



EVALUATING THE PERFORMANCE OF AQUACROP MODEL  
IN SIMULATING THE PRODUCTIVITY OF POTATO (*Solanum  
tuberosum L.*) CROP UNDER VARIOUS WATER LEVELS AT  
DEBRE BIRHAN, AMHARA REGIONAL STATE, ETHIOPIA

MSC THESIS

TSEGAYE GETACHEW MENGISTU

HAWASSA UNIVERSITY, HWASSA, ETHIOPIA

NOVEMBER, 2019

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TSEGAYE GETACHEW MENGISTU

MAJOR ADVISOR: TEWODROS ASSEFA (PhD)

CO- ADVISORS: ASHEBIR HAILE (MSc) & AWEL SEID (MSc)

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**HAWASSA UNIVERSITY**  
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**EXAMINER APPROVAL SHEET 1**

**(Submission sheet 2)**

As members of the Examining Board of the Final MSc Open Defence, we certify that we have read and evaluated the thesis prepared by **Tsegaye Getachew ID. No PGIDE/009/10** entitled “**Evaluating the performance of AquaCrop model in simulating the productivity of potato (*solanum tuberosum l.*) crop under various water levels at Debre Birhan, Amhara Regional State, Ethiopia**” and examined the candidate. This is therefore to certify that the thesis report has been accepted in fulfilling the requirement for the Degree of **Master’s with specialization in Irrigation and Drainage Engineering** of the graduate program of the Faculty of Bio-systems and Water Resources Engineering, Department of Water Resources and Irrigation Engineering, Institute of Technology.

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Name of Chairperson	Signature	Date
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## **DEDICATION**

I hereby dedicate this thesis to the Enormous God for His never-ending love throughout the course of this work and also my family that led me to success throughout my education.

## DECLARATION

I declare that this thesis entitled “**Evaluating the performance of AquaCrop model in simulating the productivity of potato (*solanum tuberosum l.*) crop under various water levels at Debre Birhan, Amhara Regional State, Ethiopia**” is my own original work and all sources of material used for this thesis has been duly acknowledged. I solemnly declare that this thesis not submitted to any other institution anywhere for an award of any academic degree, diploma or certificate.

\_\_\_\_\_  
**Name:** Tsegaye Getachew

\_\_\_\_\_  
**Signature:**

\_\_\_\_\_  
Date

**Place:** Institute of Technology, Hawassa University

**Date of Submission:** -----

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## LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of variance
CC:	Green canopy cover [percent or fraction]
CCx:	Maximum green canopy cover [percent or reaction]
CERES:	Coalition for Environmentally Responsible Economics
CWR:	Crop water requirement
DaP:	Day after Planting
EC:	Electrical Conductivity
ECe:	Electrical conductivity of the saturated soil paste extracts [dS/m]
ETc:	Specific Crop Evapotranspiration
ETo:	Reference evapotranspiration
ETWP:	Evapotranspiration water productivity
EWP:	Economic water productivity
FAO:	Food and Agriculture Organization
FC:	Field Capacity
Kc:	Crop Coefficient
Ksat:	Saturated hydraulic conductivity [mm per unit time]
ppm:	Parts Per Million
PWP:	Permanent wilting point
SED:	Standard Error of the difference of means
TAW:	Total available water
Tn:	Cold Minimum air temperature at upper threshold for cold stress affecting pollination [°C]
Tr:	Crop transpiration [mm per unit time]
Tx:	Heat Maximum air temperature at lower threshold for heat stress affecting pollination [°C]
USDA:	United States Department of Agriculture
WPB/ET:	Water productivity as the ratio of Biomass to Evapotranspiration [kg m <sup>-3</sup> ]

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## ABSTRACT

*Agricultural sector face the challenge to produce more yield with less water. In this regard, simulation models are basic tools in evaluating the effect of water on crop production. To address this need, FAO has developed yield responses to water model named AquaCrop, which simulates attainable yields of the major field and vegetable crops from their physiological and agronomic background perspective at farm level. The aim of this study was to evaluate the AquaCrop model performance on potato crop growth parameters under various water levels at Debre Birhan, Ethiopia. The AquaCrop is a user-friendly, easy to apply, accurate and robust model, and it addresses conditions where water is a key limiting factor for crop production. The experiment was arranged with Randomized Complete Block Design, with four replications under different water levels 100%, 85%, 70% and 55 % of crop water requirement of potato, which were simulated by the AquaCrop model. The results indicated that the simulated amount of irrigation water for 100% water level was 377.2 mm of water depth in growing season. The growth parameter and tuber yield were significant differences among the water levels at  $p < 0.05$ . The fresh potato tuber yield ranges from 35.25 ton/ha to 44.37 ton/ha was obtained in 55% and 100% water levels respectively. The water productivity ranges from 11.59 kg/m<sup>3</sup> to 12.67 kg/m<sup>3</sup> was obtained in 100% and 55% water level respectively. Concerning its performance, the AquaCrop model simulated very well in the canopy cover, dry aboveground and tuber biomass and soil water content of the potato crop. The statistical indicators; Nash-Sutcliffe efficiency (NSE), Normalized Root mean square error (NRMSE) index of agreement (d) and Coefficient of determination ( $R^2$ ) showed very well to excellent efficiency observed on dry aboveground and tuber biomass, there values were found to be in the ranges of 0.78 to 0.94, 35.50 to 16.30, 0.96 to 0.99 and 0.98 to 0.96 respectively. However, for soil water content before irrigation, which was found to be poor ranges 0.00 to -0.63, 10.2 to 10.8, 0.78 to 0.51, 0.45 to 0.03 were observed respectively in the above order. From the results of the study can conclude in two scenarios: first, in case of water scarce area, it may be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit of land. The saved water can be used to irrigate extra units of land. Second, in case of no water scarce area, it may be more profitable to maximize the yield harvest than crop water productivity. Under the first scenario farmers should adopt 70% of crop water requirement with a 10-days interval, which 16.65% saved water with 10.1% yield penalty over 100%. On the other hand, they should adopt 100% of crop water requirement within 10-days interval In the case of no water scarce area. The future studies shall consider various other stresses such as soil fertility and mulching.*

*Keywords: - AquaCrop, simulation, potato, water scarce, water levels, water productivity.*

# **1. INTRODUCTION**

## **1.1. Background of the Study**

Potato (*Solanum tuberosum L.*) goes to the genus *Solanum* (Correll, 1962) and it is by far the most important tuber crop in terms of quantities produced and consumed worldwide (FAO, 2005). The production volume of potato fresh tuber yield is estimated to be 368 million tons from 19.3 million hectares, which makes it the fourth-most consumed staple crop following wheat maize and rice in the world (Faberio et al., 2011; FAO, 2012). Among root and tuber crops, potato ranks top followed by cassava sweet potato and yam in that order (FAO, 2008). Potato is highly nutritious food, and one of the most promising crops to reduce hunger, malnutrition, and poverty in the world and high harvest index above 75% (Scott et al., 2000; Thiele et al., 2010). The potato crop is considered as a high-potential food security crop due to its ability to provide high yield and quality product per unit input (Hirpa, et al., 2010).

Around 1858, Schimper, a German botanist, introduced the potato crop to Ethiopia (Berga et al., 1994). Around one million farmers grow the potato tuber crop (CSA, 2008/2009). In Ethiopia, potato is grown in four major areas: the central, the eastern, and the North-western and Southern regions, which together contribute approximately 83% of the potato farmers in the country. In the central area, potato production includes the highlands surrounding the capital, Addis Ababa. About 10% of the potato farmers are located in West Shewa, and North Shewa Zones (CSA, 2008/2009). Ethiopia has possibly the greatest potential for potato production as 70% of its arable land mainly in the highlands with an altitude greater than 1,500 m mean above sea level is considered suitable for potato (Yilma, 1991). However, almost all of the potato production in Ethiopia is based on rain-fed agriculture by smallholder farmers, the production of potato in Ethiopia, in general, in Amhara Region, is considerably below the global average (CSA, 2008/2009; Tesfaye, 2016).

The development of crop growth models has increased understanding of the link between production factors and crop productivity (Hoogenboom, 2000). To improve productivity at the farm level is via better irrigation water management. This can be accomplished by using appropriate tools to predict water productivity under different

irrigation regimes or deficit irrigation approach (Bessemmer et al., 2005). Determining irrigation scheduling merely based on field research is expensive and time-consuming, so the application of models is pertinent. While the complexity of crop responses to water deficits led to the use of empirical production function as the most practical option to evaluate crop yield response to water like CROPWAT.

Some physical-based models are listed below: The Crop System model (CropSyst), which is a process-based simulation model designed to predict the performance of multiple cropping systems across genotype, soil, weather and management option (Stockle et al., 2003). The Decision Support System of Agro-Technology Transfer (DSSAT) is developed to simulate different processes on the effect of soil, crop phenotype, weather and nutrient management option (Jones et al., 2003). The World Food Studies crop growth model (WOFOST) is developed simulate crop growth model using the underlying processes of photosynthesis, respiration, carbon driven approach and the fraction of intercepted radiation (van Ittersum et al., 2013). And the AquaCrop model is water-driven used as a decision support tool in planning and scenario analysis in different seasons and location at farm level. It also elaborates the fundamental process involved in crop productivity and the response to water deficits (Hsiao et al., 2009).

CROPWAT model has been widely used as a practical management tool for irrigation scheduling and estimates yield reductions under water deficit conditions. It designed as a practical tool to carry out standard calculations design and management of irrigation schemes, and irrigation practices. Its approach is solidly based on crop-water use principles, the simplification introduced by using one empirical yield response factor ( $k_y$ ) to integrate the complex linkages between production and water use for crop production, limits its applicability for making accurate estimates of yield response to water (FAO, 2012). However, for better water use productivity more accurate predictions model are required for yield response under actual field conditions. AquaCrop provides a valid alternative for herbaceous crops, as incorporation of advanced knowledge of crop-water relationships allows a more accurate modelling of actual crop growth and yield formation processes under various soil water availability, climate and soil fertility conditions (FAO, 2012).

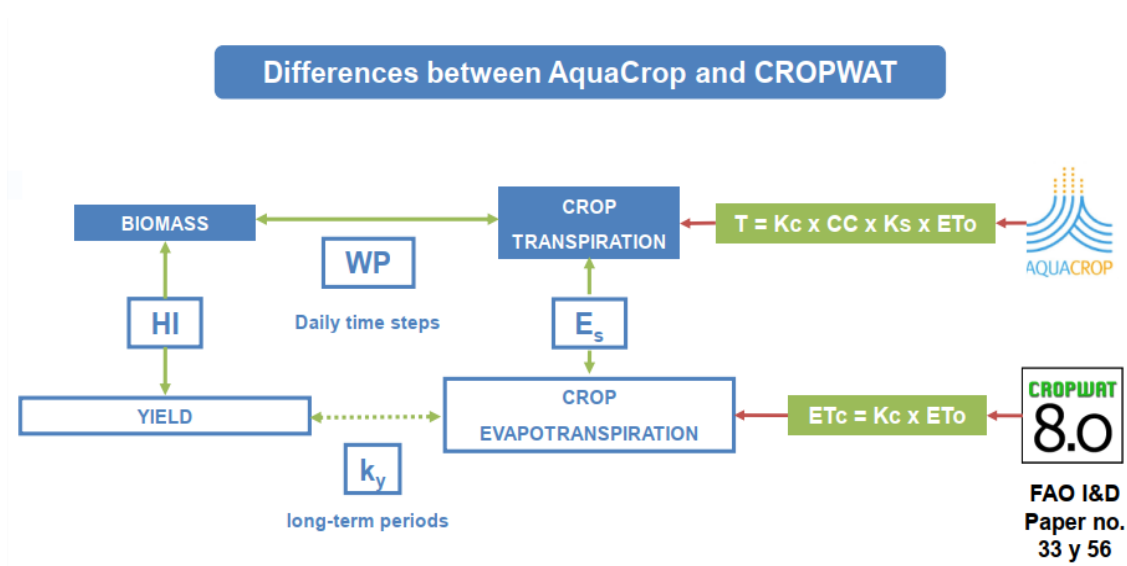


Figure 1.1. The differences between AquaCrop and CROPWAT model

FAO developed the AquaCrop model to address food security and to assess the effect of environment and management on crop production. The model designing, an optimum balance between simplicity accuracy and robustness was pursuing. It is widely applicable due to the only use the relatively small number of explicit parameters and mostly-intuitive input-variables that can be determined by simple methods. Besides, the calculation procedures are ground on the basic and often complex biophysical processes to guarantee an accurate simulation of the crop response in the plant-soil system (Steduto et al., 2009; Raes et al., 2009).

In an attempt to compare the performance of AquaCrop, CropSyst and WOFOST models, using sunflower (*Helianthus annuus L.*) as a test crop under different water regimes in a Mediterranean environment, Todorovic et al (2009) found differences in the level of complexity in a driving simulation of biomass growth, and in the number of input parameters. AquaCrop is exclusively based on the water-driven growth model, in which the transpiration converted into biomass via water productivity (WP) parameter (Raes et al., 2009). Therefore, is AquaCrop model found to be the most suitable crop growth model?

## 1.2. Statement of the Problem

Even though Ethiopia is gifted with suitable climatic and edaphic conditions for potato production, the average national fresh tuber yield is about 7-8 tons/ha, which is very low as compared to the average world's fresh potato tuber production (15 tons/ha) (FAO, 2011). The major factor to obtain a low yield of potato tuber production includes pests and diseases, soil erosion, drought, flood, the shift in rainfall pattern and decline in available water (Deressa, 2007). The Potato crop is challenged by changing seasonal rainfall patterns due to its sensitivity to soil water deficits (FAO, 2012). In the Amhara Region, the variability of the precipitation is manifested with an extended dry spell, erratic and highly variable in space and time (Bewket, 2009). Presently the outlook for food security in many developing nations including Ethiopia is a cause for serious concern. The problem of food security is intensifying by the speedy growth of population and the consequent increase in demand for food. Provided it is economically viable, an increase in irrigation could become a key source of agricultural growth as well as poverty relief for farmers, who otherwise would unjustifiably depend on low and erratic rainfall. This would help increase the productivity of the land, although to a limited extent, the need for extending the cultivated area for feeding the rapidly growing population (GIDA & JICA, 2004).

The demand for water has been the main limiting factor for crop production in much of the world where rainfall is not ample. The ever increase in the human population is stimulating the rise in demand for a large quantity of potato tubers yield (Lutaladio et al., 2009). Sustaining this population will require increasing grain production of all crops. There is also a limited amount of arable land and the resources to produce food are becoming scarcer. As population rises, less land will be devoted to agriculture, meaning increased production will have to come from increased yields (Milander, 2015).

The Amhara Region has a population of about 33 million and considerable portions of the population are food insecure, which is far below the Sub-Saharan Africa average of 23.5%. The population of the region is about 27% of the national population, and the region is one of the regions of Ethiopia suffering from food shortage every year (Tadesse, 2016). In Amhara Region, also low biomass productivity, poor water resource management and limitation of knowledge about how much and when to irrigate

efficiently. So knowing the response of crops to soil moisture stress is crucial for irrigation water saving-strategies (Dessaegn, 2015).

Therefore, there is a need to improve the water use efficiency to obtain more crop production per drop of water with declining irrigation resources and the uncertainty in the temporal and spatial distribution of rainfall. However, most of the farmers in Amhara Region have difficulties in managing irrigation water properly. This means that they do not have the required level of knowledge as to how much and when to irrigate the limited irrigation water resource they have to tackle the shortage of rainfall and dry spell throughout the length of the growing period of potato. Among many, one of the mechanisms or strategies to improve crop productivity per unit of water under rain-fed, full irrigation and deficit irrigation is the employment of the aid of models to fill the gaps during dry spells (FAO, 1990).

The particular features that distinguish AquaCrop from other crop models are its focus on water and the use of ground canopy cover instead of leaf area index. The use of water productivity values normalized for atmospheric evaporation demand and of carbon dioxide concentration that confers on the model an extended extrapolation capacity to diverse locations and seasons, including future climate scenarios. Moreover, the model is simple and has the low requirement of input parameters and its satisfactory degree of simulation precision makes it a valuable tool for estimating crop productivity. It also gives particular attention to the fundamental processes involved in crop productivity and the responses to water, from a physiological and agronomic perspective (Raes et al., 2009).

Yonas and Gizaw (2007) determined the crop water requirements (CWR) of potato crop under supplemental irrigation using CROPWAT model. The values of the CWR for the period at planting, 10th, 40th, 59th, 84th, 108th, and 128th days after planting were found to be 20.46 mm, 40.48 mm, 62.51 mm, 60.32 mm, 61.63 mm, and 61.98 mm depth of water applied, respectively at North Shewa. However, the performance of the AquaCrop model in the study area has not been evaluated yet to the best of my knowledge. This study aims to evaluate the AquaCrop model applicability on potato crop growth parameters under various irrigation water levels at Debre Birhan.

### **1.3. Objectives of the Study**

#### **1.3.1. General objective**

The general objective of this study was to evaluate the AquaCrop model performance on potato crop growth parameters under various irrigation water levels at Debre Birhan, Amhara Regional State, Ethiopia.

#### **1.3.2. Specific objectives**

The following specific objectives were:

- To determine the responses of potato to different irrigation water levels
- To validate the performance of AquaCrop model on aboveground dry biomass and tuber, soil water content and green canopy cover of the potato crop

### **1.4. Research Questions**

- What is the response of potato to different irrigation water level?
- What are the performances of the AquaCrop on aboveground dry biomass and tuber, soil water content and green canopy cover?

### **1.5. Significance of the Study**

This study will have a great contribution for irrigation users, scheme managers, researcher's decision-makers to develop the water management strategies for potato crop, to avoid the risk of crop yield reduction. Also, obtain information on how to maximize the efficiency of water uses on potato production. Moreover, to tell the extent of problems regarding water management to use the available water more efficiently. Consequently, sustainable and effective utilization of scarce water resources may promote and contribute to poverty alleviation in the area and enhance food security through maximizing potato production.

### **1.6. Scope of the Study**

This study will assess the performance of the newly developed AquaCrop model focus only for water stress factor on potato biomass production, yield and water use efficiency. This study carried out at one location in the area of the central highland of Ethiopia at North Shewa, Debre Birhan in one irrigation season (January to May 2019)

## 2. LITERATURE REVIEW

### 2.1. The AquaCrop Model Rationale

The tremendous complexity of crop responses to water deficits has led to the use of production functions as the most practical option to assess crop yield responses to water. Among the empirical function's approaches, presented a highly significant source to determine the yield response to water, for vegetable and tree crops (Doorenbos and Kassam, 1979), see (Equation 2.1).

Scientific and experimental progress in crop-water relations since 1979 to date, along with the strong demand for improving water productivity as one of the major features to handle with water scarcity, influenced FAO to revise its Irrigation and Drainage Paper 33. This was carried out through a consultative process with specialists from major scientific and academic institutions, and governmental organizations globally Raes et al. (2009), the consultation led to a revision framework that treats separately field crops from tree crops. For the field crops, it was advised to advance a model of proper structure and conceptualization that would evolve from (Equation 2.1.). Moreover, be designed for planning, management and scenario simulations (Hsiao et al., 2009). Therefore, the AquaCrop model, which varies from most models are for its balance between accuracy, simplicity and robustness (Raes et al., 200).

$$\frac{(Y_x - Y_a)}{Y_x} = K_y \left( \frac{ET_x - ET_a}{ET_x} \right) \quad \text{Equation 2. 1}$$

Where:  $-Y_x$  and  $Y_a$  are the maximum and actual yield,  $ET_x$  and  $ET_a$  are the maximum and actual evapotranspiration, and  $K_y$  is the proportionality factor between relative yield loss and relative reduction in evapotranspiration.

### 2.2. AquaCrop Model Description

The conceptual framework, underlying principles, and distinctive components and features of the model have been described and reported the structural details and algorithms of the model (Steduto et al., 2009; Raes et al., 2009). The model is a menu-driven program with a well-developed and friendly user interface. The menus (windows) are the interconnection between the user and the program, while the multiple graphs and

their schematic displays in the menus. Assist the user to detect the courses of input changes and to analyses the simulation results. The main menu gives the user access to all sets of menus where the input data is displayed and can be modified. Input data constitute climatic data, crop, management and soil characteristics that describe or define the environment in which the crop will develop. Before the simulation, in the simulation phase and the initial conditions at the beginning of the simulation considered.

The user can track changes in the soil water and corresponding changes in the crop development, soil evaporation, transpiration, (ET) rate, biomass production (B) and yield (Y) when running a simulation. Results of simulation are stored in output files. However, the data can be retrieved in a spread-sheet format for further processing and analysis. Furthermore, program settings permit the user to change default settings and reset to an individual's default values once more.

Doorenbos and Kassam (1979) developed the AquaCrop model based on Equation 1 by using separating: the evapotranspiration (ET) into soil evaporation (E) and crop transpiration (Tr) and the final yield (Y) into biomass (B) and harvest index (HI). The separation of ET into E and Tr avoids the confusing effect of the non-productive consumptive use of water (E). This is important especially during incomplete ground cover. The separation of Y into B and HI allows the distinction of the basic functional relations between environment and biomass from those between environment and harvest index. These relations are fundamentally different and their use avoids the confounding effects of water stress on B and HI. The changes described led to the following equation (Equation 2.2) at the core of the AquaCrop growth engine.

$$B = WP \times \sum Tr \quad \text{Equation 2. 2.}$$

Where: - B is biomass,  $\Sigma$  is Summation, Tr is the crop transpiration (in mm), WP is water productivity parameter (kg of biomass per m<sup>3</sup> of water).

According to Steduto (2003), both equations (Equation 2.1 and 2.2) are different expressions of a water-driven growth-engine in terms of crop modelling design. AquaCrop is in the time scale used for each one. As presented in (Figure 2.1) the AquaCrop has the structure that contains the soil-plant-atmosphere continuum. It

includes the soil with its water balance, the plant with its development, growth and yield processes, and the atmosphere with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. Additionally, some management aspects are considering (e.g. irrigation, fertilization) as they affect the soil water balance and crop development

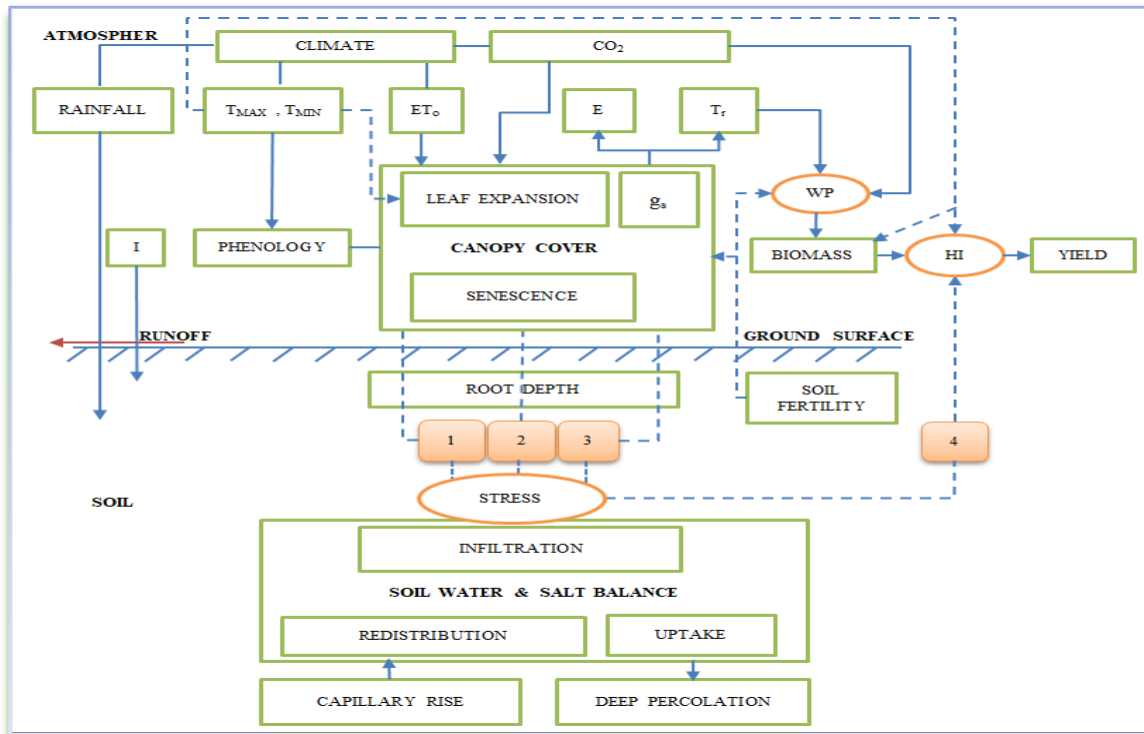


Figure 2.1 AquaCrop the main components of the soil-plant-atmosphere continuum and parameters (Allen et al., 1998)

The chart of AquaCrop showing the main components of the soil-plant-atmosphere continuum and the parameters are driving from phenology, canopy cover, transpiration, biomass production and final yield. Continues lines indicate direct links between variables and processes. Dotted lines indicate feedback. Symbols are: I, irrigation;  $T_n$ , Minimum air temperature,  $T_x$ , Maximum air temperature,  $ET_0$ , reference evapotranspiration; E, soil evaporation;  $T_r$ , canopy transpiration;  $g_s$ , stomatal conductance; WP, water productivity; HI, harvest index;  $CO_2$ , atmospheric carbon dioxide concentration; (1),(2),(3),(4), water stress response functions for leaf expansion, senescence, stomatal conductance and harvest index, respectively.

### **2.2.1. The Atmospheric environment**

The atmospheric environment of the crop is describing in the climate component of AquaCrop and deals with key input meteorological variables. Five weather input variables are required to run AquaCrop: daily maximum air temperature (Tmax) and minimum air temperatures (Tmin) (daily rainfall (R), daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo), and the mean annual carbon dioxide concentration in the bulk atmosphere. Reference evapotranspiration (ETo) is obtained following the procedures described in the FAO Irrigation and Drainage Paper 66 (Allen et al., 1998). In situations where not all the required input variables for calculating ETo are available, FAO paper 66 also describes the methods to derive them.

AquaCrop does not include the routines for calculating ETo, but a separate software program (ETo calculators) based on FAO Paper 66 is provided to the user for such purpose. Temperature (continues data set); rainfall and ETo may be provided at different time scales, specifically in daily, 10-days, and monthly records. At run time, AquaCrop capable to use and processes the 10-day and monthly records are changed into daily values. This flexibility for different time scales of weather input variables is required to use AquaCrop in areas of limited weather records (Raes et al., 2009; Steduto et al., 2009). The temperature plays a role in influencing the crop development (phenology); the rainfall and ETo are inputs for the water balance of the soil root zone, and the CO<sub>2</sub> concentration of the bulk atmosphere influences the crop growth rate and water productivity.

### **2.2.2. The Crop system**

In the AquaCrop model, the system has five major components and related to dynamic responses of the crop: phenology, aerial canopy, rooting depth, biomass production and harvestable yield. The crop grows and matures over its cycle by growing its canopy and extending its rooting system while at the same time the main developmental stages are established. During the crop cycle, crop responses to possible water stress, which can occur at any time, through three major feedbacks, reduction of the canopy expansion rate (typically during initial growth), acceleration of senescence (typically during completed

and late growth), and closure of stomata (typically during completed growth). Water stress may also affect the water productivity parameter (WP) and the harvest index (HI). The canopy, thus, represents the source for actual transpiration that gets translated in a proportional amount of biomass produced through the water productivity parameter (WP). The harvestable portion of such biomass (yield) is then determined via the harvest index (HI), as shown (Equation 2.3).

$$Y = B \times HI$$

*Equation 2. 3.*

Where: - Y is the yield, B is biomass, and HI is harvest index

Even though AquaCrop uses an HI parameter, it does not calculate the partitioning of biomass into various organs (e.g., leaves, roots, etc.), i.e., biomass production is from canopy expansion and root deepening. This choice avoids dealing with the complexity and uncertainties associated with the partitioning processes, which remain among the least understood and most difficult to model. The relationship between shoot and root is maintained through a functional balance between canopy development and root deepening.

The AquaCrop distinguishes four major crop categories because of their harvestable yields: - fruit or grain producing crops, root, and tuber producing crops, leafy vegetable producing crops and forage crops. Each of these crops types has its corresponding developmental stages. The genetic variation among species and cultivars may be recognized in the model through the variation in timing and duration of the various developmental stages, as well as through the rate of canopy expansion, rate of root deepening, the water productivity parameter and other response factors to environmental conditions. The canopy cover (CC) is a crucial feature of AquaCrop through its expansion, ageing, conductance and senescence, as it determines the amount of water transpired, which in turn determines the amount of biomass produced. The canopy expansion is expressed through the fraction of green canopy to ground cover. For non-stressed conditions, the expansion from emergence to full canopy development follows the exponential growth during the first half of the full development and follows an exponential decay during the second half. After the full development, the canopy can have a variable duration period before entering the senescence phase.

In AquaCrop the root system is simulated through its effective rooting depth and its water extraction pattern. The effective rooting depth ( $Z$ ) is defined as the soil depth where most of the root water uptake is taking place, even though some crops may have a few roots beyond that depth (Raes et al., 2009; Steduto et al., 2009). As previously indicated, the growth engine of AquaCrop is water-driven (Equation 2.2). The model does not simulate lower hierarchical processes expressing the intermediary steps involved in the accumulation of biomass. The underlying processes are “summarized” and synthetically incorporated into one single coefficient defined as biomass water productivity (WP). The basis for using (Equation 2.2) is the core of the model growth engine lies in the conservative behaviour of water productivity, WP (Steduto & Albrizio, 2005; Steduto et al., 2007).

The WP parameter of AquaCrop is normalized for  $ETo$  and the carbon dioxide ( $CO_2$ ) concentration of the bulk atmosphere, it may vary moderately in response to the fertility regime, and remains constant underwater deficits except when severe water stress is reached. The normalization of WP for climate makes the model applicable to diverse locations and seasons, including future climate scenarios. The model capable to simulate/ predict from the biomass ( $B$ ) as illustrated above (Equation 2.2). From which crop yield is derived by multiplying biomass ( $B$ ) with the harvest index, HI as (Equation 2.3). Starting from flowering, HI is simulated after a lag phase, by a linear increase with time for a given period during yield formation that depends on the crop species and cultivar. HI can be adjusted for water deficits depending on the timing and extent of the water stress during the crop cycle (Hsiao et al., 2009).

### **2.2.3. The Soil Component**

The soil component of AquaCrop is designed as a dispersed system of a variable depth allowing up to five horizons of different texture composition along with the profile. As a default, the model includes all the classical textural classes present in the USDA triangle, but the user can input their specific value. For each texture class, the model associates a few hydraulic characteristics, which can be estimated through pedo-transfer functions.

The hydraulic characteristics include the hydraulic conductivity at saturation and the volumetric water content at saturation, field capacity and wilting point (Raes et al., 2009; Steduto et al., 2009).

As for the soil profile explored by the root system, the model performs a water balance that includes the processes of runoff (through the curve number), infiltration, redistribution or internal drainage, deep percolation, capillary rise, uptake, evaporation, and transpiration. A daily step of soil water balance keeps track of the incoming and outgoing water fluxes at the boundaries of the root zone and the stored soil water retained in the root zone. A distinctive feature of the water balance in AquaCrop is the separation of soil evaporation (E) from crop transpiration (Tr) based on a modification of Ritchie's approach (Ritchie, 1972). In the simulation of AquaCrop includes the effects of mulches, withered canopy cover, partial wetting by localized irrigation, and the shading of the ground by the crop canopy.

#### **2.2.4. The field management**

The field management considers options related to the fertility level or regime to be adopted during the crop simulation, and to field-surface practices such as mulching to reduce soil evaporation, or the use of soil bunds to control surface run-off and infiltration. Four fertility levels are considered: - none- limiting, near-optimal, medium and poor fertility. These levels influence the water productivity (WP) parameter, the canopy growth development and its maximum canopy cover and the rate of decline in the green canopy during senescence. Thus, AquaCrop does not compute nutrient balances but offers the user some options to incorporate the anticipated fertility regime into the overall yield response (Hsiao et al., 2009).

#### **2.2.5. The irrigation management**

The water management are considered that the options of related to rain fed-agriculture, and irrigation where, after selecting the method (sprinkler, drip, or surface, either by furrow or flood irrigation). The user can define their schedule set based on the depth or timing criteria, or let the model automatically generates the scheduling based on a fixed interval, fixed depth, or fixed percentage of soil water content criteria. The irrigation

option is particularly suited for predicting the crop response under supplemental or deficit irrigation (Raes et al., 2009; Steduto et al., 2009).

### **2.3. The uses of AquaCrop model**

One important application of AquaCrop would be to compare the attainable against actual yields in a field or a region and to identify the constraints limiting crop production and water productivity. The AquaCrop model represents an effort to incorporate current knowledge of crop physiological responses into a tool that can predict the attainable yield of a crop based on the water supply available. The AquaCrop model can be used as a planning tool or assist in making management decisions, whether strategic or operative. It can also be very useful for scenario simulations and planning purposes for use by economists, water administrators and managers and invariably will help with land use capabilities of a country. It is suited for prospective studies such as those under climate change scenarios. Overall, it is particularly suited to develop agricultural water management strategies for a variety of objectives and applications (Raes et al., 2009; Steduto et al., 2009).

Aqua Crop is the simulation models that determine the effects of water on yield at the farm level, hence can be a valuable tool in irrigation management (Araya et al., 2010). It is a new decision-support tool used in modelling and formulating strategies for efficient management of crop water productivity at the farm level (Rinaldi et al., 2011). Aqua Crop can be used as a planning tool to assist in management decision making for both irrigation and rain-fed agriculture (Gabele, 2002). The model is particularly useful in developing irrigation strategies under water deficit condition (Parades et al., 2014). It can be used to study the effect on crop yield of various land management techniques, to compare the attainable against actual yields in a field, farm or a region, to identify the constraints limiting crop production and water productivity, and also to predict climate change impacts on crop production (Hsiao et al., 2007; Garcia et al., 2009).

### **2.4. Physiology and Growth Stage of Potato**

Potato is a cool-season crop with an optimal growth temperature between 17°C and 21°C (Struik and Ewing, 1995; Levy and Veilleux, 2007). Temperatures higher than optimum significantly affect several physiological traits of potato related to yield and

quality such as haulm (stalks or stems) growth, dry matter production and partitioning, tuber initiation and growth, photosynthetic rate, and the synthesis of hormones, enzymes, and other metabolites activities (Levy and Veilleux, 2007).

John (2007) reported that Potato plant has five growth stages (Figure 2.2): sprout development (I), plant establishment (II), tuber initiation (III), tuber bulking (IV), and tuber maturation (V). Timing and duration of these growth stages depend upon environmental factors: - such as elevation and temperature, soil fertility, moisture availability, cultivar and geographic location.

At growth stage I, sprouts develop from eyes on seed tubers and grow upward to emerge from the soil, roots begin to develop at the base of emerging sprouts, and the seed piece is the sole energy source for growth during this stage.

At stage II, leaves and branches develop on emerged sprouts; roots and stolon develop below ground and photosynthesis begin. Potato development in stages I and II lasts from 30 to 70 days, depending on planting date, physiological age of the seed tubers, cultivar, soil temperature, and other environmental factors.

At stage III, tubers form at stolon tips but are not yet appreciably enlarged, and in most cultivars, the end of this stage coincides with early flowering with an average duration of roughly two weeks.

At stage IV, tuber cells expand with the accumulation of water, nutrients, and carbohydrates. During the tuber bulking stage, tubers become the dominant site for carbohydrate and inorganic nutrient storage.

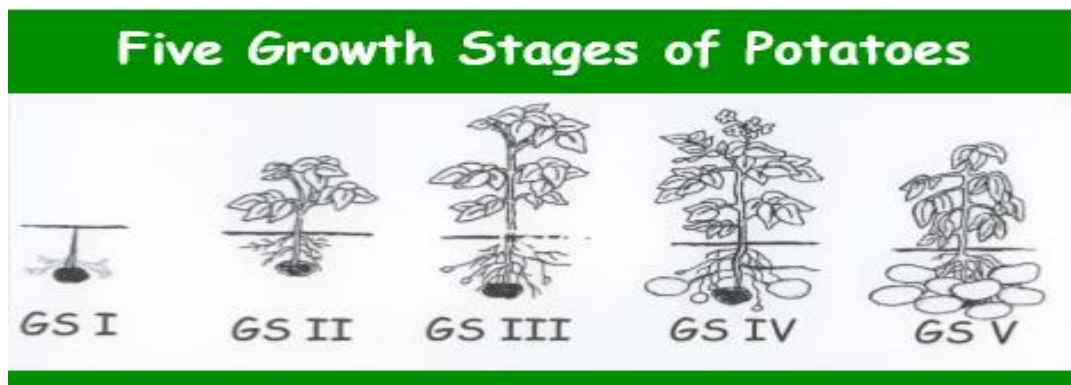


Figure 2.2. Potato growth stage; reprinted from potato production system (John, 2007)

Tuber bulking can continue up to three months as a function of the cultivar and environmental conditions. During stage (V), photosynthesis gradually decreases, leaves turn yellow, tuber growth rate slows, and the vines die. The total growing season of crops is usually divided into four stages (excluding sprout development). These are an initial stage, which includes the time from sowing to 10% ground cover; development stage, which is from 10% to 70% ground cover; mid-season stage including flowering and tuber formation, and late-season stage including ripening harvest. In general FAO 33 document Doorenbos and Kassam (1979) stated that, out of the four growth stages, the mid-season stage is the most sensitive to water shortages. This is mainly because it is the period of the highest crop water needs. Hence, if water shortage occurs during this stage, the negative effect on yield will be pronounced. To see the effect of limited water application on yield and production, consideration must be given to the effect of the limited water application during the individual growth periods of the crops.

## **2.5. Potato Crop Evapotranspiration and Irrigation Requirements**

Determination of crop water requirements and crop irrigation requirements can be carried out from basic information from the crops selected and should include, average planting date and average harvesting data (FAO, 1996). Standard information on crop coefficient, rooting depth, depletion level, and yield response factors, and length of individual growth stages are also needed.

The water requirements are different from one crop to another. Although growing crops are continuously using water, the rate of water use depends on (1) the kind of crop, (2) the degree of maturity and (3) atmospheric condition, such as radiation, temperature, wind, and humidity. The rate of growth at different soil water contents varies with different soils and crops. During the early stages of growth, the water needs are generally low, but they increase rapidly during the maximum growing period to the fruiting stage. During the later stages of maturity, water use decreases as the crops ripen (Schwab et al., 1995).

Crop consumptive water use is the amount of water transpired by the plants and the water evaporated from the soil plus the fraction of water held by the plant tissues. The amount of water retained by plant metabolic activity is about 1% of the overall water taken up by the plants. Thus, in practical terms, crop water consumption corresponds to crop evapotranspiration (ET<sub>c</sub>). Potato's ET<sub>c</sub> can be estimated using weather data and is

the amount of water to be replenished during the growing season to assure potential tuber yields at a given site. Potato's ETC is important to consider in irrigation planning and its use in irrigation scheduling is a well-developed irrigation strategy. The seasonal water requirements of a potato crop with a phenological cycle varying from 120 to 150 days ranged from 500 to 700 mm, depending on climate (Doorenbos and Kassam, 1979).

## **2.6. Tuber Yield of Potato**

Tuber yield and stomatal conductance of potato showed differential responses to water stress imposed during different growth stages (Pejic et al., 2015). Drought conditions both pre-flowering and post-flowering stages have the most adverse effect on yield. Water stress diversely affects various developmental stages and ultimately affects the yield (King et al., 2003). The fresh potato yield recorded in Ethiopia is 29.1 ton/ha under optimum conditions (Tesfaye et al., 2013). Another study obtained on fresh potato tuber yield 39.08 ton/ha and 56.85 ton/ha at Hirna, Haramaya respectively (Birhanu, 2016).

In comparison with other species, potato is very sensitive to water stress because of its shallow root system: approximately 85% of the root length is concentrated in the upper 0.3-0.4 m of the soil (Wang et al., 2006; Iwama, 2008). It is also sensitive to the changes in the soil moisture content and the decrease of water (water stress), leading to a significant reduction in tubers quantity and quality. The requirement for water irrigation of potato plants vary in different plant growth stages; tubers initiation and tubers bulking are the more sensitive stages in the plant growth life (Abd-allah et al., 1996).

King et al (2003) reported that the effect of various periods of water stress on irrigated potato tuber at vegetative stages. Their report indicated that when potato plants will be exposed to water stress from moderate (10-days) to severe (14-days), did not affect tuber yield and vegetative stages. Whereas, the stress at the tuber bulking stage might interfere with the process of starch (dry matter) accumulation and contribute to the yield losses from 7% to 14%, respectively.

During the vegetative stage of potato, total rainfall is insignificantly positive correlated with yield (Abdulhamid, 2011). Phillips et al (2009) found that the plants were the most sensitive to drought at maturity stage, which was probably due to their higher transpiration rates. Hamid et al (2012) investigated the Effect of Cutting off Irrigation

during different growth stages on agronomic traits in potato varieties in Iran, and reported that cutting/stop irrigation at reproductive stage reduced the yield than cutting/stop irrigation at vegetative stage. Table 2.1 shows four categories of crops based on the sensitivity of the crops to drought (Brouwer *et al.*, 2001).

Table 2.1. Sensitivity of Various Field Crops to Water Shortages

<b>sensitivity</b>	<b>low</b>	<b>Low to medium</b>	<b>Medium to high</b>	<b>high</b>
<b>Crops</b>	Cassava	Alfalfa	Beans	Banana
	Cotton	Citrus	Cabbage	Fresh green
	Millet	grape	Maize	Vegetable
	Pigeon	Groundnut	Onion	Paddy rice
	pea	Soybean	Peas	Potato
	sorghum	Sugar beet	Pepper	sugarcane
		wheat	Tomato	
			watermelon	

## 2.7. Potato Yield Response to Water Factor and Water Productivity

Yield response to water depends on many factors and may vary from region to region. Yields are frequently constrained by drought in most environments. Drought stresses affect the development and growth of shoots, roots, and tubers (Lahlou *et al.*, 2003). The actual evaluation of stress related to the yield due to soil water deficit during the growing season can be obtained by the estimation of the yield response factor ( $K_y$ ) that represents the relationship between a relative yield decrease ( $1 - Y_a/Y_m$ ) and a relative evaporation deficit ( $1 - ET_a/ET_m$ ) (Stewart, *et al.*, 1977). For  $K_y \leq 1$  the plant is tolerant, for  $K_y \geq 1$ , the plant is sensitive to water stress.

Doorenbos *et al.* (1986) estimated that the average value of  $K_y$  is 0.7 during the potato's growing season. The upper limits for a yield of potato are setting by soil fertility,

climatic conditions and management practices (Bauder et al., 1988). Where all of these are optimal throughout the growing season, yield reaches the maximum value as does evapotranspiration (ET<sub>m</sub>) water storage (SWS) has an impact on water availability (WA) for a crop and, subsequently, on actual yield and actual evapotranspiration (ET<sub>a</sub>) (English, 1990).

Potato crops are sensitive to the alteration in the soil moisture content. Because of the soil moisture is one of the important factors affecting the quantity and quality of tubers yield and any decline or un uniformity in irrigation (water stress), especially during initiation and growth phases of tubers resulted in a significant damage to plants, and decrease the quantity and quality of tubers yield (Bao-Zhong et al., 2003).

Water productivity is the amount of beneficial output per unit of water depleted. In its broadest sense, it reflects the objectives of producing more food and the associated income, livelihood and ecological benefits, at a lower social and environmental cost per unit of water used (Molden et al., 2007). Usually, water productivity can be defined concerning the different sectors of production involving water (e.g. crop production, fishery, forestry, domestic and industrial water use). Water productivity concerning crop production is referred to as crop water productivity (CWP) and is defined as the amount of crop produced per volume of water used (Kadigi et al., 2004). So, increasing water productivity can be an important pathway for poverty reduction, especially in the developing countries, where the variability of water productivity very high, according to a specific condition under which the crop is grown (Haileslassie et al., 2009a).

Improving agricultural water productivity is about increasing the production of rain-fed or irrigated crops. Crop water productivity has been the subject of many years of research and its assessment and means for improvement are well documented (Molden, 2007; Rockström and Barron, 2007). Opportunities for improving crop water productivity mainly lie in choosing adapted, water-efficient crops, reducing unproductive water losses and ensuring ideal agronomic conditions for crop production (Kijne et al., 2003).

## **2.8. Potato Production in Ethiopia**

Following the introduction of the potato to Ethiopia in 1858 by a German immigrant, Wilhelm Schimper, adoption by Ethiopian farmers occurred very gradually for several decades (Kidanemariam, 1980). The first available potatoes were probably of a very limited genetic base, hence vulnerable to diseases and pests. In Ethiopia, the main production season for potato is June to September ('Meher') at altitudes higher than 2,500 m mean above sea level. The off-season production in Ethiopia at higher elevations is January to May ('Belg'). However, one should keep in mind that, nowadays, the main production season for potato represents only 22 % (34,000 ha), while the off-season production is around 128,000 ha of area coverage. The reason for a gradual shift from 'Meher' to 'Belg' is the fact that the late blight pressure is increasing and farmers experience less risk with cultivation during the "small" rains combined with irrigation (Birhanu, 2014). The average potatoes production is low including the potential area in the country (i.e. at a higher altitude than favourable climate condition for potato tuber formation (EHDA, 2011).

### 3. MATERIAL AND METHODS

#### 3.1. Description of the Study Area

This study was conducted at Debre Birhan Agricultural Research Centre (DBARC) experimental site located in North Shewa Administrative Zone, Amhara National Regional State, Ethiopia (Figure 3.1). The location point is 09° 36' 30.5" North, 39 ° 30' 29.8" East and it has a mean elevation of 2815 m above mean sea level. It is at about 121 km north of Addis Ababa and 9 km far from Debre Birhan town in the direction of South.

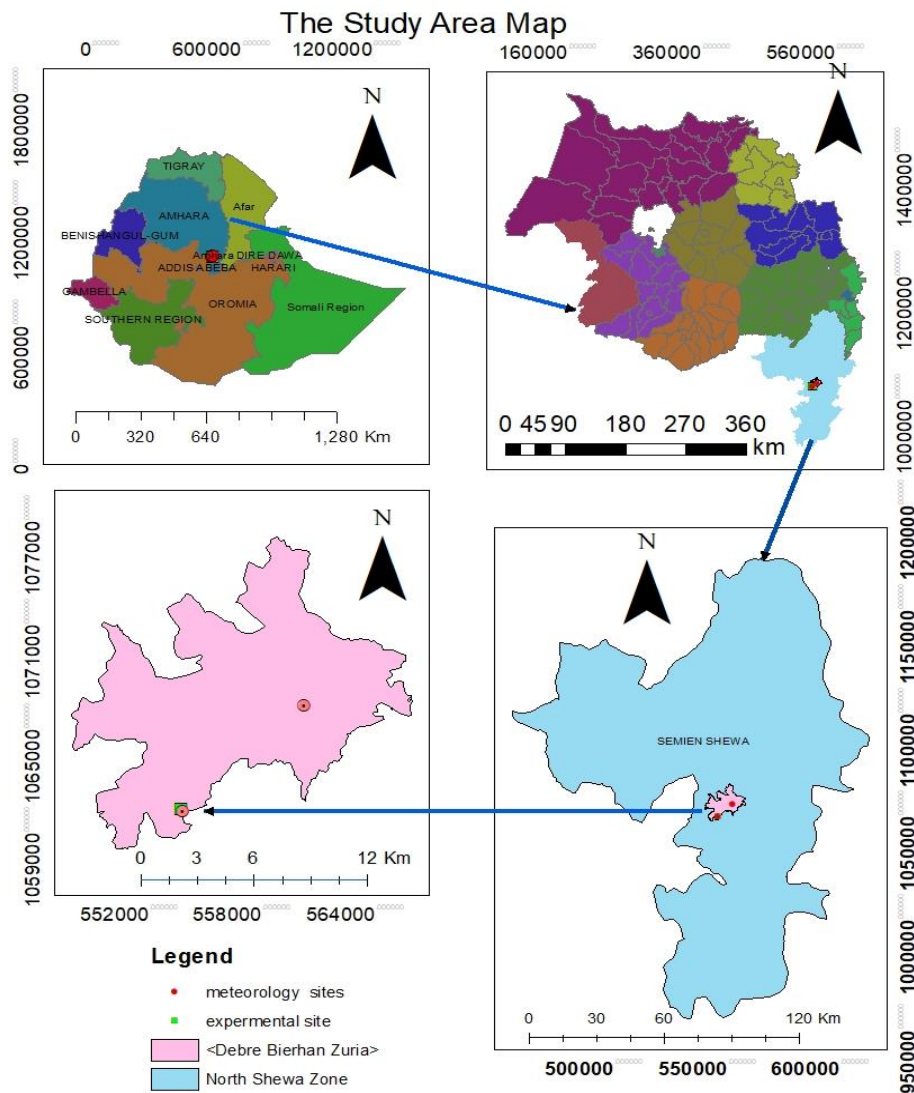


Figure 3.1. Location map of the experimental site

## **3.2. Data Collection and Analyses**

### **3.2.1. Irrigation water requirement determination using AquaCrop**

For determination of the amount of irrigation water applied for potato crop the various input data (climatic data, soil data, and crop data) were used to simulate the specific area or location using the AquaCrop model. The four components of data input files were created in the AquaCrop model namely: - climate file, crop file, soil file and management file was listed below briefly.

#### **3.2.1.1. Created a climate file**

The following files were created on daily climate file: Temperature file, ETo file, Rain file and carbon dioxide. Historical climate data (40 years 1979-2018) were used for simulation the AquaCrop model which obtained from two principal stations 9 km far apart to each other (DBARC and Debre Birhan town) (Appendix Figure 1) to fill the gap for temperatures and rainfall. While, for other parameters (wind run, sunshine duration and relative humidity) were used -999 for missed value and the model recognize it. For the CO<sub>2</sub> file was determined automatically adjusted by AquaCrop software by using the reference of the 2000-year 369.55 ppm and increment about 2 ppm ( $y=1.8034x-3234.9$  with  $R^2 = 0.9905$ ) every year (See appendix figure 2). This CO<sub>2</sub> concentration data from international rice research institute (IRRI) the model was IPCC: RCP 8.5. After inputted these climatic data the model created an ETo, rain, temperature and CO<sub>2</sub> file. Examples of how to select the climatic file in AquaCrop model (Figure 3.2).

#### **3.2.1.2. Created crop file**

For created crop file first marked the file name and described the crop type that was potato crop under root and tuber crop, and then specified parameters. The AquaCrop generated the complete set of required crop parameters from the agronomic perspective of the crop nature in that specific location. As presented an Appendix Table 5 and 6 the parameters were displayed and the values of non-conservative parameters and generated the model for conservative parameters. Example how to select the crop files in AquaCrop model (Figure 3.3).

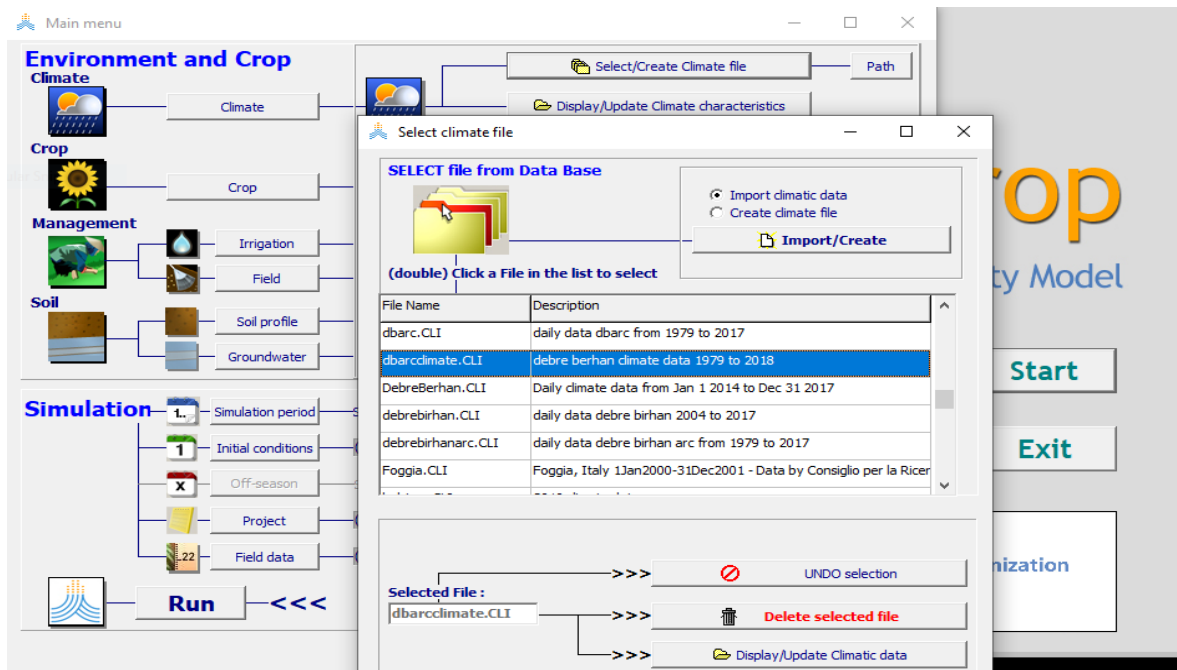


Figure 3.2. Illustrations of creating the climatic file

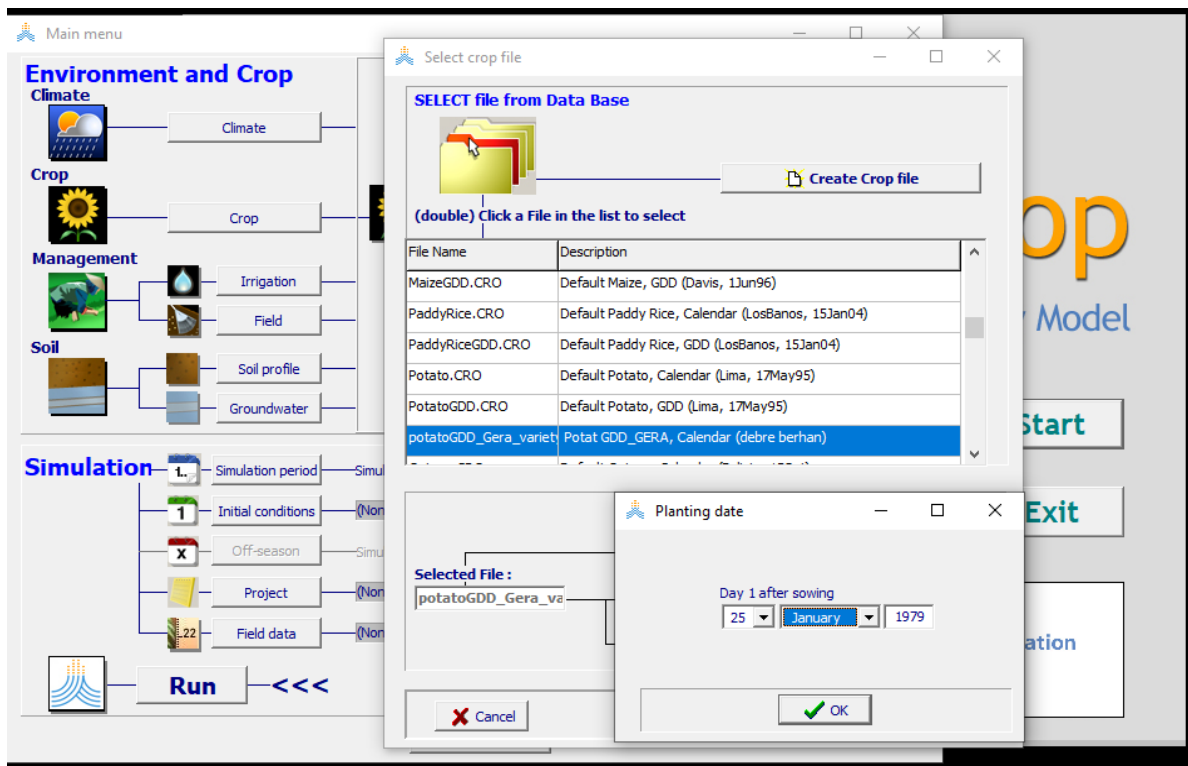


Figure 3.3. Show how to creating crop files

### **3.2.1.3. Created soil file**

In creating a soil file, the user has to specify only a few characteristics like soil type, depth of soil, texture, etc. With the assistance of this information, AquaCrop generated the complete set of soil parameters. The parameters were displayed and the values adjusted or modified in the soil profile characteristics menu. The soil physical characteristics such as field capacity, permanent wilting point bulk density and textural classes of the experimental sites already available in hand from previous studies in the study area (Ashenafi et al., 2006) see Appendix Table 2.

### **3.2.1.4. Created management file (irrigation schedule)**

For created an irrigation schedule, the user specifies the time and application depth of the irrigation events. The volume of water applied for 100 % ET<sub>c</sub> irrigation treatments were determined after several simulation of the AquaCrop model run by running several times (by trial and error) during simulating time , then accordingly for other water level treatments was determined as per their percentages and created each.

The Values of crop coefficients (K<sub>c</sub>) was used from FAO, Irrigation and Drainage Paper no 24 paper (Doorenbos and Pruitt, 1979). The coefficient of each irrigation treatment was K<sub>s</sub> (1) = 100% of ET<sub>c</sub> no stress, K<sub>s</sub> (0.85) = 85% of ET<sub>c</sub>, K<sub>s</sub> (0.70) = 70% of Etc, and K<sub>s</sub> (0.55) = 55% of ET<sub>c</sub>. The irrigation Water was applied for all treatments on the same day as that of fully irrigated plot (T<sub>1</sub>). The irrigation depths were varied as their percentage 85%, 70%, and 55%, of the full irrigation for T<sub>2</sub>, T<sub>3</sub> and T<sub>4</sub> treatments respectively. The seasonal amount of irrigation water from each treatment was recorded. In full irrigation, treatment (100%) the AquaCrop model was adjusted at 35% root zone depletion and refill to the field capacity. Before starting, the treatment there was applied equally for all treatment every 5-day interval. For other water levels irrigate at the same time as full irrigation but the amount was varied as their percentage showed as Appendix Table 1 and Figure 4.1. The irrigation method was used with a garden hose from water tanker on the average the rate of 0.20833 lit/sec. During rainfall, the irrigation water was applied after calculating the effective rainfall using the AquaCrop model.

### **3.2.2. Determination of the response of potato on different water levels**

#### **3.2.2.1. Experimental material**

The experiment was carried out in one dry season of 2019 in field. The experimental material was used potato crop (Gera) variety released by Sheno Agricultural Research Centre in 2002. The variety grown with an altitude range 2700- 3200 m above mean sea level. The seed tuber obtained from DBARC and planted at 10 cm depth the spacing was 30cm and 75cm between plants and rows, respectively. Planting was done on 25 January 2019 G.C.

Land preparation, planting date, weeding, fertilizer application and method, earthing up/heap and other agronomic practices of the crop were carried out as per the recommendation of the Debre Birhan Agricultural Research Centre. The current fertilizer recommendation for potato crop (210 kg Urea and 150 kg/ha NPS) was applied as drilled in the row. Urea was applied in a split form (the half at planting and the other half at flowering). Early blight protected with Ridomil Gold 68 WG, was applied two times every 14-day interval with the rate 2.5kg/ha. Weeds were removed by hand fork as soon as they appeared.

The water levels; 100%, 85% 70% and 55% of crop water requirement (ETc) was applied through a garden hose at a rate of 0.20833 lit/sec flows directly in the furrow. Full irrigation treatment (100% ETc) was used for calibration and the rest of them will be used for the purpose validating the AquaCrop model.

#### **3.2.2.2. Set the experimental design, treatments and field layout**

The experiment was arranged in Randomized Complete Block Design (RCBD) within five irrigation treatments. The treatments were presented in Table 3.1. The plot size was used 3 m x 3.75 m = 11.25 m<sup>2</sup> area and total experimental area 19.5 m \*15.0 m = 292.5 m<sup>2</sup>. And 1 m and 1.5 m apart between plots and blocks respectively.as shown in (Figure.3.4).

Table 3.1. Experimental treatments

<b>Treatment</b>	<b>Water levels</b>
<b>T 1</b>	100% of ET <sub>c</sub> , i.e. full
<b>T 2</b>	85% of ET <sub>c</sub> , i.e. 15% deficit
<b>T 3</b>	70% of ET <sub>c</sub> , i.e. 30% deficit
<b>T 4</b>	55% of ET <sub>c</sub> , i.e. 45% deficit

### **3.2.2.3. Field Data collection**

The actual field data was collected from each treatment to determine the responses of potato growth parameter and tuber yield.

#### **3.2.2.3.1. Rainfall data**

Daily rainfall data was collected from DBARC meteorological station located near the experimental field to maintain the amount of irrigation water was applied. The effective rainfall was calculated with AquaCrop crop software model by subtracting the runoff from rainfall using USDA Soil Conservation service (USDA, 1964).

#### **3.2.2.3.2. Soil data collection**

Composites soil samples were taken randomly from the top, middle, and bottom portion of the experimental field. The samples were taken using soil auger at a depth of 0-20 cm. Additional soil samples were taken from one pit profile up to the depth 1.2 m with 30 cm depth interval and air-dried. Soil aggregates were crushed with mortar and pestle. Then sieved 2 mm sieve diameter. Finally, the data analyses at Debre Birhan and Debre Zeit research centers soil laboratories.

#### **Soil Texture**

The soil textural class was determined using a hydrometric method of analysis. First the soil samples were air-dried and ground using pestle and mortar, and then sieved using 50 and 250-micron size sieves. Then after 25 g of soil weighted and 50 ml dispersing agents (40 g Sodium Hexametaphosphate,  $\text{NaPO}_3$  and 10 g of Sodium Carbonate,  $\text{Na}_2\text{CO}_3$ ) was mixed with distilled water in 200 ml bottle, and then shake with horizontal shaker for two hrs. Then after 24 hours, the samples were transferred to a mechanical stirrer, and shake for 5 minutes. Then transfer to the hydrometric jar by adjusting with distilled water to the volume until 500 ml then disturb the soil with a hand back and forth for about 20 times then put on table to settle and reading was taken after 40 seconds and 2 hours (Appendix Figure 5). The results were corrected to 20°C for temperature and two units subtracted from every hydrometric reading for salt correction. The results were calculated according to the national soil research center for Ethiopian agricultural research organization (ISRIC, 2000). The calculation is done with Equation 3.1 to 3.3.

$$\text{Sand\%} = 100 - \left[ (d1 \pm C1 - 2) \times \frac{100}{25} \right] \quad \text{Equation 3.1}$$

$$\text{Clay\%} = (d2 \pm C2 - 2) \times \frac{100}{25} \quad \text{Equation 3.2}$$

$$\text{Silt\%} = 100 - (\text{Sand\%} + \text{Clay\%}) \quad \text{Equation 3.3}$$

### **Soil pH and electric conductivity (EC)**

A 10 gram of air-dried soil was weighted into a 100 ml beaker to which 25ml of distilled water was added (1:2.5) soil/water ratio. Then transfer the sample to an automatic stirrer, then stir each sample well, take out the glass rod, or remove the sample from the automatic stirrer, wait for about 1 minute for the soil particles to sediment and introduce the electrode into the suspension. Wait 3-4 seconds before turning the selector knob from stand by to “pH”. Wait for the reading to stabilize and record the readings. The electrode of the pH meter was inserted into the partly settled suspension and pH value was recorded (Van Reeuwijk, 1992). After taking reading for all samples, rinse the electrodes well, and lower them into a 100ml beaker containing distilled water. This process was repeated for each sample. As well for EC, the Electrical conductivity meter was used for detecting the electric conductivity of the soil in dS/m that sampling preparation similar to pH.

### **Organic Carbon (OC)**

To determine the organic carbon content, 0.5 g of soil sample was weighted and added into a 500 ml Erlenmeyer flask. Exactly 10 ml of 1.0 N Potassium Dichromate solution was added from a burette, followed by 20 ml of concentrated H<sub>2</sub>SO<sub>4</sub>. The mixture was then swirled confirming that the solution was in contact with all the particles of the soil. The flask and content were then allowed to cool on an asbestos sheet for 30 minutes. 100 ml-distilled water was added, followed by 5 ml Orthophosphoric acid. It was left to cool after which 5 ml of Diphenylamine indicator was also added. Titration was done with 5N Ferrous Sulfate solution until the colour changed to blue and then to a green endpoint. Titer values were recorded. A sample blank was also determined in a similar manner and the endpoint determined (> 10.5). Percentage organic carbon was calculated as (Equation 3.4).

$$OC = \frac{S(B - T) \times 0.39}{\text{Weight of sample}} \times 100$$

*Equation 3.4*

Where: - S refers to molarity of Ferrous Sulfate, B is the titer value for blank and T is the titer value for the sample (Nelson and Sommers, 1996).

### **3.2.2.3.3. Soil moisture content**

The soil water dynamics was engaged at the wetted and drying cycle in the depth of 0-20 cm that monitored and taken through gravimetric method immediately before and after one day of each irrigation events for various treatments at every 10-day intervals. To determine the soil moisture content the sample was taken and weighed immediately and then put an oven for 24 hours at 105 °c then check dry weight until to get the constant value.

### **3.2.2.3.4. Crop data collection**

Samples of two plants from each experimental plot were taken to determine growth parameters every 10-days interval. The crop parameter includes the day after planting of; emergence, maximum canopy cover, senescence, and physiological maturities, maximum effective root depth..., were collected from each experimental plot which are the parameters to be needed the AquaCrop model.

- Emergence date: - The number of days from planting up to 10% of the plants emerged.
- Time to reach maximum canopy cover: - The time required reaching maximum canopy cover.
- Time to reach canopy senescence: - The time at which senescence of leaves starts
- Time to reach maximum rooting depth: - Determined after measuring root length at a series of times (at every irrigation time).
- Days to maturity: - The number of days from planting to the stage of the majority of the plants in a plot has changed the colour from green to yellow.
- Plant height (m): - It was measured at every irrigation time randomly from 10 plants.

- Canopy Cover: - An overhead digital camera was captured at 1-meter height from ground the canopy cover (every irrigation time). Then the captured picture was analysed through mobile application (canopy cover free) (Raes et al., 2009; Steduto et al., 2009).
- Dry biomass (t/ha): - The dry aboveground biomass was measured by taken two plants per plot as destructive sampling every 10 days weighted after air-drying the fresh samples and further oven drying at 65 °C for 72 hours at every irrigation time (Tekalign and Hammes, 2005).
- Root length (m): - From each treatment, two plants were randomly selected and effective main roots were measured at every irrigation time.
- Total dry tuber yield (t/ha):- The data was taken from two uprooted plant randomly at every irrigation time from each treatment by leaving the middle four rows as harvest yield. Then, the fresh biomass and oven dry (at 65 C<sup>0</sup> for 72 hours)' was weighted.

#### **3.2.2.4. Statistical analyses**

The results were subjected to the analysis of variance (ANOVA) procedure, using SAS 9.0 statistical software. To investigate whether there was a statistical difference in the parameter studied (canopy cover, water content, and water productivity, and yield and yield components) or not. The mean comparisons were done using LSD test due to small number of treatment involved and comparison was done among the treatment of water level at a probability level of  $p < 0.05$  for separation of means (Russel, 1990).

#### **3.2.2.5. Water productivity (WP)**

WP is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management. In a crop production system, WP is used to define the relationship between crop production and the amount of water used in crop production, expressed as crop production per unit volume of water (Raes et al., 2009). In this study, WP was determined the ratio between the final fresh tuber yields (Y) and applied amount of water (ETc) see (Equation 3.5).

$$WP = \frac{Y \text{ (kg)}}{ETc \text{ (m}^3\text{)}} \quad \text{Equation 3.5}$$

### **3.2.3. Performance evaluation of the AquaCrop model**

#### **3.2.3.1. Model simulation procedure**

After all, input data encoded - climatic, crop, management, and soil characteristics that described or defined the environment in which the crop was developed. The user can track changes in the soil water and corresponding changes in the crop development, soil evaporation, transpiration, biomass production and yield, when running a simulation. Results of the simulation were stored in output files in spread-sheet format to retrieve the data for further processing and analysis. Furthermore, program settings permit the user to change default settings and reset to individual's default values once more.

#### **3.2.3.2. AquaCrop model calibration and validation procedures**

Different scholars presented the AquaCrop model calibration and validation well performed for several crops were presented (Farahani et al., 2009; Garcia et al., 2009; Geerts et al., 2009; Hsiao et al., 2009; and Heng et al., 2009). The observed data set from the non-water stress conditions (that is full 100% ET<sub>c</sub> irrigation treatment) used for model calibration. The observed crop characteristics namely; time to emergence, time to attain maximum canopy cover, time to flowering, and senescence and physiological maturity (in calendar days) were used. After the calibration process, the model was validated from separated other treatment data except for 100% ET<sub>c</sub> (Yibrah et al., 2015; Zeleke, et al., 2011). The parameters were presented on appendix 5 and 6 for non-conservative and conservative parameters respectively.

##### **3.2.3.2.1. Performance evaluation and validation of the AquaCrop model**

Performance evaluation was done through validation of Aquacrop model: - canopy cover (CC), biomass yield and water use efficiency (WUE) by comparing predicted outputs against the observed data that was obtained from the experimental plot (Figure 3.6). The performance indicators were used in the following statistical techniques.

##### **3.2.3.2.2. Coefficient of determination ( $R^2$ )**

The coefficient of determination  $R^2$  is defined as the squared value of the Pearson correlation coefficient.  $R^2$  signifies the proportion of the variance in measured data explained by the model, or can also be interpreted as the squared ratio between

covariance and the multiplied standard deviations of the observations and predictions. It ranges from 0 to 1, with values close to 1 indicating a good agreement, and typically values greater than 0.5 was considered acceptable in watershed simulations (Moriasi et al., 2007), as illustrated in (Equation 3.6).

$$R^2 = \left[ \frac{\sum (o_i - \bar{o}_i)(p_i - \bar{p}_i)}{\sqrt{\sum (o_i - \bar{o}_i)^2 (p_i - \bar{p}_i)^2}} \right]^2 \quad \text{Equation 3.6}$$

Where: -  $R^2$  is Coefficient of determination,  $P_i$  is Predicted value,  $O_i$  is observed value,  $\bar{O}_i$  is mean of  $O_i$  and  $\bar{P}_i$  is mean of  $P_i$ .

A major drawback of  $R^2$  is that only the dispersion is quantified, which means that a model which systematically overestimates (or underestimates) the observations can still have a good  $R^2$  value. In the context of atmospheric sciences, coefficients of determination ( $R^2$ ) were insufficient and often misleading when used to evaluate model performance.

### 3.2.3.2.3. Root Mean Square Error (RMSE)

The Root Mean Square Error (RMSE) is one of the most widely used statistical indicators given as functions of the difference between predictions and observations. It ranges from 0 to 1 the value 0 indicating good and the value 1 indicating poor model performance. A big advantage of the RMSE is that it summarizes the mean difference in the units of Predicted and observed. It does, however, not differentiate between over and underestimation. Root mean square error (RMSE) will be calculated (Loague and Green, 1991), as illustrated in (Equation 3.7).

$$RMSE = \frac{\sqrt{\sum (p_i - o_i)^2}}{N} \quad \text{Equation 3.7}$$

Where: -  $P_i$  is Predicted value, ( $O_i$ ) is observed value, and  $N$  is number of observations

A disadvantage of RMSE is the fact that the residual errors are calculated as squared values. The higher values in a time series data are given a larger weight compared to lower values overly sensitive to extreme values or outliers of the residual variance is

squared.

#### 3.2.3.2.4. Normalized Root Mean Square Error (NRMSE)

Because RMSE is expressed in the units of the studied variable, it does not allow model testing under a wide range of metro-climatic conditions (Jacovides et. al., 1995). Therefore, RMSE can be normalized using the mean of the observed variable ( $O_i$ ). The Normalized RMSE expressed in percent, was determined as (Equation 3.8) (Loague and Green, 1991). A model can be considered excellent if NRMSE is smaller than 10%, good if between 10 and 20%, fair if between 20 and 30% and poor if larger than 30 (Yibrah, 2015).

$$NRMSE = \frac{1}{\bar{O}_i} X \frac{\sqrt{\sum (p_i - o_i)^2}}{N} X 100 \quad \text{Equation 3.8}$$

Where: -  $P_i$  is predicted value, ( $O_i$ ) is observed value, and  $N$  = number of observations  
 $\bar{o}_i$  is mean of  $O_i$ .

#### 3.2.3.2.5. Nash-Sutcliffe Coefficient of Efficiency (NSE)

The Nash-Sutcliffe coefficient of efficiency coefficient (NSE) determines the relative magnitude of the residual variance compared to the variance of the observations. A plot of observed data versus simulated data is that to fits the 1:1 line indicates a perfect match between the model and the observations. NSE was as accurate as of the average of the observed data. A negative NSE occurs when the mean of the observations is a better prediction than the model. (Yibrah, 2015) The Nash-Sutcliffe coefficient of efficiency coefficient (NSE) calculated as (Equation 3.9). NSE is very commonly used, which means that there are a large number of reported values available in literature (Moriasi et al., 2007). However, like  $R^2$ , NSE is not very sensitive to systematic over-or underestimations by the model (Krause et al., 2005).

$$NSE = 1 - \frac{\sum (o_i - p_i)^2}{\sum (o_i - \bar{o}_i)^2} \quad \text{Equation 3.9}$$

Where: -NSE is Nash-Sutcliffe Coefficient of Efficiency,  $P_i$  is a predicted value,  $O_i$  is observed value, and  $\bar{o}_i$  is mean of  $O_i$ .

### 3.2.3.2.6. Willmott's index of agreement (d)

The index of agreement was proposed by Willmott (1982) to measure the degree to which the observed data are approached by the predicted data. It represents the ratio between the mean square error and the “potential error”, which is defined as the sum of the squared absolute values of the distances from the predicted values to the mean observed value and distances from the observed values to the mean observed value. It overcomes the insensitivity of  $R^2$  and EF to systematic over or underestimations by the model (Legates and McCabe, 1999; Willmott, 1984). It ranges between 0 and 1, with 0 indicating no agreement and 1 indicating a perfect agreement between the predicted and observed data: illustrated (Equation 3.10). A disadvantage of Willmott's (d) is that relatively high values may be obtained (over 0.65) even when the model performs poorly. The intentions of (Willmott, 1982) d is still not very sensitive to systemic over or underestimations (Krause et al., 2005).

$$d = 1 - \frac{\sum (p_i - o_i)^2}{\sum (|p_i - \bar{o}_i| + |o_i - \bar{o}_i|)^2} \quad \text{Equation 3.10}$$

Where: - d is Willmott's index of an agreement;  $P_i$  is predicted value  $O_i$  is observed value, and  $\bar{O}_i$  is mean of  $O_i$ .

After all fundamental parameters fulfilled simulation results were obtained based on the (Equation 2.2) (Steduto et al., 2007). The harvestable portion (yield) is then determined via the harvest index HI (Equation 2.3)

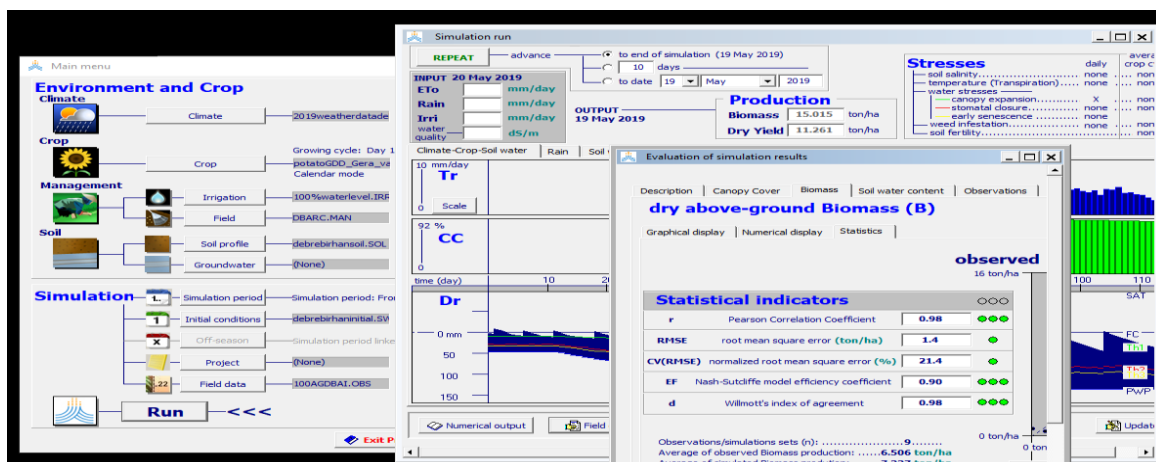


Figure 3.4. Examples of how to show the output of validating statistical efficiency

## 4. RESULTS AND DISCUSSION

### 4.1. Results of the Amount of Water for Potato on AquaCrop Model

As presented in Appendix Table 1 and Figure 4.1 the amount of irrigation water used for every 10-day was determined. The AquaCrop model simulated results showed that for 100% was 377.2 mm/m growing season used in growing season. For the rest of other water levels used as corresponding of their percentage of the 100% water level (345.79 mm/m, 314.38 mm/m and 282.98 mm/m of water used for 85%, 70% and 55% of water level respectively). The results agreed with the previous study of the water requirement of potato during the growing season in India ranges 350.0 mm/m to 650.0 mm/m (Sood and Singh, 2003). Another study results presented that for potato crop ranges 357.3 mm/m to 511.4 mm/m in Iraq (Ati, et al., 2012). The data label represented for 100% water level.

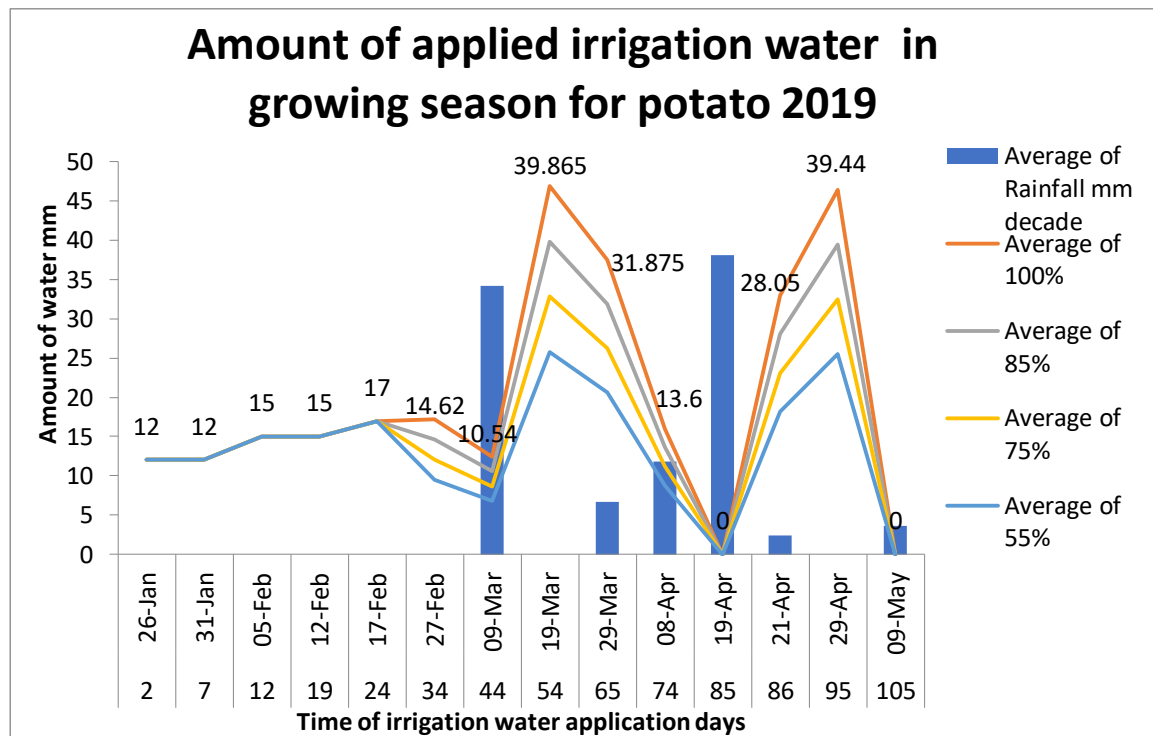


Figure 4.1. Amount of irrigation water applied and rainfall mm in growing season

## 4.2. Response of Potato on Irrigation Water Levels

### 4.2.1. Effects of irrigation water levels in soil water content

Appendix Table 3 and 4 show the soil water content influenced by different water levels corresponding to days after planting both before and after irrigation. The results were laid between the field capacity and permanent wilting point (Figure 4.2). Soil moisture content was no significant differences among the water levels from the initial soil moisture content until to 34<sup>th</sup> day after planting (DaP). While there were a highly significant differences among the various irrigation water levels, after the 35<sup>th</sup> day after planting (DaP) to maturity.

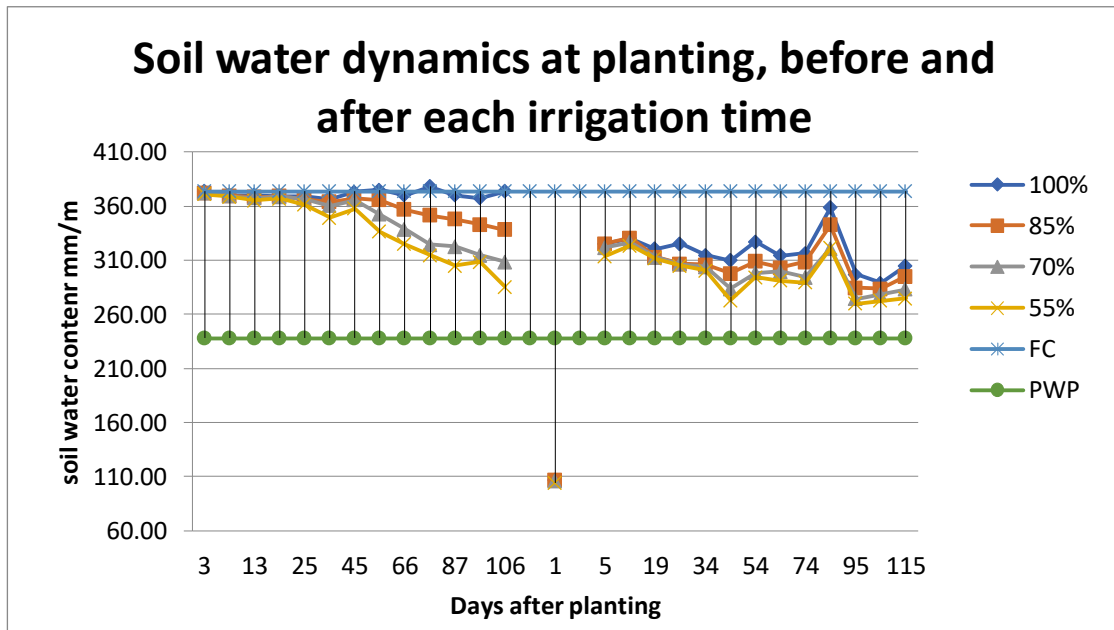


Figure 4.2. Soil water content initial, before and after irrigation with water levels

### 4.2.2. Effects of different irrigation water levels on canopy cover

As presented Table 4.1 the canopy, cover results were linearly increased up to 74<sup>th</sup> day after planting then after declined to maturity. The maximum canopy covers recorded at 74<sup>th</sup> day after planting (DaP) (88.375%, 85.27%, 84.108% and 82.967% were observed at 100%, 85%, 70%, and 55% water levels respectively. There was a highly significant difference among the water level after 34<sup>th</sup> day after planting (DaP) in all observation time except at 44<sup>th</sup> and 85<sup>th</sup> day after planting. The results agree with as simulated by the AquaCrop model (Table 4.7)

Table 4.1. Results of canopy cover (%) with different irrigation water levels

DaP	Treatments CC%				Grand Means	LSD	CV (%)	R <sup>2</sup>	p <0.05
	100%	85%	70%	55%					
34	6.80 <sup>a</sup>	6.30 <sup>b</sup>	5.79 <sup>c</sup>	5.67 <sup>c</sup>	6.14	0.44	4.44	0.87	0.0009
44	52.35	50.31	49.68	48.93	50.32	Ns	5.45	0.32	0.3834
55	84.84 <sup>a</sup>	83.16 <sup>ab</sup>	81.48 <sup>b</sup>	77.38 <sup>c</sup>	81.72	1.96	1.50	0.91	<0.0001
64	84.63 <sup>a</sup>	81.69 <sup>b</sup>	81.61 <sup>b</sup>	81.35 <sup>b</sup>	82.32	2.53	1.91	0.57	0.0506
74	88.38 <sub>a</sub>	85.27 <sup>b</sup>	84.11 <sup>b</sup>	82.97 <sup>b</sup>	85.18	2.76	1.94	0.81	0.0088
85	84.11	83.56	83.56	81.1	83.08	Ns	1.15	0.93	<0.9284
96	84.98 <sup>a</sup>	81.97 <sup>b</sup>	81.27 <sup>b</sup>	74.66 <sup>c</sup>	80.72	2.81	2.03	0.90	<0.0001
106	71.07 <sup>a</sup>	68.83 <sup>ab</sup>	67.69 <sup>ab</sup>	65.33 <sup>b</sup>	68.23	4.61	4.04	0.68	0.1045
115	68.07 <sup>a</sup>	64.88 <sup>ab</sup>	61.98 <sup>b</sup>	57.51 <sup>c</sup>	63.11	4.21	3.97	0.85	0.0019

(Field experiment, 2019) DaP is day after planting, CC is canopy cover

#### 4.2.3. Effects of different water levels on dry aboveground and tuber biomass

As presented Table 4.2 the dry aboveground and tuber biomass results were linearly increased from 34<sup>th</sup> the day after planting increased up to maturity. The maximum dry aboveground and tuber biomass recorded at maturity 12.30 ton/ha, 11.63 ton/ha, 11.17 ton/ha, and 10.03 ton/ha observed at 100%, 85%, 70%, and 55% water levels respectively. There was a highly significant difference among the water level at each observation time at  $p < 0.05$ . This results agree with the simulated value in the model (table 4.6.)

Table 4.2. Results of dry aboveground biomass and tuber

DaP	<i>Treatments AGDB ton/ha</i>				Grand Means	LSD	CV (%)	R <sup>2</sup>	p <0.05
	100%	85%	70%	55%					
34	0.0773 <sup>a</sup>	0.0731 <sup>b</sup>	0.0654 <sup>b</sup>	0.0538 <sup>c</sup>	0.07	0.006	5.47	0.92	<0.0001
44	0.6279 <sup>a</sup>	0.586 <sup>a</sup>	0.5351 <sup>b</sup>	0.5167 <sup>b</sup>	0.57	0.044	4.86	0.93	<0.0001
54	2.3258 <sup>a</sup>	2.138 <sup>b</sup>	2.0447 <sup>b</sup>	1.9062 <sup>c</sup>	2.10	0.136	4.04	0.88	0.0005
64	4.6175 <sup>a</sup>	4.121 <sup>ab</sup>	3.6627 <sup>bc</sup>	3.2772 <sup>c</sup>	3.92	0.744	11.87	0.74	0.0143
74	7.7811 <sup>a</sup>	7.059 <sup>b</sup>	6.1747 <sup>c</sup>	5.9247 <sup>c</sup>	6.74	0.511	4.74	0.91	<0.0001
86	9.641 <sup>a</sup>	8.711 <sup>b</sup>	8.325 <sup>c</sup>	7.764 <sup>d</sup>	8.61	0.278	2.02	0.97	<0.0001
96	11.495 <sup>a</sup>	11.47 <sup>a</sup>	10.409 <sup>b</sup>	9.762 <sup>c</sup>	10.78	0.340	1.97	0.96	<0.0001
106	11.856 <sup>a</sup>	11.49 <sup>b</sup>	10.553 <sup>c</sup>	10.044 <sup>d</sup>	10.99	2.262	1.95	0.96	<0.0001
115	12.301 <sup>a</sup>	11.63 <sup>b</sup>	11.169 <sup>b</sup>	10.032 <sup>c</sup>	11.28	0.569	3.15	0.92	<0.0001

(Field experiment, 2019), DaP is day after planting, AGDB is aboveground dry biomass

#### 4.2.4. Effect of water level on plant height and tuber diameter

As presented Table 4.3 the effect of different irrigation water levels on the mean plant height of the potato crop ranges from 42.2 cm to 49.93 cm. A highly significant difference had observed in plant height among the water levels at  $p < 0.05$ . The water levels 100% had the highest value 49.93 cm followed by 85% water level had 46.68 cm was recorded, however, the 70% and 55% water level have smallest value 43.18cm and 42.2 cm respectively in plant height was recorded. The plant height increased with as irrigation water increased. This result was observed lower than Birhanu (2016), who

reported on plant height 61.13 cm and 68.83 cm at Haramaya and Hirna respectively for Gera variety.

The effect of different irrigation water levels on the mean tuber diameter of the marketable potato tuber ranges 4.82 cm to 5.14 cm. A highly significant difference had observed in marketable tuber diameter among the water levels at ( $p < 0.05$ ). The water levels 100% and 85% had the highest value 5.14 cm and 5.05 cm respectively, however the 70% and 55% water level had smallest value 4.95 cm and 4.82 cm respectively in marketable tuber diameter recorded. The marketable tuber diameter increased with as irrigation water increased.

Table 4.3. Results of Plant Height and Tuber Diameter on Different Water Levels

Parameters	Treatments				Grand Means	LSD	CV (%)	R <sup>2</sup>	p <0.05
	100%	85%	70%	55%					
Ph cm	49.93 <sup>a</sup>	46.68 <sup>b</sup>	43.18 <sup>c</sup>	42.2 <sup>c</sup>	45.49	1.84	2.52	0.94	<0.0001
TD cm	5.14 <sup>a</sup>	5.05 <sup>ab</sup>	4.95 <sup>bc</sup>	4.82 <sup>c</sup>	4.99	0.13	1.68	0.93	0.0025

(Field experiment, 2019) Ph is plant height, TD is tuber diameter

#### 4.2.5. Effect of water level on effective root depth

As presented the Table 4.4 the effect of different irrigation water levels on the mean effective root depth of the potato crop ranges 18.80 cm to 28.00 cm. A highly significant difference had observed in root depth among the water levels at ( $p < 0.05$ ). The water levels 100% had highest value 28.00 cm respectively followed by 85% and 70% water level had 25.63 cm recorded. However, the 55% water level had smallest value 25.25 cm in root depth was recorded. The root depth increased trend until highest root depth occurred on 85<sup>th</sup>-day after planting then decreased to maturity.

Table 4.4. Results of root depth on the different water level and days after planting

DaP	<i>Root depth cm</i>				Grand Means	LSD	CV (%)	R <sup>2</sup>	p
	100%	85%	70%	55%					
34	21.13 <sup>a</sup>	20.13 <sup>ab</sup>	19.88 <sup>ab</sup>	18.88 <sup>c</sup>	20.00	2.19	4.85	0.54	0.08
44	23.13 <sup>a</sup>	22.50 <sup>ab</sup>	20.75 <sup>ab</sup>	20.25 <sup>b</sup>	21.66	2.66	4.73	0.50	0.23
55	23.38	23.25	22.00	21.63	22.56	Ns	1.59	0.57	0.09
64	28.00 <sup>a</sup>	25.63 <sup>ab</sup>	25.63 <sup>ab</sup>	23.88 <sup>b</sup>	25.78	3.23	1.96	0.79	0.01
74	27.63 <sup>a</sup>	26.63 <sup>ab</sup>	24.38 <sup>bc</sup>	23.75 <sup>c</sup>	25.59	2.79	1.94	0.78	0.00
85	28.00	27.13	26.38	25.25	26.69	Ns	1.15	0.57	0.15
96	26.13 <sup>a</sup>	24.75 <sup>a</sup>	24.50 <sup>ab</sup>	22.88 <sup>b</sup>	24.56	1.69	2.03	0.85	0.01
106	24.63	23.88	23.00	22.88	23.59	Ns	4.04	0.60	0.03
115	24.38 <sup>a</sup>	23.00 <sup>b</sup>	22.88 <sup>b</sup>	21.38 <sup>c</sup>	22.91	1.09	3.97	0.86	0.00

(Field experiment, 2019) DaP is day after planting

#### 4.2.6. Effect of water level on, tuber yield and crop water productivity

As presented Table 4.5 the effect of different irrigation water levels on the mean marketable fresh tuber, weight ranges from 35.25 ton/ha to 43.02 ton/ha observed. There was highly significant difference among treatments at ( $p < 0.05$ ). The water levels 100% water levels had significantly highest value 43.02 ton/ha followed by 85% and 70 % water level had 40.06 ton/ha and 38.63 ton/ha respectively, but 55% water level had the least value (35.25 ton/ha) recorded. The results are on the line of FAO I & D paper 66 document 40 ton/ha to 50 ton /ha (FAO, 2012). The results showed that for 85%, 70% and 55% water level had 6.83%, 10.11% and 17.98% yield penalty that compared to 100% water level. This results agree with on fresh tuber yield was obtained in Iraq 35.23 ton/ha in furrow irrigation (Ati, et al., 2012). And also Birhanu (2016) who reported 56.85 ton/ha and 39.08 ton/ha fresh potato tuber yield observed in Hirna and Haramaya respectively in 2013, during the main season.

As presented Table 4.5 the effect of different irrigation water levels on the mean unmarketable fresh tuber weight ( $< 2g$ ) Birhanu (2016). There was no significant difference among treatments at  $p < 0.05$ . but numerically 100% water levels had the highest value 0.69 ton/ha was obtained followed by 85 % water level had 0.67 ton/ha

respectively, an 70%, and 55% water level had the least value (0.66 and 0.61) ton/ha was recorded. This results agree with Birhanu (2016) who reported for the Gera variety ranges 0.33 ton/ha to 2.88 ton/ha Haramaya and Hirna respectively.

As presented Table 4.5 the water productivity on fresh potato tuber ranges 11.59 kg/m<sup>3</sup> to 12.67 kg/m<sup>3</sup> were observed. There was highly significant difference among treatments at (p < 0.05). The water levels 55% and 70% water levels had the lowest value 11.59 kg/m<sup>3</sup> and 11.78 kg/m<sup>3</sup> respectively followed by 85% water level had 12.49 and the 100% water level had 12.67 kg/m<sup>3</sup>. This result little higher value than FAO I & D paper 66 document recorded in the range of 4 kg/m<sup>3</sup> to 11 kg/m<sup>3</sup> (FAO, 2012). Another research was found the water productivity on potato crop in Iraq ranges 5.129 kg/m<sup>3</sup> to 7.379 kg/m<sup>3</sup> (Ati et al., 2012).

As presented the Figure 4.3 the 85%, 70% and 55% of water level had 8.33%, 16.65%, and 24.98% of water saved and could irrigate extra land respectively as compared to 100%. The 55% of water level had highest extra (25% of) land opportunity from saved water but the yield punished by 18% as compared to a 100% of water level.

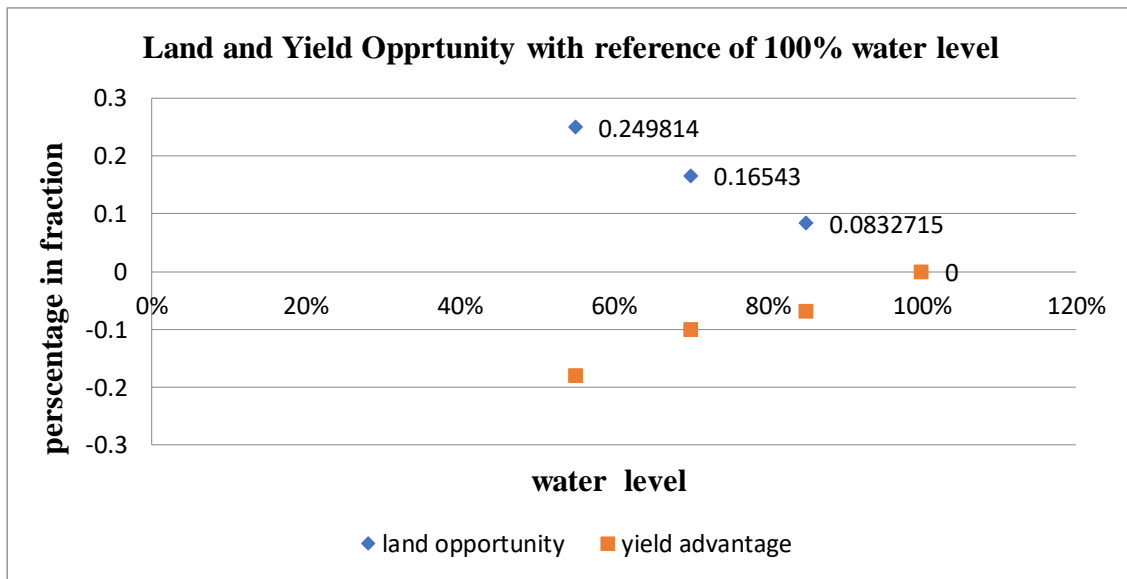


Figure 4.3. Land and yield opportunity with reference to 100% water level

Table 4.5. Results yield and yield parameters and water productivity

Parameters	Treatments				Grand Means	LSD	CV (%)	R <sup>2</sup>	P <0.05
	100%	85%	70%	55%					
Fresh unmarketable yield ton/ha	0.69	0.67	0.66	0.61	0.67	ns	8.74	0.75	0.234
Fresh marketable yield ton/ha	43.02 <sup>a</sup>	40.06 <sup>b</sup>	38.63 <sup>b</sup>	35.25 <sup>c</sup>	39.24	2.0837	3.32	0.91	0.0001
Total yield ton/ha	43.71 <sup>a</sup>	40.73 <sup>b</sup>	39.29 <sup>b</sup>	35.85 <sup>c</sup>	39.90	2.0987	3.29	0.91	0.0001
Crop water productivity kg/m <sup>3</sup>	11.59 <sup>b</sup>	11.78 <sup>b</sup>	12.5 <sup>a</sup>	12.67 <sup>a</sup>	12.13	0.6068	3.13	0.81	0.007
Irrigation mm	280.4 <sup>a</sup>	249 <sup>b</sup>	217.6 <sup>c</sup>	186.1 <sup>d</sup>	233.28	0	0	1	<0.0001
Irrigation + rainfall mm	377.2 <sup>a</sup>	345.8 <sup>b</sup>	314.4 <sup>c</sup>	282.9 <sup>d</sup>	330.08	0	0	1	<0.0001

(Field experiment, 2019)

### **4.3. Results of the Performance Evaluation of the AquaCrop Model**

#### **4.3.1. Performance of AquaCrop on dry-aboveground biomass and tuber yield**

As presented Table 4.6 the dry aboveground and tuber biomass yield had excellent in the Nash-Sutcliffe Efficiency (NSE) (0.94, 0.90, 0.84 and 0.78) was obtained for the water levels 100%, 85%, 70% and 55% respectively. For normalized root mean square error (NRMSE) had fair to poor values (16.3%, 21.6%, 28.1% and 35.5%) was observed for the water levels 100%, 85%, 70% and 55% respectively. As well for index of agreement (d) had excellent value (0.99, 0.98, 0.97 and 0.96) for the water levels 100%, 85%, 70% and 55% respectively. The simulated result on coefficient of determination ( $R^2$ ) had excellent value (0.96, 0.96, 0.98 and 0.98) for the water levels 100%, 85%, 70% and 55% respectively. The results show that the well correlated as simulated value, however, the value that observed after senescence 95<sup>th</sup>-day after planting to 117<sup>th</sup> (maturity days) was observed lower for all treatments. Thus, results showed the AquaCrop model excellent simulated in all water levels except for 70% and 55% water level that was poor. The AquaCrop model performance in Tigray on potato was found a satisfactory result on the NRMSE (Yibrah et al., 2015).

#### **4.3.2. Performance of AquaCrop in simulating canopy cover**

As presented Table 4.7 the canopy cover as indicated by excellent to good model efficiency NSE (0.82, 0.76, 0.68 and 0.54) for the water levels 100%, 85%, 70% and 55% respectively. For normalized root mean square error NRMSE very good to good (fair) (15%, 18.7%, 20.5% and 25%) for the water levels 100%, 85%, 70% and 55% of water level respectively. As well for the index of agreement (d) was excellent (0.96, 0.95, 0.93 and 0.91) for the water levels 100%, 85%, 70% and 55% respectively. The simulated result on the coefficient of determination  $R^2$  was excellent (0.94, 0.94, 0.94 and 0.92) for the water levels 100%, 85%, 70% and 55% respectively. The results showed that the AquaCrop model very well simulated value observed on in all water levels. This result agreed with Yibrah (2015), in Tigray, Ethiopia. Another results show index of agreement (d) and coefficient of determination ( $R^2$ ) was found > 90% in Spain (Montoya et al., 2016).

Table 4.6. Observed and simulated dry aboveground biomass and dry tuber weight

DaP	100% DAGB		85% DAGB		70% DAGB		55% DAGB	
	t/ha OBS	t/ha SIM	t/ha OBS	t/ha SIM	t/ha OBS	t/ha SIM	t/ha OBS	t/ha SIM
34	0.077	0.092	0.073	0.092	0.065	0.092	0.054	0.092
44	0.628	0.941	0.586	0.941	0.535	0.941	0.517	0.941
54	2.326	2.891	2.138	2.891	2.045	2.89	1.906	2.89
64	4.618	4.965	4.121	4.965	3.663	4.964	3.277	4.963
74	7.781	7.028	7.059	7.028	6.175	7.027	5.925	7.027
86	9.641	9.47	8.711	9.47	8.326	9.469	7.764	9.467
95	11.495	11.264	11.474	11.264	10.409	11.263	9.762	11.082
106	11.856	13.372	11.491	13.372	10.553	13.267	10.044	12.72
117	12.301	15.015	11.6255	15.015	11.169	14.628	10.032	13.671
<b>R</b>		0.98 <sup>***</sup>		0.98 <sup>***</sup>		0.99 <sup>***</sup>		99 <sup>***</sup>
<b>RMS</b>		1.10 <sup>*</sup>		1.40 <sup>*</sup>		1.70 <sup>+</sup>		1.8 <sup>+</sup>
<b>E</b>								
<b>NRM</b>		16.30 <sup>*</sup>		21.60 <sup>*</sup>		28.10 <sup>+</sup>		33.5 <sup>+</sup>
<b>SE</b>								
<b>NSE</b>		0.94 <sup>***</sup>		0.90 <sup>***</sup>		0.84 <sup>***</sup>		0.78 <sup>***</sup>
<b>d</b>		0.99 <sup>***</sup>		0.98 <sup>***</sup>		0.97 <sup>***</sup>		0.96 <sup>***</sup>
<b>R<sup>2</sup></b>		0.96 <sup>***</sup>		0.96 <sup>***</sup>		0.98 <sup>***</sup>		0.98 <sup>***</sup>

(Field experiment, 2019) DaP is day after planting DAGB is dry aboveground biomass OBS is observed, SIM is simulated \* good, \*\* very well, \*\*\* excellent, and + poor

Table 4.7. Observed and simulated canopy cover (%)

<b>date G.C.</b>	<b>DaP</b>	<b>100 % OBS</b>	<b>100 % SIM</b>	<b>85% OBS</b>	<b>85 % SIM</b>	<b>70 % OBS</b>	<b>70 % SIM</b>	<b>55% OBS</b>	<b>55 % SIM</b>
<b>02/27/2019</b>	<b>34</b>	6.8	5.8	6.3	5.8	5.792	5.8	5.667	5.8
<b>03/09/2019</b>	<b>44</b>	52.35	62.7	50.308	62.7	49.683	62.7	48.933	62.7
<b>03/19/2019</b>	<b>54</b>	85.008	89.6	83.158	89.5	81.475	89.5	77.375	89.4
<b>03/29/2019</b>	<b>64</b>	84.633	91.8	81.692	91.8	81.608	91.8	81.35	91.8
<b>04/08/2019</b>	<b>74</b>	88.375	92	85.267	92	84.108	92	82.967	92
<b>04/20/2019</b>	<b>86</b>	84.108	92	83.558	92	81.1	92	79.45	92
<b>04/30/2019</b>	<b>96</b>	84.975	90.9	81.967	90.9	81.267	90.9	74.658	90.9
<b>05/10/2019</b>	<b>106</b>	71.067	89.2	68.825	89.2	67.675	89.2	65.325	89.2
<b>05/19/2019</b>	<b>115</b>	68.067	87.2	64.883	87.2	61.983	87.2	57.508	87.2
<b>R</b>			0.97 <sup>***</sup>		0.97 <sup>***</sup>		0.97 <sup>***</sup>		0.96 <sup>***</sup>
<b>RMSE</b>			10.4 <sup>*</sup>		12.4 <sup>*</sup>		13.6 <sup>*</sup>		16 <sup>*</sup>
<b>CV(NRMSE)</b>			15 <sup>*</sup>		18.7 <sup>*</sup>		20.5 <sup>*</sup>		25 <sup>*</sup>
<b>NSE</b>			0.82 <sup>***</sup>		0.76 <sup>***</sup>		0.68 <sup>**</sup>		0.54 <sup>*</sup>
<b>d</b>			0.96 <sup>***</sup>		0.95 <sup>***</sup>		0.93 <sup>***</sup>		0.91 <sup>***</sup>
<b>R<sup>2</sup></b>			0.94 <sup>***</sup>		0.94 <sup>***</sup>		0.94 <sup>***</sup>		0.92 <sup>***</sup>

(Field experiment, 2019) DaP is day after planting OBS is observed, SIM is simulated \* good, \*\* very good, \*\*\* excellent

#### **4.3.3. Performance of AquaCrop in simulating soil water content before and after irrigation**

As presented Table 4.8 the soil water before and after irrigation had very poor model efficiency observed on NSE (-0.63, -0.48, -0.19 and -0.00) for the water levels 100%, 85%, 70% and 55% respectively. For normalized root mean square error, NRMSE very well (fair) simulated value observed (10.8%, 10.7%, 10.7% and 10.2%) for the water levels 100%, 85%, 70% and 55% respectively. As well for index of agreement (d) had from poor to good values were observed (0.51, 0.58, 0.70 and 0.78) for the water levels 100%, 85%, 70% and 55% respectively. The simulated result on the coefficient of determination ( $R^2$ ) was very poor to poor simulated values were obtained (0.0289, 0.1369, 0.3025 and 0.4489) for the water levels 100%, 85%, 70% and 55% respectively. The results show that the poor correlated as simulated value however, the value of lower water levels better simulated than highest water level treatments. Generally the soil water content before and after irrigation validation results poor efficiency was observed.

#### **4.3.4. Performance of AquaCrop in simulating soil water content after irrigation**

As presented Table 4.9 the soil water before and after irrigation had poor to excellent model efficiency NSE (0.43, 0.96, 0.97 and 0.98) for the water levels 100%, 85%, 70% and 55% respectively. For normalized root mean square error, NRMSE excellent simulated as (0.8%, 0.75, 1.1% and 2.2%) for the water levels 100%, 85%, 70% and 55% respectively. As well for the index of agreement (d) was from very well to excellent values were observed (0.85, 0.99, 0.99 and 0.98) for the water levels 100%, 85%, 70% and 55% respectively. The simulated result on the coefficient of determination  $R^2$  was very well to excellent simulated (0.689, 0.96, 0.98 and 0.96) for the water levels 100%, 85%, 70% and 55% respectively. The results show that the well correlated as simulated values, however, the value of lower water levels better simulated than highest water level treatments. Generally the soil water content after irrigation the simulation result was observed very well to excellent result validation results obtained.

Table 4.8. Observed and simulated soil water content at planting, before and after irrigation

<b>DaP</b>	<b>100% BI</b>		<b>85% BI</b>		<b>70% BI</b>		<b>55% BI</b>	
	<b>OBS</b>	<b>SIM</b>	<b>OBS</b>	<b>SIM</b>	<b>OBS</b>	<b>SIM</b>	<b>OBS</b>	<b>SIM</b>
	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>	<b>mm/m</b>
<b>1</b>	106.1		106.6		107.2		104.4	
<b>3</b>	373.8	376.4	374.4	376.4	371.2	376.4	372.2	376.4
<b>5</b>	325.4	364.2	325.5	364.2	314.2	364.2	322.0	364.2
<b>7</b>	369.9	366.6	370.3	366.6	371.5	366.6	369.0	366.6
<b>12</b>	326.7	369.8	330.3	369.8	323.4	369.8	330.1	369.8
<b>13</b>	370.0	365.9	368.2	365.9	367.3	365.9	365.0	365.9
<b>19</b>	322.9	367.8	313.1	367.8	311.4	367.8	320.4	367.8
<b>20</b>	367.2	364.7	369.4	364.7	372.4	364.7	369.0	364.7
<b>24</b>	325.2	371.4	306.6	371.4	305.1	371.4	306.1	371.4
<b>25</b>	369.1	368.0	366.8	368.0	366.8	368.0	361.3	368.0
<b>34</b>	314.8	369.2	305.9	367.2	303.8	364.2	300.7	361.2
<b>35</b>	366.5	365.5	360.4	363.5	364.0	360.5	349.3	357.5
<b>44</b>	309.6	376.6	297.6	374.0	283.5	369.5	273.2	366.4
<b>45</b>	373.4	371.9	367.0	369.3	365.5	364.8	357.8	361.7
<b>54</b>	327.1	377.0	308.7	367.5	298.4	356.3	294.4	346.6
<b>55</b>	374.8	372.7	365.6	363.1	352.3	352.0	336.5	342.3
<b>64</b>	314.5	338.5	302.9	328.9	299.4	317.8	291.3	308.1
<b>66</b>	370.2	371.0	357.0	355.5	338.8	338.4	324.9	323.7

<b>Continued</b>								
<b>74</b>	316.3	376.9	308.3	356.4	294.2	334.4	289.2	315.7
<b>75</b>	378.0	371.9	351.5	351.4	324.6	329.3	314.9	310.6
<b>85</b>	358.5	361.4	342.5	341.1	321.0	319.1	312.2	300.4
<b>87</b>	370.2	368.0	348.0	345.7	322.6	320.7	304.9	300.0
<b>95</b>	296.8	372.2	284.6	345.0	274.3	314.9	269.9	292.5
<b>96</b>	367.6	368.7	343.0	341.5	314.5	311.4	308.3	289.0
<b>105</b>	289.1	375.2	283.8	341.0	278.3	306.2	272.6	286.0
<b>106</b>	373.9	370.4	338.0	336.1	308.5	301.3	285.5	281.1
<b>115</b>	304.9	338.2	295.2	304.0	283.2	374.5	274.9	262.3
<b>r</b>		0.17 <sup>++</sup>		0.37 <sup>++</sup>		0.55 <sup>+</sup>		0.67 <sup>+</sup>
<b>RMSE</b>		37.20 <sup>**</sup>		35.80 <sup>**</sup>		34.70 <sup>**</sup>		32.60 <sup>**</sup>
<b>CV(NRMSE)</b>		10.80 <sup>**</sup>		10.70 <sup>**</sup>		10.70 <sup>**</sup>		10.20 <sup>**</sup>
<b>NSE</b>		-0.63 <sup>++</sup>		-0.48 <sup>++</sup>		-0.19 <sup>++</sup>		0.00 <sup>++</sup>
<b>d</b>		0.51 <sup>+</sup>		0.58 <sup>+</sup>		0.70 <sup>*</sup>		0.78 <sup>*</sup>
<b>R<sup>2</sup></b>		0.0289 <sup>++</sup>		0.1369 <sup>++</sup>		0.3025 <sup>+</sup>		0.4489 <sup>+</sup>

(Field experiment, 2019) DaP is day after planting BI is before irrigation OBS is observed, SIM is simulated \* good, \*\* very good, \*\*\* excellent, + poor, and ++ very poor

Table 4.9. Observed and simulated soil water content after irrigation

<b>DaP</b>	<b>100% AI OBS mm/m</b>	<b>100% AI SIM mm/m</b>	<b>85% AI OBS mm/m</b>	<b>85% AI SIM mm/m</b>	<b>70% AI OBS mm/m</b>	<b>70% AI SIM mm/m</b>	<b>55% AI OBS mm/m</b>	<b>55% AI SIM mm/m</b>
<b>2</b>	373.8	376.4	374.4	376.4	371.2	376.4	372.2	376.4
<b>8</b>	369.9	366.6	370.3	366.6	371.5	366.6	369.0	366.6
<b>13</b>	370.0	365.9	368.2	365.9	367.3	365.9	365.0	365.9
<b>20</b>	367.2	364.7	369.4	364.7	372.4	364.7	369.0	364.7
<b>25</b>	369.1	368.0	366.8	368.0	366.8	368.0	361.3	368.0
<b>35</b>	366.5	365.5	360.4	363.5	364.0	360.5	349.3	357.5
<b>45</b>	373.4	371.9	367.0	369.3	365.5	364.8	357.8	361.7
<b>55</b>	374.8	372.7	365.6	363.1	352.3	352.0	336.5	342.3
<b>66</b>	370.2	371.0	357.0	355.5	338.8	338.4	324.9	323.7
<b>75</b>	378.0	371.9	351.5	351.4	324.6	329.3	314.9	310.6
<b>85</b>	358.5	361.4	342.5	341.1	321.0	319.1	312.2	300.4
<b>87</b>	370.2	368.0	348.0	345.7	322.6	320.7	304.9	300.0
<b>96</b>	367.6	368.7	343.0	341.5	314.5	311.4	308.3	289.0
<b>106</b>	373.9	370.4	338.0	336.1	308.5	301.3	285.5	281.1
<b>r</b>		0.83**		0.98***		0.99***		0.98***
<b>RMSE</b>		2.80***		2.40***		4.00***		7.5***
<b>CV(NRMSE)</b>		0.80***		0.70***		1.10***		2.2***
<b>NSF</b>		0.43*		0.96***		0.97***		0.93***
<b>d</b>		0.85**		0.99***		0.99***		0.98***
<b>R<sup>2</sup></b>		0.69**		0.96***		0.98***		0.96***

(Field experiment, 2019) DaP is day after planting AI is after irrigation OBS is observed, SIM is simulated \* good, \*\* very good, \*\*\* excellent, and + poor.

**4.3.5. Compare the results on AquaCrop model simulated, experimental site and farmers tuber yield**

In Figure 4.2 the model output showed that linearity increased over the year due to the increasing CO<sub>2</sub> concentration (see appendix table 2) with net irrigation application and estimated higher than the actual yield while the farmers yield showed that decreased trends and very low production as compared both the model simulation and observed values. This year tuber yield was near as the model simulated 43.714 ton/ha.

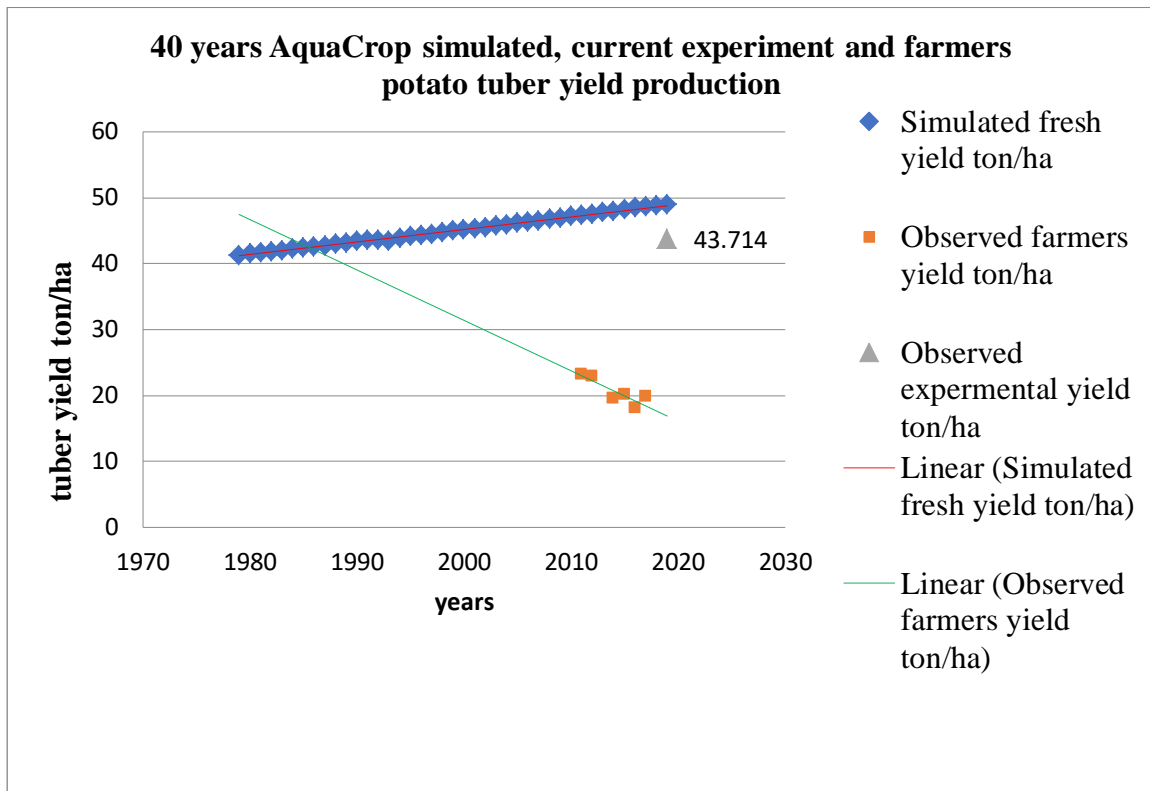


Figure 4.4. Potato tuber yield from AquaCrop, current experiment and farmer’s

**4.3.6. Water productivity**

As presented Figure 4.6 the water productivity had, 11.59 kg/m<sup>3</sup> obtained from actual field experiment. The results showed that the AquaCrop model well simulated as actual value observed in this year (2019). In this year the water productivity result as compared to the 40 years average lower value was obtained.

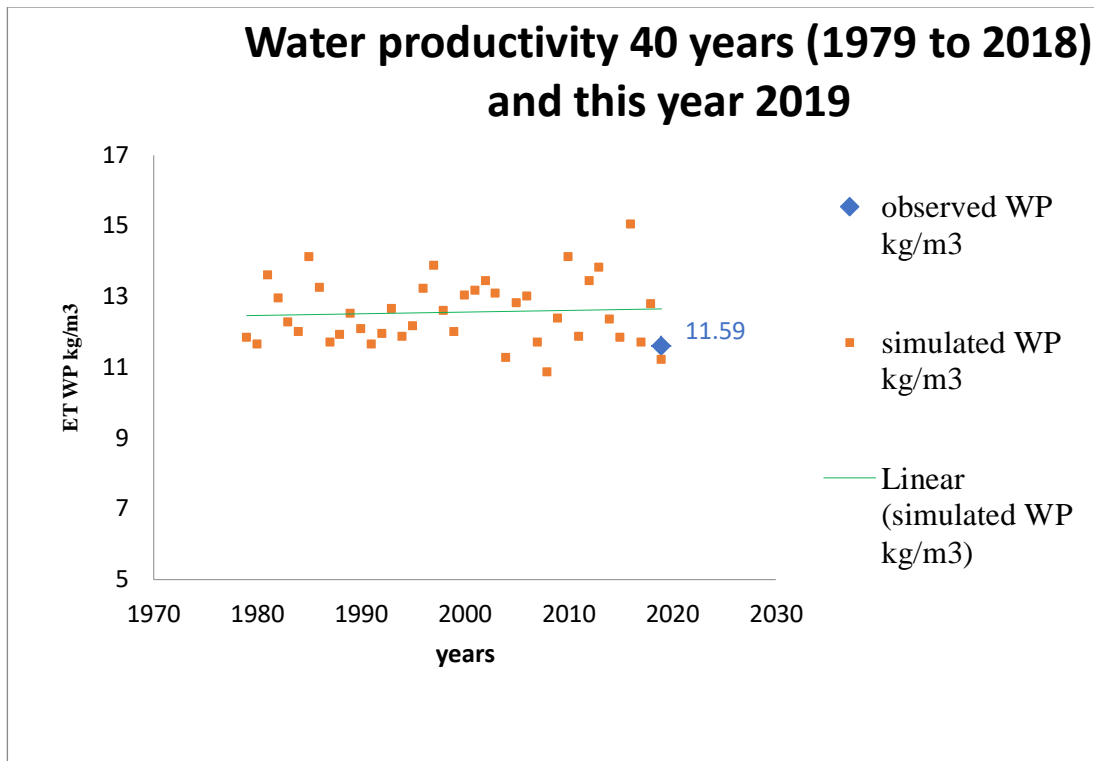


Figure 4.5. Results of the water productivity in terms of fresh tuber

## **5. SUMMARY AND CONCLUSION**

### **5.1. Summary**

Maximizing crop productivity at the farm level is through better irrigation water management. This can be accomplished by using appropriate tools to predict water productivity under different irrigation regimes or deficit irrigation approach. This study was conducted on the performance evaluation of the AquaCrop model for potato under different irrigation water levels of 100%, 85%, 70% and 55%, these amounts of water determined using AquaCrop model. The statistical analysis had significantly affected at  $p < 0.05$  the root depth, plant height, tuber diameter, canopy cover, soil water content, tuber yield, dry tuber biomass and the water productivity of potato crop. The performance of the AquaCrop model with the statistical parameter indicators; Nash-Sutcliffe efficiency (NSE), Normalized Root mean square error (NRMSE) index of agreement (d) and Coefficient of determination ( $R^2$ ) showed very well to excellent efficiency observed on dry aboveground and tuber biomass, there values were found to be in the ranges of 0.78 to 0.94, 35.50 to 16.30, 0.96 to 0.99 and 0.98 to 0.96 respectively. However, for soil water content before irrigation, which was found to be poor ranges 0.00 to -0.63, 10.2 to 10.8, 0.78 to 0.51, 0.45 to 0.03 were observed respectively.

The potato tuber yield results showed 100% water level had highly significant difference among the water levels followed by 85% and 70% the lowest tuber yield was observed in 55% water level. While on water productivity 55% and 70% water level had highest values followed by 85% while the least water productivity was obtained on 100% water level. But there is no significant difference between 70% and 55% water level on water productivity. The AquaCrop model simulated results had 70% and 100% of water levels were the best options to obtain the maximum potato tuber yield.

### **5.2. Conclusion**

The aim of this thesis was to evaluate the performance the AquaCrop model in simulating potato crop growth parameters under various irrigation water levels during the off season 2019 at Debre Birhan, Amhara Regional State, Ethiopia. Hear could be answered the research questions:

- I. The AquaCrop model simulated results showed that for 100% was 377.2 mm/m used in growing season. For the rest of other water levels used as corresponding of their percentage of the 100% water level (345.79 mm/m, 314.38 mm/m and 282.98 mm/m of water used for 85%, 70% and 55% of water level respectively.
- II. The statistical analysis had highly significant affected on growth parameters and yield of potato crop on different water level. The marketable fresh potato yield ranges from 35.248 ton/ha to 43.01 ton/ha was obtained in 55% and 100% water levels respectively. The water productivity ranges from 11.59 kg/m<sup>3</sup> to 12.67 kg/m<sup>3</sup> was obtained in 55% and 100% water level respectively.
- III. The performance of the AquaCrop model with the statistical parameter indicators; Nash-Sutcliffe efficiency (NSE), Normalized Root mean square errors (NRMSE) and index of agreement (d) showed that, the AquaCrop model well simulated with observed values in all parameters considered except soil water content during before irrigation time.

From the results of this study, the following points can be recommended by taking into two scenarios:-

- The first scenario is in case of water scarce area. In this scenario it might be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit of land. The saved water could be used for other purposes or to irrigate extra units of land.
- The second scenario is in case no water scarce area. In this scenario it might be more profitable for a farmer to maximize the yield than crop water productivity.

Under the first scenario farmers and users should adopt 70% of the AquaCrop model output of the irrigation water level for potato crop in 10-days interval. On the other hand under the second scenario farmers and users should adopt 100% of the AquaCrop model output of the irrigation water level for potato crop in 10-days interval. Therefore, the water level 70% and 100% with 10-day interval was recommended for scarce water and non-scarce water scenarios respectively.

As a result of the performance evaluation, the AquaCrop model is very useful and well simulate under various water level, therefore, more research activities related water should be done with the help of this model due to its merit a user-friendly, easy to an application, accuracy and robustness and address conditions where water is a key limiting factor for crop production.

This study is limited to deal with only one crop, potato and most of the analyses focused only the water stress. Crop yield depends on many factors including soil fertility, mulching, and soil and water salinity. Further research activities should be considered to address thus factors. Therefore, from this result can be concluded that the future studies focus to address various stresses such as on soil fertility stressed, and mulching with various location and crops.

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## APPENDICES

### Appendix I: Tables in the Appendices

Appendix Table 1. Amount of irrigation water applied during irrigation

date G.C.	DaP	Rainfall mm decade	irrigation applied per treatments			
			<b>100%</b>	<b>85%</b>	<b>75%</b>	<b>55%</b>
26-Jan	<b>2</b>	0.0	12.0	12.0	12.0	12.0
31-Jan	<b>7</b>	0.0	12.0	12.0	12.0	12.0
05-Feb	<b>12</b>	0.0	15.0	15.0	15.0	15.0
12-Feb	<b>19</b>	0.0	15.0	15.0	15.0	15.0
17-Feb	<b>24</b>	0.0	17.0	17.0	17.0	17.0
27-Feb	<b>34</b>	0.0	17.2	14.6	12.0	9.5
09-Mar	<b>44</b>	34.2	12.4	10.5	8.7	6.8
19-Mar	<b>54</b>	0.0	46.9	39.9	32.8	25.8
29-Mar	<b>65</b>	6.7	37.5	31.9	26.3	20.6
08-Apr	<b>74</b>	11.8	16.0	13.6	11.2	8.8
19-Apr	<b>85</b>	38.1	0.0	0.0	0.0	0.0
21-Apr	<b>86</b>	2.4	33.0	28.1	23.1	18.2
29-Apr	<b>95</b>	0.0	46.4	39.4	32.5	25.5
09-May	<b>105</b>	3.6	0.0	0.0	0.0	0.0
Sum		96.8	280.4	249.0	217.6	186.2
Rainfall mm			96.8	96.8	96.8	96.8
total water mm			377.2	345.8	314.4	283.0
Total applied m3/ha			3772.0	3457.9	3143.8	2829.7

**(Field experiment, 2019) DaP = day after planting**

Appendix Table 2. Soil characteristics of the study site

Soil Profile	Soil depth (cm)	Texture %				pH, H <sub>2</sub> O 1:2.5	EC, 1:2.5 (mS/m)	C (%)	ESP	Humidity Sat. (θSat.) (% vol.)	Hydraulic Con. (Ksat.) (mm/j)	BD (g/cm <sup>3</sup> )	FC (%vol.)	PWP (% vol.)
		Sand (%)	Silt (%)	Clay (%)	Class									
<b>Horizon-1</b>	0-24	27	38	35	CL	5.6	0.040	2.60	0.859	-	31.20	1.31	37.99	28.87
<b>Horizon-2</b>	24-58	15	28	57	Clay	5.4	0.035	0.80	0.712	49.000	18.50	1.35	31.04	29.81
<b>Horizon-3</b>	58-92	13	20	67	Clay	5.9	0.055	0.50	0.749	49.500	20.90	1.34	46.19	30.71
<b>Horizon-4</b>	92-127	13	18	69	Clay	6.0	0.069	0.30	1.024	-	-	1.24	43.70	32.20

(Source: Ashenafi et al, 2006)

Appendix Table 3. Results of soil water content in different water levels after irrigation

		<i>Treatments SWC mm/m</i>					<b>Grand Means</b>	<b>LSD</b>	<b>CV (%)</b>	<b>R<sup>2</sup></b>	<b>F<sub>pr</sub> value &lt;0.05</b>
		<b>DaP</b>	<b>100%</b>	<b>85%</b>	<b>70%</b>	<b>55%</b>					
<b>Day After Planting (days)</b>	<b>after irrigation</b>	<b>3</b>	373.84	372.20	372.18	371.15	372.88	ns	1.80	0.09	0.8966
		<b>8</b>	370.31	369.90	369.35	368.99	370.17	ns	1.39	0.32	0.9208
		<b>13</b>	370.04	368.25	367.29	365.05	367.65	ns	1.34	0.45	0.4401
		<b>20</b>	369.45 <sup>a</sup>	369.38 <sup>ab</sup>	368.96 <sup>ab</sup>	367.15 <sup>b</sup>	369.46	4.98	0.84	0.63	0.1944
		<b>25</b>	369.07 <sup>a</sup>	366.78 <sup>ab</sup>	366.78 <sup>ab</sup>	361.28 <sup>b</sup>	366.00	7.03	1.20	0.52	0.1487
		<b>35</b>	366.47 <sup>a</sup>	363.99 <sup>a</sup>	360.43 <sup>ab</sup>	349.27 <sup>b</sup>	360.04	12.74	2.21	0.56	0.0576
		<b>45</b>	373.38 <sup>a</sup>	367.02 <sup>ab</sup>	365.55 <sup>b</sup>	357.81 <sup>c</sup>	365.94	7.04	1.20	0.80	0.0055
		<b>55</b>	374.82 <sup>a</sup>	365.60 <sup>b</sup>	352.32 <sup>c</sup>	336.49 <sup>d</sup>	357.31	5.53	0.98	0.97	<0.0001
		<b>66</b>	370.25 <sup>a</sup>	356.97 <sup>b</sup>	338.85 <sup>c</sup>	324.87 <sup>d</sup>	347.73	8.56	1.54	0.95	<0.0001
		<b>75</b>	377.97 <sup>a</sup>	351.49 <sup>b</sup>	324.62 <sup>c</sup>	314.88 <sup>d</sup>	342.24	3.98	0.73	0.99	<0.0001
		<b>87</b>	370.24 <sup>a</sup>	347.99 <sup>b</sup>	322.57 <sup>c</sup>	304.90 <sup>d</sup>	336.42	6.28	1.17	0.99	<0.0001
		<b>96</b>	367.65 <sup>a</sup>	342.99 <sup>b</sup>	314.48 <sup>c</sup>	308.35 <sup>d</sup>	333.36	27.93	5.24	0.78	0.0033
<b>106</b>	373.87 <sup>b</sup>	338.02 <sup>c</sup>	308.50 <sup>d</sup>	285.51 <sup>e</sup>	326.48	6.43	1.23	0.99	<0.0001		

**(Field experiment, 2019) DaP is day after planting, SWC is soil water content**

Appendix Table 4. Soil water content in different water levels before irrigation

	DaP	<i>Treatments SWC mm/m</i>				Grand Means	LSD	CV (%)	R <sup>2</sup>	F.pr value <0.05
		100%	85%	70%	55%					
Day After Planting (days) before irrigation	1	107.02	106.59	106.06	104.43	106.08	ns	3.19	0.37	0.6903
	5	325.40	325.14	322.00	314.00	321.78	ns	5.06	0.32	0.7418
	12	330.34	330.82	326.74	323.38	327.64	ns	2.96	0.52	0.7200
	19	320.40	313.11	312.79	311.43	316.95	ns	3.84	0.24	0.5107
	24	325.25	306.64	306.10	305.12	310.78	ns	5.91	0.36	0.3957
	34	314.83	305.90	303.84	300.65	306.31	ns	3.51	0.40	0.3386
	44	309.64 <sup>a</sup>	297.63 <sup>b</sup>	283.50 <sup>c</sup>	273.15 <sup>d</sup>	290.98	9.64	2.07	0.92	<.0001
	54	327.07 <sup>a</sup>	308.71 <sup>ab</sup>	298.40 <sup>b</sup>	294.40 <sup>b</sup>	307.14	20.92	4.26	0.71	0.0262
	64	314.47 <sup>a</sup>	302.94 <sup>b</sup>	299.41 <sup>bc</sup>	291.29 <sup>c</sup>	302.02	9.26	1.92	0.81	0.0023
	74	316.31 <sup>a</sup>	308.29 <sup>b</sup>	294.21 <sup>c</sup>	289.21 <sup>c</sup>	302.01	5.73	1.19	0.94	<0.0001
	85	358.51 <sup>a</sup>	342.49 <sup>b</sup>	320.97 <sup>c</sup>	321.25 <sup>d</sup>	333.36	5.32	1.00	0.98	<0.0001
	95	296.83 <sup>a</sup>	284.55 <sup>b</sup>	274.31 <sup>c</sup>	269.90 <sup>c</sup>	281.40	5.82	1.29	0.95	<0.0001
	105	289.07 <sup>a</sup>	283.81 <sup>ab</sup>	278.26 <sup>bc</sup>	272.56 <sup>c</sup>	280.93	8.05	1.79	0.80	0.0066
115	304.86 <sup>a</sup>	295.23 <sup>ab</sup>	283.17 <sup>bc</sup>	274.87 <sup>c</sup>	289.53	14.86	3.21	0.77	0.0064	

(Field experiment, 2019) DaP = day after planting, SWC = soil water content

Appendix Table 5. Non-conservative parameters used for AquaCrop Potato Model

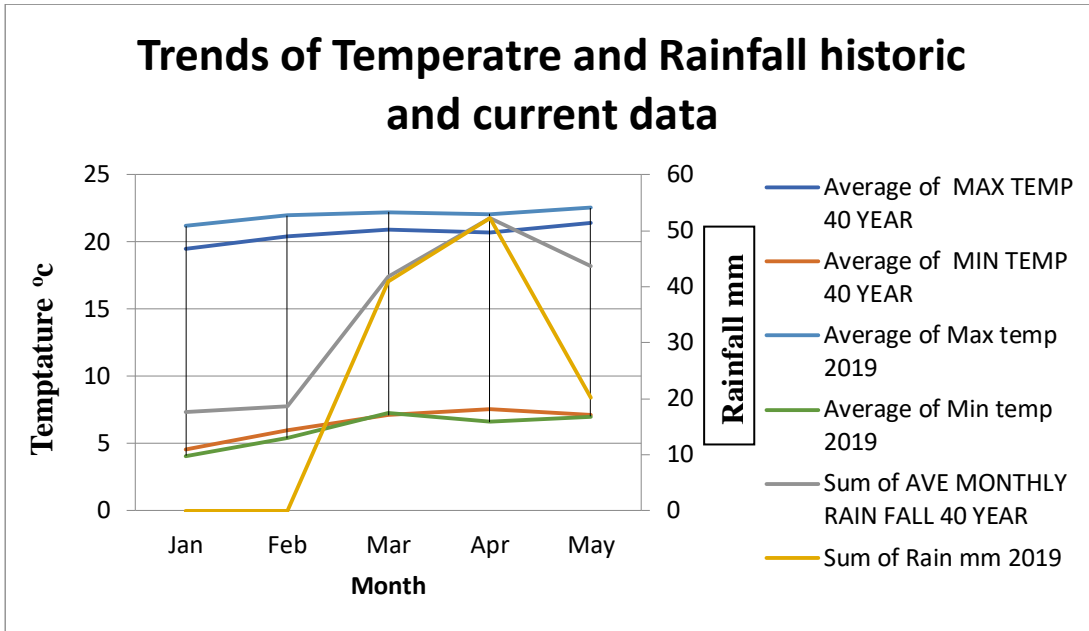
<b><u>Non-conservative (crop specific) parameters</u></b>	<b><u>Values</u></b>
Plant density (plants ha <sup>-1</sup> )	44444.44
Initial canopy cover CCo (%)	0.67
Maximum canopy cover CCx (%)	88
Time to maximum canopy cover (d)	60
Time to flowering (d)	51
Length of the flowering stage (d)	27
Time to senescence (d)	95
Time to maturity (d)	115
Maximum rooting depth (m)	0.70
Minimum effective rooting depth (m)	0.50
Reference harvest index HIo (%)	75

**(Field experiment, 2019) d is days**

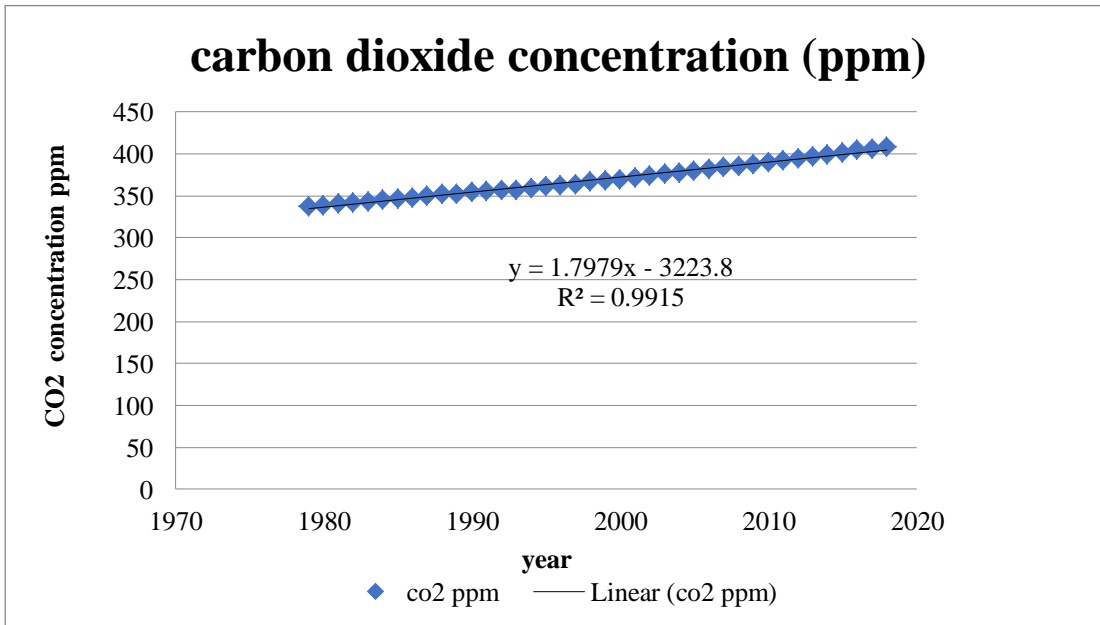
Appendix Table 6. Conservative parameters used for AquaCrop Potato Model

<u>conservative parameters</u>	<u>Values</u>
Base temperature (°C)	2
Upper temperature (°C)	26
Cover per seedling (cm <sup>2</sup> plant <sup>-1</sup> )	0.4
Canopy growth coefficient CGC (% d <sup>-1</sup> )	0.14
Canopy decline coefficient CDC (% d <sup>-1</sup> )	0.08
Soil water depletion factor for canopy expansion, upper limit	0.25
Soil water depletion factor for canopy expansion, lower limit	0.55
Shape factor for Water stress coefficient for canopy expansion	none
Soil water depletion factor for stomata closure	none
Shape factor for Water stress coefficient for stomata closure	none
Soil water depletion factor for early canopy senescence	none
Shape factor for Water stress coefficient for canopy senescence	none
Normalized water productivity WP* (g m <sup>-2</sup> )	18
Normalized water productivity during yield formation WP* (g m <sup>-2</sup> )	18
<b>(Field experiment, 2019) d is days</b>	

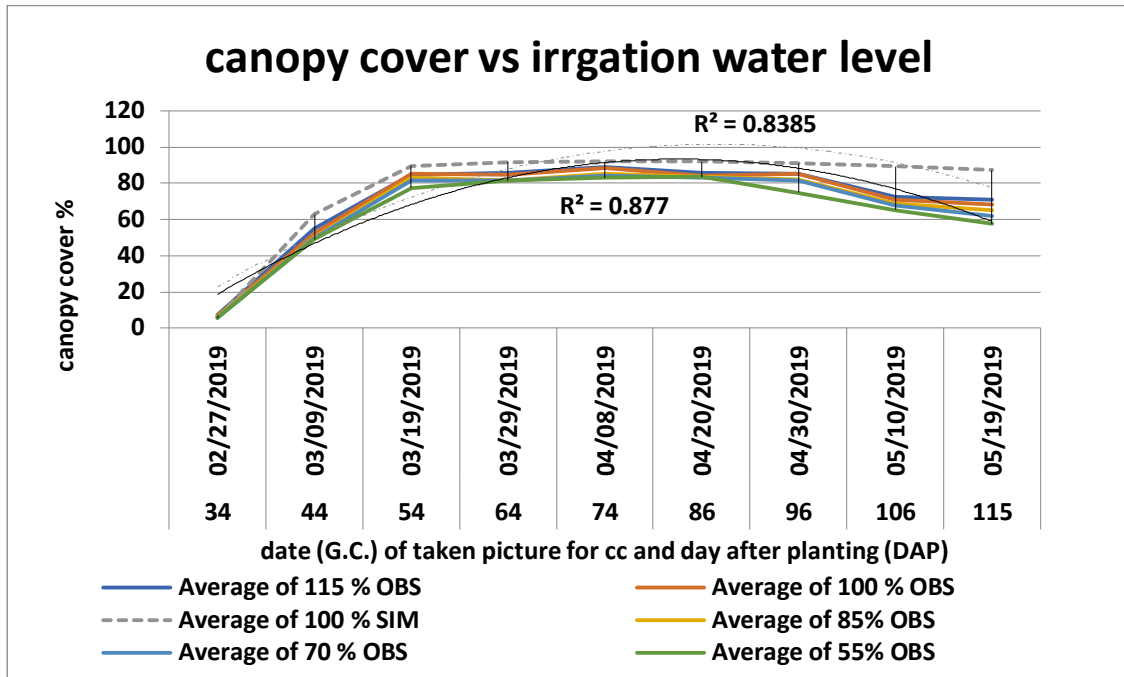
Appendix 2: Figures and illustrations in appendixes



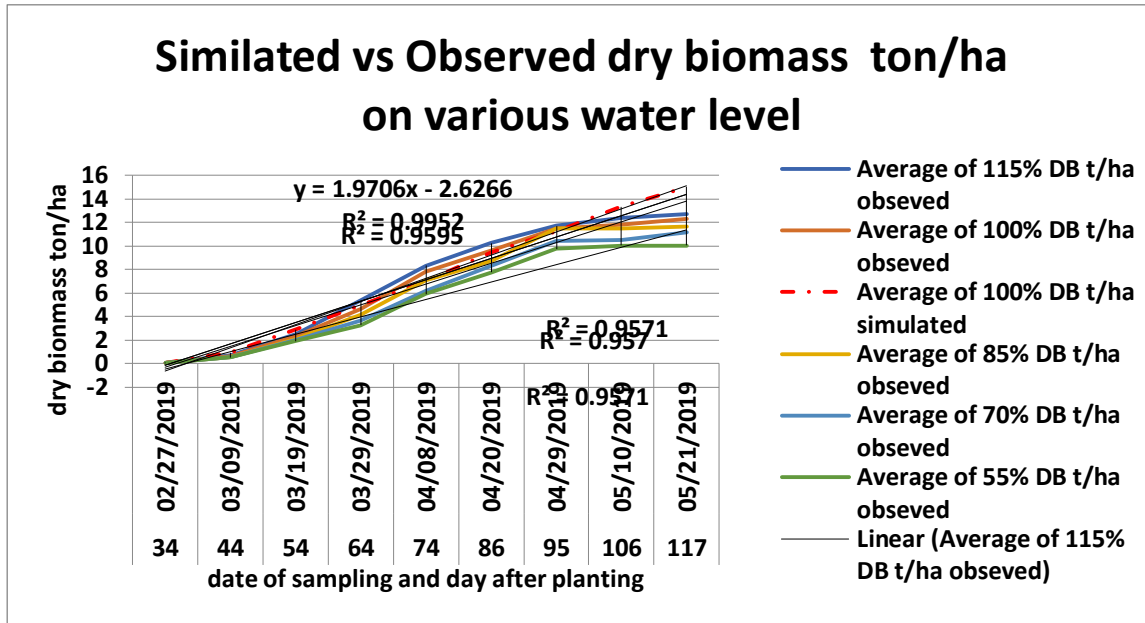
Appendix Figure 1. Trends on temperature and rainfall



Appendix Figure 2. Carbon dioxide concentration trends



Appendix Figure 3. Canopy covers versus irrigation water level



Appendix Figure 4. Dry biomass versus irrigation water level



Appendix Figure 5. Picture at planting and land management



Appendix Figure 6. Soil profile pit and texture reading



Appendix Figure 7. Pictures of potato canopy cover at 10-days interval



Appendix Figure 8. Pictures tuber yield at different treatments in block one



Appendix Figure 9. The performance of the experiment

## **BIOGRAPHICAL SKETCH**

Tsegaye Getachew was born in Worreilu town, South Wollo Zone Amhara, Ethiopia in 1974. He attended primary and secondary education at Worreilu Delbeal and Worreilu secondary school respectively. He then joined Kombolcha ATVET College in diploma in plant science in 2008, and then joined at Debre Birhan University in water resource and irrigation management in Bachelor of Science in 2013. He works in Amhara Agricultural Research Institute (ARARI), at Debre Birhan Agricultural Research Center (DBARC) since, 1982 to update. The current position is as an Assistant Researcher II on soil and water management research directorate in agricultural water management case team. He continued his studies in master program at faculty of bio system and water resources engineering, specializations in irrigation and drainage engineering, institute of technology of Hawassa University in 2017. He was married and has three children's and lives in Debre Birhan town.