popular it uses relatively few numbers of explicit parameters and mostly-intuitive input-variables which can be determined by simple procedures. On the other hand, the calculation methods are based on simple and often complex biophysical processes to ensure an accurate simulation of the crop response in the plant-soil system. [15].

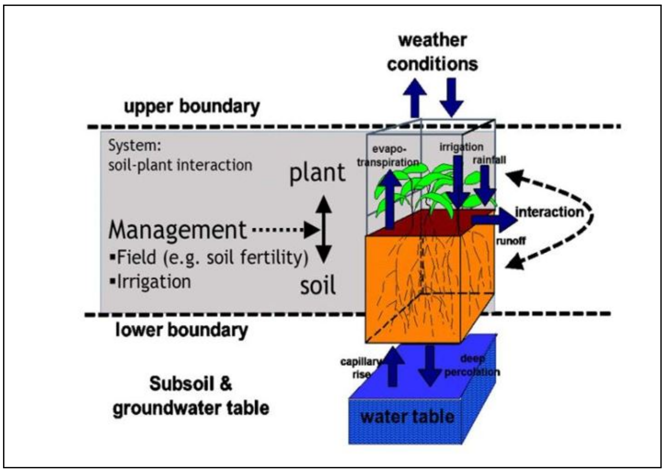

Figure 1: The aspect of reality that AquaCrop describes[15].

3. Study Area

Major maize cultivation areas in Nepal lies in the hill region. Pyuthan district was taken as the study area for this research, which is one of the mid hill districts of Nepal. Pyuthan district lies between 27° 52' to 28° 21' N latitude and 82°36' to 83°6' E longitude Figure 2. It is a hill district which is about 250km west of Kathmandu and belongs to Lumbini Province. The district has altitude 350-3659 m above mean sea level (MSL) with its total area of 1,309 km². Pyuthan district lies between upper tropical to temperate climatic zone. Its ecological zones are upper tropical (36.1%) and subtropical (53.3%) sub-tropical (9.7%) and temperate (0.9%)[16]. Maize production area is 11,330 ha, its production is 28,887 mt with yield of 2.55 mt/ha[1].

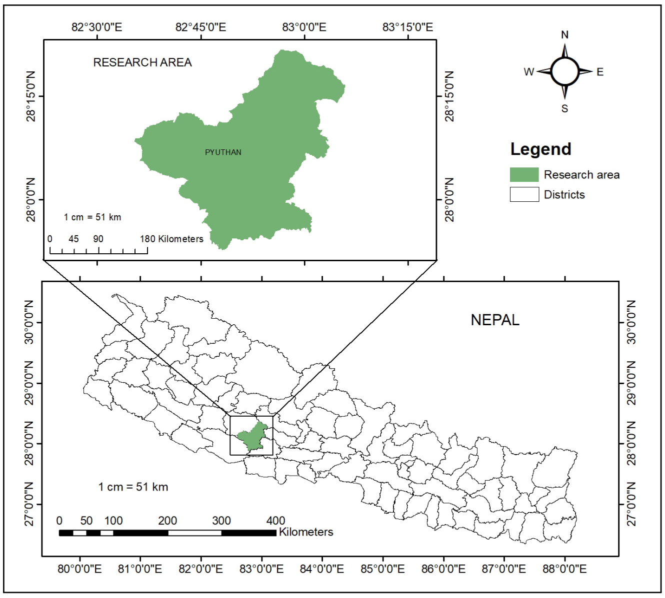

Figure 2: Location of Pyuthan district in Nepal.

4. Methods

A crop water productivity model was used to assess the yield gap and its constraints for maize in Pyuthan district. Unlike various crop models (i.e., carbon driven or light driven), AquaCrop model[12][13][6] is water driven model, which is accurate, robust and simple [6] was selected for this research. This model is specifically designed to simulate the growth and yield of various herbaceous crops under different water and environmental conditions. This model was successfully used in Nepal for different crops in different climate[17][18]. Data collection and preparation is a crucial through the research. Reliable and accurate data input in AquaCrop model can simulate more realistic outcomes. In AquaCrop there are group of parameters that are dependents on location, crop cultivar, and management practices and these must be input by the user[19]. The maize crop files were updated from the study of Shrestha (2014) by the data obtained from farmer household survey. For crop phenology and field management data, household survey was conducted in the regions where agriculture is predominant. Survey was carried out by randomly visiting the households in that region. Climatic data was collected from the Department of Hydrology and Metrology (DHM). Soil raw data was downloaded from National Agriculture Research Council and were analyzed by using pedo-transfer functions from soil texture with SPAW

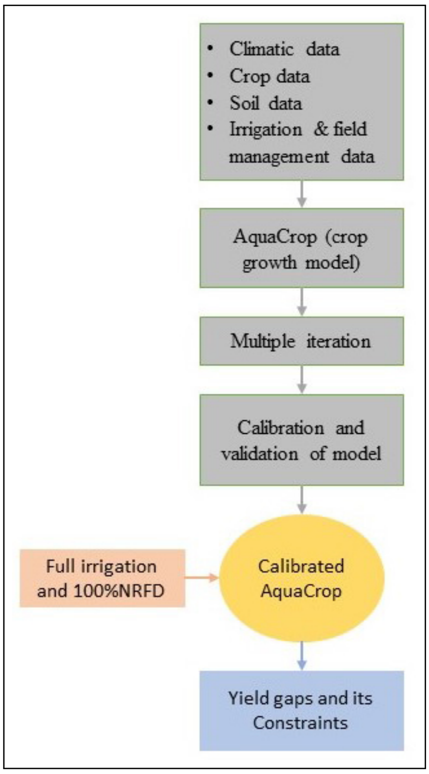

Figure 3: Methodological flowchart for this research.

software package[20]. All of these data were imported into the AquaCrop model, after multiple iteration model was calibrated and validated. Calibration and Validation was done by comparing the simulated output with farmer's and Ministry of Agriculture and Livestock Development (MoALD) reported yield. Yield gap was determined by running calibrated AquaCrop model in non-limiting field management and with farmer field management scenarios, difference between these two scenarios gave the crop yield gap. Constraints for crop yield was determined by running calibrated AquaCrop with farmer field management and with full irrigation and 100% national recommended fertilizer dose, difference between these scenarios gave water constraints and fertilizer constraints respectively. 100% national recommended fertilizer dose is the non-limiting fertilizer dose for maximum maize production recommended by Agriculture and livestock diary published by Agriculture Infromation and Training Center (AITC)[21], for non-limiting fertilizer dose AquaCrop model have provision to consider it, for this research non-limiting (0% soil fertilizer stress) was chosen during simulation.

4.1 Data preparation for model

Data preparation is very important step for Model simulation.The accuracy of its simulations relies heavily on the quality and completeness of the input data. Different types of data required for AquaCrop model is shown in Figure 4.

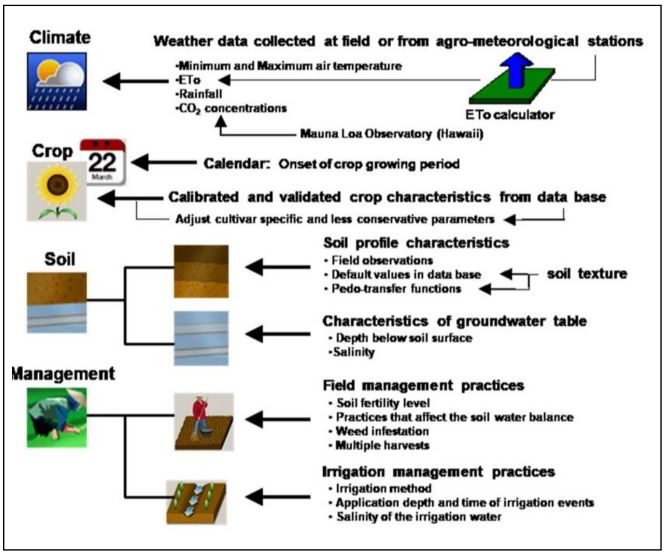

Figure 4: Required input data for AquaCrop[15].

4.1.1 Climate data

Climatic data can be collected from meteorological database, local weather stations, or generated through Local Climate Estimator i.e., NewLocClim. The Department of Hydrology and Meteorology (DHM) in Nepal is responsible for collecting and providing climatic data for various regions in the country. The rainfall, relative humidity, maximum and minimum temperature data were collected from DHM other necessary data were taken default data that are present in the library of AquaCrop. After collected necessary data climatic files were created for the researched area, process to create climatic file is show in Figure 5.

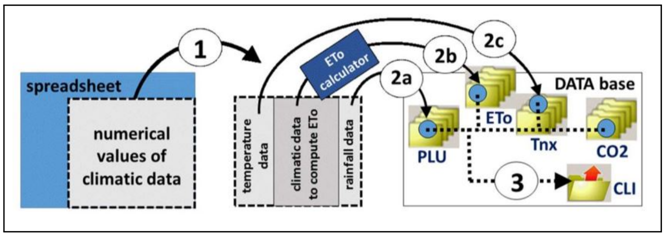

Figure 5: Different steps to create the enveloping climate files (CLI) in AquaCrop model. [15].

4.1.2 Crop data

In the data base of AquaCrop it contains the crop files where calibrated and fully validate crop parameters are stored, some of these parameters need to be finetuned. There are two types of crop parameters (a) conservative crop parameter, these parameters do no change with climate, management practices and time (b) Cultivar specific and non-conservative parameters, which might require finetune with local environment conditions[19] as shown in Figure 6.The crop data that required for crop files were updated from the study of Shrestha (2014) by the data obtained from farmer household survey. Household survey was conducted in the regions where agriculture is predominant.

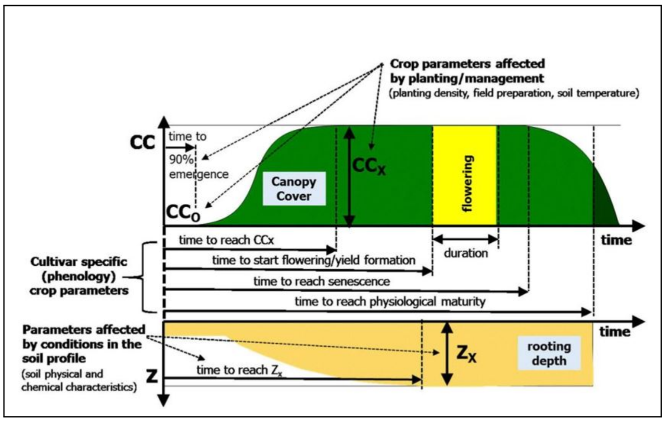

Figure 6: Crop parameters that need to be finetuned to the local environments and selected cultivar conditions [15].

4.1.3 Soil data

Properties and characteristics of soil effect how water is stored, flow and take by the crops. Soil profile characteristics and characteristics of groundwater table need to be imported in the model. Groundwater table information was obtained from the field survey while soil profile characteristics was determined by using Pedo-transfer function. For this research soil data were collected from National Agriculture Research Council (which were raw data) and were analyzed by using pedo-transfer functions from soil texture with SPAW software package.

4.1.4 Field management data

Field management data were collected at research area by the interview with the farmer. In this section two management practices were determined first one is field management practices, in these practices, soil fertility level, practices that affects the soil water balance, weed infestation and multiple harvests were identify another one is irrigation management practices, where we find out irrigation method, application depth and time of irrigation events and salinity of the irrigation water were determined.

5. Results and Discussions

5.1 Insights from field study

For crop phenology and field management data, household survey was conducted in the regions where agriculture is predominant. Survey was carried out by randomly visiting the households in that region. At Pyuthan district twenty household survey was carried out.

5.1.1 Maize phenology

Maize phenology was collected at site, these data were analyzed by using MS excel. The Maize phenology that was inputted in AquaCrop model was shown in Table 1.

Table 1: Maize phonology at Pyuthan district.

Phenological stages/description	Unit	Min.	Avg.	Max.
Sowing rate	kg/ha	14.1	22.4	31
Sowing date	days	23-April	3-May	15-May
Emergence	days	5	7	9
Maximum Canopy	days	40	60	70
Starting time of flowering	days	45	70	85
Ending time of flowering	days	65	88	105
Duration of flowering	days	20	18	20
Starting time of grain filling	days	65	79	95
Ending time of grain filling	days	75	101	115
Start of canopy Senescence	days	85	106	120
Maturity	days	110	130	150
Crop yield 2020/2021	kg/ha	1447	2326	3100
Crop yield 2019/2020	kg/ha	1550	2389	3100
Maximum yield till date	kg/ha	2232	3213	4650

5.1.2 Field management

The majority of farmers in Pyuthan use traditional farming techniques, such as using livestock (in recent years tactors are use in plain land) to prepare field, old seeds, livestock waste as manure and local labor. Weeds were controlled manually and it was generally removed one time before flowering. Different crops were also cultivated along with maize such as local beans and vegetables. Majority of farmers' grow maize with rainfed irrigation. This research only considered rainfed irrigation system for simulation.

5.1.3 Soil data

Soil raw data was downloaded from National Agriculture Research Council (https://soil.narc.gov.np/getdata), these data were analyzed by using pedo-transfer functions from soil texture with SPAW software package[20]. Three major categories of soil were found these were loam (40%), silt loam (32.6%) and Loamy sandy (27.4%), physical characteristic of these soils is shown in Figure 2

Table 2: Physical properties of soils found in Pyuthan district.

Soil Type	Saturation point (mm) θ_{SAT}	Field capacity θ_{FC}	Permanent wilting point θ_{PWP}	Saturated hydraulic conductivity K_{Sat}	Average TAW
	vol %			mm/day	mm/m
Loamy sandy	50.36	18.44	8.85	938.54	95.9
Loam	52.35	22.49	8.45	492.36	140.3
Silt Loam	50.44	21.41	2.94	594.37	184.7

5.2 AquaCrop model performance

Performance of AquaCrop model was checked for maize by comparing six years (2015 to 2020) yield presented by MoALD and two years (2019/20 to 2020/21) yield reported by the farmers with the simulated yield by calibrated AquaCrop. The comparison bar graph and table are shown in the Figure 7 and Table 3.

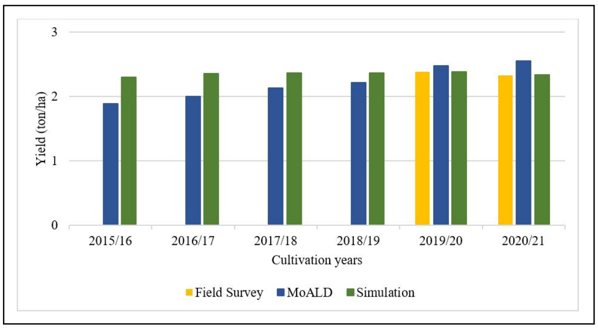

Figure 7: Comparison bar graph of maize yield for field survey, MoALD reported and simulation by calibrated AquaCrop.

Table 3: Comparison table for maize yield by field survey, MoALD reported and from simulation

Year	Maize Yield (ton/ha)			Difference (%)	
	Field Survey	MoALD	Simulation	Simulated to MoALD	Simulated to Survey
2015/16		1.89	2.299	21.6	
2016/17		2	2.359	18	
2017/18		2.129	2.369	11.3	
2018/19		2.217	2.369	6.9	
2019/20	2.389	2.475	2.385	-3.6	-0.2
2020/21	2.326	2.55	2.339	-8.3	0.6

5.3 Yield gap

In Pyuthan district, from simulation, average maize production for the last 32 years was 2.3 ton/ha and the potential yield was 7.36 ton/ha. It was observed that there is 5.06 ton/ha of yield gap, which is equivalent to 220%. Figure 8 shows the district average yield and potential yield from the calibrated AquaCrop model from 1989/90 to 2020/21 cultivation years.

5.4 Fertilizer constraints

For maize production in Pyuthan district, it was found that farmers were using very low amount of fertilizer. If farmer use fertilizer dose 100% national recommended fertilizer dose, then the average yield will increase by 5.03 ton/ha which is 218.69%. Figure 9 shows the comparison plot for maize yield by use of 100% national recommended fertilizer dose, average district yield and potential yield obtain from calibrated AquaCrop model.

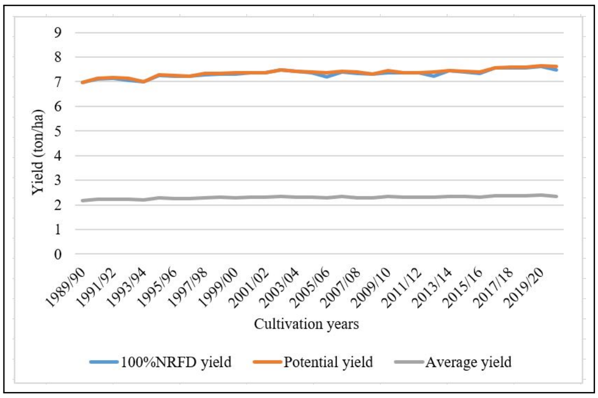

Figure 9: District average yield, yield by the use of 100% national recommended fertilizer dose and potential yield.

5.5 Water constraints

Maize in Pyuthan district is cultivated with rainfed irrigation system. From the simulation it was observed that there is negligible water constraint for maize production. The average maize yield from rainfed irrigation system is 2.29 ton/ha while the maize yield from full irrigation is 2.30 ton/ha which is almost same this is mainly due to farmer sown maize after enough rainfall.

6. Conclusions

The performance of AquaCrop model for six cultivation years (2015/16 to 2020/21) was found satisfactory. It was found that the average maize yield is 2.3 ton/ha whereas the potential yield is 7.36 ton/ha, around 5 ton/ha yield gap was observed. Two constraints (fertilizer and water) were analyzed and it was found farmer were using low dose of fertilizer, they can increase yield around 220% by using 100% of national recommended fertilizer dose whereas there is negligible water constraint. It can be concluded that Maize is cultivated in monsoon season, the main constraints during wet season is fertilizer whereas, water constraints is negligible. This study was carried out considering mix crops, weeds, insect infestations and crop diseases. It should also be noted that, for whole district one station climatic data was taken.

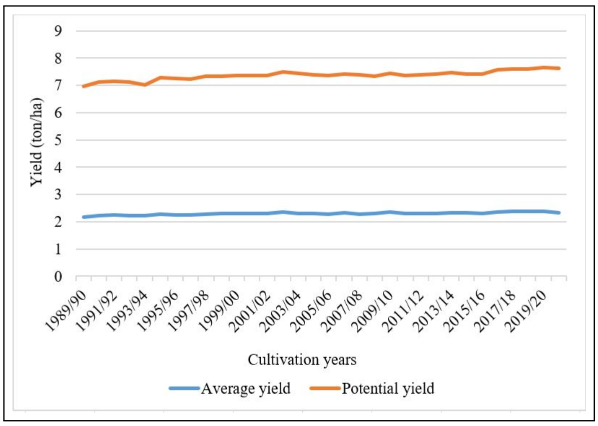

Figure 8: District simulated average yield and potential yield for maize production in Pyuthan district from 1989/90 to 2020/21.

Acknowledgments

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