COMPARISON AND VALIDATION OF AQUACROP AND WaPOR DERIVED WATER PRODUCTIVITY OF IRRIGATED WHEAT USING GROUND DATA FOR SELECTED SITES IN AWASH RIVER BASIN, ETHIOPIA

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Comparison and Validation of AquaCrop and WaPOR Derived Water Productivity of Irrigated Wheat Using Ground Data for Selected Sites in Awash River Basin, Ethiopia

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APPROVAL PAGE

I, the advisor of the thesis entitled "Comparison and Validation of AquaCrop and WaPOR Derived Water Productivity of Irrigated Wheat Using Ground Data for Selected Sites in Awash River Basin, Ethiopia" and developed by Tolosa Balemi Tola; hereby certify that the recommendation and suggestion made by board of examiners are appropriately incorporated into the final version of the thesis.

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Major Advisor Signature Date

We, the undersigned, members of the Board of Examiners of the thesis by Tolosa Balemi have read and evaluated the thesis entitled "Comparison and Validation of AquaCrop and WaPOR Derived Water Productivity of Irrigated Wheat Using Ground Data for Selected Sites in Awash River Basin, Ethiopia and examined the candidate during the open defense. This is therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Resources Engineering (Specialization of Irrigation Engineering).

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Reviewer 2 Signature Date

Final approval and acceptance of the thesis proposal is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

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Department Head Signature Date

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School Dean Signature Date

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Office of Postgraduate Studies, Dean Signature Date

DECLARATION

I hereby declare that this Master's thesis, entitled "Comparison and Validation of AquaCrop and WaPOR Derived Water Productivity of Irrigated Wheat Using Ground Data for Selected Sites in Awash River Basin, Ethiopia" is my own work. That is not submitted for the award of any academic degree, diploma, or certificate at any other university. All sources of material that were used for this thesis have been duly acknowledged through citation. It is being submitted for partial fulfillment for the award of the degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering) at Adama Science and Technology University School of Civil Engineering and Architecture.

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read and evaluated this thesis entitled "Comparison and Validation of AquaCrop and WaPOR Derived Water Productivity of Irrigated Wheat Using Ground Data for Selected Sites in Awash River Basin, Ethiopia" prepared under my guidance by Tolosa Balemi Tola and submitted in partial fulfillment of the requirements for the degree of Masters of Science in Water Resources Engineering (Specialization in Irrigation Engineering). Therefore, I recommend that the candidate has fulfilled the requirements and can submit the thesis to the department.

Mesfin Benti Tolera (PhD)	____________________	________________
Major Advisor	Signature	Date

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ACRONYMS

AGBP	Above Ground Biomass Production
AquaCrop	FAO's Crop Water Productivity Model
BWU	Beneficial water use
CC	Canopy cover
CCo	Initial canopy cover
CWP	Crop Water Productivity
EOS	End of season
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
AETI	Actual Evapotranspiration and Interception
FAO	Food and Agricultural Organization
FC	Soil Moisture Content at Field Capacity
FAPAR	Fraction of absorbed photo synthetically active radiation
GDD	Growing degree day
GDP	Gross Domestic Product
GPP	Gross primary Production
GPS	Geographical Positioning System
HI	Harvest Index
LUE	Light Use Efficiency correction factor
Mc	Fresh moisture content of yield
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Production
NRMSE	Normalized root mean square error
PWP	Permanent wilting point
QGIS	Quantum Geographic Information System
RMSE	Root mean square errors

SOS	Start of season
Tr	Crop transpiration
WaPOR	Water Productivity through Open Remotely Sensed
WP	Water Productivity
WPb	Biomass water productivity
WPy	Yield water productivity

ABSTRACT

Population growth and socioeconomic flux have forced people to compete for land and water resources. The increasing competition for limited land and water resources and the basic need to feed a growing population necessitate the development of innovative approaches for improving land and water productivity. The open-source remotely sensed WaPOR database and AquaCrop model are frequently used as affordable tools to monitor irrigation water productivity. The main objective of the study was to compare and validate of AquaCrop mode and WaPOR derived land and water productivity of irrigated wheat using ground data for selected sites in the Awash River basin (Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields). Based on WaPOR remotely sensed data, the spatial resolutions used to estimate crop water consumption (AETI), crop yield, and irrigation performance indicators for Alge Metehara and Kuruftu Wonji were 30 m and 100m for Kataba Gumbichu irrigation fields. Additionally, AquaCrop simulations for the chosen irrigation fields have been carried out using weather data from nearby climate stations, field soil data, field crop data, field management data, and crop canopy cover was for calibration and validation. WaPOR estimated AETI (162 mm, 138.2 mm, and 96.9 mm), seasonal yield (3.2 tons/ha, 3.3 tons/ha, and 3.6 tons/ha), crop water productivity (1.6 kg/m^3, 2.1 kg/m^3 and 2.7 kg/m^3) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively. The AquaCrop model simulates AETI (577.5mm, 250.6 mm, and 440.3mm), yield (5.3 tons/ha, 4.9 tons/ha, and 4.5tons/ha), and crop water productivity (0.92 kg/m^3, 1.98 kg/m^3, and 1.03 kg/m^3) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively. WaPOR yield values were lower compared to AquaCrop yield values and actual yield data (3.5 ton/ha, 3.8ton/ha, and 4.5ton/ha) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields respectively. Generally, we conclude that WaPOR-based results and AquaCrop model based simulations were consistent with expectations for all irrigation fields. Therefore, the WaPOR portal and the AquaCrop model were useful tools for managing water productivity in agriculture sector. While this study is done for wheat in one crop season, but it doesn't considered temporal variation and different crop season, so for the future research work, it is recommended to evaluate the temporal variation of the wheat water productivity in different crop season.

Key words: *AquaCrop, Awash River Basin, Performance Indicators, WaPOR, Water Productivity*

1. INTRODUCTION

1.1 Background

Globally, agricultural sector consume more than 70% of freshwater to secure the food demand increase by 60% and 110% in developed and underdeveloped countries in 2050, respectively (Foley et al., 2011; Brauman et al., 2013). These days, due to socioeconomic and demographic factors, freshwater supplies are under significant pressure. Among the major challenges facing water resources are population growth, fast industrialization, growing urbanization, the increase of agricultural land, climate change, and the loss of agricultural water (Mali, 2016). Also the degradation of freshwater resources is caused by a lack of innovation and new technology (Agarwal et al., 2000). Due to this reason, water scarcity poses a serious threat to many regions of the world, including Ethiopia in particular.

Ethiopia's economy is primarily depend on agriculture, which accounts for 40% of Gross Domestic Product (GDP), 80% of exports, and an estimated 75% of the country's workforce (USAID, 2021). The agricultural sector is facing the challenges of feeding the increasing population, providing raw materials for the growing agro-industries, and substituting agricultural import goods. Increasing land degradation, decreasing landholding sizes per capital, and climate change are worsening the challenges of the agricultural sector (FAO, 2017).

The government, in its ten-year economic development plan (2021–2030), has considered agriculture as top priority sector. The plan has laid out enhancing agricultural production and productivity as one of the major strategic pillars. According to Edgerton, (2009), there are two ways of enhancing agricultural production to satisfy the food demands of the growing population: expanding the area under production and improving the productivity on existing farmlands. With increasing population and land degradation, the land areas suitable for agricultural production in many areas of Ethiopia are exhausted. Thus, agricultural area expansion as a means to enhance production is no longer a viable option in many areas. Most of the agricultural growth reported in Ethiopia since the recent year emanates largely from area expansion. Expansion of agriculture to marginal and lowland areas requires huge investment to convert these areas to productive lands. As a result, future sustainable agricultural growth will necessitate a greater emphasis on productivity improvement as suitable land for expansion has decreased(Asenso-Okyere & Jemaneh, 2012).

The most viable and immediately implementable option at any scale is boosting agricultural productivity on existing farmlands. Also, the availability of water resources will be significantly stressed by population growth and a rise in living standards. As a result, securing the food supply for future generations is the main issue these days (Zwart et al., 2010a).

Currently, the Ethiopian government is actively pushing irrigated wheat farming across the entire country to address issues related to food scarcity. Wheat is the most commercially significant crop in Ethiopia, farmed by small-scale farmers to large-scale farmers using irrigation and rainfed. Wheat crops are essential for human nourishment, particularly in carbohydrate content, and also to fulfill the food demand in Ethiopia. This initiative decreases the gap between wheat grain supply and demand. Gebrie, (2022) stated that irrigation farming systems can produce more harvest with irrigated wheat cultivation than rain-fed cultivation. Eighty to ninety percent of the water used in this sector is utilised by the irrigation and agricultural sectors. According to Karimi et al., (2019) and Hamdy et al., (2003), the water use efficiency in the agricultural sector is extremely low, rarely beyond 45%, with more than 50% water losses.

Given the scarcity of water and the growing competition between agriculture and other sectors, water productivity (WP) in this sector needs to be significantly improved in order to meet future water demand (Ahmad et al., 2004). An essential part of maintaining and enhancing food production to achieve long-term food security is agricultural water productivity. As a result, in order to increase agricultural water use productivity, we must first understand the quantity, distribution, and pattern of water productivity across a certain region.

According to Molden et al., (2010), the ratio of crop yield to the total quantity of water used by evapotranspiration is known as agricultural water productivity. Appropriate water productivity targets are necessary to identify and treat inefficiencies in agricultural production and water management in irrigated systems (Grassini et al., 2011). Water productivity has different values depending on both spatial and temporal factors. It's possible to underestimate evapotranspiration, and measurements might not accurately capture regional variance. In most cases, agricultural models are used to simulate water productivity (W. G. Bastiaanssen et al., 2000).

Future food security can be ensured by improving water productivity with the help of emerging technology. The Food and Agricultural Organization (FAO) recently created the AquaCrop model and the WaPOR portal which contain datasets. An appropriate theoretical foundation for examining crop yield responses to environmental stress is provided by the FAO AquaCrop simulation model. The calibration and validation of this model do not require a high level of expertise and do not require many input parameters. The soil-crop-atmospheric ecosystem in which the crop develops is described by the small number of input data points (Geerts and Raes, 2009).

With a starting resolution of 250 m (level I), 100 m (level II), and 30 m (level III), WaPOR is the FAO portal used for monitoring water productivity over the countries of Africa and the Near East (FAO, 2018b). According to Cai et al., (2009), the WaPOR database was created to estimate crop patterns, evapotranspiration, biomass, and yield accumulation with increased spatial coverage and spatial detail over time. These models' objectives are to track water productivity gaps, suggest ways to close them, and help sustainably increase agricultural output (FAO, 2017). If the models' reliability and precision are considered acceptable, it will greatly assist farmers, agronomists, water managers, and all other interested parties in making decisions.

Given the above background, the main objective of this work was comparison and validation of the AquaCrop model and WaPOR derived land and water productivity of irrigated wheat using ground data.

1.2 Statement of the Problem

Globally, for both the present and future generations, ensuring food security while utilizing limited land and water resources in a sustainable way is a major problem (Zwart et al., 2010a). Competition between water users, scarcity of water and land resources, as well as the negative economic, social, and environmental effects of expanding agricultural land, all posed a threat to food security (Hess et al., 2016). To ensure food security, optimization of water use and land resources could reinforce crop yield production.

Ethiopia's economy is mainly depends on agriculture. The agricultural sector is facing the challenges of feeding the increasing population, providing raw materials for the growing agro-industries, and substituting agricultural import goods (USAID, 2021). Increasing land degradation, decreasing landholding sizes per capital, and climate change are worsening the challenges of the agricultural sector. Another problem is high rate of water loss due to poor management practice such as in efficient irrigation techniques, in adequate water storage and distribution system contribute to significant water losses, which reduce the productivity of agricultural sector and increase the vulnerability of communities to water scarcity (FAO, 2017). In order to evaluate the effectiveness of agricultural management methods and spatially identify areas with good and poor on-farm management practices, water productivity (WP) at the field is a prerequisite(Zwart et al., 2010b). As the result, increasing crop water productivity (kg/m^3), which is crop yield per unit of water consumed, is the essential method to ensure efficient agricultural and land use (Molden et al., 2010).

Traditionally, Crop water productivity was conducted by using field experiment to access and evaluate alternative way irrigation water management. But to conduct field experiment collecting the field data were expensive, laborious and time consuming, especially if it's for many years. Also measurement of water balance component like evaporation, transpiration, and percolation were difficult and it needs instrumentation. However, most places do not have access to the such information (Olivera-Guerra et al., 2020) due to the nature of spatial variability at the basin scale and regular measurements challenges that make it impossible to cover spatial trends over a large areas make field data collecting challenging as well (Biggs et al., 2016).

To estimate crop patterns, evapotranspiration, biomass, and yield accumulation with increased geographic coverage and spatial detail across time, the FAO has recently developed WaPOR portal (using the open-source remotely sensed WaPOR data) (Cai et al., 2009). Therefore, properly evaluating the spatial variability of irrigated wheat land and water productivity using the WaPOR portal (using the open-source remotely sensed WaPOR data) is curial in order to access to high quality data, improve water management, enhanced decision making, and increase transparency which help to improve land and water productivity and promoting sustainable water management practices. Moreover, selection of the WaPOR model requires comparison with observed field data.

1.3 Objective of the Study

1.3.1 General objective

The main objective of this study was to compare and validate the AquaCrop model and WaPOR derived land and water productivity of irrigated wheat using ground data.

1.3.2 Specific objectives

The following three specific objectives were formulated to achieve the general objective of the study.

- To evaluate the spatial variation of wheat water consumption, yield, and water productivity using the AquaCrop and WaPOR database.
- To assess the spatial patterns of land and water productivity performance indicators by using the WaPOR database for the selected sites.
- To compare and validate crop water consumption (AETI), crop water productivity and crop yield estimated by using the WaPOR derived with the output of AquaCrop model, and field observed yield data.

1.4 Research Questions

The following three research questions were formulated to achieve the specific objective of this study.

- How do the water consumption, crop yield, and water productivity vary spatially with selected irrigated wheat farms?
- What are the extents of the spatial patterns of irrigated wheat field performance indicators, when combined with land and water productivity?
- How well do the WaPOR portal and AquaCrop model simulate crop water consumption, yield, and water productivity in the irrigated field of the study?

1.5 Significance of the Study

In an effort to reduce the gap between supply and demand for wheat grain, the Ethiopian government is aggressively encouraging irrigated wheat farming throughout the country(Gebrie, 2022a). Water productivity enhancement is required to satisfy these future demands in order to address water scarcity and competition in the agriculture sector (Ahmad et al., 2004).

In most cases, water productivity is estimated using field data on yield and water application or by using agricultural models like Aqua Crop. However, measurements might not accurately capture spatial variation, and true actual evapotranspiration and interception may be unknown (W. G. Bastiaanssen et al., 2000). In order to overcome such problems, readily available satellite data is used to estimate the variability of the irrigation yield and water productivity. This study considered the WaPOR based and AquaCrop models to evaluate wheat irrigation practices in three selected areas in the Awash River basin (Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat irrigation farms).

The crucial significance of this study is to evaluate the use of the FAO-based (WaPOR) remotely sensed database and AquaCrop model simulation. Moreover, the analysis and results obtained helped policymakers, planners, and decision makers to evaluate wheat production for efficient use of land and water resources.

1.6 Scope and Limitation of the study

The scope of this study is limited to evaluating the spatial variability of wheat water productivity analysis at a selected site in the Awash River basin, specifically Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation farms, using the WaPOR based and AquaCrop models. Primary collected yield field data validates the WaPOR and AquaCrop models. The study mainly considers wheat crop production using furrow irrigation and its water consumption, yield, and water productivity. However, the study doesn’t consider the variety of crops, socio-economic conditions, and temporal changes in land use. During the simulation of the AquaCrop model, soil fertility stress and weed infestations were not considered due to a lack of data.

1.7 Thesis Organization

This thesis is organized into five chapters. The first chapter is the introduction, which consists of the background, statement of the problem, objective of the study, research question, significance of the study, scope of the study, and limitations of the study. The second chapter is the literature review, which describes the concept of water productivity. Additionally, it goes into detail about the AquaCrop model and covers the WaPOR database's application in irrigation, WaPOR data coverage, WaPOR data components and their relationships, irrigation water management, and irrigation water application. It also provides a chronological overview of Ethiopia's irrigation development and irrigated wheat production and other related studies on WaPOR and AquaCrop. The material and methods are incorporated in Chapter 3. The study area, its climate characteristics, and its topography were highlighted. Materials and software used sources of data used, data analysis, and the methodological steps taken to achieve the objective of the research. In Chapter 4, the study's results and discussions are described in relation to the objective of the research mentioned in Chapter 1 of this work. Chapter five concludes with conclusions and suggestions.

2. LITERATURE REVIEW

2.1 Irrigation Development in Ethiopia and Irrigation of Wheat Crop

Since ancient times, Ethiopia has employed irrigation to grow crops for food and income. On the other hand, modern irrigation techniques were initially used in the Awash Valley in the 1960s to cultivate industrial crops. The first official irrigation systems were started in the upper and lower Awash Valleys in the late 1950s by private concessionaires who maintained farms for producing commercial crops like cotton, sugarcane, and horticulture crops. Irrigated agriculture was developed in the Lower Rift Valley and the Awash Valley in the 1960s. In light of the water management made possible by the construction of the Koka dam and reservoir, which controlled flows with the advantages of flood control, electricity, and a guaranteed supply of irrigation water, the Awash Valley had the greatest expansion (Awulachew et al., 2007). In order to increase productivity and lessen a nation's vulnerability to climatic change, irrigation expansion and agricultural water management are essential.

Ethiopia's agricultural industry does not entirely benefit from water management and irrigation technologies, while having adequate rainfall and water resources (Awulachew et al., 2007). The government is currently focusing more attention on the industry by improving the nation's food security situation. To enhance the productivity of irrigated agriculture, efforts are being made to gradually involve farmers in various facets of small-scale irrigation system management, beginning with planning, implementation, and management aspects, particularly in water distribution, operation, and maintenance.

According to Nigussie et al., (2019), Ethiopia has more than 74 million hectares of land suitable for agriculture. The potential irrigable land is 7.5 million hectares (Tiruneh et al., 2017). Although irrigation has numerous potential advantages, many irrigated regions of the country have far less success than they could; less than 3% of households have access to irrigation, and only around 5% of the country's irrigated acreage is currently irrigated. According to Makobe et al. (2011), Ethiopia is blessed with a variety of water resources, including 12 rivers, 22 natural and man-made lakes, and ground water. The majority of its population is still directly or indirectly involved in irregular rainfall-dependent agriculture, despite having 5.3 million hectares of irrigation potential (3.7 million from gravity-fed surface water, 1.1 million from groundwater, and 0.5 million from rainwater harvesting) (Awulachew et al., 2010).

The development strategy of the country, regional states, and non-governmental organizations is encourages the development of small-scale irrigation schemes in order to improve and maintain the country's agricultural production (Abdissa et al., 2017). As Ethiopia competes with other African wheat-producing nations, it is important to take into account the number of irrigable rivers in the nation that are suitable for large-scale production. This will allow for the design of an appropriate agricultural policy that encourages large-scale farming industries to produce wheat by expanding irrigable land (Anteneh & Asrat, 2020). The Ethiopian government is currently promoting the wheat crop to be grown under irrigation in the lowland temperate regions of the nation.

It has been shown that Ethiopia's wheat output increase from 39 million tons in the 2016–17 crop years to 50.03 million tons in the 2020–21 crop year, even though the region remained relatively unchanged (Gebrie, 2022b). This growth was mostly caused by better farming practices, the use of irrigation, and more assistance for wheat producers. Although the nation's production of wheat is increasing, global demand for the crop is growing steadily at an average annual rate of 9%, while domestic production is only expanding at a pace of 7.8%.

These factors increasing population size, shifting food preferences, and occasionally declining crop productivity are the main causes of these disparities. However, 90% of Ethiopia's wheat production still takes place on small farms without irrigation (Bergh et al., 2019), and the country's present import deficit in wheat is straining its foreign exchange reserves. In an effort to close the gap between supply and demand for the crop, the Ethiopian government is currently actively encouraging the production of irrigated wheat throughout the entire nation. This is so that irrigation farming systems with irrigated wheat cultivation may provide a greater crop than they can with rain-fed wheat cultivation.

2.2 Irrigation Application and Management

The irrigation water application method, or how water is applied, has an impact on irrigation water efficiency. Water conservation and effective utilization have been addressed using a variety of techniques. In the production of vegetables, common irrigation techniques include overhead, sprinkler, furrow, and micro (drip) irrigation. Varied irrigation techniques have different application efficiencies, such as sprinklers (60–80%), furrows (40–60%), and drips (75–90%) (Knox et al., 2012). While drip irrigation takes skilled labour, has high maintenance costs, and is relatively expensive despite having the highest efficiency; furrow irrigation requires a lower initial investment than the other application methods. Farmers consistently over irrigate when irrigation water availability is not a concern, but they switch to increasing irrigation intervals when water is scarce, which stresses the crops and leads to low and poor-quality harvests (Goldhamer & Fereres, 2004).

Planning and managing irrigation water applications to satisfy agricultural water demands while minimizing the loss of water, soil, plant nutrients, and energy is known as irrigation water management. It involves giving crops the water they need in levels that can be held in the soil and made available to them, as well as at rates that are compatible with the soil's capacity to absorb moisture and the erosion risk of the area. It is believed that conserving water through better irrigation supply management is critical for meeting future water needs (D. Molden et al., 2010). To calculate the amount and duration of irrigation, it is essential to identify the crop type and its developmental stage because various crops have varied water requirements at different stages of growth. The conventional local irrigation technique disregards the current weather and soil moisture conditions.

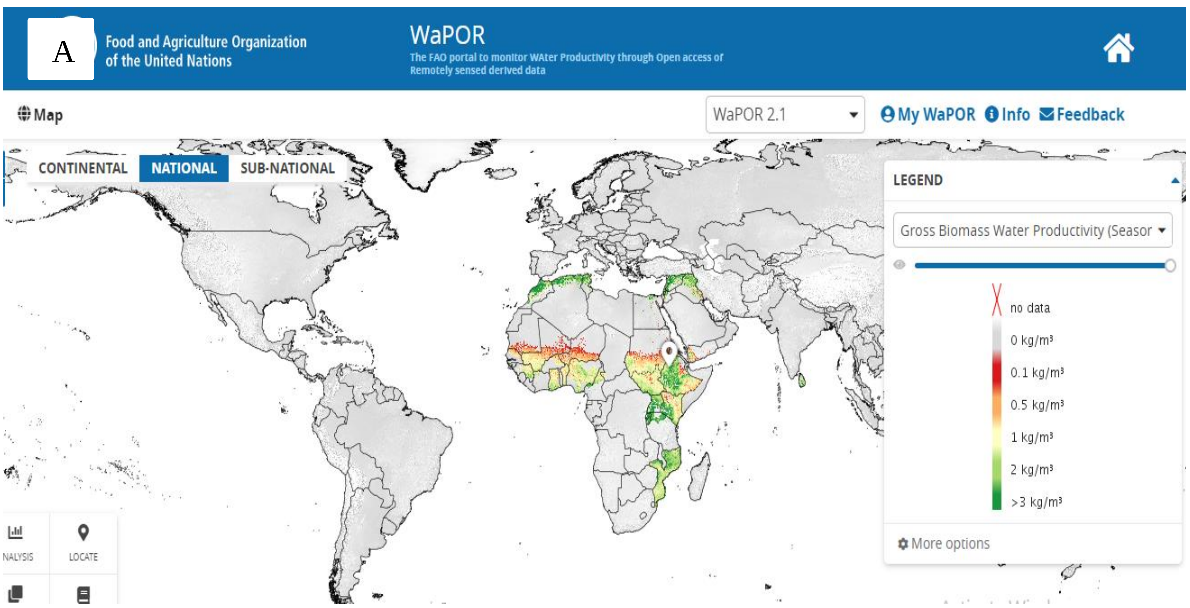
2.3 Application of WaPOR Database in Irrigation

Ensuring food security while making sustainable use of finite land and water resources represents an enormous challenge for both the present and future generations. Expanding agricultural acreage or raising the productivity of the current agricultural regions is two ways to increase agricultural production in order to feed the expanding world population. Due to the growing competitiveness, the scarcity of water and land resources, and the economic, social, and environmental implications of expanding agricultural land (Hess et al., 2016).

Using remote sensing techniques to continuously monitor water productivity can help identify water productivity gaps and assess suitable ways to address them. WaPOR was launched on April 20, 2017. A new version of WaPOR 1.0 was released in June 2018 based on the methodology review process, focusing first on the coarser resolution level (Level 1), covering all of Africa and the Near East at a ground resolution of 250 m, and then the national or river basin level (Level 2) at a resolution of 100 m. The WaPOR Version 1.0 release (https://wapor.apps.fao.org) has made the methods used to create the database at Level 3 (30 m) public since August 2018 (FAO, 2019).

2.3.1 WaPOR Data Coverage

Figure 2.1 shows data on water, land and climate for determine parameter like, evaporation, transpiration, intercept, net primary productivity, above-ground biomass output, and land cover classifications at all three levels are available in the WaPOR database. Reference Precipitation and evapotranspiration are the only Level 1 data components generated, and it should be noted that they are both produced daily with a significantly lower spatial resolution than the other Level 1 data components. For Levels 2 and 3, phenology is supplied, and HI is only delivered for Level 3 (enabling crop yield calculation) (FAO, 2019).



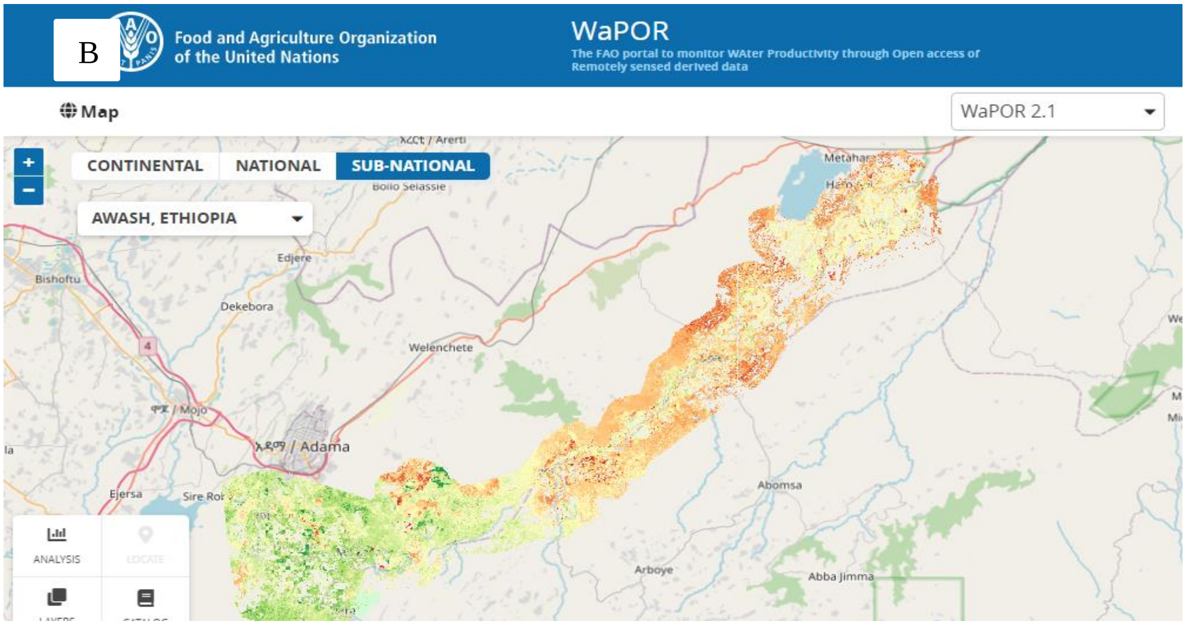


Figure 2:1 WaPOR data coverage national level (A) and at sub national level (B) (https://wapor.apps.fao.org)

2.4 WaPOR data components

Table 2.1 shows the lists data elements that are generated for the WaPOR database. At all three levels, there is production of above-ground biomass (AGBP), water productivity (WP), evaporation (E), transpiration (Tr); interception (I), net primary productivity(NPP), and land cover classifications (LCLU). Reference evapotranspiration (ETo) and precipitation (Pcp) are the only Level 1 data components provided; it should be noted that these two data components are produced daily and have a significantly lower spatial resolution than the other Level 1 data components. For Levels 2 and 3, phenology is provided, while HI is only provided for Level 3 (FAO, 2019).

Table 2:1 WaPOR data elements, per Level, with defined temporal and spatial resolutions

Data components	Level-I	Level-II	Level-III	Remarks
WP	yearly	Decadal/ Seasonal	Decadal/ Seasonal	Level specific calculations
Ev	Decadal / yearly	Decadal /yearly	Decadal / yearly	
Tr	Decadal / yearly	Decadal / yearly	Decadal / yearly	
Int	Decadal / yearly	Decadal / yearly	Decadal / yearly	
NPP	Decadal	Decadal	Decadal	
AGBP	yearly	Seasonal	Seasonal	
Phenology		Seasonal	Seasonal	
HI			Seasonal	
ETo	Daily			20km resolution
Pcp	Daily			5km resolution
LCLU	yearly	yearly	Decadal	Level detailed class

Source :- (FAO, 2019)

2.4.1 Net primary production

The net primary production (NPP), which measures how well photosynthesis transforms carbon dioxide into biomass, is an essential component of an ecosystem. NPP is a part of a collection of definitions that explain how ecosystems and the atmosphere exchange carbon. Gross primary production, or GPP, is the measure of the photosynthesis-related carbon uptake by the standing biomass. NPP is the same as GPP minus losses from autotrophic respiration, losses from the conversion of basic products (glucose) to higher-level photosynthesis (starch, cellulose, lipids, and proteins), and respiration necessary to keep the standing biomass. The contribution of soil respiration, or the soil micro flora’s conversion of leaf and other litter to

CO_2, is also taken into consideration by NEP, or net ecosystem production. Finally, the net biome production (NBP) is obtained by deducting the losses resulting from disturbance and anthropogenic removals. All three levels of NPP are supplied on a decadal basis, with pixel values denoting the average daily Net primary production in gC/m2/day for that particular dekadal. It is sometimes preferable to quantify dry matter production (DMP, expressed in kgDM/ha/day), such as when farming. A constant scaling factor of 0.45gC/gDM can be used to convert NPP to DMP(Ajtay, 1979). Thus, 1 gC/m2/day (NPP) equals 22.222kgDM/ha/day (DMP) for one day. Although greater values can occur (theoretically up to 320 kgDM/ha/day), typical NPP values in the region range from 0 to 5.4 gC/m2/day (NPP) or 0 to 120 kgDM/ha/day (DMP)(FAO, 2020).

2.4.2 Biomass water productivity

Biomass water productivity (WPb) is a commonly used metric to assess the relationship between biomass production and water use (Gemechu et al., 2020); (Sharma et al., 2015). According to (Sharma et al., 2015) WPb is "the ratio of the net benefits to the amount of water used to produce those benefits." WPb is defined in this study as the proportion of real evapotranspiration to above-ground dry biomass production (B). When B and AETI are not taken into account, the ratio of WPb alone is of little significance (Zoebl, 2006). A high B may not always follow from a high WPb. For instance, biomass may be low and AETI may be very low, yet WPb may be high. As a result, B and AETI should be considered in order to get useful conclusions for irrigation managers and farmers.

According to (Zoebl, 2006) for the purpose of identifying and comprehending regional or temporal fluctuations in WPb, additional parameters, such as crop water requirements, should be taken into account in addition to biomass and AETI. The effectiveness of the irrigation system may be adequately examined when all these elements are taken into account. A thorough grasp of the local agronomic practices and irrigation system performance is required to improve WPb and water consumption in a given area. Understanding the performance can help farmers in the Awash River Basin overcome the problem of water scarcity.

2.4.3 Crop Water Productivity

In order to emphasize that improving local irrigation efficiency could not result in basin-wide water savings, then the term water productivity (WP) originated(Lamm et al., 2019). Since then, many other authors have defined WP differently, revolving around crop per drop. According to (Schillinger & Wuest, 2014), water productivity is the proportion of a company's outputs to its inputs. The economic or biophysical benefit from the utilization of a unit of water consumed in crop production is what FAO (2017) defines as agricultural water productivity.

Water productivity also shows which plots are very efficient and non-efficient with water and at the same time a high or low food production (W. G. M. Bastiaanssen & Steduto, 2017). The food production can be calculated using the biomass or yield. Using biomass the water productivity will be called 'Gross/Net biomass water productivity', using yield the water productivity will be called 'crop water productivity'. Yield data is calculated and used in this analysis. The water consumption can be calculated by the evapotranspiration of the plant (FAO, 2019). Crop water productivity (CWP), here defined as grain yield per ETIa, expresses the relationship between yield and the consumption of water (Moriasi et al., 2007).

2.4.4 Actual Evapotranspiration and Interception

Actual evapotranspiration and interception is the total of soil evaporation, canopy transpiration, and interception. Rainwater that is captured by plant leaves and afterwards evaporates from their surface is referred to as "interception". Climate (wind speed, radiation, and air temperature) and soil conditions (soil moisture content) have an impact on evaporation, transpiration, and interception. To calculate agricultural water usage, add up the three variables: evaporation, transpiration and interception which gives (actual evapotranspiration and interception). Agricultural water productivity can be calculated by combining AETI with biomass yield or production (Blatchford et al., 2020).

2.4.5 Moisture Content of Yield (mc)

Grain moisture will ultimately reach a condition of environmental equilibrium for a particular atmospheric temperature and RH. Equilibrium moisture content is the term for this grain characteristic. The drying air's temperature and relative humidity therefore influence the grain's moisture content. Soybean, rice, and wheat will ultimately attain the EMC of 15.2%, 15.2%, and 14.6%, respectively, if air under the same RH (75%) and temperature (75°F) is circulated through them over an extended period of time(Brennan et al., 2019). When seeds are collected with high moisture content and are not dried right away, the high moisture causes the seeds to heat up, molds to form, and the seeds soon perish. The seed cannot even be utilised for grain if it is severely damaged. When seeds are "harvest mature," the majority of seed crops are collected.

Most grain crops have a moisture content of about 12–14%; oily seeds like soybean, peanut, or cotton have a moisture level of about 8–10%. The ideal moisture level for wheat, however, ranges from 14 to 17%. Low seed moisture content harvesting of wheat seed harvests reduces mechanical damage to the seed and aids in resolving Ethiopian highland difficulties with seed drying. According to research, wheat must have a critical moisture level of 14.6% in order for respiration to rise(Agumas et al., 2014).

2.4.6 Harvest Index (hi)

Utilizing the harvest index, biomass production is divided into harvestable and non-harvestable fractions. It is feasible to determine agricultural production and crop water productivity using the harvest index. The harvest index, which shows how much of the biomass production contributes to the portion of a crop that can be harvested (yield), is typically used to evaluate the productivity of a particular plant type. The ratio of the weight of dry grains to the total dry matter is used to express it. Due to the seasonal nature of the harvest index, it indicates the harvest index at the conclusion of the growing season.

The index can reach a theoretical maximum of 1 when all of the AGBP is harvested, ranging from 0 (no percentage that is harvestable). The harvest index for the major crops wheat, maize, potatoes, fruit trees, olives, grapes, rice, and sugarcane is provided for Level 3. The harvest index can only be accurately understood with knowledge of both crop phenology and land cover, claims the FAO's Aqua Crop model (FAO, 2017). The first links the harvest index to a particular crop, and the second to a particular growing season. For the Level 3 crops, typical reference harvest index values include, for example: rice (0.43), wheat (0.48), maize (0.48), and sugarcane (0.35) (FAO, 2020).

2.5 Studies on Open-Source Remotely Sensed WaPOR Database

Several research works were undertaken on evaluation of crop water productivity and irrigation field performance by using open-source remotely sensed WaPOR dataset in various parts of the world. The Xinavane sugarcane estate in Mozambique was the subject of a study by Chukalla et al., (2022) on a framework that uses WaPOR data to evaluate irrigation performance parameters, including uniformity, equality, sufficiency, and land and water productivity differentiated by irrigation mode (furrow, sprinkler, and center pivot). The WaPOR data on water, land, and climate are distributed geographically in virtually real-time, with the best spatial resolution in the 100m range. Before using the WaPOR data to systematically study seasonal indicators for the years 2015 to 2018 across an area of 8000ha, the biomass reaction to water was used to ergonomically analyze the data. It was discovered that there was only a 20% difference between the WaPOR-based yield estimations and the estate-measured yields, a root mean square error of 192.5tha-1, and a mean absolute error of 15±1.6tha−1. The comparison of performance indicators throughout space and time is made possible by the application of a climate normalization factor. The analysis shows that no single irrigation technique in Xinavane performs well across all performance indicators. Centre pivot irrigation has higher adequacy, equity, and land productivity than sprinkler and furrow irrigation, but lower water productivity. With the exception of 2016, when a drought was noted, the three irrigation technologies had satisfactory sufficiency for most of the seasons and outstanding uniformity (94%) in all four seasons. The approach used for this study, which focused on sugarcane in a particular irrigation scheme, may be applied to other crops in irrigation schemes or fields across Africa with different management structures and agro climatic zones covered by the FAO WaPOR. They come to the conclusion that utilizing the WaPOR dataset, the framework may be used to evaluate irrigation performance.

Using data acquired from remote sensing, (Gemechu et al., 2020)conducted a study on the mapping of temporal and geographical variability of agricultural water productivity of sugarcane crop in three significant irrigation schemes of Ethiopia (Wonji, Fincha'a, and Metehara). The datasets used in this study came from WaPOR, an open access site, and included decadal data on Actual Evapotranspiration and Interception (AETI) and Net Primary Production (NPP) with a geographical resolution of 100m. As a consequence, data on the average fresh weight yields per hectare and average seasonal AETI for the schemes from January 1, 2009, to June 30, 2019, were collected. By utilizing yield as the numerator and AETI as the denominator, one may calculate the water productivity in kilograms per cubic meter. Calculations were made for the agricultural water productivity in Wonji (7 kg/m3) and Fincha'a (4.3 kg/m3). At Metehara, it was 7.5 kg/m3. Visualizations of the measured performance of the acquired multi-seasonal average variable water production and comparison of sub-irrigation plans over space and time. From January 1 to June 30, 2019, Dodota, Sodare, and Wake-Tiyo in the Wonji irrigation scheme showed high WP values of 7.6 to 9 kg/m3, while the Wonji main sub-irrigation scheme recorded a lesser value of 5.7 to 7 kg/m3 from July 1 to December 31, 2013. Many plots in the northern and southern sectors of the East and West banks, as well as the Neshie sub-schemes, of the Fincha'a irrigation scheme, show a high water productivity range, ranging from 7.3 to 11.2 kg/m3. Strong water production is seen in plots in the southern portion of the Metehara irrigation project, which range from 6.7 to 10.6 kg/m3.

On other hand, the study was carried out by Widengren, (2022) analysed the WaPOR database's freely accessible remote sensing data on land and water production. The WaPOR data and primary field data for three irrigation schemes in the Malwathu Oya river basin were compared using the crop water model AquaCrop as part of the evaluation. The spatio-temporal variability in crop water usage within and across these three irrigation schemes was also assessed using indicators gathered from the WaPOR site. The principal growing season, or Maha, was covered by the review from 2010 to 2021. WaPOR and AquaCrop measurements of actual evapotranspiration (ETa) were found to have pretty good agreement (312-537 and 400-465 mm, respectively). This might be explained by variations in calculation techniques, possible sources of inaccuracy in calculations involving WaPOR conversion, and precision constraints brought on by cloud cover during satellite data collecting. As a result, previous knowledge and accurate allocation of the crop type and attributes used in WaPOR conversion calculations have a significant influence. The spatiotemporal variation evaluation using WaPOR indicators (CV 11-19%) showed a decent amount of water distribution uniformity within irrigation systems. The beneficial water use (BWU) in irrigation schemes showed lower values (50–90% allocated to T) when the amount of available water was larger, which might be explained by a higher rate of water loss through soil evaporation. As the amount of accessible water increased crop water productivity (CWP) values modified (by around 0.70 kgDM/m3), proving that yield production is sensitive to circumstances with restricted water availability. Applying a yield boundary function, which indicates the greatest attainable yield in terms of water resource, showed that the same yield could be produced with less water. The three irrigation plans under examination therefore have the potential to raise the amount of water produced.

According to Safi et al., (2022), a common method for identifying the causes of WP changes is contrasting high-performing fields (also known as bright spots) with low-performing fields (also known as hotspots), utilising open-source remote sensing data. Applying the concept to a case study on the Bekaa Valley in Lebanon while taking into account table grapes, potatoes, and wheat. To determine their impact on WP and yield, six parameters (crop water stress, irrigation uniformity, soil salinity, nitrogen application, crop rotation, and soil type) were examined. This study shows that nitrogen stress, non-uniform irrigation, and water stress throughout the crucial crop growth phases all have a negative impact on the growth of wheat and potatoes. Potatoes planted on clay-loam soil were also discovered to have greater WP and yield than potatoes cultivated on loam soil. Such knowledge of WP factors aids practitioners in identifying priority areas and taking steps to improve WP at the agricultural field level. This research demonstrates the viability and practical usefulness of the diagnostic paradigm while acknowledging the flaws, uncertainties, and restrictions associated with the use of remote sensing data.

2.6 AquaCrop Model

Numerous crop models have been designed to address the issue of food security and evaluate how crop output responds to the environment and management. With only a small number of explicit inputs, the FAO's freely accessible AquaCrop model (Raes et al., 2009) simulates water-limited crop production under a variety of environmental and agronomic situations (Vanuytrecht et al., 2014). The functional connections between the various model components are illustrated in (Figure 2.2), along with the mechanism of the AquaCrop model and how water stress (dashed red lines) influences plant development(Steduto et al., 2009).

2.6.1 AquaCrop operation

The AquaCrop model simulates ultimate crop yield in four simple phases that are transparent in their modeling methodology, according to the AquaCrop manual (Muroyiwa et al., 2022). At each daily time step, the four stages (which run sequentially) simulate:

Crop development:-The expansion of the canopy and the extension of the root zone are separated in the simulation of crop development. Through water stress, shoot and root interaction is indirect. Green canopy cover (CC), a measure of crop progress, is used by AquaCrop. An important component of AquaCrop is the canopy. It influences the quantity of water transpired (Tr), which in turn determines the amount of biomass generated (B), and the overall yield (Y), through its expansion, ageing, conductance, and senescence. The maximum rooting depth may not be attained if water stress occurs because the simulated CC will be lower than the potential canopy cover (CCpot) for no stress circumstances (dark shaded regions in Figure 2.4).

Crop transpiration (Tr):- The crop coefficient is multiplied by the evaporating power of the atmosphere (ETo), which is how crop transpiration is calculated. The crop coefficient (KcTr) is continually modified since it is related to CC. The FAO Penman-Monteith equation determines the reference grass evapotranspiration (ETo), which is used to express the evaporating power. Water stress may cause stomatal closure in addition to having an impact on canopy formation, which directly impacts crop transpiration. The source of transpiration is represented by the green canopy cover and duration, while the degree of transpiration is represented by stomatal conductance;

Above ground biomass production (B):- A proportionate quantity of biomass is generated based on the biomass water productivity and the total amount of water transpired (Tr). The water productivity (WP*) that has been normalized for atmospheric demand and air CO_2 concentrations is utilised in AquaCrop. It conveys the significant correlation between biomass output or photosynthetic CO_2 uptake, regardless of environmental circumstances, and transpiration. There is no division of above-ground biomass among different organs in addition to the division of biomass into yield. By making this decision, one can avoid having to deal with the complexity and uncertainty related to partitioning processes, which are still among the least known and hardest to understand;

Yield (Y) formation: - The Harvest Index (HI) is used to calculate crop production from the simulated above-ground biomass (B). During the yield formation process, HI is continually changed in response to water and/or temperature stressors.

$$B = WP * \sum \frac{Tr}{ET_O} \tag{2.1}$$

$$Y = B * HI \tag{2.2}$$

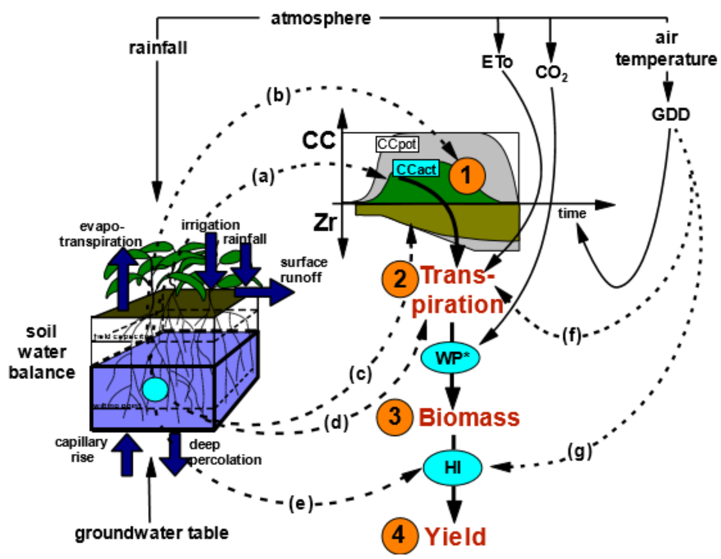


Figure 2:2 Flow chart of the calculation scheme of AquaCrop (Raes, 2022)

Where, a dotted arrow denotes the processes that are impacted by temperature (arrows 'f' to 'g') and water stress (arrows 'a' to 'e'). The terms "CC" and "CCpot" stand for "simulated canopy cover," "potential canopy cover," "potential canopy cover," "rooting depth," "reference evapotranspiration," "growing degree days(GDD)," "WP*," and "Harvest Index," respectively. By taking into consideration the entering and outgoing water fluxes at its borders, the volume of water stored in the root zone is simulated. The extent of water stresses affecting (a) green canopy (CC) expansion, (b) canopy senescence and decline, (c) the rate at which the root system is deepening, (d) stomatal conductance and consequently transpiration, and (e) the harvest index are all dependent on the root zone depletion (figure 2.4). Cold temperature stress (f) lessens crop transpiration. Hot and cold temperature stresses (g) inhibit pollination and reduce HI.

2.6.2 Studies on AquaCrop Model

Based on experimental data, Gebreselassie et al., (2015) employed an AquaCrop model to estimate the yield response of a maize crop under deficit watering. The central rift valley of Ethiopia served as the site of this investigation, which ran from February through June of that year. The intention was to ascertain how different deficit irrigation levels will affect the growth, grain output, and water consumption effectiveness of the maize (BH-14) crop at various developmental phases. The AquaCrop model was calibrated and validated using data from field studies. The crop water requirement for maize for full irrigation application was calculated using CropWat 8.0. 100%, 75%, 50%, and 25% of crop evapotranspiration were considered when determining how much water to apply. Based on these irrigation levels and the four phases of maize crop growth, ten treatments were created. The study's conclusions show that for the majority of treatments, the model did an excellent job of simulating the growth of aboveground biomass, grain yield, and canopy cover (CC), but that it performed less well at forecasting the growth performance of treatments under prolonged water constraint. Since it is easy to use, takes little input data, and has a good level of simulation accuracy, the AquaCrop model is a valuable tool for analyzing crop production under deficit irrigation and on-farm water management to increase the efficiency of water usage in agriculture.

(Wale et al., 2022) carried out a research study on Evaluating the Performance of AquaCrop Model for Potato Production Under Deficit Irrigation. This research has shown that, compared to full irrigation requirements, deficit irrigation dramatically boosted crop evapotranspiration, yield, and water usage efficiency. However, due to the fact that drought tolerance varies greatly by growth stage, species, and cultivars, this strategy necessitates detailed understanding of crop responsiveness to water. In order to assess the impacts of water scarcity on potato production and water use efficiency, as well as to test the AquaCrop model for potato-producing areas, this study was carried out in the Lasta district for two consecutive years. 100%, 75%, and 50% of crop evapotranspiration (ETc) were the irrigation water levels for potatoes. A randomised complete block design was used to organise six treatments. Utilizing measured crop parameters from the 2018–19 growing season, climate, soil, and crop data were calibrated using observed weather factors. Observed data collected during the 2019–20 growth season was used to validate the model. Based on the outcomes, the model's calibration showed a good fit for canopy cover (CC) and a good biomass forecast. Similar to this, the validation result revealed a good fit for CC by applying 100% water at the development and mid-season stages and 75% water at all other stages. The AquaCrop model is an effective tool for projecting crop production under deficit irrigation and water management to promote agricultural water efficiency in data-scarce environments because it is straightforward to use, takes fewer input data, and has a high level of simulation precision.

2.7 Wheat water productivity

Several research works were undertaken on wheat water based on a review of 84 literature sources with results of experiments not older than 25 years, it was found that the ranges of CWP of wheat, rice, cotton and maize exceed in all cases those reported by FAO earlier. Globally measured average CWP values per unit water depletion for wheat 1.09 Kg/m3, with the range of CWP is very large (wheat, 0.6–1.7 kg/m3) (Zwart & Bastiaanssen, 2004).

Similarly, study carried out on Koga Irrigation Scheme, north-west Ethiopia on statistical analysis of changes in water productivity (i.e. yield versus water usage), wheat yield and irrigation amount by implementation of irrigation scheduling. Highest water usage (570 mm), lowest water productivity (0.5 kg m^3) and lowest yield (2800 kg/ha) were obtained for the control group (i.e. traditional irrigation scheduling, based on experience). All groups which implemented some irrigation scheduling displayed higher water productivity than the control group(Svedberg, 2019).

Another study on study carried out by Tezera et al., (2019) by using field experiment to estimate wheat water consumption (ETc) during wet growing season under lysimeter in Melkessa Agricultural Research Center, Ethiopia and observed CWP of (1.1Kg/m^3) and observed ETc mean seasonal value 414 mm. The variability of CWP can be due to climate factor, irrigation water management and soil (nutrient) management, among others.

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Location

This study was conducted at three irrigated wheat farm in Awash River Basin namely Kataba Gumbichu, Kuruftu Wonji and Alge Metehara farm (Figure 3.1). Kataba Gumbichu Wheat farm is located in the North East Shoa Zone of Oromia Regional State, at a distance of 69 km from Addis Ababa, the capital city of Ethiopia. Geographically, it is situated at 8° 53′ 6″ to 8° 55′ 12″N and 39° 2′ 6″ E and altitude of 1900 to 2300 m m.a.s.l. The source of water used for Kataba Gumbichu irrigated wheat farm was Balbala-Wadecha River, and irrigated by the furrow irrigation method with a total area of 435 ha.

Kuruftu Wonji Shoa Wheat farm is located in the South East Shoa Zone of Oromia Regional State, at a distance of 110 km from Addis Ababa, the capital city of Ethiopia. Geographically, it is situated at 8° 27′ 54″ to 8° 29′ 6″N and 39° 13′ 20″ E and altitude of 1223 to 1552 m m.a.s.l. The source of water used for Kuruftu Wonji irrigated wheat farm was from Awash River, and irrigation is applied by the furrow irrigation method with total area of 150 ha.

The third site was Alge Metehara wheat field is located in the East Shoa Zone of Oromia regional state, approximately 200 km east of Addis Ababa. Geographically, it is situated at 8° 48′36″ to 8° 49′ 49″ N and 39° 53″60′ E and altitude of 956 m m.a.s.l. The Awash River, which runs through the study area, is used for irrigation through furrow irrigation method over a total area of 94 ha.

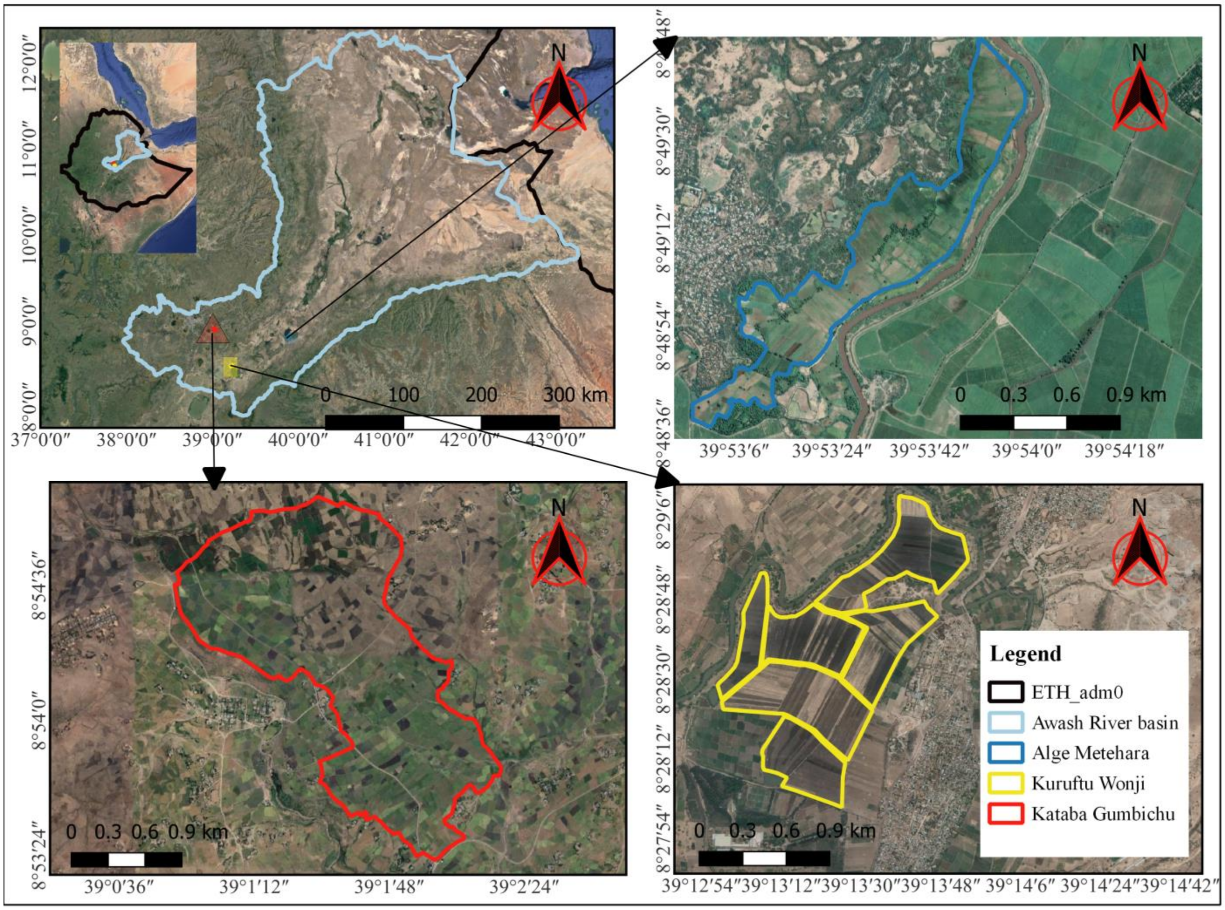


Figure 3:1Location map of the study area

3.1.2 Climate

Figure (3.2 and 3.3) shows the mean precipitation distribution and mean temperature distribution of the study areas. The climate of the Kataba Gumbichu Wheat farm is Woyna Dega (sub-humid), with the rainy season ranging from June to September. The amount and distribution of rainfall in the area is erratic. The average annual rainfall in the area is 1200 mm, with annual maximum and minimum temperatures of 22.5 and 12 °C, respectively.

The climate of the Kuruftu Wonji farm is semi-arid, with the major rainy season ranging from June to September. The amount and distribution of rainfall in the area is erratic. The average annual rainfall in the area is 831 mm, with annual maximum and lowest temperatures of 27 and 15 °C, respectively.

The Alge Metehara wheat farm has a semi-arid climate, with an average annual precipitation of 556 mm and mean annual maximum and lowest temperatures of 30 and 21 °C, respectively. The rainy season was from June to September.

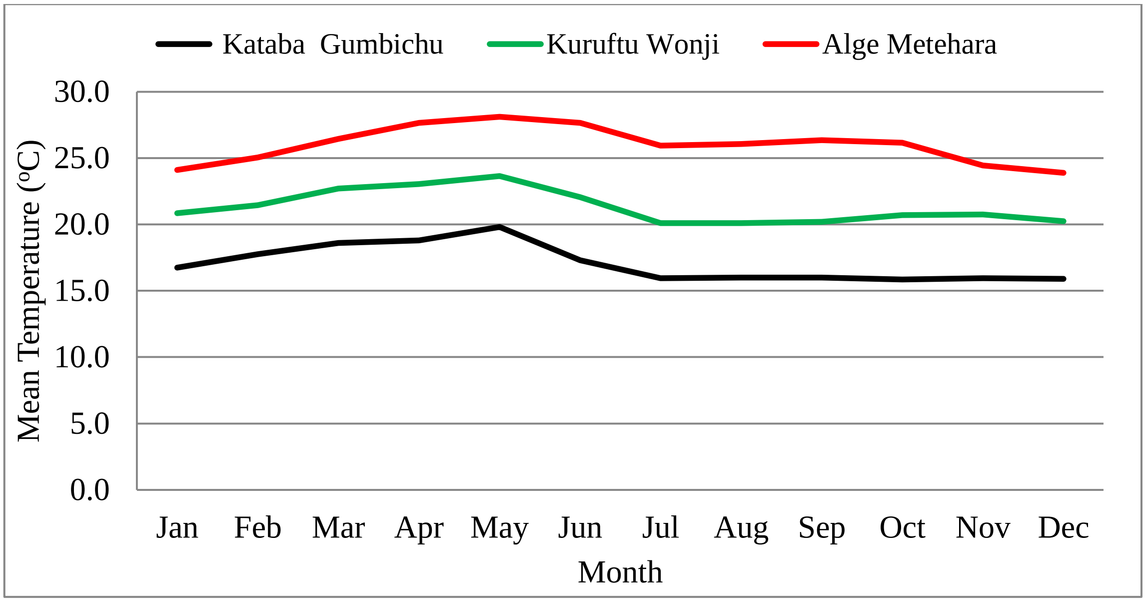


Figure 3:2 Mean monthly temperature distribution of the study Area

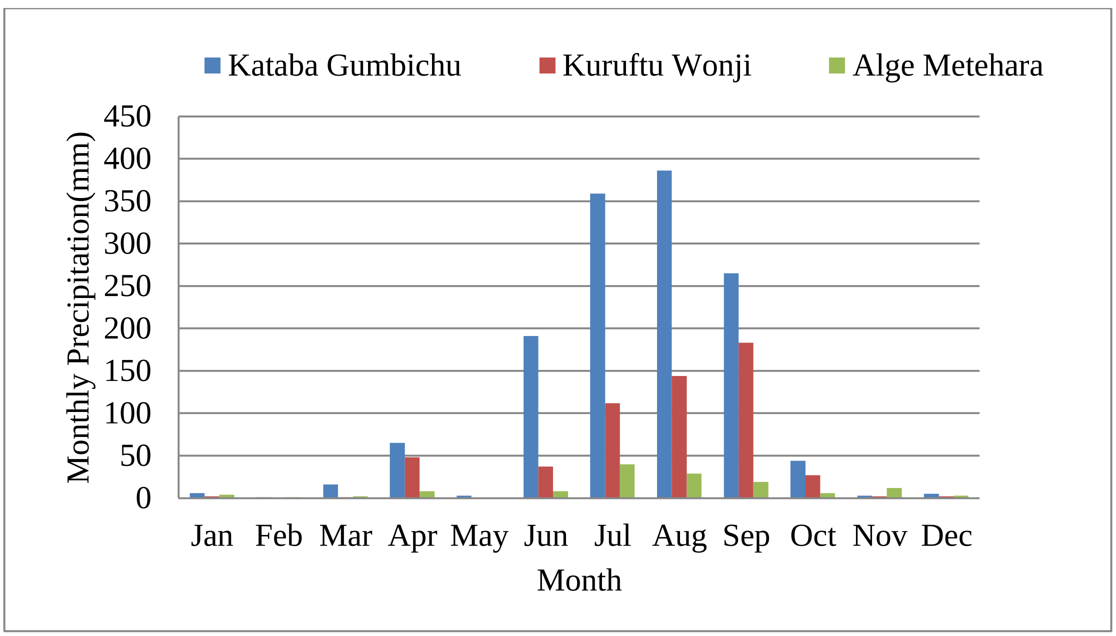


Figure 3:3 Mean monthly Precipitation distribution of the Study Area

3.2 Major Tools Used

To achieve the study's objective to compare and validate the AquaCrop model and WaPOR derived land and water productivity of irrigated wheat using ground data at the selected location in the Awash River basin, the following materials and software tools were used. Data for calculating water productivity was downloaded from the FAO-based WaPOR database (https://wapor.apps.fao.org). This database contains information on net primary production (NPP), reference evapotranspiration (ETo), actual evapotranspiration and intercept (ETIa), and precipitation. The field boundary was done by using Google Earth Pro and converting it to Quantum Geographic Information System (QGIS) to prepare a shape file. The QGIS platform was also used for processing the spatial wheat water productivity parameters such as NPP, above-ground biomass production, crop yield and land-water productivity, and analyzing other field performance indicators (beneficial water use, equity, uniformity, and adequacy). The AquaCrop Model was used for the processing of spatial wheat water productivity, crop yield, and biomass production simulations. The Geographical Positioning System (GPS) was used to collect coordinates of the irrigation field boundary. Canopeo Software was used to collect the average percent canopy cover. An auger and plastic bag were also used to collect soil samples from the irrigation field for the laboratory. And also, Microsoft Excel and other statistical tools were used for the comparison of AquaCrop and WaPOR.

3.3 WaPOR Databases for Water Productivity

In this investigation, two types of data were used: remote sensing data and field data. Field information such as field boundary, crop season, and actual yield were gathered from the field. While harvest index (HI), moisture content of fresh produce (Mc), crop coefficient (Kc), and crop light use efficiency (LUE) were derived from the literature. Water productivity data was obtained from the FAO-based WaPOR database (https://wapor.apps.fao.org). This data was resampled and aggregated, and the analyses were performed at spatial resolutions of 30m for (Kuruftu Wonji and Alge Metehara farms) and 100m for Kataba Gumbichu farm. This database contains information on WP such as biomass, evapotranspiration, reference evapotranspiration, precipitation, net primary production (NPP), actual evapotranspiration (AETI) Table (3.1).

Table 3:1The WaPOR layers that were utilised in the analyses

WaPOR layer	Spatial resolution (m)	Temporal resolution
Evaporation	30 and 100	Dekadal from January 2023 to May 2023
Transpiration	30 and 100	
Actual evapotranspiration	30 and 100	
Net Primary Production	30 and 100	

The Schematic frame work of the WaPOR- based used to analyze the remotely sensed derived data where shown in Figure (3.4)

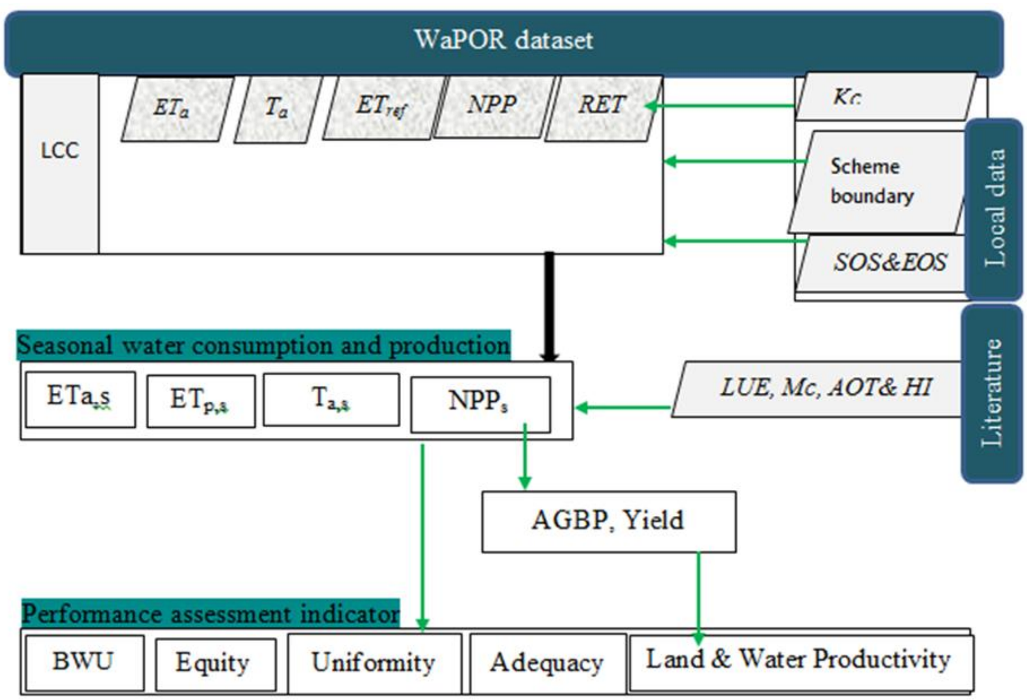


Figure 3:4 Schematic overview of the WaPOR protocol used to analyze the WaPOR data (Chukalla et al., 2022).

3.3.1 Actual evapotranspiration and interception (AETI)

Actual evapotranspiration and interception data were obtained from the WaPOR portal at dekadal (10-day) intervals. The monthly value of real evapotranspiration was estimated and summed by the length of growth time of the wheat crop to determine the seasonal value of actual evapotranspiration and interception and given by Eq. (3.1).

$$\mathrm{AETI\ (D)} = \mathrm{AETI} * 0.1 * \mathrm{n} \tag{3.1}$$

Where, AETI (D) is dekadal evapotranspiration and interception (mm/day), and AETI is original evapotranspiration and interception (mm/day) retrieved via the WaPOR portal. 0.1 is the WaPOR portal's correction factor for converting raster values to numeric values, and n is the number of days in each decade. The real dekadal evapotranspiration and interception were then converted to monthly or seasonal by adding all decadal values together. Monthly and seasonal actual evapotranspiration and interception were given in Eq. (3.2) and Eq. (3.3) respectively.

$$\mathrm{AETI(M)} = \sum_{\mathrm{D}=1}^{3} \mathrm{AETI(D)} \tag{3.2}$$

$$\mathrm{AETI}(S) = \sum_{\mathrm{M}=1}^{4} \mathrm{AETI(M)} \tag{3.3}$$

Where, AETI (M) and AETI (S) are the monthly and seasonal evapotranspiration and interception (mm/day) values. The average wheat age (growing season) for all three irrigation projects is four months and there is three dekadal in each month.

3.3.2 Above-Ground Dry Biomass Production

To determine the areal Above-Ground Dry Biomass Production, the dekadal (10-day interval) value of net primary production (NPP) was obtained from the WaPOR site and translated to monthly data by multiplying average daily data by the number of months. The seasonal value was then computed by adding all monthly data for each growing season as shown Eq. (3.4), Eq. (3.5) and (3.6).

$$\mathrm{NPP\ (D)} = \mathrm{NPP} * 0.001 * \mathrm{n} \tag{3.4}$$

Where, NPP (D) is dekadal net primary production (g/m^2), NPP is original net primary production collected from WaPOR portal (g/m^2), 0.001 is WaPOR portal correction factor to convert raster value to numeric value, and n is the number of days in each decade.

$$\mathrm{NPP(M)} = \sum_{\mathrm{D}=1}^{3} \mathrm{NPP(D)} \tag{3.5}$$

$$\mathrm{NPP}(S) = \sum_{\mathrm{M}=1}^{4} \mathrm{NPP(M)} \tag{3.6}$$

Where, NPP (M) is monthly net primary production (g/m2), NPP(S) is seasonal net primary production (g/m2), and 4 is the wheat crop's growth season (months). And 3 is the number of dekadal in a month. The seasonal net primary output is then translated to cumulative biomass production using the Eq. (3.7).

Above-ground dry biomass production (B) can be calculated by

$$\mathrm{AGBP} = \mathrm{AOT} * \mathrm{LUE} * \frac{\mathrm{NPP(s)}}{1-\mathrm{Mc}} * 22.222 \quad (3.7)$$

Where, AGBP denotes above ground biomass production [kgDM/ha], AOT denotes the above ground over total biomass ratio for wheat crop 0.85 (FAO, 2020c), and LUE denotes the light usage efficiency adjustment factor. The WaPOR calculated NPP adopts general light usage efficiency (LUE of 2.7) appropriate for wheat crops (Villalobos and Fereres, 2016). NPP stands for net primary production [gC/m^2], 22.222 is a dry matter (DM) conversion factor that converts gC/m^2 to kgDM/ha, and Mc is the moisture content in fresh biomass, which is fixed at 0.15 (Agumas et al., 2014; FAO, 2020 and Ajour, 2021)

3.3.3 Crop Yield

To determine the areal crop yield, the seasonal AGBP denotes above ground biomass production [kgDM/ha], was multiplied Crop harvest index Eq. (3.8).

$$\mathrm{Y} = \mathrm{AGBP} * \mathrm{HI} \quad (3.8)$$

Where, Y= yield (kg/ha), AGBP (Above Ground Biomass Production (kg/ha)), and HI (Harvest index (0.48) (FAO, 2020a).

Table 3:2 Parameters used for biomass and yield analyses

Parameter	Description	Value	Source
AOT	Ratio of above-ground over total biomass	0.85	(FAO, 2020c)
MC	Moisture content of fresh crop yield	0.15	(Abebe, 2014)
LUE	Light use efficiency correction factor	2.7	(Villalobos and Fereres 2016.)
HI	Harvest index	0.48	(FAO, 2020c)

3.4 Land and Water Productivity Indicators

Productivity and irrigation performance indicators help us to analyses irrigation systems and quantify the efficacy of resource application. Water consumption, equality (as assessed by the uniformity of water usage), and land and water production were among them. The definitions and methodologies used for each indicator are taken from (Chukalla, 2020a).

3.4.1 Beneficial Water Use (BWU)

BWU was determined by obtaining Dekadal ETIa and Dekadal Tr values from the WaPOR database and then aggregating them to seasonal values in QGIS. The Tr/ETIa ratio was then computed. Water consumption is the quantity of water lost from the root zone as a result of transpiration and direct soil evaporation in a crop. In this study, the primary water consumption indications are seasonal evapotranspiration and seasonal transpiration (beneficial use) and given by Eq. (3.9).

$$\mathrm{BWU} = \frac{\mathrm{Trs}}{\mathrm{AETIs}} \tag{3.9}$$

Where, BWU (beneficial water use), T_r (seasonal transpiration), and AETI (seasonal actual evapotranspiration and interception).

3.4.2 Equity

Equity is a measure of the evenness of water consumption amongst fields within an irrigation system with a homogeneous crop, which can serve as a proxy for an even allocation of water to the various irrigated areas. It is estimated as the coefficient of variation (CV) of seasonal ETIa was used to describe the homogeneity of irrigation distribution in the schemes. The WaPOR database's decadal AETI values were obtained and then combined into seasonal AETI values in QGIS. By first calculating the mean value and standard deviation (SD) of the seasonal AETI values, the CV of AETI was computed by using Eq. (3.10). Since, CV was the ratio of the SD to mean AETI (Bastiaanssen et al, 2017). Good equity is described as a CV of 0 to 10%, fair equity as a CV from (10 – 25) %, and poor equity as a CV of > 25% (D. J. Molden & Gates, 1990).

$$\mathrm{CV} = \frac{\mathrm{SD}}{\mathrm{mean}} * 100 \tag{3.10}$$

3.4.3 Land and Water Productivity

Productivity defined as land and water productivity. Land productivity is well-defined as the amount of biomass or agricultural output produced per unit of land. In the case of water, we distinguish between biomass water productivity (WPb) and crop yield water productivity (WP). WPb is defined as the biomass over seasonal AETI,s ratio, whereas WP is defined as the yield over AETI,s ratio. Water production is influenced by a variety of variables. For example, crop management, soil preparation, soil type, crop variety, and climate. Depending on the crop, varying amounts of water are needed. Water is always used to grow crops, although the amount of water used varies on the type of crop, its maturity, and environmental factors including radiation, temperature, wind, and humidity. Varying soils and crops have different growth rates at various soil water contents. Water requirements are typically minimal in the early stages of growth, but they rise quickly from the extreme growing period through the maturing stage. As the crops mature into their final phases, water use declines (Abu baker, 2009). From Eq. (3.11) yield (Y) divided by Actual Evapotranspiration and Interception (AETI) is how Crop Water Productivity (CWP) is determined. A low AETI and high yield will result in high water productivity due to the plant's high production and low water use. A high AETI and low yield will result in low water productivity since the plant is not producing much while using a lot of water. Above ground biomass production was calculated by obtaining dekadal net primary production (NPP) from the WaPOR database and aggregating results in QGIS to seasonal values. Dekadal AETI values from WaPOR were combined, and QGIS transformed these into seasonal values. The ratio of yield over AETI was then used to determine the CWP.

$$\mathrm{WP} = \frac{\mathrm{Yield}}{\mathrm{AETI}} \tag{3.11}$$

$$\mathrm{WPb} = \frac{\mathrm{AGBP}}{\mathrm{AETI}} \tag{3.12}$$

Where, WP (crop water productivity), AETI (actual evapotranspiration and interception) AGBP (above ground biomass production), and WPb (biomass water productivity)

3.4.4 WaPOR data consistency check

Before analyzing the data, it was necessary to check for consistency by plotting B vs T and B vs AETI for all irrigation fields. Since, the changes in B and T and B vs AETI for wheat crop almost linear (De Wit, 1958; Steduto & Albrizio, 2005). A linear relation would indicate consistency between the two independently generated datasets, while the slope of the line accounts for the effect crop variety and soil fertility (Steduto et al., 2007). WaPOR data consistency check was done for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat irrigated farm.

3.5 Aqua Crop Modeling

To properly model the crop growth, the AquaCrop model requires input data on climate, crop, soil, and field management characteristics. The closest weather station provided the climatic data used as input in the model. The weather data consisted of daily maximum and minimum temperature time series, daily maximum and minimum relative humidity, monthly solar radiation, monthly wind speed, and daily ETo determined from climatic data using the P-M equation. Data on daily precipitation was obtained from the nearest rain station. Primary field data collected, on soil properties, crop characteristics, and management practices are used as inputs in the AquaCrop model.

3.5.1 Weather Data

The meteorological station near the irrigation farm was providing Metrologic data including rainfall; maximum and minimum temperature, mean daily relative humidity, and daily sun shine hours wind speed. The default an annual CO_2 concentration level included in the model. (Appendix A.3).

3.5.2 Crop data

Crop data required from the field included wheat significant phonological growth indicators such as days for sowing to: emergency maximum canopy cover, canopy senescence, physiological maturity, maximum rooting depth, and dry biomass.

Green Canopy Cover

The canopy cover value was determined by measuring the field image at a perpendicular height of 1 meter above the crop with Canopeo Software loaded on a cell phone. The software computes the average percent canopy cover automatically. The results have been incorporated into the AquaCrop model. When there was no increase in the percent canopy cover, the duration and maximum canopy cover were determined (Appendix A.2).

3.5.3 Soil Data

Soil samples were taken diagonally across the field using an auger at three soil depths (0-15 cm, 15-30 cm, and 30-60 cm) to determine bulk densities, textures, and soil moisture content at field capacity and permanent wilting point. The depth is thought to cover the wheat's effective root depth. The soil sample was analyzed in the Bishoftu Agricultural Research

Center's laboratory. The soil characteristics were examined using standard laboratory procedures and manual methods (Appendix A.1).

3.5.4 Field Management Parameters

Field management parameters include phenology (sowing date, commencement of flowering, complete canopy cover date, harvest date), irrigation management (irrigation type, irrigation frequency, and irrigation depth), fertilizer management, and field control. Input data used for AquaCrop based simulation were shown in (Table 3.3). And also the schematic framework for AquaCrop was also shown in (Figure 3.5).

Table 3:3 Input data for AquaCrop simulation

General Information	Irrigation Farm		
	Alge Metehara	Kuruftu Wonji	Kataba Gumbichu
Crop Type	Wheat	Wheat	Wheat
Soil type	Clay loam	Loam	Sandy loam
Root depth(m)	1	1	1
Crop Area(ha)	94	150	435
CCo (%)	3.38	4.5	4.92
Maximum CC (%)	93	96	98
FC at top layer (%)	37.4	29.61	24.2
FC at bottom layer (%)	45.2	37.25	27
Planting date	01/01/2023	02/01/2023	03/01/2023
Harvesting date	03/05/2023	01/05/2023	04/03/2023

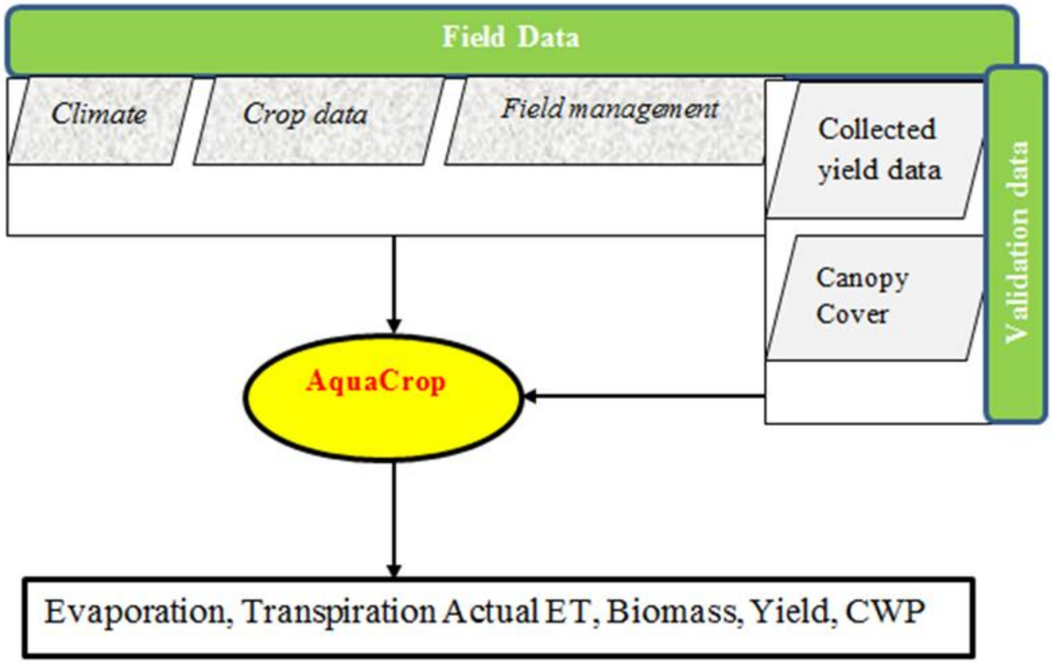


Figure 3:5 Schematic frameworks for AquaCrop model

3.5.5 Model Performance Evaluation

Calibration is the process of adjusting particular model parameters such that the model matches the observed value at a certain place. In the calibration, crop phonological parameters (time to emergency, time to obtain maximum canopy cover, time leading to senescence, and physiological maturity in calendar days) were observed. Above-ground dry matter was calibrated after the canopy cover (CC). Validation involves running the model without changing its parameters or source code and comparing the results to actual field data. The calibrated mode was being used for model validation. Statistical variables used for validation of the model such as coefficient of determination (R^2), NRMSE (normalized root mean square error), root mean squared error (RMSE) and Willmott's index of agreement (d)(Raes et al., 2009).

Coefficient of determination (R^2) in observed data, the coefficient of determination explains a percentage of the overall variation. The coefficient of determination has a value between 0 and 1 computed as Eq. (3.13)

$$R^2 = \left[\frac{(Oi-O)(Si-S)}{\sum_{i=1}^{N}(Si-S)\sum_{i=1}^{N}(Oi-O)} \right]^2 \quad (3.13)$$

The RMSE is a synthetic indication of the absolute model error since it shows the entire differences between observed and simulated data. In reality, the optimal model simulation performance requires the same unit of variable being simulated and is near to zero. And it's computed as Eq. (3.14)

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(O - S)^2} \tag{3.14}$$

The NRMS shows the extent by which the overall deviation between observed and simulated values differs from the overall deviation between observed and mean values (O) and computed as Eq. (3.15)

$$\mathrm{NRMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{N}(O - S)^2} * \frac{100}{Oi} \tag{3.15}$$

Willmott's index of agreement, d, is used to calculate how close the simulated and observed data are. It has a value between 0 and 1, with 0 representing no agreement and 1 representing full agreement between the simulated and observed data. Eq. (3.16) is used to calculate d.

$$d = 1 - \frac{\sum_{i=1}^{N}(Si - Oi)^2}{\sum_{i=1}^{N}(|S - O| + |Oi - O|)^2} \tag{3.16}$$

Where, Oi is measured values, Si is simulated value, O is measured mean S is simulated mean and N is number of observations.

3.6 Flow Chart for Methodology

This study used remote sensing data from the WaPOR database to evaluate crop water productivity for Alge Metehara, Kuruftu Wonji and Kataba Gumbichu. Using QGIS, decadal and monthly data was examined. Then, the WaPOR data was compared to the AquaCrop model (which uses primary data gathered from the field) and the farms actual yield data. Additionally, indications collected from the WaPOR site were used to evaluate the performance of irrigation fields (Figure 3.6).

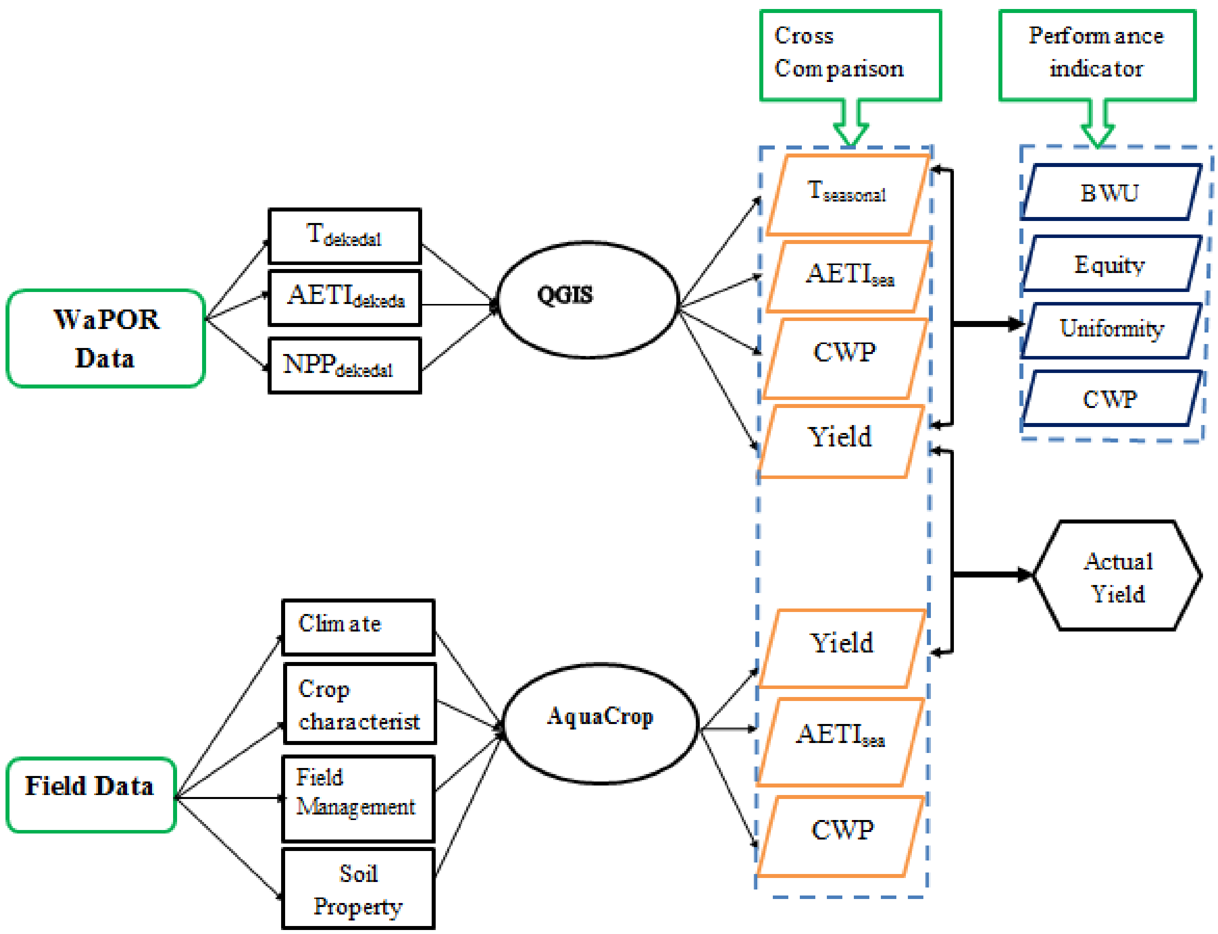


Figure 3:6 Conceptual framework of the research methodology

4. RESULTS AND DISCUSSIONS

The results and discussion of the spatial variability of wheat water productivity and the irrigation field performance indicators are discussed in this section. For each irrigation field, the outcomes of the WaPOR protocol and AquaCrop are presented and discussed in the following sub-section.

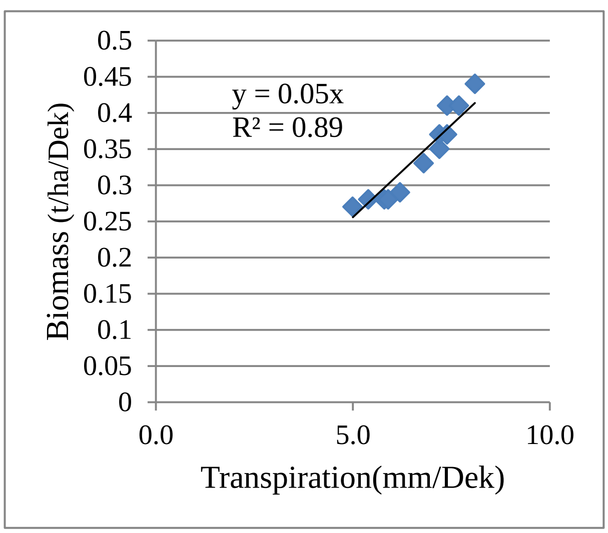
4.1 WaPOR Analysis

To compare the three farms' performance with various agronomic indicators, including biomass, yield output, CWP, and Tr, and AETI first WaPOR data consistency was done. These indicators were generated using the average values of all the pixels that defined the boundaries of the irrigation farm. In this study, the various agronomic indicators were examined using the area time series method.

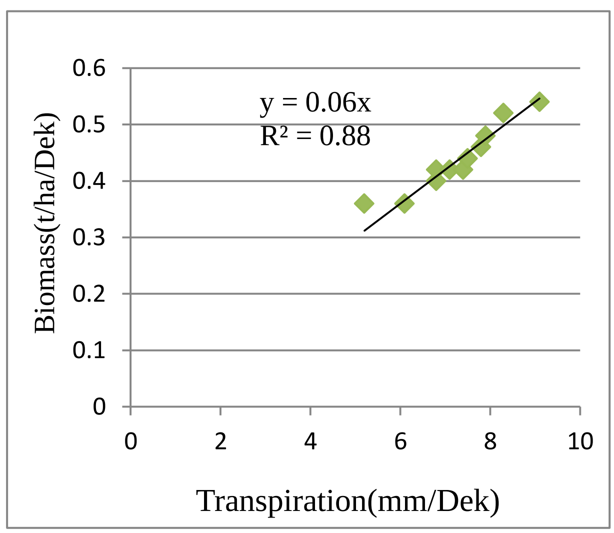
4.1.1 WaPOR data consistency check

Before analyzing the data, it was necessary to check for consistency by plotting B vs T and B vs AETI for all irrigation fields as shown in (Figure 4.1). Since, the changes in B and T and B vs AETI for wheat crop almost linear. WaPOR data consistency check was for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat irrigation farm show consistent relations.

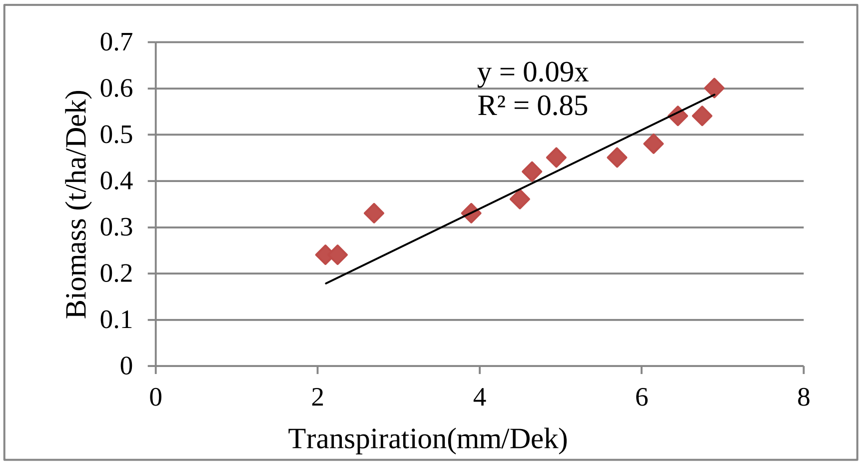
Alge Metehara B vs T



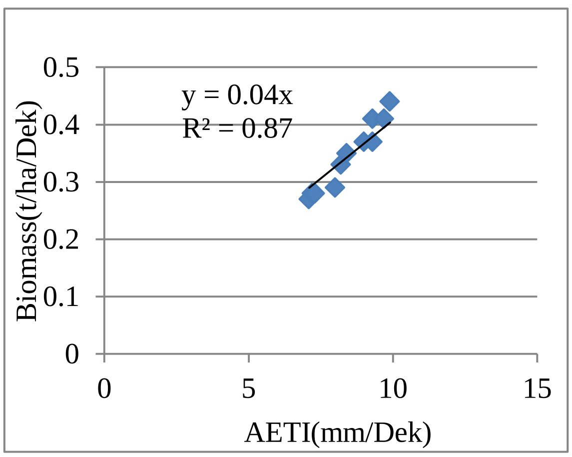
Kuruftu Wonji B vs T



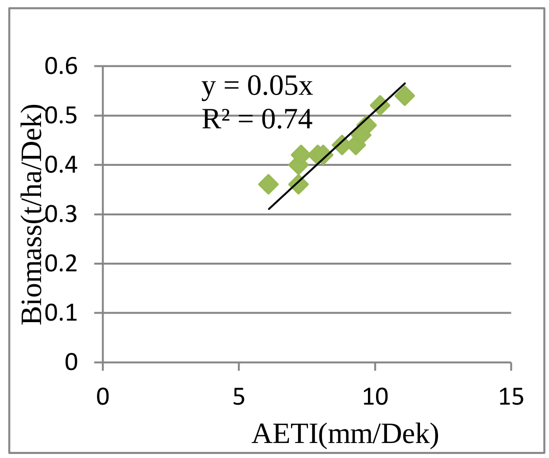
Kataba Gumbichu B vs T



Alge Metehara B vs AETI



Kuruftu Wonji B vs AETI



Kataba Gumbichu B vs AETI

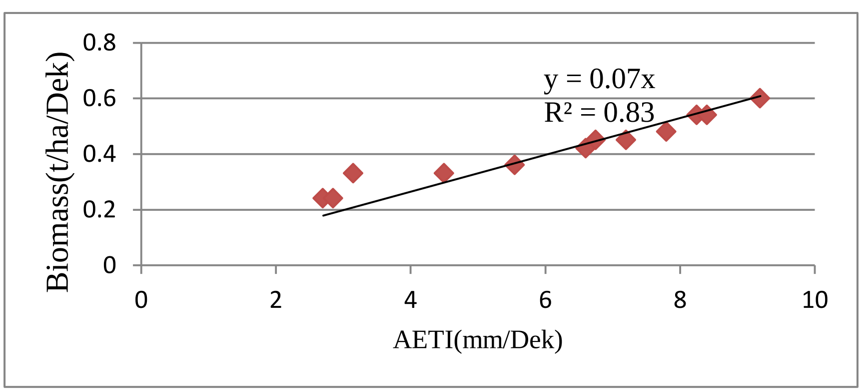


Figure 4:1Relationships between mean dekadal above ground biomass vs average dekadal Tr and AETI

Table (4.1) shows the regression parameters for the linear correlations shown in (Figure 4.1). The linear association of biomass with transpiration was relatively high. The steeper relationship between biomass and actual evapotranspiration was attributable to the presence of unexpected evaporation within actual evapotranspiration. Evaporation has no linear relationship with biomass, so linear relation between biomass and actual evapotranspiration is also less when we compare with transpiration.

Table 4:1 Regression parameters from the WaPOR consistency check for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu

	Linear Regression parameters	Alge Metehara	Kuruftu Wonji	Kataba Gumbichu
B vs T	Slope	0.05	0.06	0.09
	R^2	0.89	0.88	0.85
	Interception	0	0	0
B vs AETI	Slope	0.04	0.05	0.07
	R^2	0.87	0.74	0.83
	Interception	0	0	0

4.1.2 Seasonal Water Consumption

Actual seasonal evapotranspiration and interception (AETI) and transpiration (Tr) varied spatially during the cropping period. The mean values of AETI were (162 mm, 138.2 mm, and 96.9 mm) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively Figure (4.3a). AETI were highest for Alge Metehara and followed by Kuruftu Wonji irrigation farm. Alge Metehara irrigation farm 14% difference from Kuruftu Wonji and 40% varies from Kataba Gumbichu irrigation farms. The transpiration is also highest for Alge Metehara irrigation farm and followed by Kuruftu Wonji and Kataba Gumbichu irrigation farm. With the mean values of (141.8 mm, 118 mm, and 56.8 mm) Figure (4.3b) and varies with (16%, 59%) for the Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively. There is a significant variation in water consumption within the study area. Changes in agro-climatic elements including wind speed, radiation, and air temperature are responsible for the variation. Due to the high air temperature, solar radiation, and wind in the area, the Alge Metehara irrigation fields need more water than those of the other fields(Hess et al., 2016). This result compared the past study carried out by (Ranjan & Denis, 2022) by using a field experiment at Harrai village, Prayagraj, during the wet growing season. In this study, they found a mean seasonal ETc value of 277mm.

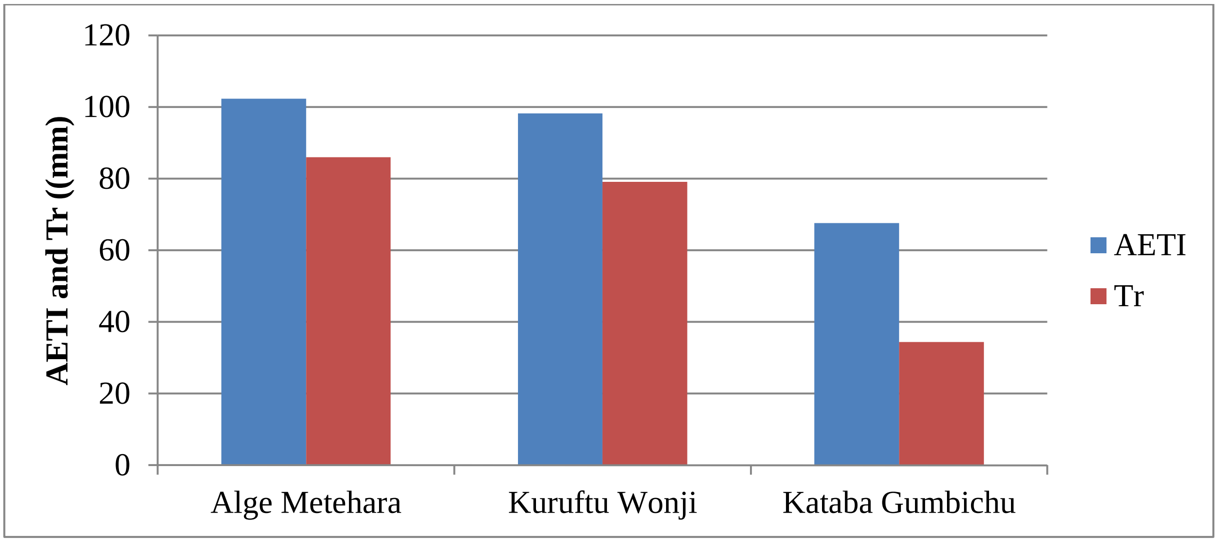
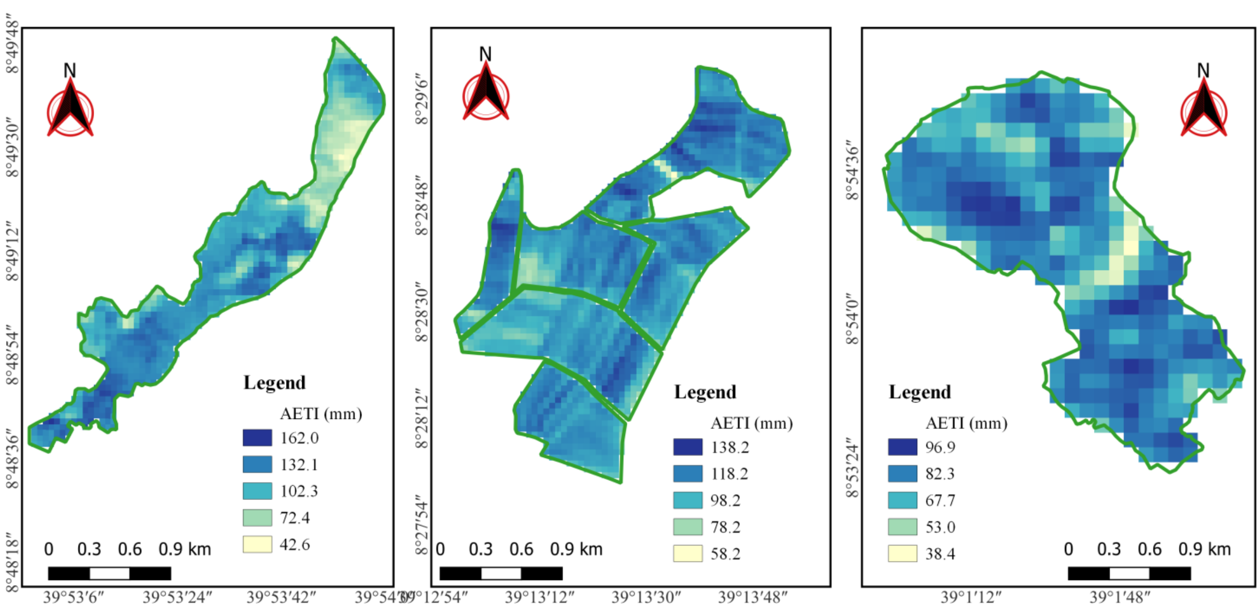
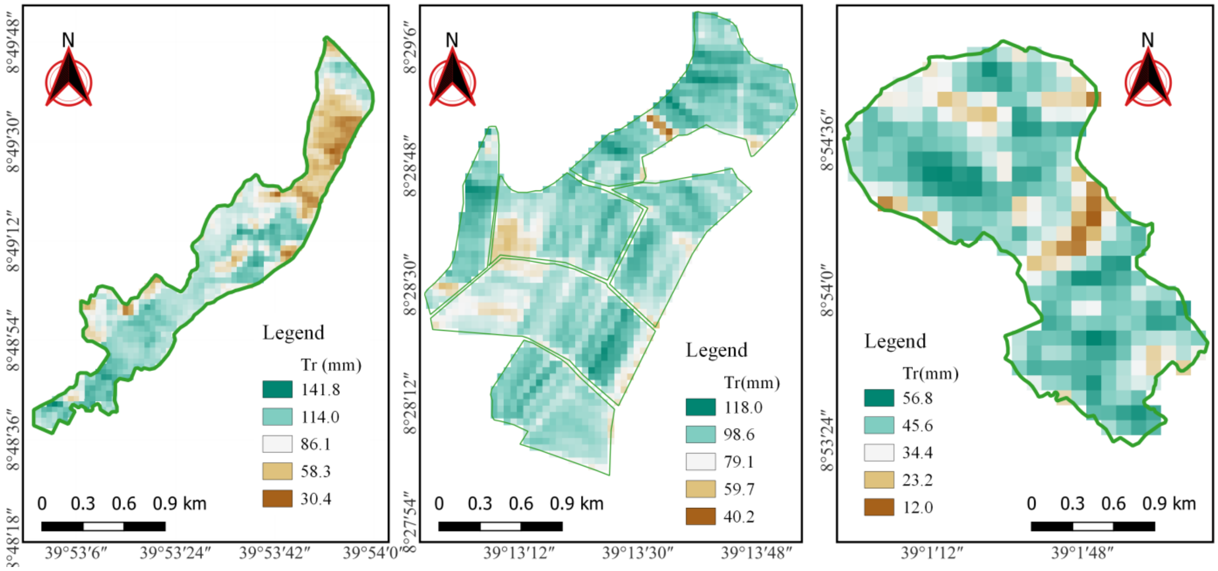


Figure 4:2 Mean seasonal actual evapotranspiration and interception (AETI) and transpiration (T), for Alge Metehara, Kuruftu Wonji and Kataba Gumbichu wheat irrigation farm



(a)



(b)

Figure 4:3 spatial variations in seasonal irrigation water consumption (AETI) (a) and transpiration (b) for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.1.3 Net Primary Production (NPP)

Seasonal NPP during the crop period was spatially variable (Figure 4.4). For Alge Metehara (A) irrigation farm, the maximum value of net primary productions was 113.2 kg/ha and the minimum value was 16.5 kg/ha; Kuruftu Wonji (B) had a maximum of 116 kg/ha and a minimum of 33 kg/ha; and Kataba Gumbichu (C) had a maximum of 125 kg/ha and a minimum of 19.8 kg/ha. Although greater amounts can occur (theoretically up to 320 kgDM/ha/day), the typical range for NPP in the area is 0 to 120 kg/ha (FAO, 2020a).

Therefore, the NPP of the irrigation farms of Alge Metehara (A), Kuruftu Wonji (B), and Kataba Gumbichu (C) was within the range recommended by FAO.

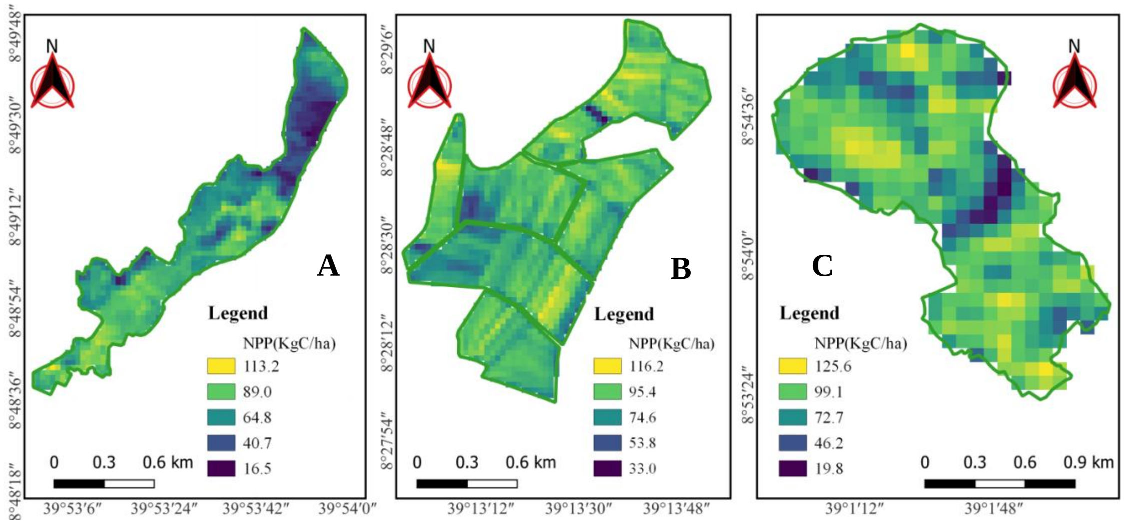


Figure 4:4 Average seasonal Net primary productions [Kg/ha/season] for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.1.4 Above Ground Biomass production (AGBP)

During the crop period, seasonal (AGBP) was spatially varied (Figure 4.5). The maximum value of above ground biomass production for Alge Metehara (A) irrigation farm was 6790.9 Kg/ha and minimum value of 989 Kg/ha, for Kuruftu Wonji (B) was 6970.7 Kg/ha of maximum biomass and minimum biomass of 1977.8 Kg/ha, and The maximum value of above ground biomass production for Kataba Gumbichu (C) irrigation farm was 7533.3 Kg/ha and minimum value of 1186.0Kg/ha.

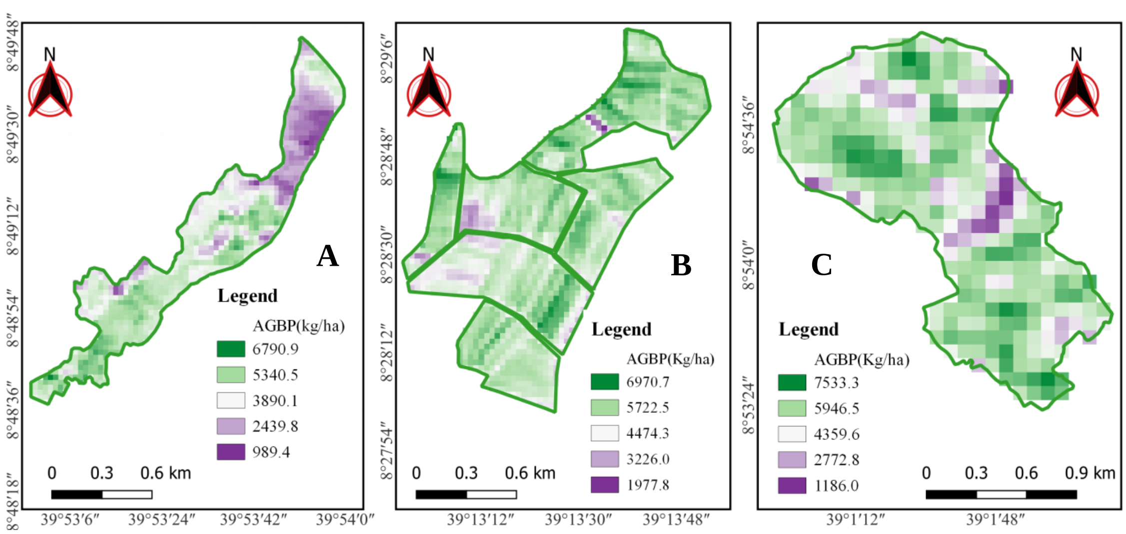


Figure 4:5 Average seasonal biomass productions [Kg/ha/season] for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.1.5 Crop Yield

Figure (4.6 and 4.7) average seasonal WaPOR-based crop yield was 475-3260 Kg/ha for Alge Metehara, 949-3346 Kg/ha for Kuruftu Wonji, and 569-3616 Kg/ha for Kataba Gumbichu. WaPOR yield value were lower compare to the field-measured wheat yield, 3500 Kg/ha, 3800 Kg/ha, and 4500Kg/ha for fields of Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat farms, respectively. The variation was due to the selection of crop characteristics parameter, such as harvest index and moisture content, may have contributed to the small gap between the WaPOR and field-measured yields. Also WaPOR affected by atmospheric variability and cloud coverage when collecting satellite data. Similar study was done by Widengren, (2022) on evaluation of crop water use and rice yield using remote sensing and AquaCrop Model for three irrigation schemes in Sri Lanka and the study shows WaPOR yield minimum and maximum values 2.5–2.9 ton/ha were lower compared to historical yield data 4.4–5.6 ton/ha.

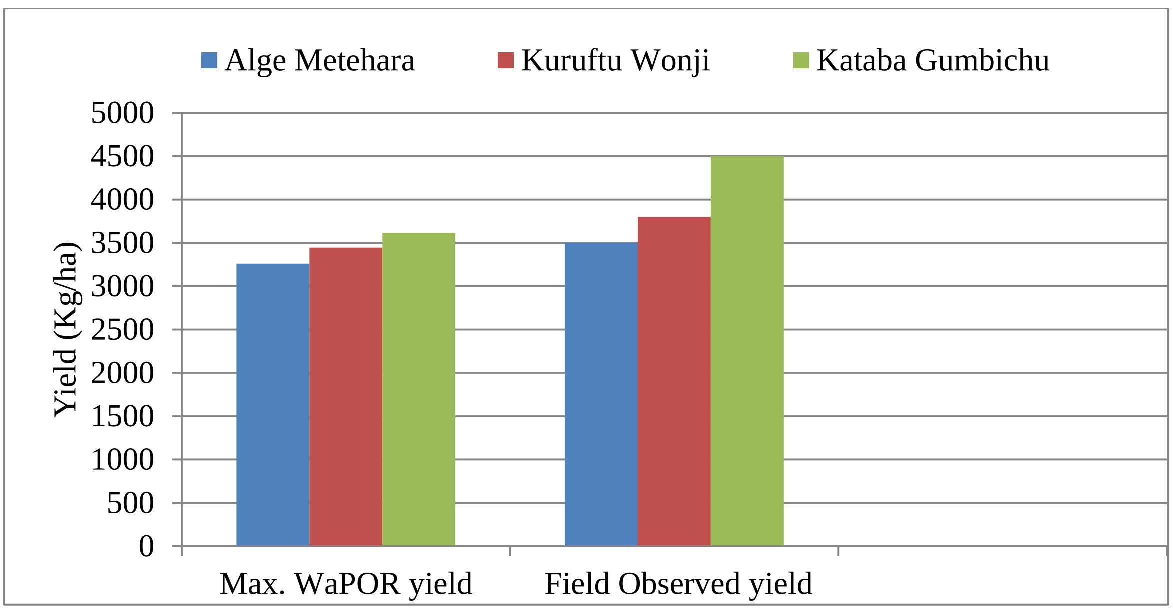


Figure 4:6 comparison of average seasonal yield productions WaPOR based and field observed yield [Kg/ha/season] for the Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat farms

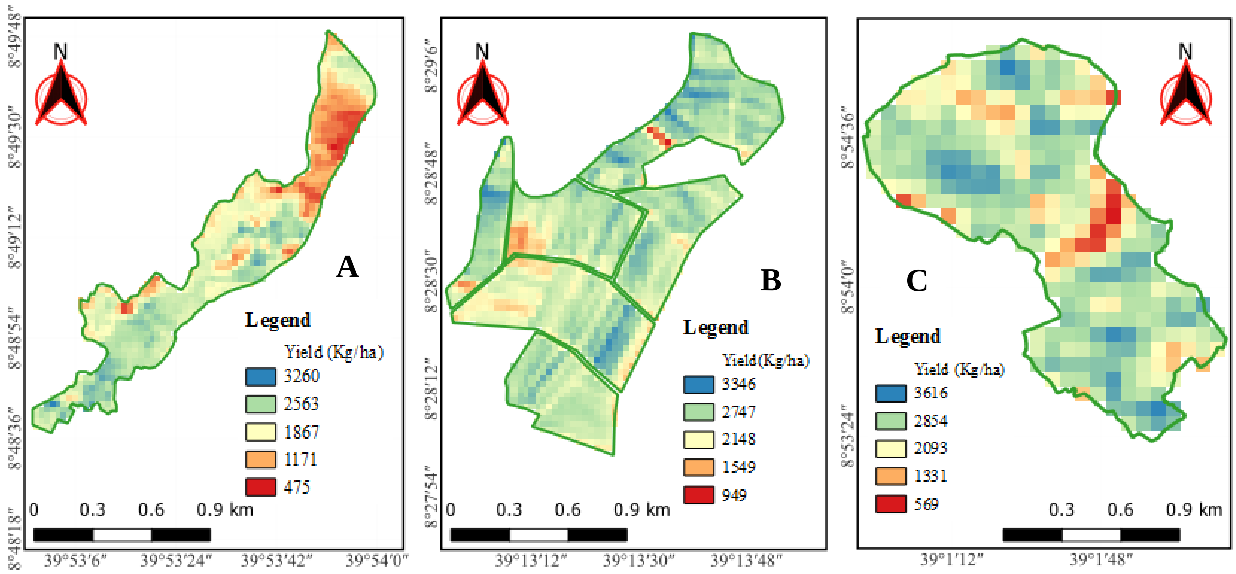


Figure 4:7 WaPOR based spatial variations of Crop yield for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.2 Land and Water Productivity Indicators

4.2.1 Equity

The average seasonal coefficient of variation (CV) of AETI varies spatially across the Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields (Table 4.2). Alge Metehara irrigation field with CV (23.5%) has the highest heterogeneity in water consumption compared to Kataba Gumbichu irrigation field with CV (15.04%) and Kuruftu Wonji irrigation field with CV (10.54%). A CV of 0% to 10% is considered good equity, a CV of 10% to 25% is considered acceptable equity, and a CV of >25% is considered poor equity, according to (D. J. Molden & Gates, 199; Karimi et al., 2019). The equity of water use across all fields is therefore determined by the coefficient of variance of water consumption between irrigation fields.

Table 4:2 the irrigation field's coefficient of variation (CV) data indicate the equity of the water distribution for selected irrigation fields

Irrigation Scheme	Mean Seasonal AETI	Standard deviation of Seasonal AETI	CV of Seasonal AETI	Result
Kuruftu Wonji	55.20	5.82	10.54	Fair
Kataba Gumbichu	25.95	3.90	15.04	Fair
Alge Metehara	54.48	12.79	23.50	Fair

4.2.2 Beneficial Water Use (BWU)

The average season beneficial water use for Alge Metehara irrigation field (A) was (61-94%), which means (61-94%) of AETI allocated for transpiration. For Kuruftu Wonji irrigation fields (B) (69-88%), of AETI were allocated for transpiration and (47-89%) of AETI allocated for transpiration for Kataba Gumbichu irrigation field (C) as shown in (Figure 4.8 and Figure 4.9); while the left one is irrigation water loss by evaporation and deep percolation. From the result, a greater BWU value corresponds to a larger ratio of T over ETIa, which means that more water is being used by the plant to produce biomass. In the figures, a higher BWU value indicate a higher ratio of T over ETIa, meaning that there is a higher amount of water being beneficially taken up by the plant to generate biomass.

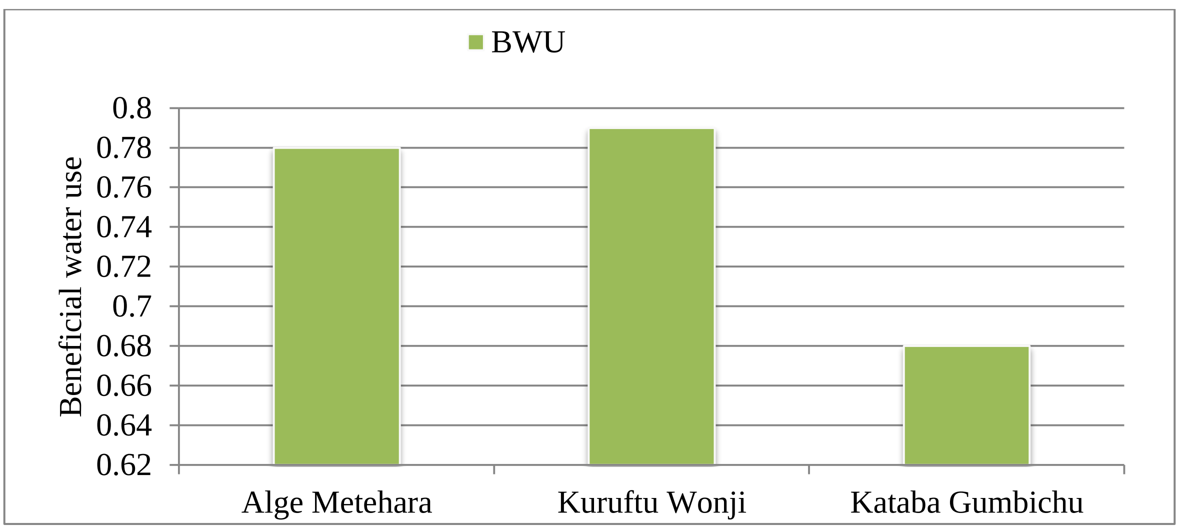


Figure 4:8 BWU of the average seasonal water consumption for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu wheat farms

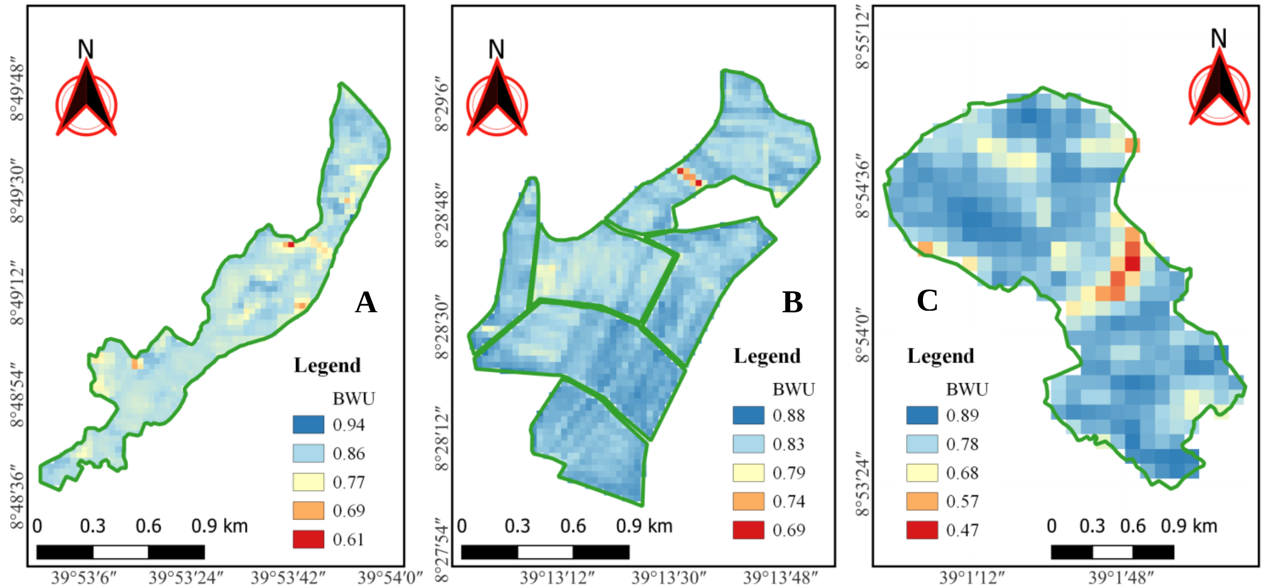


Figure 4:9 spatial distribution of Beneficial Water use for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.2.3 Crop Water Productivity

The average seasonal water productivity is the highest for Kataba Gumbichu irrigation fields (2.7 kg/m^3), compared to the values for Kuruftu Wonji (2.1 kg/m^3) and Alge Metehara irrigation fields (1.6 kg/m^3) Figure (4.11). The variances in crop water productivity existed is the percentage of AETI used for productive purposes (transpiration) against non-productive evaporation and agro-climatic diversity within the research area. Figure (4.10) shows Alge Metehara irrigation field consume more water and followed by Kuruftu Wonji irrigation field while Kataba Gumbichu irrigation field consume low water. This is the main cause of the variation of CWP within the irrigation field since CWP is the ratio of yield to AETI. According to Zwart and Bastiaanssen, (2004) review on wheat crop water productivity; globally measured average wheat water productivity was 1.09 kg/m^3 and extended to (wheat, 0.6–1.7 kg /m^3). The variability of CWP can be due to climate factors, irrigation water management, and soil (nutrient) management, among others.

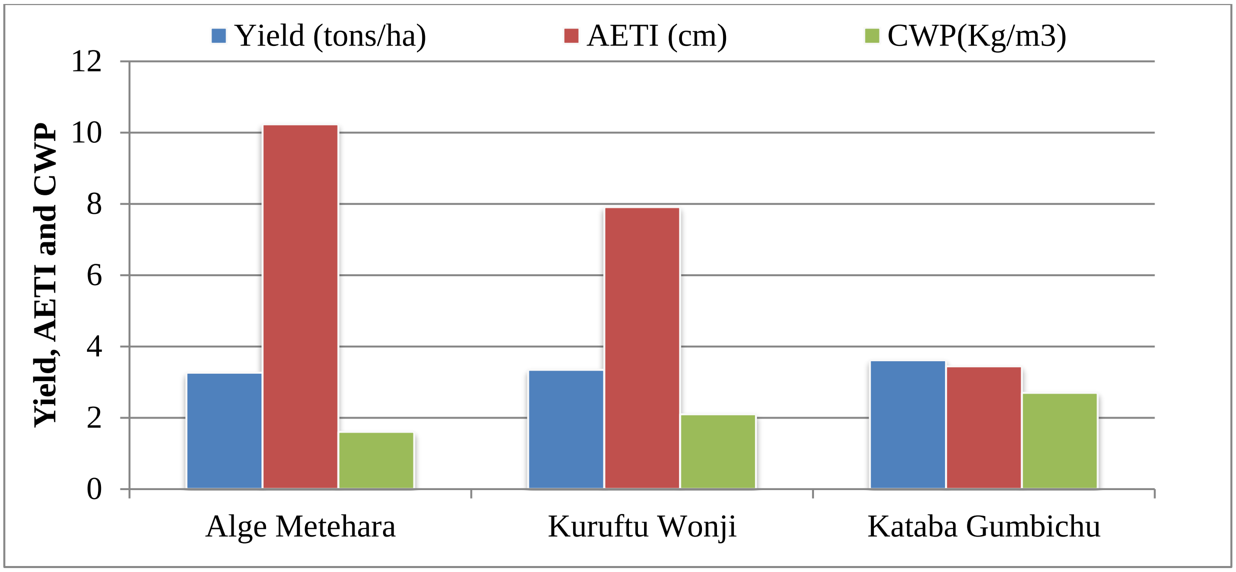


Figure 4:10 the relationship between water consumption, yield and crop water productivity for selected irrigation field

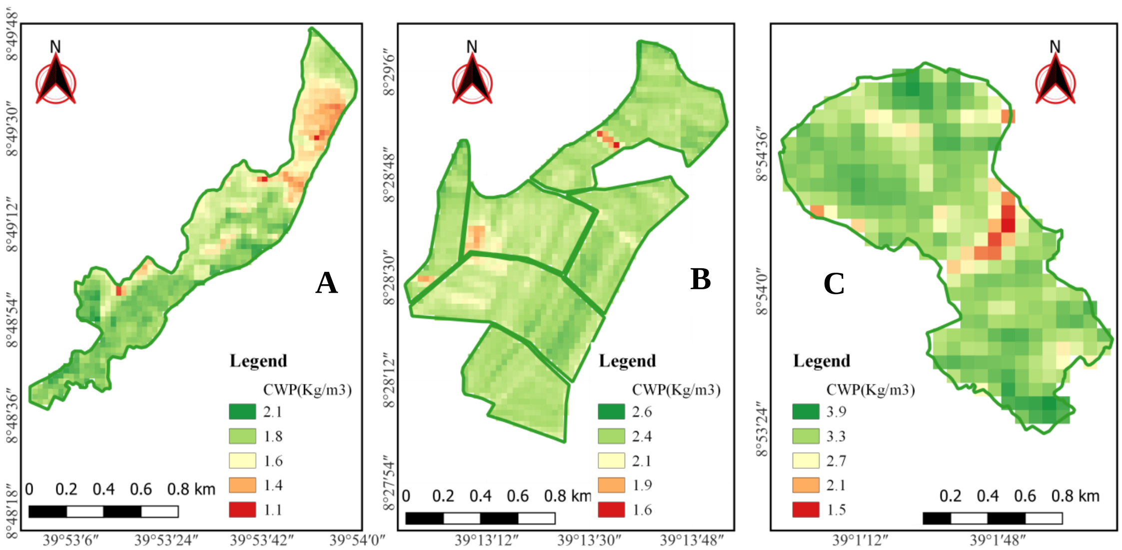


Figure 4:11 spatial variations in irrigation seasonal crop water productivity for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

4.2.4 Biomass Water Productivity

Based on the analysis in Figure (4.12), biomass water productivity is highest for Kataba Gumbichu irrigation field with 8.1 kg/m^3, compared to the values for Kuruftu Wonji 5.4 kg/m^3 and Alge Metehara irrigation field 4.3 kg/m^3. The reasons for such variances are due to the value of biomass and AETI within the research area. As a result, greater WPb values result in higher amounts of above ground biomass developed per water application (AETI).

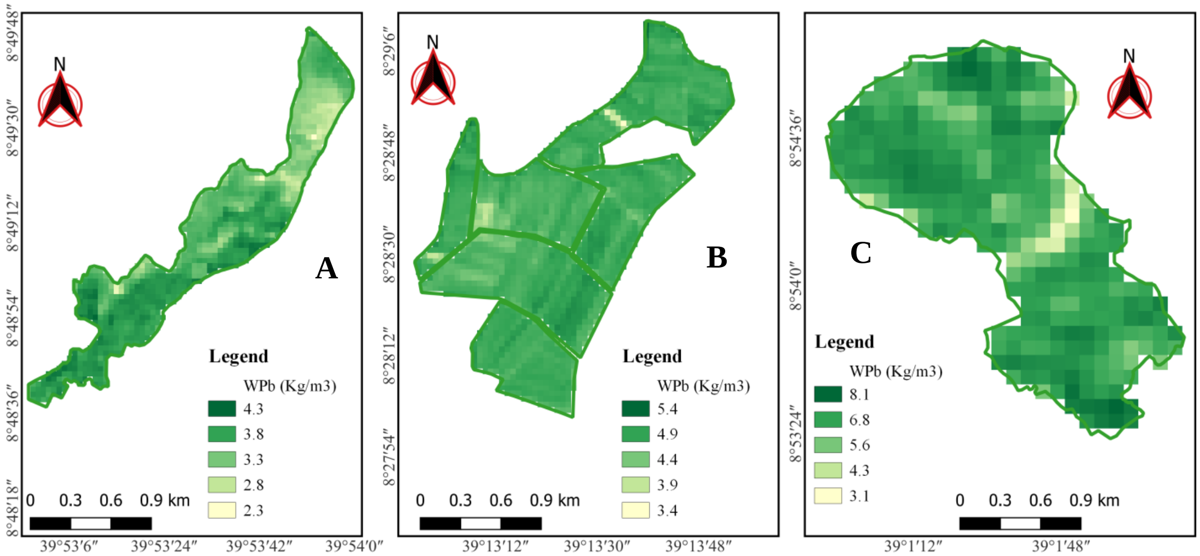


Figure 4:12 spatial variations in irrigation seasonal biomass water productivity for Alge Metehara (A), Kuruftu Wonji (B) and Kataba Gumbichu(C)

Table 4:3 Summary of WaPOR based and water productivity parameters

Parameters	Alge Metehara		Kuruftu Wonji		Kataba Gumbichu	
	Max.	Min.	Max.	Min.	Max.	Min.
Evaporation(mm)	20.6	6.8	19.2	9.2	13.6	3.8
Transpiration	141.8	30.4	118	40.2	56.8	12
AETI(mm)	162	42.6	138	58.2	96.9	38.4
NPP(KgC/ha)	113.2	16.5	116.2	33	125.6	19.8
Biomass(Kg/ha)	6791	989	6971	1978	7533	1186
Yield(Kg/ha)	3259	475	3346	949	3616	549
CWP(Kg/m^3)	2.1	1.1	2.6	1.6	3.9	1.5
WPb(Kg/m^3)	4.3	3.3	5.4	3.4	8.1	3.1

4.3 AquaCrop Base Land and water productivity Analysis

Soil and crop characteristics data were collected in the field to calibrate the AquaCrop model. The land use of research area was agricultural land with good soil fertility and near-optimal weed infestation. Because the farmers use fertilizer and pesticides for weed control on their farm. Table (4.5) shows the final crop parameter after model calibration. The AquaCrop model was calibrated using the essential conservative and non-conservative input parameters. Crop parameters were gradually changed until good agreement between measured and simulated canopy cover and yield grain was reached.

Table 4:4 Crop parameter for wheat obtained after calibration

		Alge Metehara	Kuruftu W.	Kataba G.
	Initial CC	1.9	1.92	2.25
	Maximum CC (no stress)	85	85	85
Growing Cycle (GDD)	Emergence	226	173	43
	Max CC	1593	1286	419
	Senescence	1829	1486	528
	Maturity	2795	2452	2400
Yield formation (GDD)	Length of building HI	876	966	393
	Duration of flowering	612	600	246
	Begin of flowering	1360	1106	311
Root depth	Max rooting depth (m)	1	1	1
	Max depth length (Days)	1593	1286	419

4.3.1 Alge Metehara Wheat Farm

AquaCrop based simulations for Alge Metehara irrigation fields have been carried out using weather data from Fentale meteorological stations, soil data, field crop data, and field management data for calibration of the model. After calibration, the model simulates average seasonal AETI (577.5mm), crop yield (5.3 tons/ha) and (0.92 Kg/m^3) Table (4.6) and Appendix (B.3). The canopy cover field data and actual field yield collected were used for Alge Metehara farm validation.

Table 4:5 AquaCrop model based simulation results for Alge Metehara

Simulated parameter	Result
Evaporation (mm)	155.2
Transpiration (mm)	422.3
Evapotranspiration until harvest (mm)	577.5
ETo until harvested (mm)	644.6
Rainfall(mm)	15
Potential Biomass (ton/ha)	11.3
Yield simulated (ton/ha)	5.3
Actual observer Yield(ton/ha)	3.5
Actual Biomass (ton/ha)	11
WP (kg yield/m^3 ET)	0.92
Temperature (transpiration) stress (%)	0
Harvest Index (adjusted) (%)	48
R^2	0.96
RMSE (% CC)	12.2
Observe. CC (%)	43.7
Simulated CC (%)	48.6

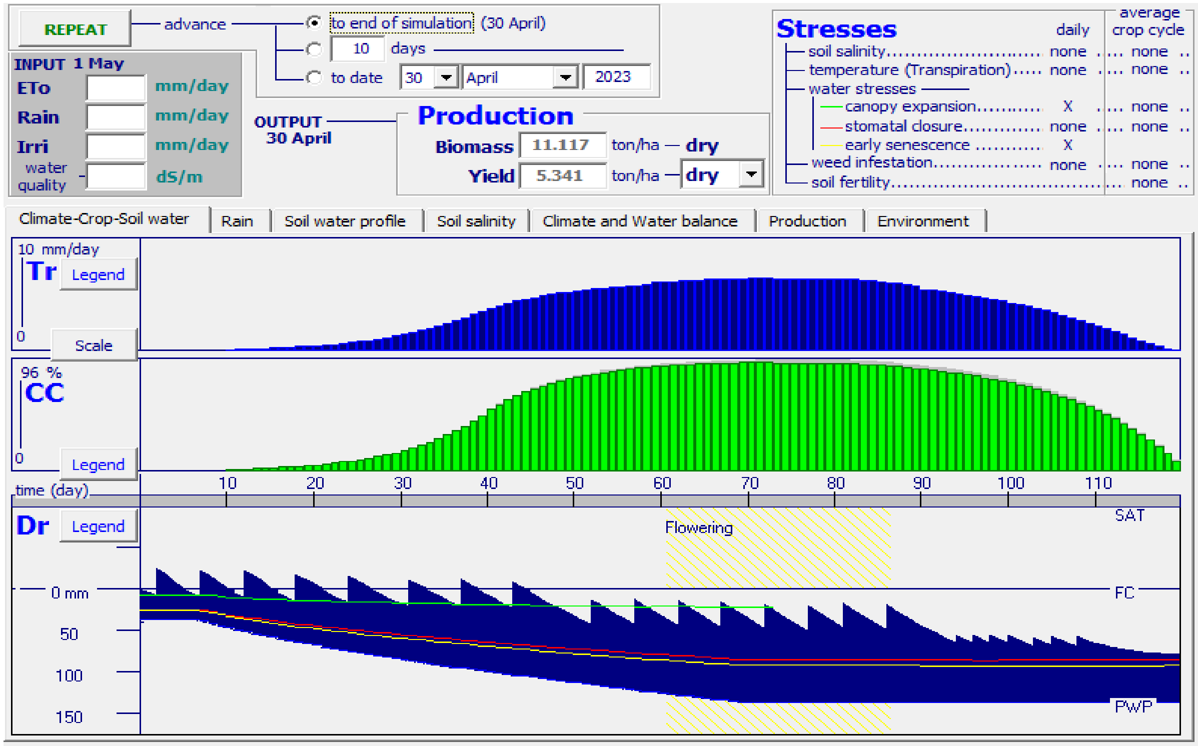


Figure 4:13 AquaCrop results for Alge Metehara irrigation Wheat farm

Starting from sowing days to 30 days of the growing cycle, excess irrigation water applied to the root zone that exceeds the upper threshold canopy cover (green line; see Figure 4.13 see Dr Graph). This happens because evaporation exceeds transpiration at this period of time. This is because crop canopy cover is less and soil evaporation is high. The crop begins flowering, and yield development after 60 days of the growth cycle, whereas water level decreases. At yield development season, transpiration has reduced from this point forward (Tr graph), yet there is no water stress, as shown by the CC graph. As a consequence, there was no water stress throughout yield formation. This has a beneficial effect on the HI, which is 48% (see Table 4.6). According to the model, there is no water stress due to canopy cover development, and there is no stomatal closure.

The canopy cover data from the field observations and the AquaCrop simulation with R^2 = 0.96 correlation Figure (4.14). The connection between simulated and field-obtained canopy cover is acknowledged to be good.

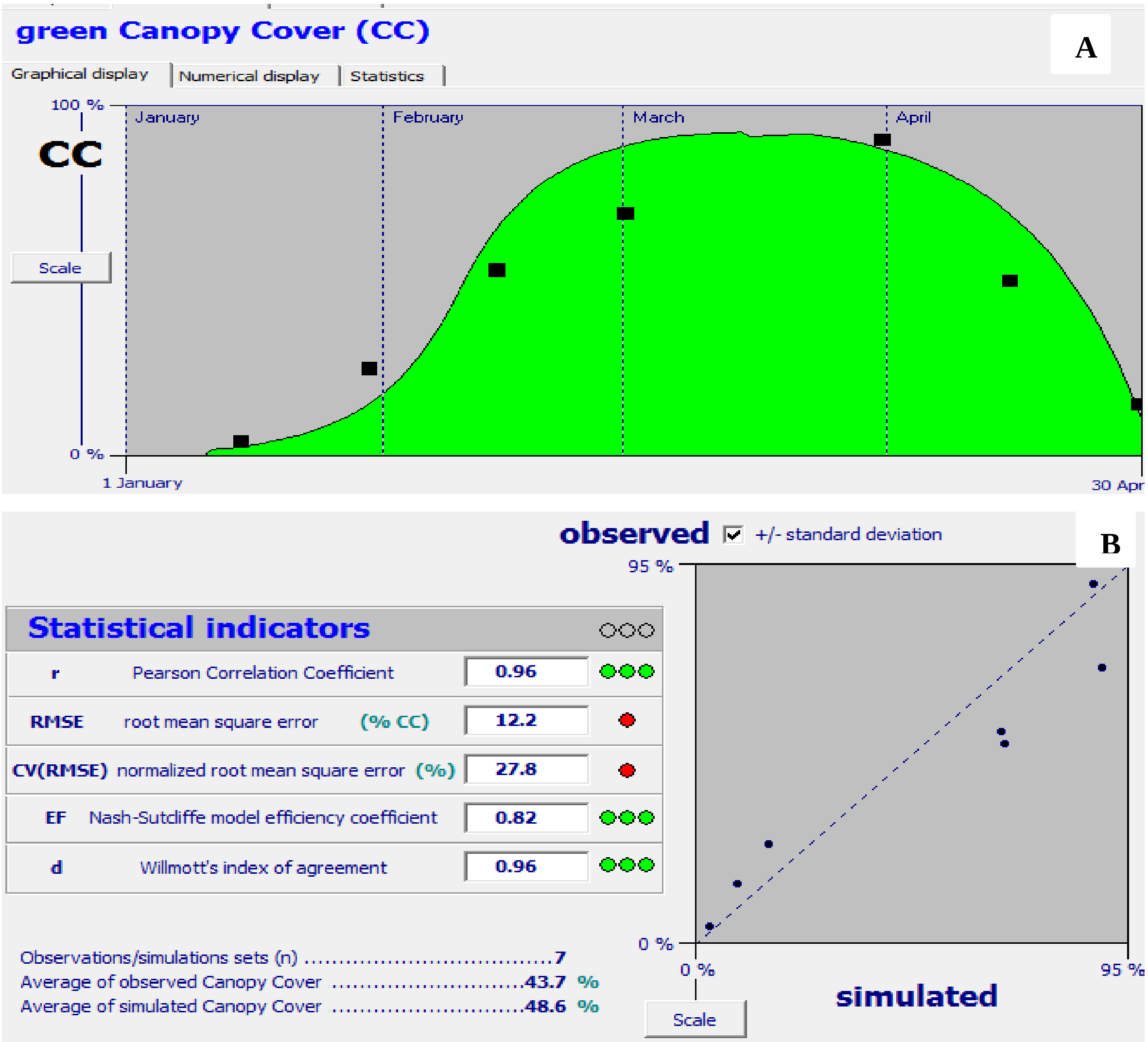


Figure 4:14 Reflections on Field Observed Canopy Cover data on Simulated (A) and Statistical indicator (B) for Alge Metehara farm

4.3.2 Kuruftu Wonji Wheat Farm

AquaCrop based simulations for Kuruftu Wonji irrigation fields have been carried out using weather data from Melkessa Research Center meteorological stations, soil data, field crop data, and field management data for calibration of the model. After calibration, the model simulates average seasonal AETI (250.6mm), crop yield (4.9 tons/ha) and (1.98 Kg/m^3) Table (4.7) and Appendix (B. 4). The canopy cover field data and actual field yield collected were used for Kuruftu Wonji farm validation.

Table 4:6 AquaCrop model based simulation results for Kuruftu Wonji farm

Simulated parameter	Validated Result
Evaporation (mm)	72.4
Transpiration (mm)	178.2
ETa until harvest (mm)	250.6
ETo until harvested (mm)	315.4
Rainfall(mm)	407.5
Potential Biomass (ton/ha)	10.4
Yield simulated (ton/ha)	4.9
Actual observer Yield(ton/ha)	3.8
Actual Biomass (ton/ha)	10
WP (kg yield/m3 ET)	1.98
Temperature (transpiration) stress (%)	0
Harvest Index (adjusted) (%)	48
R^2	0.97
RMSE(% CC)	11.5
Observed CC (%)	47.4
Simulated CC (%)	39.4

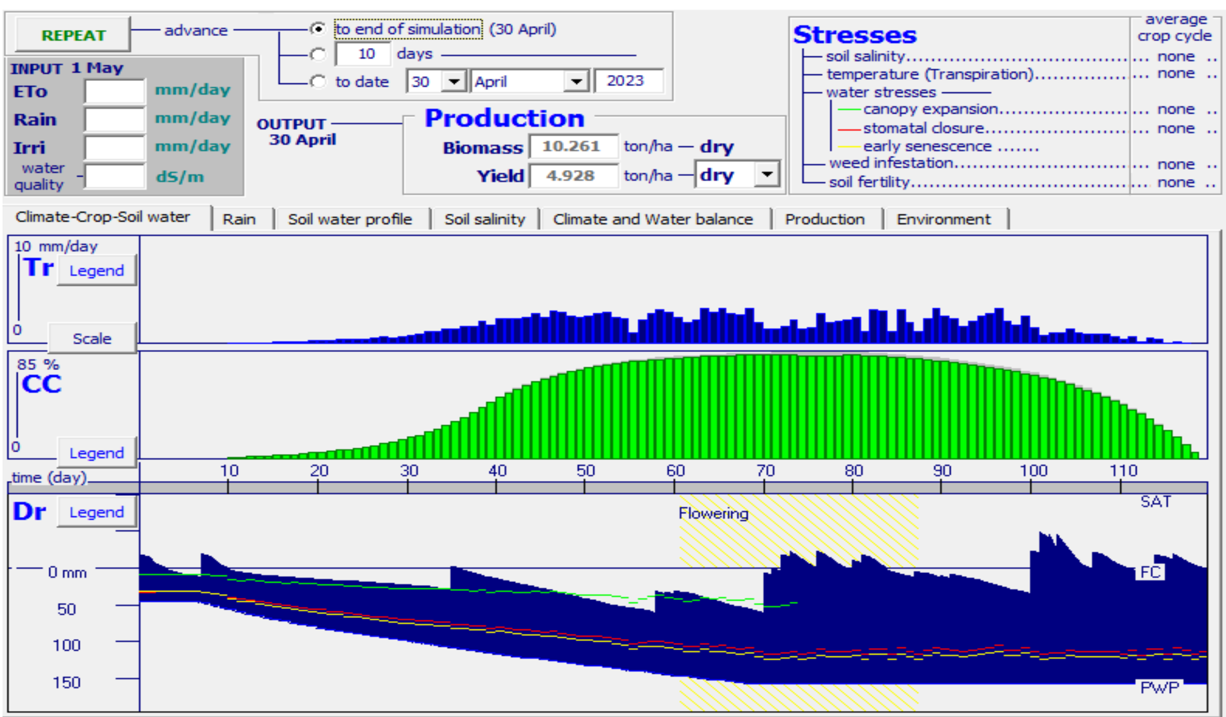


Figure 4:15 AquaCrop results for Kuruftu Wonji irrigation Wheat farm

During the first 10 days of the growth cycle, there is excess water in the root zone that surpasses the upper threshold for field capacity (FC) (Figure 4.15). There is enough water delivered to the field at this time, and there is no water stress or canopy expansion. Flowering and yield development begin 60 days into the growth cycle. When maximal canopy cover develops, flowering generally lasts half as long. Due to excessive rainfall during this season, water levels rose above field capacity beginning around the midway point of the flowering season (Figure 4.16). As a result, there was no water stress throughout yield formation. This provides the HI, which is computed at 48% (see Table 4.7).

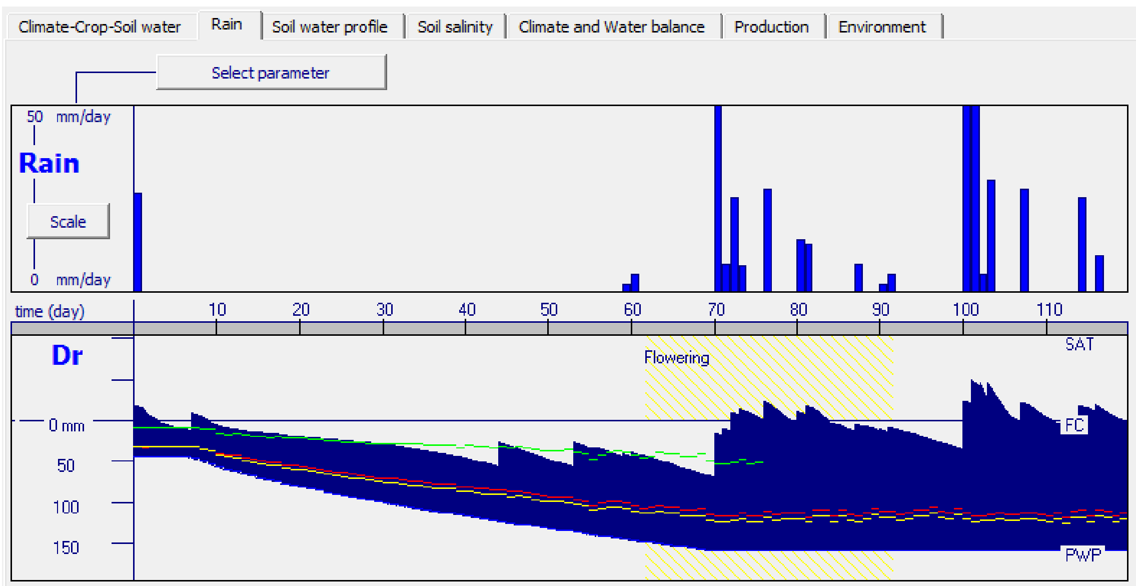


Figure 4:16 Rain pattern in Kuruftu Wonji irrigation farm in relation crop root development

The AquaCrop simulation (from R^2=0.95). The relationship between the canopy cover obtained in the field and the simulation is acknowledged to be good (Figure 4.17).

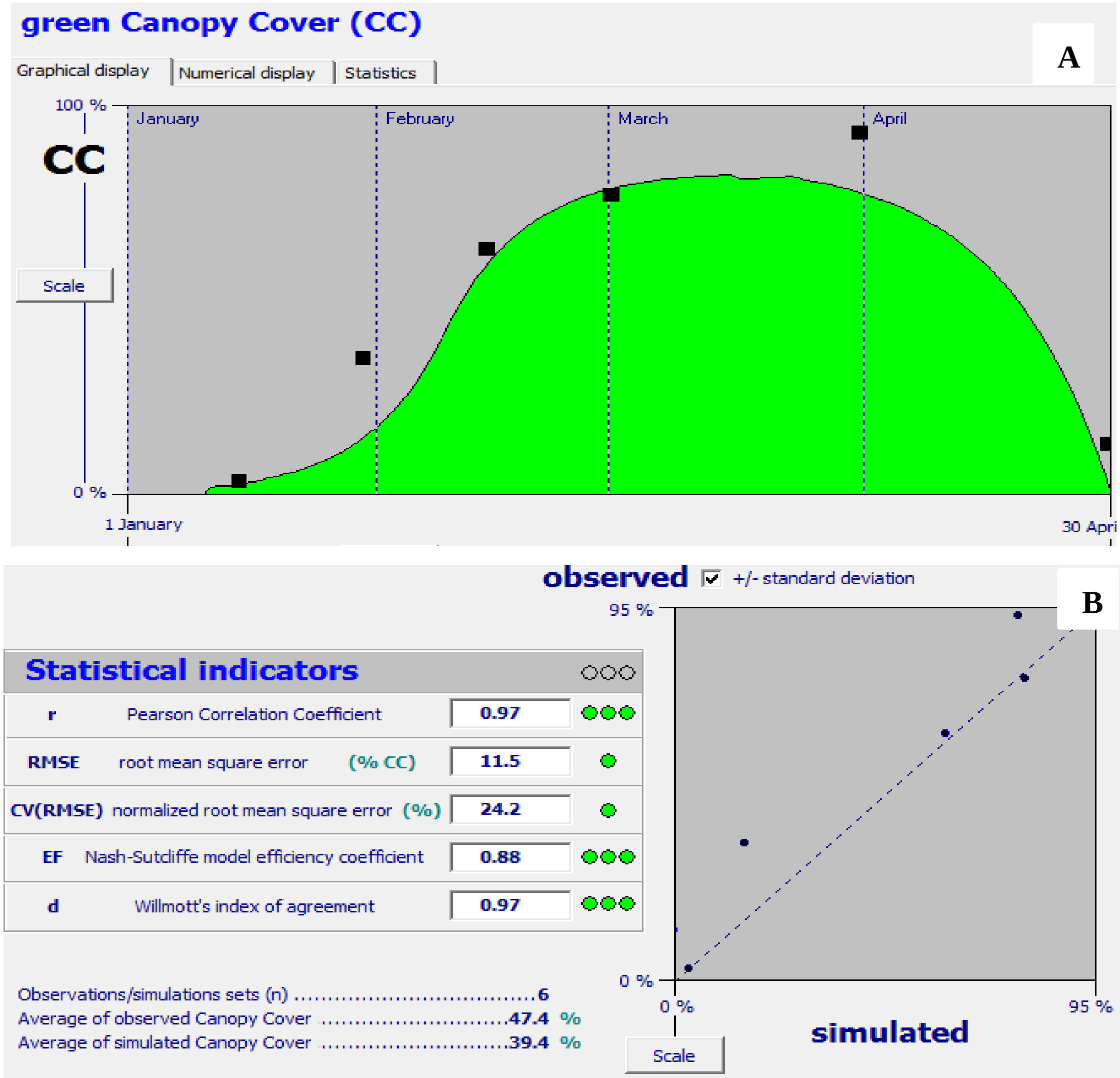


Figure 4:17 Reflections on Field Observed Canopy Cover data on Simulated (A) and its statistical indicator (B) of Kuruftu Wonji irrigation wheat farm

4.3.3 Kataba Gumbichu Wheat Farm

AquaCrop based simulations for Kataba Gumbichu irrigation fields have been carried out using weather data from the nearest stations at the Bishoftu Research Center, soil data, field crop data, and field management data for calibration of the model. After calibration, the model simulates average seasonal AETI (440.3mm), crop yield (4.5 tons/ha) and (1.03 Kg/m3) Table (4.8) and Appendix (B. 5). The canopy cover field data and actual field yield collected were used for Alge Metehara farm validation.

Table 4:7 AquaCrop model based simulation results for Kataba Gumbichu farm

Simulated parameter	Validated Result
Evaporation (mm)	158.8
Transpiration (mm)	281.5
Evapotranspiration until harvest (ETa) (mm)	440.3
ETo until harvested (mm)	596.9
Rainfall(mm)	520.7
Potential Biomass (ton/ha)	9.6
Actual Biomass (ton/ha)	9.4
Yield simulated (ton/ha)	4.5
Actual observed Yield(ton/ha)	4.5
WP (kg yield/m^3 ET)	1.03
Temperature (transpiration) stress (%)	32
Harvest Index (adjusted) (%)	48
R^2	0.95
RMSE (% CC)	14.5
Observed CC (%)	56.4
Simulated CC (%)	46.5

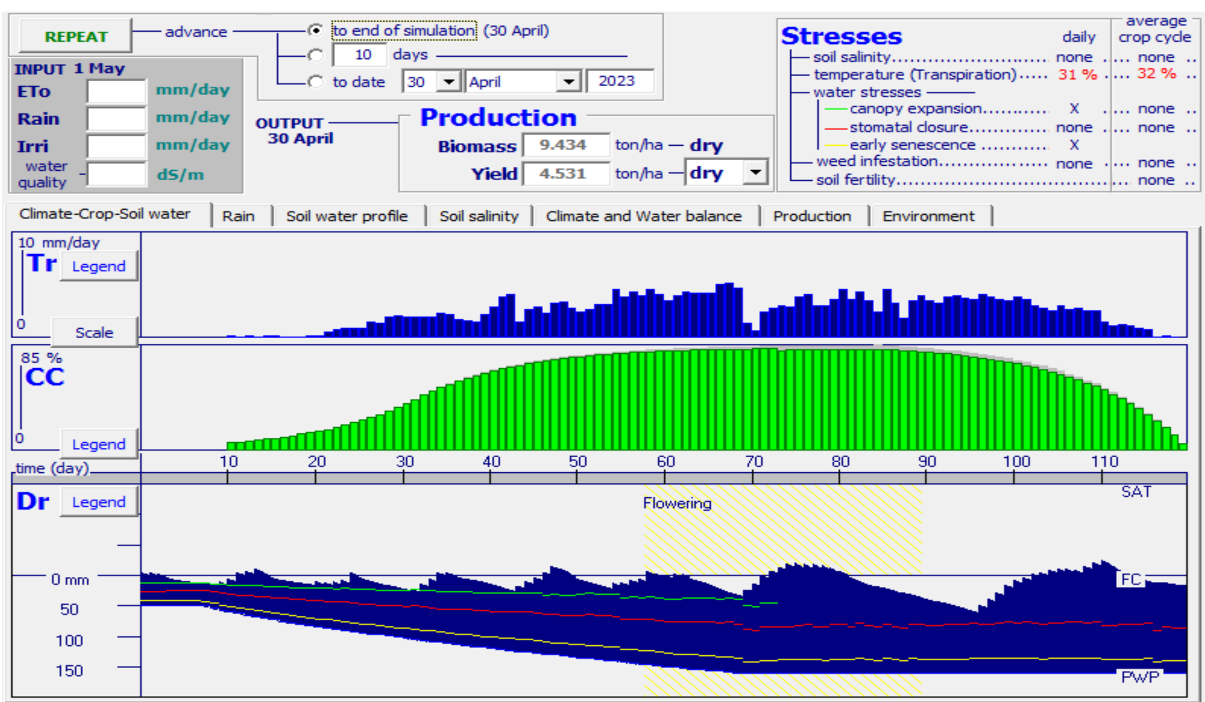


Figure 4:18 AquaCrop results for Kataba Gumbichu irrigation Wheat farm

From the sowing season to the harvest season of the growing cycle, there is no water stress. At this temperature, evaporation exceeds transpiration. The crop begins flowering and yield development at 60 days into the growth cycle. When maximum canopy cover is attained, flowering generally lasts half as long. The water level drops to some extent at 95 days into the growth cycle. But, due to excessive rainfall during this season, water levels rose above field capacity beginning around the midway point of the flowering season (Figure 4.18 graph Dr). As a result, there was no water stress throughout yield formation. This provides the HI, which is computed at 48% (see Table 4.6). However, there is 32% temperature stress during the crop period (Figure 4.18). There was high cold stress during the initial growing season starting in January (Figure 4.19). This cold stress was caused by the altitude of the Kataba Gumbichu wheat farm, which is 2200m above mean sea level.

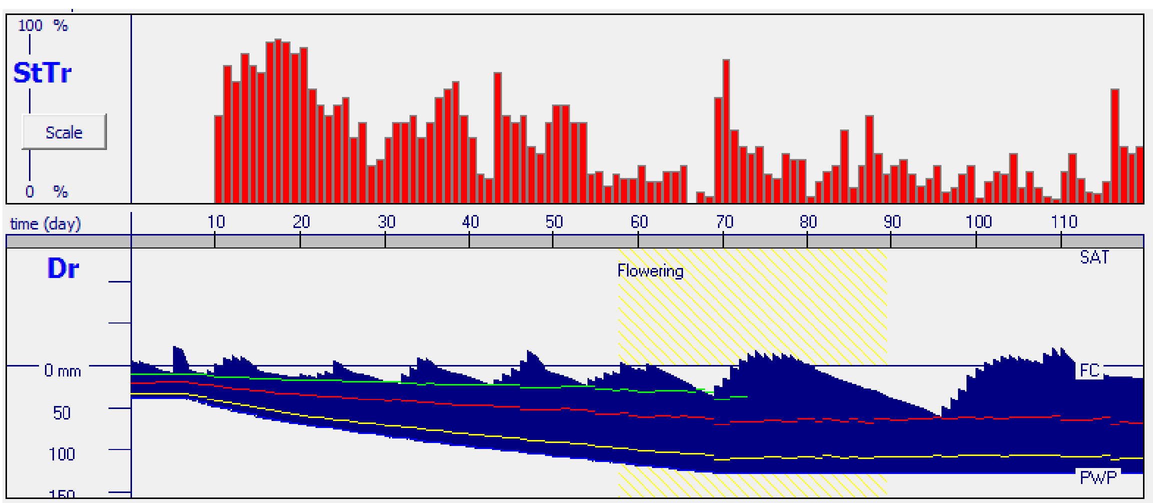


Figure 4:19 Cold temperature stress for Kataba Gumbichu irrigation farm

The transpiration rate, biomass output, and grain yield are all determined by accurate calibration for CC. The simulated and field observed CC development were fitted with a statistical value of (from R^2=0.95) after calibration (Figure 4.20). The relation between field canopy cover and simulation is commonly regarded to be good.

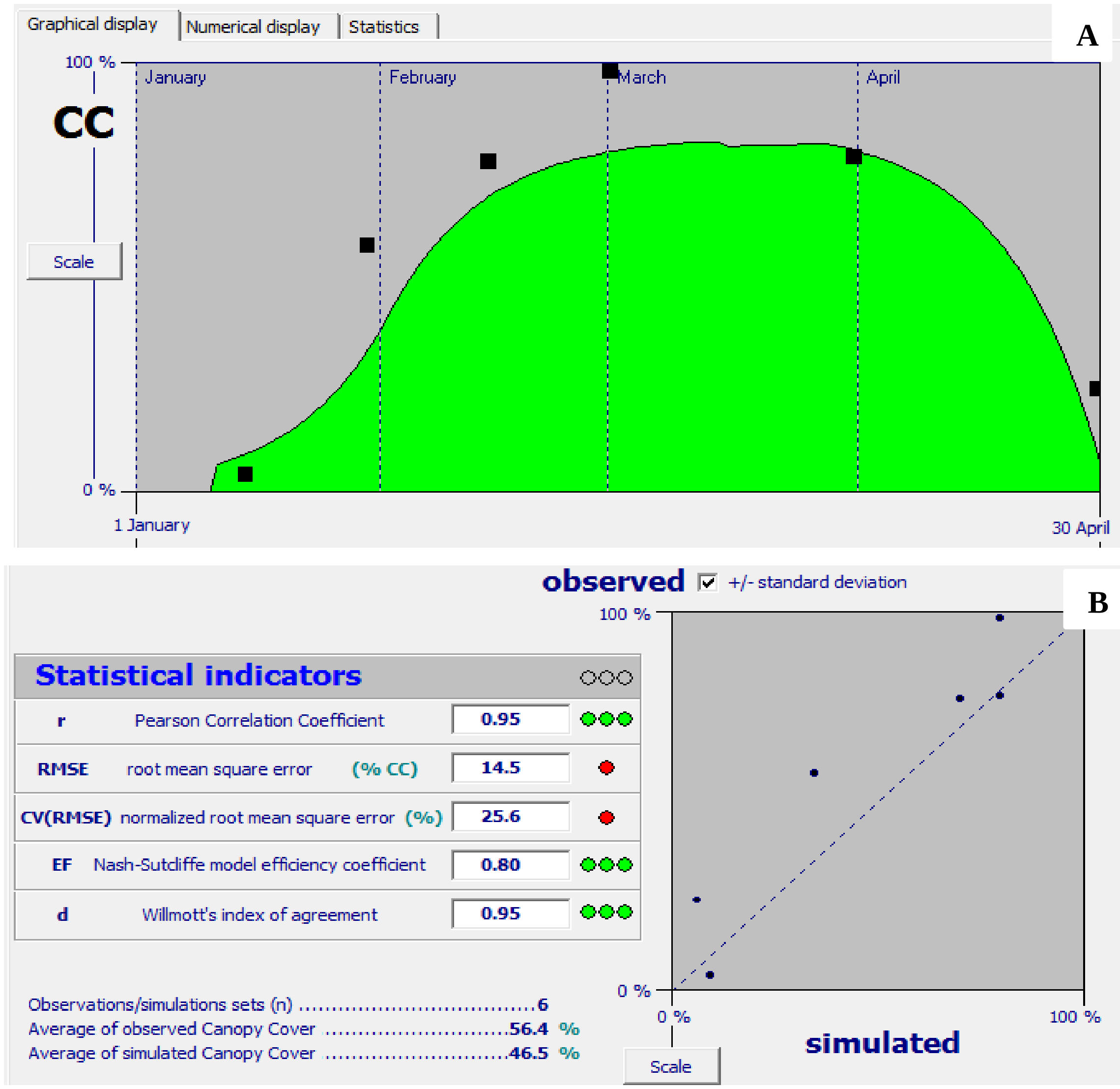


Figure 4:20 Reflections on Field Observed Canopy Cover data on Simulated (A) and it's statistical indicator (B) for Kataba Gumbichu farm

4.4 General Evaluation of AquaCrop Results

The outcomes of all irrigation farms' simulations are shown in (Table 4.9). The FAO Penman-Monteith equation and climate data were used to compute ETo for all irrigated fields using the in-built ETo calculator in AquaCrop.

Table 4:8 Summary of AquaCrop model based simulation Result

	Irrigation Farm		
Simulated Parameters	Alge Metehara	Kuruftu Wonji	Kataba Gumbichu
R^2	0.96	0.97	0.95
RMSE (% CC)	12.2	11.5	14.5
Observed CC (%)	43.7	47.4	56.4
Simulated CC (%)	48.6	39.4	46.5
Evaporation (mm)	155.2	72.4	158.8
Transpiration (mm)	422.3	178.2	281.5
ETa until harvest (ETa) (mm)	577.5	250.6	440.3
ETo until harvested (mm)	644.6	315.4	596.9
Harvest Index (adjusted) (%)	48	48	48
Potential Biomass (ton/ha)	11.3	10.4	9.6
Actual Biomass (ton/ha)	11	10	9.4
Actual observed Yield (ton/ha)	3.5	3.8	4.5
Yield simulated (ton/ha)	5.3	4.9	4.5
WP (kg yield/m^3 ET)	0.92	1.7	1.03
Cold stress (%)	-	-	32

4.5 Comparison WaPOR based and of AquaCrop based simulated Results

The AquaCrop model and WaPOR based results were compared during the whole agricultural season, from planting to harvest.

Table 4:9 AquaCrop – WaPOR comparison for wheat farms

	Irrigation Farm								
	Alge Metehara			Kuruftu Wonji			Kataba Gumbichu		
Simulated Parameters	AquaCrop	WaPOR	Difference	AquaCrop	WaPOR	Difference	AquaCrop	WaPOR	Difference
E (mm)	155.2	20.6	134.6	72.4	19.2	53.2	158.8	13.6	145.2
T (mm)	422.3	141.8	280.5	178	118	60	281.5	56.8	234.7
ETa (mm)	577.5	162	415.5	250.6	138.2	112.4	440.3	96.9	343.4
HI (%)	48	48	0	48	48	0	48	48	0
Biomass (ton/ha)	11	6.8	4.2	10	7	3	9.4	7.5	1.9
Actual yield ton/ha)	3.5			3.8			4.5		
Yield simulated ton/ha)	5.3	3.2	2.1	4.9	3.3	1.6	4.5	3.6	0.9
WPy (kg Y/m^3 ET)	**0.92**	**1.6**	**-0.68**	**1.98**	**2.1**	**-0.12**	**1.03**	**2.7**	**-1.67**

For all irrigation wheat farms, the values of actual evapotranspiration and interception varied (Table 4.10). For Alge Metehara irrigation farm, the difference in actual evapotranspiration is high: 162 mm of WaPOR against 577.5 mm of AquaCrop simulated. The difference in actual evapotranspiration for Kuruftu Wonji irrigation farm: 138.2 mm of WaPOR against 250.6 mm of AquaCrop. Also, for Kataba Gumbichu farm, the difference in actual evapotranspiration is also high (96.9 mm) for WaPOR, compared to 440.3 mm, which is simulated by AquaCrop. For estimation of AETI, both WaPOR and AquaCrop use the Penman Monteith, but, the input parameters have different values. The data used for WaPOR was global meteorological data from remote sensing. Therefore this data can be influenced by different parameters, such as cloud cover and the resolution of the pixel (Allen et al., 1998). While AquaCrop uses field collected data and meteorological data from the station, Due to this reason, AquaCrop simulates a higher value of AETI, and there is also unlimited water in the model environment. This result compared the past study carried out by (Ranjan & Denis, 2022) by using a field experiment at Harrai village, Prayagraj, during the wet growing season. In this study, they found a mean seasonal ETc value of 277mm. A similar study was carried out by Tezera et al., (2019) by using a field experiment to estimate wheat water consumption (ETc) during the wet growing season under a lysimeter in Melkessa Agricultural Research Center, Ethiopia, and an ETc mean seasonal value of 414 mm was observed. The ETa values of WaPOR and AquaCrop were also shown to be similar to what has been obtained in previous studies on lowland rice (312–537 and 400–465 mm respectively) (Widengren, 2022).

Table (4.10) shows that the AquaCrop simulated yield was in good agreement with the actual field collected yield values for all irrigation fields of study, with (5.3 tons/ha, 4.9 tons/ha, and 4.5 tons/ha) simulated by AquaCrop varying from the (3.5 tons/ha, 3.8 tons/ha, and 4.5tons/ha) actual field observed yield for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu fields, respectively. But the WaPOR based yield estimate indicates a potential underestimation of yield, with the average values of (3.2 ton/ha, 3.3 tons/ha and 3.6 tons/ha) which is lower than the actual field observed yield for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu fields, respectively. Similar study done by Widengren, (2022) on Evaluation of Crop Water Use and Rice Yield Using Remote Sensing and AquaCrop Model for Three Irrigation Schemes in Sri Lanka. The study shows WaPOR yield values (2.5–2.9

ton/ha) were lower compared to AquaCrop yield values and historical yield data (4.6–5.7 and 4.4–5.6 ton/ha respectively). These variations occur due to the difference in estimation methods when calculating the yield in both models. The WaPOR database uses the remotely sensed data to determine yield from above ground total biomass production by using global crop parameters (FAO, 2020b). From the past study on comparing remote sensing with field, broad literature reviews were shown, and it was concluded that there is high variation in reported and remote sensing yield. Selecting crop parameters such as LUE, MC, and HI has a significant effect on crop yield (Blatchford et al., 2019). Another reason for the lower yield in WaPOR was cloud coverage and atmospheric variation when collecting satellite image data specifically on NDVI. NDVI data is used to estimate net primary production, which is used for yield calculation and also for the determination of AETI (FAO, 2020b). AquaCrop uses field collected data inputs. But this model does not consider crop diseases such as fungus, insects, and birds. So, AquaCrop simulates a higher crop yield than the actual field-collected yield of grain wheat for all irrigation farms.

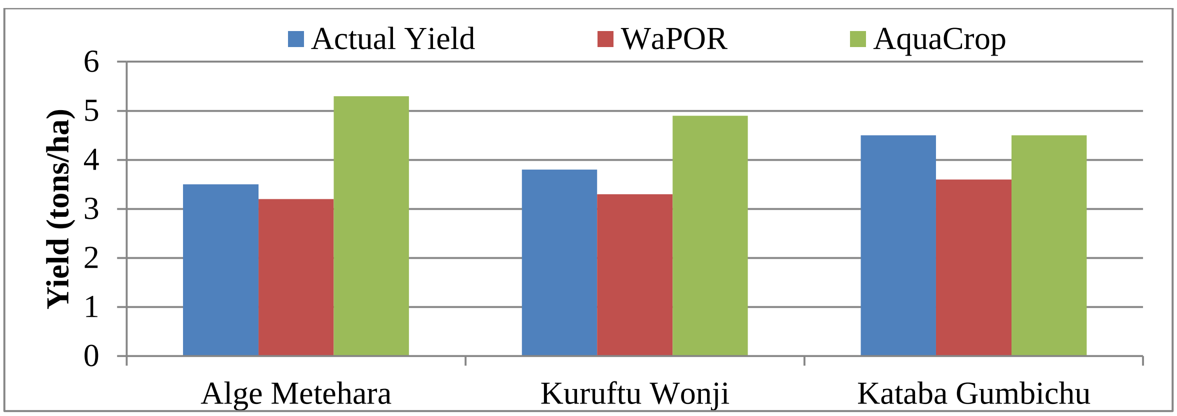


Figure 4:21 Comparison average seasonal yield of WaPOR based and AquaCrop model based with actual observed yield

Similarly, Table (4.10) shows the maximum seasonal biomass production of the WaPOR values (6.8 tons/ha, 7 tons/ha, and 7.5 ton/ha) were lower compared to AquaCrop values (11tons/ha, 10 tons/ha, and 9.4 tons/ha) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu fields, respectively. However, the biomass result is comparatively high for the estimated corresponding real evapotranspiration, resulting in a less severe reduction in transpiration than AquaCrop simulates for all wheat farm. The overestimation of biomass also has an effect on yield, which is overstated for the corresponding real evapotranspiration levels. The AquaCrop simulation shows that there is no water stress on the wheat crop. But WaPOR does not yet have the capability to model the effects of stress on yield formation. Study carried out by Tezera et al., (2019), by using field experiments, also estimated wheat grain yield and above ground biomass. They obtained the maximum grain yield and the above-ground biomass yield of 4559.1 and 10897.1 kg/ha, respectively.

These results affect the crop water productivity (CWP) values of the irrigation farms. The value of crop water productivity for Alge Metehara Farm 0.92 kg/m^3 of AquaCrop simulation and 1.6 kg/m^3 of WaPOR, for Kuruftu Wonji farm, 1.7 kg/m^3 AETI of AquaCrop simulation and 2.1 kg/m^3 AETI of WaPOR, and for Kataba Gumbichu farm, 1.03 kg/m^3 of AquaCrop simulation and 2.7 kg/m^3 AETI of WaPOR. Crop water productivity is the ratio of crop yield to AETI, and because of this, the variations in yield and water consumption (AETI) are different. As AETI from the WaPOR is low, it contributes a high CWP. According to (Zwart & Bastiaanssen, 2004) review wheat crop water productivity; globally measured average wheat water productivity was 1.09kg/m^3 and extend to (wheat, 0.6–1.7 kg /m^3). Similar study carried out by Tezera et al., (2019) by using field experiments to estimate wheat water consumption (ETc) during the wet growing season under lysimeter in Melkessa Agricultural Research Center, Ethiopia, and observed a CWP of 1.1 kg/m^3. The variability of CWP can be due to climate factor, irrigation water management, and soil (nutrient) management, among others.

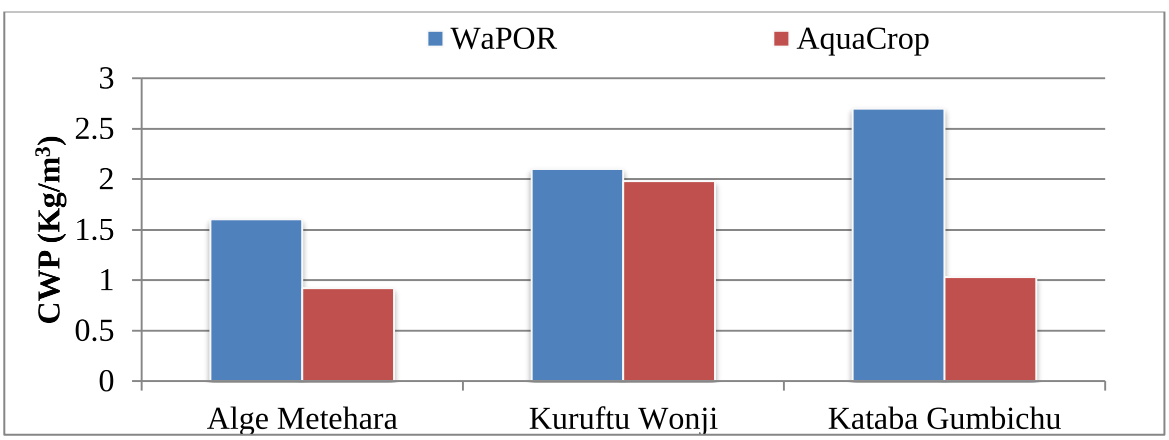


Figure 4:22 Comparison average seasonal CWP of WaPOR based and AquaCrop model for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu fields.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Evaluating and assessing land and water productivity is very important for policymakers and planners to evaluate irrigation wheat production for efficient use of land and water resources. This study assesses the spatial variability of wheat water productivity using the WaPOR database and Aqua Crop-Model in the selected site of the Awash River basin (Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, with a total area of 94 ha, 150ha, and 435 ha, respectively) based on their agroclimate zone. The WaPOR data on water, land, and climate are distributed spatially in near-real time. The most accurate spatial resolution of WaPOR data used to estimate crop water consumption (AETI), crop yield, and irrigation performance indicators for Alge Metehara and Kuruftu Wonji sites was at 30 m and 100 m for Kataba Gumbichu irrigation field was 100m. AquaCrop simulations for the chosen irrigation fields have been carried out using weather data from nearby climate stations, field crop data, and other variables like the start of the growing season, the harvest date, and the crop yield. This model was calibrated by using field collected soil and crop data, and model performance was validated in simulated wheat canopy cover with R^2 of (0.96%, 0.97%, and 0.95%) and RMSE of (12.2%, 11.5%, and 14.6%) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively.

The WaPOR estimated average AETI (102.3mm, 98.1 mm, and 67.7mm) and yield (3.2 tons/ha, 3.3 tons/ha, and 3.6 tons/ha) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively. Since all of the irrigation fields were irrigated by the furrow irrigation method, the assessment highlights field performance indicators such as equity (10.54%, 15.04%, and 23.5%) which is fair, with excellent uniformity of (76.5%, 89.5%, and 84.9%) , BWU (61-94%, 69-88%, and 47-89%)of AETI allocated for transpiration, land productivity (3.2 tons/ha, 3.3 tons/ha, and 3.6 tons/ha), and water productivity (1.6 kg/m^3, 2.1 kg/m^3, and 2.7 kg/m^3). Whereas, the AquaCrop model simulates AETI (577.5 mm, 250.6 mm, and 440.3 mm), yield (5.3 tons/ha, 4.9 tons/ha, and 4.9 tons/ha), and water productivity (0.92 kg/m^3, 1.98 kg/m^3, and 1.03 kg/m^3) for Alge Metehara, Kuruftu Wonji, and Kataba Gumbichu irrigation fields, respectively.

The comparison between WaPOR-based results of wheat water consumption, wheat grain yield, biomass, and wheat water productivity with the AquaCrop model based simulation; the AquaCrop based simulation was overestimation than WaPOR based. Since, WaPOR data is affected by several factors such as, cloud cover, pixel resolution and coverage, land noise of non-agricultural (non-wheat) land considered; crop parameters, and sources of climate data to calculate AETI. While AquaCrop uses field collected soil data, crop data and meteorological data from the station. As the result, AquaCrop simulates a higher result than WaPOR portal.

Generally, we conclude that WaPOR-based results and AquaCrop model based simulation were consistent with expectations for all irrigation fields. Therefore, WaPOR portal (using the open-source remotely sensed data) and the AquaCrop model were useful tools for managing water productivity in agriculture, and help farmers and water managers make more informed decision about how to use water resources more efficiently and sustainably.

5.2 Recommendations

From the research results, the following recommendations are drawn:

- This study evaluates the spatial variability of wheat water productivity for one crop season; but it doesn't considered temporal variation and different crop season, so for the future research work, it is recommended to evaluate the temporal variation of the wheat water productivity in different crop season with diverse irrigation systems.
- For future research, it is better to perform a sensitivity analysis for WaPOR and ground truth with field data such as crop water consumption, evapotranspiration, biomass, and yield data to obtain a better understanding of the potential and limitations of the WaPOR based assessment.
- To obtain more accuracy in modeling land and water productivity; field data such as soil fertility stress, weed infestation, crop disease, and other crop parameters shall be considered with field descriptions are important in the AquaCrop model.
- To achieve food self-sufficiency, the government and agricultural actors shall exercise modern technology, which is the most efficient irrigation methods recommended to improve land and water productivity.

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APPENDICES

Appendix A

Appendix A. 1 Soil parameters of the study Area

Farms	particle distribution				textural class
	Depth(cm)	%sand	%silt	%clay(Wt/Wt)	
Kuruftu Wonji	0-15	33	48	20	Loam
	15-30	35	40	22	Loam
	30-60	35	42	29	Loam
	Average	34.3	43.3	23.7	Sandy loam
Kataba Gumbichu	0-15	33	48	20	Sandy loam
	15-30	35	40	22	Sandy loam
	30-60	35	42	29	Sandy loam
	Average	34.3	43.3	23.7	Sandy Loam
Alge Metehara	0-15	37	33	35	Clay Loam
	15-30	33	37	32	Clay Loam
	30-60	29	31	30	Clay Loam
	Average	33.0	33.7	32.3	Clay Loam

Appendix A. 2 Canopy covers of wheat crop at different stage of growth

Date	Average Canopy Cover (%)		
	Kuruftu Wonji	Kataba Gumbichu	Alge Metehara
15	3.38	4.5	4.92
30	35	26.2	30
45	63	57.3	61.2
60	77	77	80
90	93	98	94
105	51	52.4	44.1
120	13	24	21

Appendix A. 3 Alge Metehara irrigation Field observed Actual crop yield

S/No	Farmer Code	Site Name	Area (ha)	Sowing Date in GC	Harvest Date in GC	Y(ku/A)	Y(ton/ha)
1	301	Alge	0.5	25/12/2022	9/4/2023	19	3.8
2	302	Alge	0.75	28/12/2022	10/4/2023	20	2.9
3	303	Alge	0.25	20/12/2022	16/04/2023	9	3.6
4	304	Alge	1	30/12/2022	20/04/2023	45	4.5
5	305	Alge	0.5	22/12/2022	13/04/2023	18	3.6
6	306	Alge	0.5	23/12/2022	17/04/2023	17	3.4
7	307	Alge	1	23/12/2023	11/4/2023	32	3.2
8	308	Alge	1	26/12/2023	15/04/2023	36	3.6
9	309	Alge	0.5	26/12/2024	18/04/2023	16	3.2
10	310	Alge	0.5	3/1/2023	22/04/2023	19	3.8
11	311	Alge	0.5	1/1/2023	24/04/2023	16	3.2
12	312	Alge	0.75	2/1/2023	20/04/2023	28	3.7
13	313	Alge	0.5	5/1/2023	23/04/2023	21	4.2
14	314	Alge	0.25	8/1/2023	25/04/2023	9	3.6
15	315	Alge	0.25	10/1/2023	28/04/2023	9	3.6
16	316	Alge	0.5	1/1/2023	25/04/2023	15	3
17	317	Alge	0.75	8/1/2023	22/04/2023	24	3
18	318	Alge	1	1/1/2023	26/04/2023	38	3.8
19	319	Alge	0.75	1/1/2023	30/04/2023	28	3.7
20	320	Alge	0.5	8/1/2023	29/04/2023	15	3
						Average	**3.5**

Appendix A. 4 Kuruftu Wonji irrigation Field observed Actual crop yield

Site Name	Latitudinal	Longitudinal	Sowing Date in GC	Harvest Date in GC	Area (Ha)	Y(ton/ha)
Kuruftu	524565.5	936029.2	15/12/2022	18/4/2023	0.75	3.3
Kuruftu	524523.2	936145.8	16/12/2022	19/4/2023	0.75	3
Kuruftu	524334.1	936387.1	19/12/2022	16/04/2023	0.25	4
Kuruftu	524225.6	936387.1	20/12/2022	23/04/2023	0.5	4
Kuruftu	524265.4	936477.5	22/12/2022	24/04/2023	0.75	3.5
Kuruftu	524612.8	936475.3	24/12/2022	17/04/2023	0.5	3.8
Kuruftu	524710	936674	23/12/2022	15/4/2023	0.5	4.4
Kuruftu	524489	936656	27/12/2022	16/04/2023	0.75	3.7
Kuruftu	524356	936771	26/12/2022	19/04/2023	1	4.2
Kuruftu	524008	936701	27/12/2022	22/04/2023	0.5	3.6
Kuruftu	524774	936925	29/12/2022	22/04/2024	0.25	3.6
Kuruftu	524295	937122	30/12/2022	26/04/2023	0.5	3.4
Kuruftu	524024	937228	25/12/2022	26/04/2024	0.25	4
Kuruftu	525030	937210	1/1/2023	26/04/2025	0.25	3.6
Kuruftu	524776	937257	3/1/2023	25/04/2023	0.5	4
Kuruftu	524626	937343	5/1/2023	25/04/2024	1	4
Kuruftu	524725	937384	4/1/2023	25/04/2025	0.5	3.8
Kuruftu	524945.3	937650.5	6/1/2023	24/04/2023	0.25	4
Kuruftu	525360.7	937682.6	3/1/2023	26/04/2023	0.5	4.4
Kuruftu	525107.4	937971	5/2/2023	27/04/2024	0.75	3.3
					Average	**3.8**

Appendix A. 5 Kataba Gumbichu irrigation field observed Actual crop yield

S/No	Site Name	Area (Ha)	Sowing Date in GC	Harvest Date In GC	Crop yield(ku/Area)	Crop yield(ku/ha)
1	Kataba	0.5	27/12/2022	12/4/2023	24	48
2	Kataba	0.25	25/12/2022	7/4/2023	13	52
3	Kataba	1	24/12/2022	19/04/2023	55	55
4	Kataba	0.75	27/12/2022	26/04/2023	35	47
5	Kataba	0.5	26/12/2022	14/04/2023	21	42
6	Kataba	0.25	28/12/2022	21/04/2023	12	48
7	Kataba	1	24/12/2023	16/4/2023	46	46
8	Kataba	1	27/12/2023	23/4/2023	50	50
9	Kataba	0.5	26/12/2024	28/04/2023	24	48
10	Kataba	0.75	5/1/2023	30/04/2023	31	41
11	Kataba	0.25	4/1/2023	21/04/2023	14	56
12	Kataba	0.75	7/1/2023	24/04/2023	30	40
13	Kataba	1	9/1/2023	29/04/2023	42	42
14	Kataba	0.25	10/1/2023	27/04/2023	9	36
15	Kataba	0.5	11/1/2023	26/04/2023	10	40
16	Kataba	0.5	6/1/2023	25/04/2023	15	30
					Average	**45**

Appendix A. 6 Average daily weather data of Kuruftu Wonji from January to April

Month	Rainfall (mm)	Temp.Min (°C)	Temp .Max (°C)	Rel. Hum. (%)	Wind speed (m/s)	Sun shine ($J\ m^{-2}\ day^{-1}$)
Jan	0.9	11.7	28.3	83.5	2.5	9.6
Feb	0.0	9.4	29.8	82.7	2.5	9.5
Mar	5.3	14.1	28.7	74.1	2.2	5.8
Apr	7.2	14.5	29.2	74.0	2.2	6.3

Appendix A. 7 Average daily weather data of Kataba Gumbichu from January to April

Month	Rainfall (mm)	Temp. min. (°C)	Temp. max. (°C)	Rel. Hum. (%)	Sun shine (J m^{-2} day^{-1})	Wind speed (m/s)
Jan	6	11.2	22.3	38.5	22	3.9
Feb	1	11.6	23.9	33.6	24	3.9
Mar	16	12.3	24.9	34.1	25	3.9
Apr	65	12.7	24.9	39	24	3.6
May	3	12.5	27.1	27.4	25	3.3

Appendix A. 8 Average monthly weather data of Alge Metehara from January to May

Month	Rainfall (mm)	Tmp. min. (°C)	Tmp. max. (°C)	Rel. Hum. (%)	Sun shine (J m^{-2} day^{-1})	Wind speed (m/s)
Jan	4	19.1	29.1	41.4	21	1.7
Feb	1	19.6	30.5	36.5	24	2
Mar	2	21.1	31.8	36.4	24	2.5
Apr	8	22.5	32.8	38	23	2.2
May	0	22.3	33.9	31.9	23.7	2.7

Appendix B

Appendix B. 1 Collecting Soil sample at different depth from different location

Appendix B. 2 Green Canopy covers at different stage of growth

i. initial stage of canopy cover

ii. Development stage of canopy cover

iii. Maximum stage of canopy cover

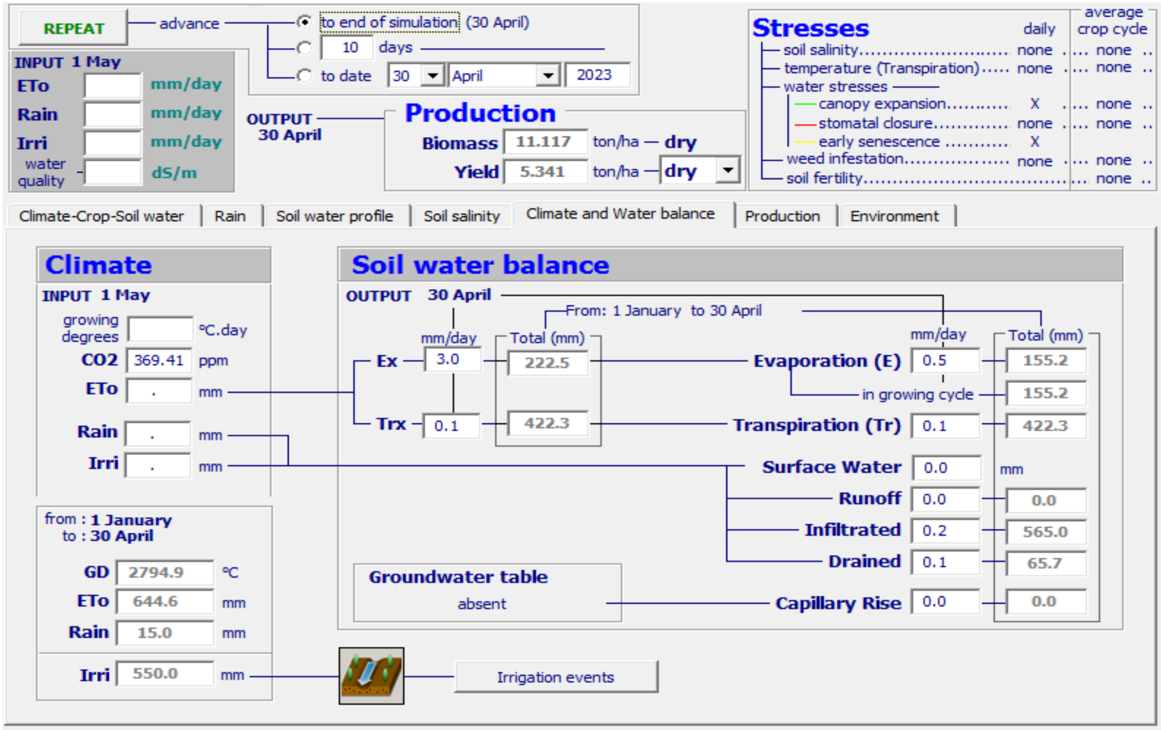
iv. Fully flowering canopy cover

v. Starting maturity stage canopy cover

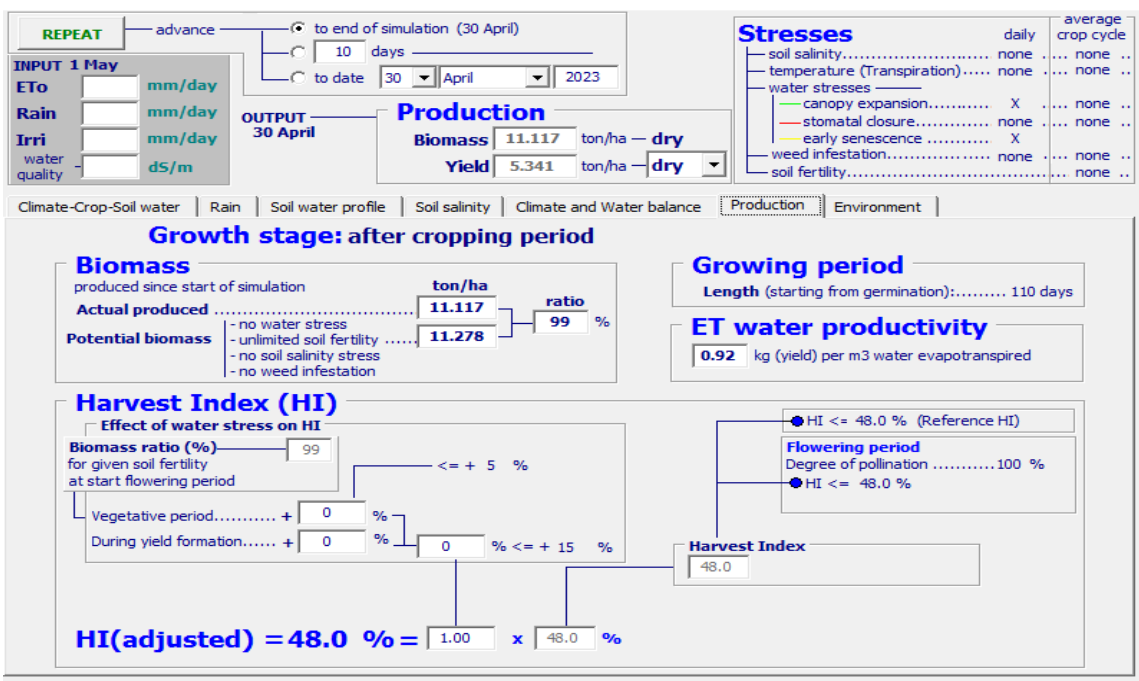
vi. Maturity stage of canopy cover before harvesting

Appendix B. 3 AquaCrop Simulated output for Alge Metehara irrigation farm

i. Climate and water balance

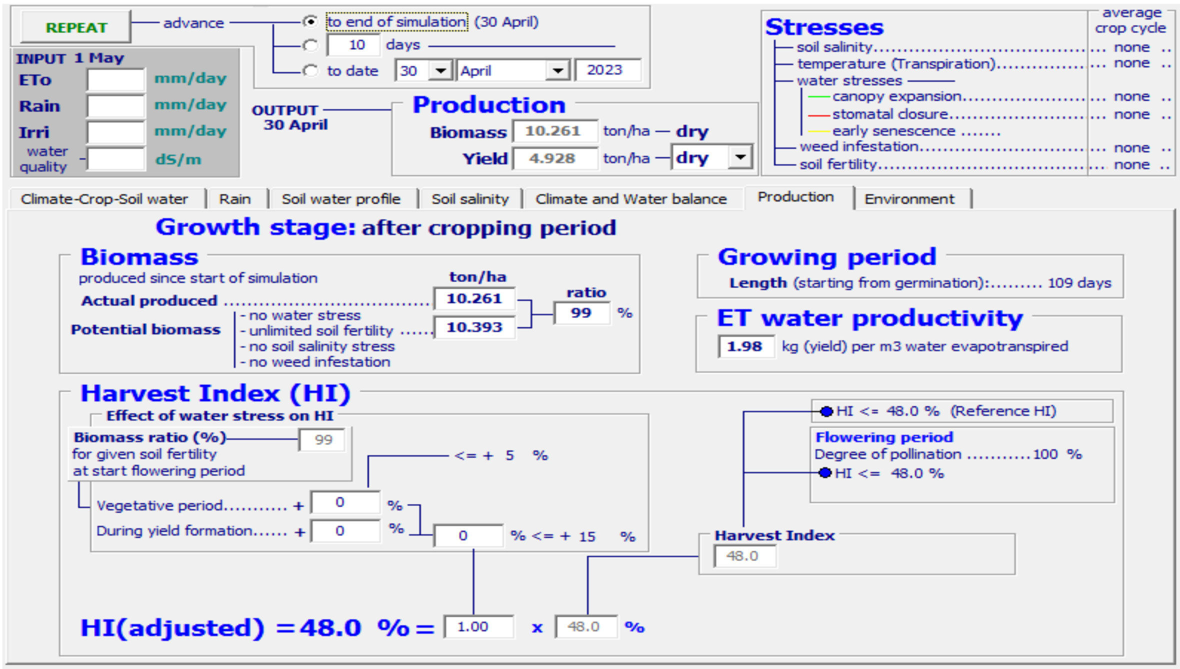


ii. Crop production

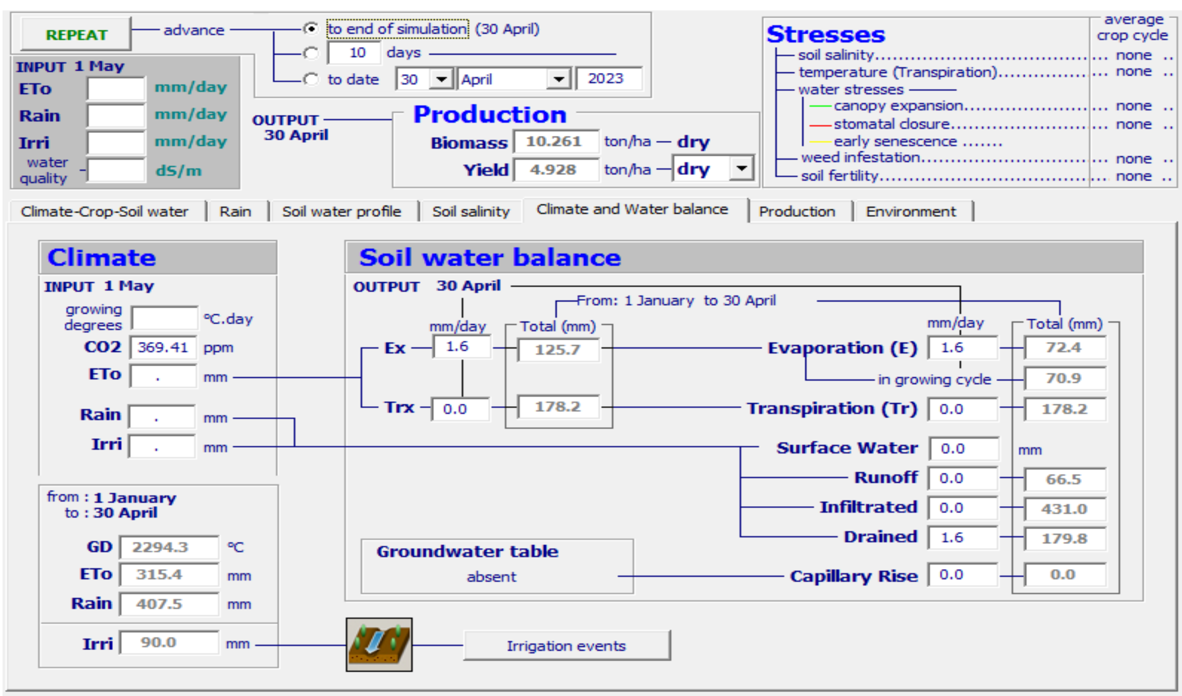


Appendix B. 4 AquaCrop Simulated output for Kuruftu Wonji irrigation farm

i. Climate and water balance

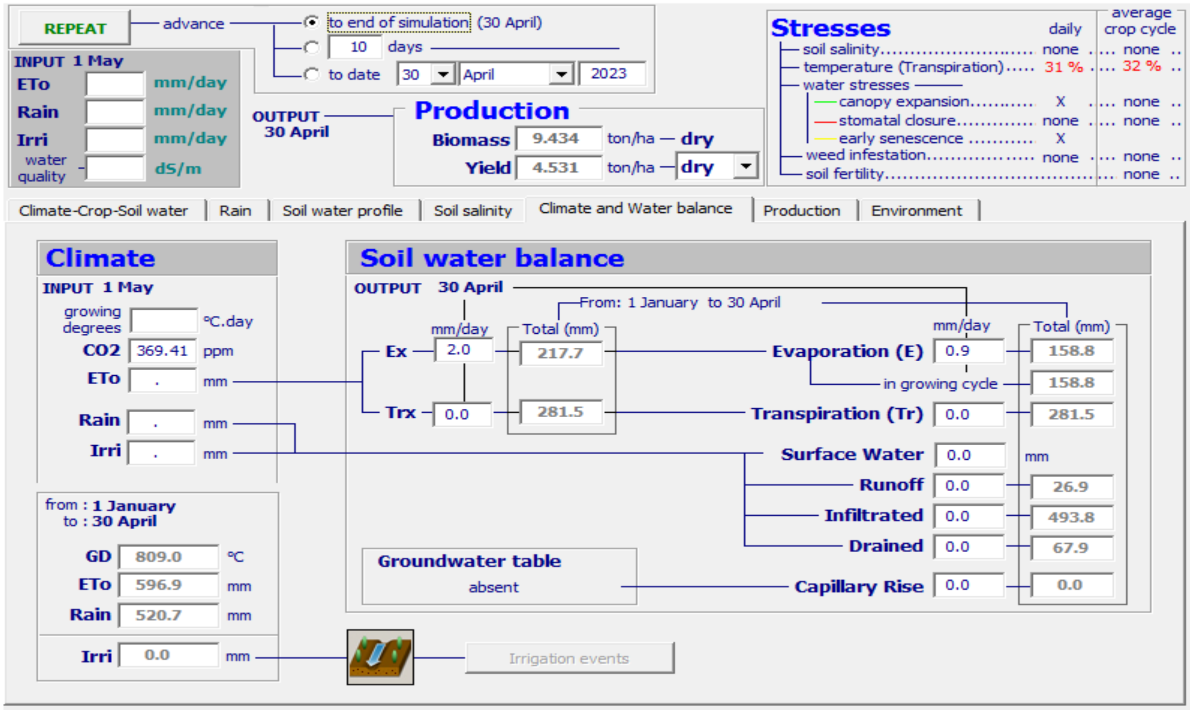


ii. Crop production



Appendix B. 5 AquaCrop Simulated output for Kataba Gumbichu irrigation farm

i. Climate and water balance



ii. Crop production