UNIVERSITY FOR DEVELOPMENT STUDIES

MODELLING BIOMASS AND BULB YIELD OF ONION (*Allium cepa*) UNDER DIFFERENT IRRIGATION REGIMES USING THE AQUACROP MODEL

YAYRA KWAME AGBEMABIESE

A DISSERTATION SUBMITED TO THE DEPARTMENT OF AGRICULTURAL MECHANISATION AND IRRIGATION TECHNOLOGY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN SOIL AND WATER CONSERVATION AND MANAGEMENT

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BY

YAYRA KWAME AGBEMABIESE (MPhil SOIL AND WATER CONSERVATION AND MANAGEMENT) (UDS/MSWC/0009/12)

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NOVEMBER, 2015

DECLARATION

I Yayra Kwame Agbemabiese, hereby declare that I obtained the results in this thesis, “modelling biomass and bulb yield of onion (*allium cepa*) under different irrigation regimes using the AquaCrop model” through a research conducted by me from January 2014 to May 2014 at the Bontanga irrigation scheme. The thesis was then submitted to the Department of Agricultural Mechanization and Irrigation Technology of the Faculty of Agriculture at the University for Development Studies. References made to previous works of others have been duly acknowledged, however no previous submission of this work has been made to this University or elsewhere nor has publications been done with respect to this work.

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ABSTRACT

Crop water productivity models are important tools in evaluating the effect of different irrigation regime on crop yield. AquaCrop model is a crop water productivity model adopted by the Land and Water Division of FAO in the year 2009. It simulates yield responds to water for herbaceous crops, and it is particularly suitable in addressing conditions where water is a key limiting factor in crop production such as in northern Ghana. The objective of this study was, to calibrate the AquaCrop model for different irrigation regimes for onion (*Allium cepa*), to determine its effect on crop growth and yield parameters of the crop at the Bontanga irrigation scheme. This was done by determining the crop and economic water productivity for each irrigation regime of onion. To achieve these, the Randomised Complete Block Design (RCBD) was used on *Red Creole* onion variety. Randomised Complete Block Design was made up of four irrigation treatment regime of 117%, 100%, 80% and 60% of the crop water requirement of onion with five replicate blocks. Results indicated that there was no significant variation in yield, dry bulb biomass and total biomass, but there was difference for dry leaf biomass of onion at 0.05 level of significance. Results also showed that crop water productivity and economic water productivity of onion increases with increasing irrigation deficit, whereas evapotranspiration water productivity of onion increases with increasing irrigation regime. The AquaCrop model simulated satisfactorily the crop yield, biomass and evapotranspiration water productivity of onion. There was a strong correlation and a significant linear relation between the simulated and measured crop yield, biomass and evapotranspiration water productivity. Validation of AquaCrop model using Nash-Sutcliffe efficiency (E), Root mean square errors (RMSE) and index of agreement (d) showed that, AquaCrop model can therefore be used to simulate bulb like crops such as onion.

DEDICATION

I hereby dedicated this dissertation to the Almighty God for his everlasting love throughout the course of this work. Also to my parents, Mr. and Mrs. Agbemabiese who served as instruments of God to play music that led me to success throughout my education.

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LIST OF ACRONYMS

AAS: Atomic Absorption Spectrophotometer.

ANOVA: Analysis of Variance

ARI: Agricultural Research Institute

CEC: Cation Exchangeable Capacity

Cmol: Concentration per Mole

RCBD: Randomised Complete Block Design

CSIR: Council for Scientific and Industrial Research

CWP: Crop water productivity

EC: Electrical Conductivity

ETWP: Evapotranspiration water productivity

EWP: Economic water productivity

FAO: Food and Agricultural Organisation

GIDA: Ghana Irrigation Development Authority

GPS: Global Positioning System

IFA: International Fertilizer Industry Association

IITA: International Institute of Tropical Agriculture

IWUE: Irrigation Water Use Efficiency

JICA: Japan International Co-operation Agency

Kc: Crop Coefficient

LAI: Leaf Area Index

LSD: Least Significant Difference

MoFA: Ministry of Food and Agriculture

ppm: Parts Per Million

RMSE: Root Mean Square Error

SARI: Savannah Agriculture Research Institute

SSIPP: Small Scale Irrigation Agriculture Promotion Project

WAT: Weeks after Transplanting

WP: Water Productivity

WUE: Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background

Irrigation is defined as the process of artificially supplying water to soil for raising crops. It is a science of planning and designing an efficient, low-cost, economic irrigation system tailored to fit natural conditions. It is the engineering of controlling and harnessing the various natural sources of water by the construction of dam and reservoirs, canals and head works and finally distributing the water to agricultural field (Punmia and Lal, 1992). Irrigation water is supplied to supplement the water available from rainfall and the contribution to soil moisture from ground water. In many areas of the world the amount and timing of rainfall are not adequate to meet the moisture requirement of crops, making irrigation essential to raise crops necessary to meet the needs of food and fibre (Micheal, 1978).

One way to address the issue of water shortage is through development of irrigation scheduling techniques such as deficit irrigation, which are not necessarily based on full crop water requirement. Deficit irrigation serves as a means of reducing water consumption while minimizing adverse effects of limited water on yield (English and Nakamura, 1989, English and Raja, 1996, Kirda, 2002). In this method, the crop is exposed to a certain level of water stress, either during a particular period or throughout the whole growing season. The expectation is that any yield reduction (especially in water-limiting situations) will be compensated by increased production from the additional irrigated area with the water saved by deficit irrigation as discussed in the report by Bazza (1999), Kirnak *et al.*, (2002), Ali *et* *al.*, (2007). However, the grower must have prior knowledge of the crop yield responses to deficit irrigation.

Many research works have been carried out worldwide with regards to the effects of deficit irrigation on yield of mainly horticultural crops (Sezen *et al.*, 2008). Experiment using onion (Bekele and Tilahun, 2007) showed that deficit irrigation throughout the growing season of onion resulted 50 and 75% reduction in yields, compared to full irrigation with high water saving and crop water use efficiency. Kumar *et al.*, (2007) investigation of the impact of deficit irrigation strategies on onion yield and water savings showed that the application of 80 and 60% of crop water requirements resulted in mean yield decreases of 14 and 38% and saved 18 and 33% of irrigation water compared to full irrigation in 2 years, respectively.

1.2 Potential Onion Production Areas in Ghana

In many parts of the world, onion (*Allium cepa* L.) is considered as an important vegetable crop and is mostly grown on irrigated lands (Martin *et al.*, 1989). According to Obeng *et al.*, (2007), the cultivation of onion in West Africa is concentrated in Burkina Faso, Northern Nigeria, Niger, Senegal and Northern Ghana. In Ghana, however, the crop is grown commercially in the Northern and Upper Regions, especially in areas around Bawku, Bolgatanga and the Kusasi. Other production areas are Ashiaman, Dawhenya, Akatsi, Nsawam, Prestea, Koforidua, Kwahu, Mankessim and Berekum. In Ghana, the most popular onion *(Allium cepa* L.) cultivar is Bawku Red whereas Early Texas Grano and Red Creole are exotic cultivars which are also grown. In 1995, shallots and onion production in the country was 29,000 tonnes, covering an area of 1,970 ha (Vordzorgbe, 1997).

In the Northern Region of Ghana and in Tolon and Kumbungu districts specifically, the crops cultivated per percentage of households are as follows; cereals 99.8%, legumes 88.3% and tubers 80.6% (Tolon-Kumbungu District Assembly, 2012). About 36% of the farming households cultivate vegetables, whilst 15.3% cultivate fruits. The main problem facing crop production is the hazardous environment for crop farming reflected in perennial flooding of farmlands, unfavourable weather conditions due to erratic rainfall sometimes resulting in drought, perennial bush fires and declining soil fertility. Some of these problems are, however, due to poor environmental management relating to inefficient farming practices and hunting for fuel wood (Tolon-Kumbungu District Assembly, 2012).

1.3 The Onion Crop

Onion, a monocotyledonous crop, belongs to the genus *Allium*, and to the family *Alliaceae*. Onion is shallow rooted and sensitive to water stress. Drost, (2010) indicated that the crop requires regular watering throughout its growth for best production. Kadayifci *et al.* (2005) also stated that in order to obtain a high bulb yield at harvest water deficits should be avoided especially during the period of bulb formation.

Onion is used widely in Ghana and many parts of the world for flavouring and seasoning foods, as a vegetable and for medication. It forms an essential part of the daily diet, creating year round demand for it. Norman (1992) indicated that a 100g edible portion contains 31gcal of energy, 1.5g of protein, 0.6g of fat, total sugar 7.2g; other carbohydrate, 0.3g; thiamine, 0.04g; riboflavin, 0.02g; miacin, 0.1g; vitamin c, 7mg; Ca, 30mg; Fe, 0.5mg; Mg, 16.5mg; P, 35mg; K, 150mg and Na, 7mg.

1.4 AquaCrop model

AquaCrop was developed by FAO to simulate crop water productivity. This resulted from a series of scientific experiments designed to quantify and understand crop growth in relation to water. The model simulates yield of several herbaceous crops under any of the four conditions, which are rain-fed, supplemental, deficit, and full irrigation (Steduto *et al.*, 2009b; Steduto *et al.*, 2009a). It is used for irrigation management, project planning, and scenario simulations at different scales. The model strikes a balance in simplicity, accuracy, and robustness while using fewer parameters as reported by Izzi *et al.*, 2009 and Steduto *et al.*, 2009b.

1.5 Problem Statement and Justification

Given current demographic trends and future population growth projections, as much as 60% of the global population may suffer water scarcity by the year 2025 (Qadir *et al.*, 2007). Declining water resources and increasing food requirement require a greater efficiency in water use, both under rain-fed and irrigated agriculture. Irrigated agriculture is the largest water consuming sector and it faces competing demand from other sectors such as the industrial and domestic sector (Graham *et al.*, 2003). About one-third of the world's irrigated lands has reduced productivity as a consequence of poorly managed irrigation that has led to water logging and salinization (Alicia *et al.*, 2009)

The agricultural sector faces the challenge to produce more food with less water (Kijne *et al.* 2003). However, deficit irrigation has widely been reported as a valuable strategy for dry regions (English, 1990; Fereres and Soriano, 2007) where water is the limiting factor to crop production.

Increase in food production has, in the past, been achieved through a combination of opening up new lands and increased land productivity through the application of improved agricultural techniques and farm inputs. Demographic changes in human populations and the concomitant demand for land for several other purposes have led to a decrease in the availability of arable lands, forcing farmers to adopt strategies which are based on conservation and improvement of productivity of existing land (Abbey and Oppong-Konadu, 1997).

Generally, onions are grown extensively throughout Ghana with commercial production occurring in the Northern, Upper East and Upper West regions. However, yields are rather low and highly variable compared to other countries in Africa, although high levels of organic and inorganic fertilizers are used.

Nkansa (1989), reported that the comparatively lower onion bulb yields in Ghana could be attributed to inappropriate agronomic practices, pest and disease problems and lack of genetically-improved progagules. As a result, Ghana import onions from other countries in the West African sub-region to complement the quantity produced. For instance, in 1992, Ghana imported 1100 t (equivalent to US $ 600,000.00) of dry onion bulbs (FAO, 1992), and 1341 t in 1996 (Vordzorgbe, 1997). Consequently, the contribution of onions to national earnings from horticultural crops is effectively zero, if not negative.

Ghana web Business News on Wednesday, 31 October 2012 disclosed that about five million dollars is lost annually from the importation of onions from Niger and Burkina Faso to Ghana, which can be produced locally.

Irrigation needs for onion, like any other crop are location specific. The crop water requirement of onion is not evenly spread over the growing season, but depends largely on a number of factors, including the specie, growth stages, soil properties and climatic conditions.

Farmers in the Kumbungu District cultivate various crops by guessing the available moisture content of the soil by means of observation and feeling methods (Abagale and Tetteh, 2011). One of the major drawbacks with this method is that the estimation of soil moisture is subjective (Schneekloth *et al.,* 2007). In this regard, excess irrigation water supply may not only result in a yield decrease but may also in turn produce other negative effects, such as leaching of nutrient and rise of ground water. This then requires modelling tools that support management decisions with regard to efficient water use in crop production. AquaCrop model is a decision support tool useful in modelling and devising strategies for efficient management of crop-water productivity at farm level. To make AquaCrop globally applicable, it must be tested in different locations with different soil conditions, crops, agronomic practices and climatic conditions (Sam-Amoah *et al.*, 2013). Calibration and performance evaluation has been done for various crops, such as hot pepper by Sam-Amoah *et al.* (2013), cotton by Farahani *et al.* (2009) and Garcia-Vila *et al.* (2009) and for maize by Heng *et al.* (2009) and Hsiao *et al.* (2009).

Given the limitations with regards to onion production in Ghana, AquaCrop model could be used to study the crop's response to various levels of water application. Ultimately, this would lead to a better understanding of how to improve on the yield of onion through the adoption of optimal water management practices.

1.6 Objectives

The primary objective of this work was to calibrate the AquaCrop model for onion using different irrigation regimes of the Bontanga irrigation scheme, located in the Northern Region of Ghana.

The specific objectives of this study were to,

i. Determine the effect of irrigation regimes on soil nutrients (nitrogen, phosphorus, potassium, magnesium, carbon and calcium), soil P^H and soil cation exchange capacity.

ii. Determine the effects of different irrigation regimes on onion growth and yield.

iii. Determine the crop water productivity, evapotranspiration water productivity and economic water productivity of onion under the irrigation water regimes.

iv. To compare yield results from field and simulated AquaCrop.

1.7 Scope of Work

To calibrate the AquaCrop model for onion (*Allium cepa*) under different irrigation regimes.

1.8 Limitation of the Research Work

The following limitations were realised in the course of the research.

- The research was undertaken in only one cropping season.
- Experiment was carried out on one variety of onion.
- The experiment was undertaken on one lateral of the Bontanga irrigation scheme.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin and Distribution of Onion

Onions are one of the most ancient vegetables under continuous cultivation dating back to at least 4,000 BC. The ancient Egyptians are known to have cultivated this crop along the Nile River. Afghanistan and the surrounding region are believed to be the centre of origin as though there are no known wild ancestors (Boyhan, 2007). It was grown at the time of the Egyptian Pharaohs and was mentioned in the Bible during the Exodus (Numbers 11:4). Onion was introduced into West Africa by the early Europeans. The popular cultivar, Bawku Red, was introduced into Ghana around 1930 and was first grown at Bugri, near Bawku (Norman, 1992). Onion is now a principal vegetable crop in Niger and plays a major role in Niger's economy (Nabos, 1971). It is the second most important vegetable crop in Nigeria. In West Africa, onion production is concentrated in Nigeria, Niger, Ghana, Burkina Faso and Senegal (Norman, 1992).

Onions are among the most widely adapted vegetable crops. They can be grown from the tropics to sub-arctic regions. Onion (*Allium cepa* L.) belongs to the family *Alliaceae* (Messian, 1998). It is one of the most important commercial vegetables cultivated in Ghana. It is a high value and high income generating vegetable crop for most farmers or producers. In Ghana, onion is mainly cultivated in the Northern parts of the country especially the Upper East Region. The most cultivated onion (*Allium cepa* L.) cultivar is the Bawku Red. Exotic cultivars which are also grown include Red Creole and Early Texas Grano.

It is a necessary part of the human diet in all parts of the world. Onion is a rich source of several minerals and vitamins (Raemaekers, 2001). Onion can be eaten raw, boiled, baked, fried, dried or roasted and commonly used in salads, soups, spreads, curries and other dishes

(Ageless, 2009; Choudhry, 1979). Medically, onion is used for relaxing sparms, reducing blood pressure and sugar levels and for the treatment of acne, boils and wounds (Ageless, 2009). Block, (1985) reported that onion extract can be a potent cardiovascular and anticancer agent with hypocholestrolemic thrombolytic and antioxidant effect. Several antioxidant compounds, mainly polyphenols and sulphur containing compounds have been found in onion (Nuutila *et al*., 2003).

2.2 Botany / Morphology of Onion

Onion (*Allium cepa* L.) belongs to the family *Alliaceae*. The onion is most frequently a biennial or a perennial plant, but is often treated as an annual and harvested in its first growing season. Modern varieties typically grow to a height of 15 to 45 cm (6 to 18 in). The leaves are blueish-green and grow alternately in a flattened, fan-shaped swathe. They are fleshy, hollow and cylindrical, with one flattened side. They are at their broadest about a quarter of the way up beyond which they taper towards a blunt tip. The base of each leaf is a flattened, usually white sheath that grows out of a basal disc. From beneath the disc, a bundle of fibrous roots extends for a short way into the soil. As the onion matures, food reserves begin to accumulate in the leaf bases and the bulb of the onion swells. The inflorescence takes the form of a globular umbel of white flowers with parts in sixes. The seeds are glossy black and triangular in cross section (Brickell, 1992).

It is characterised by a pungent alliaceous compound, ally-propyl-disulphide. The onion bulb consists of thickened bases of leaves attached to a small conical stem. The bulbs vary from flat to round in shape. The leaves are long, round and hollow. The flowers are small in terminal umbels and corolla colour which is often greenish white (Norman, 1992).

2.3 Cultural and Management Practices for Onion Production

Onion is propagated mainly from seed, either by direct sowing into the soil in rows and later thinning out to about 10-20 cm apart or sowing in nurseries (containers and seed beds) and transplanting seedlings in the field 5-8 weeks after sowing depending on cultivar. Age of the seedlings is important for establishment and higher final bulb yield. Seedlings are ready for transplanting at 45-55 days after sowing or when 3-4 true leaves emerge. This is just before bulb formation starts. If seedlings overstay on beds for more than 60 days after sowing, bulb formation starts and potential for bulb size development reduced with consequent significant yield reduction (Olani, 2010). The planting distance of 30-40 cm between rows and 7.5-12.5 cm in rows is used. Wider spacing enhances the production of split bulbs. Raised beds are used where drainage is not sufficient and most preferred in wet seasons (Norman, 1992).

Onion requires frequent weeding during establishment of young seedlings. This may be done periodically or when necessary. Onions are shallow-rooted and therefore deep cultivation must be avoided in order not to destroy the root system. Hand pulling or hoeing of weeds can be done but is quiet expensive and labour intensive. Chemical weed control is ideal for commercial production. Irrigation in onion production is essential to ensure that during the initial crop growth stages, the plant do not suffer from lack of water. Moisture must be maintained in the surface 15-30 cm of the soil for maximum yield. However, dry season is the best period for cultivating onion. Excessive watering during the late season stage tends to make the onion watery and reduced their storability. Initiation of second root growth may also start when there is too much water (Norman, 1992).

Exposed onions must be earthed up during periods of heavy down pour. In cultivars that flower like Bawku onion, the flower bud must be nipped or cut off immediately they develop or sprayed with maleic hydrazide which suppresses flowering resulting in larger bulb formation (Sinnadurai *et al.*, 1971).

Incorporation of well-decomposed organic matter is sufficient to supply nitrogen to avoid production of bull-neck or thick-necked onions. 30 t/ha farmyard manure or compost can be worked into the soil 3-4 weeks before planting. A top dressing of 250-300 kg/ha 15-15-15 compound fertilizer may be applied in soils low in organic matter. On easily leached soils, a side dressing of 125 kg/ha of sulphate of ammonia or calcium ammonium nitrite should be done before bulbing start (Amans *et al*., 1982).

2.4 Environmental Requirements for Onion Production

Aside a genetic factor, onion production is also influenced by environmental factors such as climatic factors and soil conditions.

2.4.1 Temperature

Onion is adapted to a wide range of temperatures and is frost-tolerant. It requires an optimum air temperature of 18-27°C. Temperature above 30°C may result in early crop maturity and yield reduction. Best production is established when cool temperatures prevail over an extended period of time, allowing significant foliage and root development before bulbing begins. However, bulb formation is favoured by relatively high temperatures (Raemaekers, 2001). A variety like Red Creole requires very low temperature and cannot produce sufficient seeds when the temperature is very high.

Sinnadurai (1992) reported that, onion needs cool temperatures during its early stages of growth and warm temperatures during bulbing. Bulbing is influenced by temperature, in that bulbing is accelerated by high day temperatures and greatly delayed by low temperatures if the day length is short. However, cool night temperatures encourage both bulbing and flowering in the West Africa cultivar. After bulbing begins, high temperature and low relative humidity extending into the harvest and curing period are desirable. According to Tindal (1983), at high temperatures, bulbs will be produced in shorter day length than under lower conditions. Flowers are rarely produced at high temperatures since cool period is required after bulb formation for the initiation of the inflorescence and flower stalk. Undesirable growing conditions may result in onions bolting or seeding up flower stalks. Carefully cutting the stalks will enhance bulbing.

An important aspect of onion development is the length of day or photoperiod. The day length requirement ranges from 12 hours for early cultivars to 15 hours for late cultivars. The time of bulbing is determined by the day length and the capacity of bulbing differs with cultivar. Some onion varieties are short-day in response, and form bulbs when the day lenght is 12 hours where as other varieties are long-day plants, forming bulbs when there is 15 or more hours of daylight. This effect of day length makes some onion cultivars unsuitable for northern climates because they start to bulb when the plants are too small (Sinnadurai, 1992). GIDA-JICA-SSIPP, (2004) however established that for optimum yield, cool temperature and abundant soil moisture during the early stages of growth before bulbing, higher temperatures of over 35 ^{O}C and long days during the dry season favour good bulbing in the drier savannah areas.

2.4.2 Soil Texture and pH

Onions prefers sandy to loamy soils. It grow best in a loose, well-drained soil of high fertility and plenty of organic matter. Soils with clay and silt loams unless modified with organic matter to improve aeration and drainage should be avoided. Although humus containing heavy or too wet soils may produce high yield, they should be avoided as they produce bulbs with poor storage qualities. Sinnadurai (1992) stated that sandy-loam and silt-loams are ideal because they can retain fair amount of moisture around the roots and as well be loose enough for ease inter-cultivation to allow bulbs to expand during their formation.

Brady (1996) stated that influences of pH in soil concentration influences the availability of plant nutrient. Soil pH is also responsible for the solubility of numerous nutrient elements. Onions are also sensitive to highly acid soils and grow best when the pH is between 6.2 and 6.8. According to Raemaekers, (2001), Karim and Ibrahim, (2013) and FAO (2013) onion has average tolerance to soil pH ranging from 6 to 7.

Soils with high organic matter have a lower pH because organic matter moderates some of the negative effects of excessive soil acidity. If the pH of a soil is significantly low, agricultural lime (stone) is needed to add to neutralise the acidity and raise the pH (Anonymous, 2012). A study conducted at Columbia Basin in order to determine the effect of lime application on onion production proved that liming on the soil with pH below 5.5, increased the soil pH in the 6.0 × 2.54 cm zone. Although the onion stands were not significantly improved but the bulb size increased and the total yield were significantly increased by liming **(**Stevens *et al*, 2003).

2.4.3 Soil Moisture

Soil moisture is important in the growth of new roots and it must reach the base of the bulb periodically if the newly formed roots from the stem are to grow into the soil. Optimum level of the moisture content in the soil should be maintained for the need of onion growth. Therefore frequent irrigation is important, but do not tolerate water logging (Sen *et al*, 2006). FAO (2013) reported that for optimum yield, onion requires 350 to 550 mm water. According to Tindal (1986) seedlings are fairly tolerant to high rainfall and adequate soil moisture is required throughout the growing period, and that is adequate water supply is particularly important at the time of bulb formation. Light mulch also helps conserve moisture for uniform growth. During flowering, seed development and maturity, excessive rainfall and very cool condition is undesirable as they lead to disease development and poor seed setting.

The actual requirement of soil moisture is difficult to determine because it depends on the types of soil, temperature and day length received by the crop. However, proper irrigation scheduling and types of irrigation system can help to maintain appropriate soil moisture in onion (Karim and Ibrahim, 2013).

Onion yields and size are closely related to irrigation practices, especially when it is in the vegetative stage. High yields of onion, better bulb storability and internal quality can be gained when careful attention is given to irrigation scheduling (Shock, 1998 and Shock, 2012). Several factors may influence soil moisture such as variety of onion, types of soil, physiological and environmental factors (Woldetsadik, 2003). According to Shock *et al,* (1998) and Shock *et al,* (2010) irrigation scheduling is directly related to marketable onion production and sustainable agricultural practices. Onion yields and size are closely related to irrigation practices, especially when it is in growing stage. High yields of onion, better bulb storability and internal quality can be gained when careful attention to irrigation scheduling is undertaken.

2.4.5 Soil Fertility

Decline in soil fertility is an important challenge facing food security in developing countries (Amalu, 2002). It occurs frequently on smallholder farms that are continuously cultivated. Fertility drop occurs when farmers do not compensate with tolerable nutrient amendments through the application of fertilizers or return of much needed organic matter from plant debris or most importantly, the use of agroforestry technology that could subsidise substantial amounts of nutrients used by crops (Gaisie, 2011).

However, Fawusi *et al.* (1981) reported that although farmers know that chemical fertilizers were important for maintaining soil fertility, healthy plant growth and raising good harvest, the high cost of chemical fertilizers for resource poor farmers and the indiscriminate application of fertilizers affect the pH of the soil and ion antagonism.

Also aside the use of chemical fertilizers, soil fertility amendment could be maintained or increased through the cultivation of leguminous plants as green manures, and the incorporation of organic matter such as compost, straw, poultry manure, cattle manure and peat. IFA, (2000), further reports that the application of both organic manure and inorganic fertilizers is sufficient to improve the soil fertility for the sustainable levels of vegetable production. Nutrient needs and fertilizer recommendations are based on the nutrient supplying capability of the soil and the additional nutrient needed by crops to achieve their potential yields. The amount of nitrogen, phosphorus and potassium (NPK) required by most crops to achieve long term economic yield in Ghana is achieved after soil testing. This can disclose whether addition of limestone, P or K is required for optimum productivity (Gaisie, 2011).

A survey undertaken by MoFA, (2010) indicated that in the Northern region of Ghana, soil pH ranges from 4.5-6.7, organic matter 0.6 — 2.0%, total nitrogen 0.02 — 0.05%, available phosphorus 2.5 — 10.0(mg/kg soil) and available calcium 45 — 90(mg/kg soil). This resulted from high level of environmental and land degradation, bush fires, fragmented land, and deforestation for farming, urbanization, continued cropping and over grazing.

Phosphorus deficiency is widespread in most soils of northern Ghana, and ferruginous nodules contained in some soils in the region highlight the deficiency problems, because they act as P sinks. Ferruginous nodules are present in many soils in Ghana and constitute a major problem in P nutrition (Abekoe and Tiessin, 1998). According to Fosu *et al.*, (2004), organic matter content in the Guinea and Sudan savanna zones of Ghana is generally low with a mean around 1% in cultivated fields.

Table 2.1: Description of Soil Fertility Classes for Crop Production for Tropical Soils.

soil properties	Soil fertility class/rating				
	Very high	High	Medium	Low	Very low
pH a		5.0-6.5	4.5-5.5 or 7.5-7.8	4.0-4.5 or 7.8-8.0	
Organic Matter (%)a		>3	1-3.0	<1	
ECEC (Cmol/kg)a		>15	8-15	<8	
P (mg/kg)a		>10	6-10	<6	
K (cmol/kg)a		>0.4	0.15-0.4	<0.15	
N% b	>1.0	0.5-1.0	0.2-0.5	0.1-0.2	<0.1
OC% c	>20	10-20	4-10	2-4	<2
Porosity d	>40	15-40	5-15	2-5	<2

a= source FAO (1976) b=source adapted from Metson (1961) c= source Udo *et al*, (2009) d= Guidelines for Soil Description (2006)

Whereas sandy loams are good as they are low in sulphur, clayey soils are usually high in sulphur content and produce pungent bulbs. Onions require a high level of nutrients in the soil. Phosphorus is often present in sufficient quantities but may be applied before planting because of its low level of availability in cold soils. Nitrogen and potash can be applied at intervals during the growing season, the last application of nitrogen being at least four weeks before harvesting (Boyhan *et al*, 2007). Since nitrogen is a constituent of chlorophyll, the increase of which with added nitrogen might have resulted in increased synthesis of photosynthates, leading to better vigour. The second major nutrient phosphorous being essential constituent of cellular protein and nucleic acid might have encouraged meristematic activity of plants resulting in increased plant height, number of leaves per plant and leaf area (Black, 1968). The other major nutrient potassium is an activator of enzymes involved in protein and carbohydrate metabolism and plays an important role in the translocation of photosynthates from leaves to bulb. The added potassium might have resulted in increased synthesis and translocation of photosynthates, which were further utilized in building up of new cells leading to better vigour and more number of leaves per plant. Several workers have also reported increased plant height (Singh *et al.*, 1993; Varu *et al.*, 1997; Bagali *et al.*, 2012) and number of leaves per plant (Singh *et al.*, 1993; Varu *et al.*, 1997) with increased levels of nitrogen, phosphorus and potassium.

Also Mohammad and Moazzam, (2012) and Yadav *et al.*, (2003) agreed that significant reduction in bulb yield when nitrogen fertilization is reduced may be because of reduction in size and weight of onion bulb. Subsequently, dry matter yield reduced considerably with the reduction in nitrogen. Contrary, Rumple (2003) also observed that reduction of nitrogen fertilization from 200 to 125 kg/ha does not reduce yield of onion crop.

A research undertaken at Wolaita, Southern Ethiopia to determine the effect of variety, nitrogen and phousphorous fertilization on growth and bulb yield of onion revealed that nitrogen affected positively and significantly ($P < 0.05$) plant height, produced the bulbs of greatest marketable yield and total bulb yield whereas Phosphorous affected positively and significantly ($P < 0.05$) plant height, Harvest index, bulb diameter and bulb dry matter content (Tibebu *et al.*, 2014).

Drip irrigation treatments decrease pH, ESP, EC and exchangeable sodium and increased CEC and organic carbon of the soil as compared to the conventional methods of irrigation (Dubey *et al*, 2003). Findings of Fiuczek, (1976), Bhalarao *et al.*, (2001) and Treder *et al.*, (1997) established that higher doses of NPK and better soil moisture conditions under the drip irrigation/ fertigation systems maintained higher levels of available nutrients in the soil. Petterson *et al.*, (1983) also reported an increased content of magnesium, calcium and sulphur under fertigation and is mainly ascribed to the positive interactions of the nutrients and moisture and also their greater availability due to increased organic inputs. Hasan *et al.*, (2013) reported that the effect of different doses of sulphur was significant on leaf area index at different days after transplanting. Result revealed that leaf area index rapidly increased until 65 days after transplanting and it increased slowly up to 75 days after transplanting followed by a sharp decline because of leaf shedding.

2.5 Irrigation

According to Brouwer *et al.*, (2001), the amount of irrigation water which can be given during one irrigation application is limited. The maximum amount which can be given has to be determined and may be influenced by the soil type, root depth and the irrigation method.

The soil type influences the maximum amount of water which can be stored in the soil per metre depth. Sand can store only a little water. On sandy soils it will thus be necessary to irrigate frequently with a small amount of water. Clay on the other hand has high available water content and for that matter larger amounts can be given, less frequently (Brouwer *et al.*, 2001).

The root depth of a crop also influences the maximum amount of water which can be stored in the root zone. Where the root system of a crop is shallow, little water can be stored in the root zone and frequent but small irrigation application is needed. With deep rooted crops, more water can be stored and as well applied, which can be less frequently. Young plants have shallow roots compared to fully grown plants. Thus, just after planting, the crop needs smaller and more frequent water applications than when it is fully developed. The mode of irrigation also influences the amount of water that infiltrates the soil. Where basin irrigation method is used, more water can be infiltrated during one irrigation application than when furrow irrigation is used. However, with small-scale irrigation it is often the irrigation method which is the most limiting factor when determining the maximum irrigation application (Brouwer *et al.*, 2001).

2.5.1 Irrigation Scheduling

Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation. Proper scheduling is essential for efficient use of water, energy and other production inputs, such as fertilizer. It allows irrigation to be coordinated with other farming activities including cultivation and chemical applications. Among the benefits of proper irrigation scheduling are improved crop yield and quality, water and energy conservation and lower production costs. Irrigation schedules are designed to either fully or partially provide the irrigation (Brouwer *et al.*, 2001).

Climatic data can be used for estimating crop water requirements, and is a handy management tool when it is used in conjunction with scheduling methods. Scheduling irrigation based on crop water use reduces chances of under or over watering. Proper irrigation also minimises leaching of fertilizers beneath the root zone. How much and how often water has to be given depends on the irrigation water requirement of the crop. The irrigation water requirement is however defined as the crop water need minus the effective rainfall. It is usually expressed in mm/day or mm/month (Brouwer *et al.*, 2001).

2.5.2 Crop Water Requirement

The irrigation requirement of a crop is the total amount of water that must be supplied by irrigation to a disease free crop, growing in large field with adequate soil water and fertility, and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977). For a given crop variety, fertility level, and climate there is a well-established linear relation between plant biomass (leaves, stems, roots, grain) and transpiration (Tanner and Sinclair, 1983; Steduto and Albrizio, 2005). More biomass production requires more transpiration because when stomata open, carbon dioxide flows into the leaves for photosynthesis and water flows out. Water outflow is essential for cooling and for creating liquid movement in the plant for transporting nutrients. Stomata close during drought, limiting transpiration, photosynthesis, and production. Different kinds of plants are more water efficient in terms of the ratio between biomass and transpiration (Steduto *et al*, 2007). Crop water requirement is however estimated using the equation;

$$Ecrop = kc.Eref \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where, the specific characteristics of the crop are represented by crop coefficient kc and the metrological conditions by the reference crop evaporation $Eref$. $Ecrop$, refers to the crop water requirement.

FAO (2010) however reported that for optimum yield, onion requires 350 to 550 mm water. The crop coefficient (kc) relating reference evapotranspiration ($Eref$) to water requirement ($Ecrop$) for different development stages after transplanting is, for the initial stage 0.4 – 0.6 (15 to 20 days), the crop development stage 0.7 – 0.8 (25 to 35 days), the mid-season stage 0.95 – 1.1 (25 to 45 days), the late-season stage 0.85 – 0.9 (35 to 45 days) and at harvest 0.75 – 0.85. Swaider *et al.*, (1992), indicated that a crops water requirement may also include water for other purposes, including leaching, frost protection, crop cooling and seed germination. Part of this water can be supplied previously in the growing season, through precipitation and ground water within each of the roots. Water which is not supplied by any of these sources must be applied from irrigation during the growing season. Rooting depth is an important factor affecting the crops water requirements. It determines the depth of the soil profile that roots can utilize as a water source (Swiader *et al.*, 1992). Most of the water applied to meet the water requirement of a crop is used in evaporation and transpiration (Smajstrla *et al.*, 2002).

Scherer *et al.*, (1996) outlined that without enough water, normal plant functions are disturbed and the plant gradually wilts, stops growing and dies. Plants are most susceptible to damage from water deficiency during the vegetative and reproductive stages of growth. Most of the water that enters the plants is actually used in photosynthesis. The rest of the water moves to the leaf surfaces where it transpires to the atmosphere.

2.6 Deficit Irrigation

Irrigation water represents 85% of the water consumption in developing countries and 62% in developed countries (Mark, 2010). Kanber *et al.*, 2007 defines deficit irrigation technique as an optimisation strategy in which the plant is faced with water deficiency at a certain level along with planned or known yield decreases.

Anschutz *et al*, (1997), reports that apart from different water requirements, crops differ in their response to water deficit. According to English, (1990), deficit irrigation requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest. This would enhance accurate application of deficit irrigation. While this inevitably results in plant drought stress and consequently in production loss, deficit irrigation maximises irrigation water productivity, which is the main limiting factor (English, 1990). Zhang and Oweis, (1999), reported that deficit irrigation aims at stabilising yields and at obtaining maximum crop water productivity rather than maximum yields.

Under irrigation, crops ideally do not suffer from water shortages. Irrigation water is applied before the crops suffer drought stress. It may not be possible to apply the irrigation water exactly when it would be best. For instance, in a dry year when the river may not have enough water to irrigate all the fields on time, the farmers may be badly organised and lose too much water at the upstream end of the scheme, thus causing problems downstream. The scheme management may decide to spread the available water over a large area by allowing more farmers to irrigate, although less than the optimal amount (Brouwer *et al.*, 2001).

In such cases of unexpected or sometimes even planned water shortages, it is good to know the crops which suffer most from water shortages and the growth stages during which the various crops suffer most from water shortages. Crops mainly grown for their fresh leaves or fruits are more sensitive to water shortages than those grown for their dry seeds or fruits. As such, other factors such as the economic value of the crops may influence the decision on how best to divide the scarce water (Brouwer *et al.*, 2001). Table 2.2 shows four categories of crops based on the sensitivity of the crops to drought.

Table 2.2: Sensitivity of Various Field Crops to Water Shortages

Sensitivity	**Low**	**Low-medium**	**Medium-high**	**High**
Crops	Cassava	Alfalfa	Beans	Banana
	Cotton	Citrus	Cabbage	Fresh green
	Millet	Grape	Maize	Vegetables
	Pigeon pea	Groundnut	Onion	Paddy rice
	Sorghum	Soybean	Peas	Potato
		Sugar beet	Pepper	Sugarcane
		Sunflower	Tomato	
		Wheat	(Water) melon	

Source: (Brouwer *et al.*, 2001)

From the table, crops like paddy rice, banana, potato and sugarcane are very sensitive to water shortages. This means that if they suffer even little water shortages, their yields will be reduced considerably for which reason such water shortages must be avoided. Millet and sorghum, on the other hand, are only slightly sensitive to drought; they are drought resistant. If the water shortage does not last too long, the effect on the yield will be minimal.

FAO (2013) indicated that for high yield, soil water depletion should not exceed 25 percent of available soil water. When the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Irrigation should be discontinued as the crop approaches maturity to allow the tops to desiccate, and also to prevent a second flush of root growth. Also adequate water supply is essential for a high quality crop. A good bulb yield under irrigation is 35 to 45 ton/ha. The water utilization efficiency for harvested yield for bulbs containing 85 to 90 percent moisture is 8 to 10 kg/m^3. Martin de Santa *et al.* (1994) established that bulb diameter and weight are directly related to amount of water applied. According to Pelter *et al.* (2004), onions are more sensitive to water stress during bulb elongation than they do in the vegetative stage. It has also been established that the most critical growth period of onions to water stress is the bulb formation and development stage (Al-Kaisi and Broner, 2005).

2.7 Crop Water Productivity and Water Use Efficiency

Water productivity is defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits (Steduto *et al.*, 2007). An assessment of the potential for reducing water needs and increasing production and values requires an understanding of basic biological and hydrological crop-water relations. Increasing water productivity can be important pathway for poverty reduction, especially in developing countries, where the variability of water productivity of within and between fields is very high, according to the specific conditions under which the crop are grown (Zward and Bastiaanssen, 2004). Amarasinghe and Sharma (2014) indicated that water productivity can be increased significantly by increasing yield by bridging the gap between actual and maximum yield at present, or by providing additional irrigation or selecting appropriate crop choices in mainly rainfed districts.

Crop water productivity is an essential parameter to assess the performance of irrigated and rainfed agriculture (Wesseling and Feddes, 2006). It can be represented in physical or economic units (Molden *et al.,* 1998). Physical water productivity is defined as the ratio of the mass of agricultural output to the amount of water used, and economic productivity is defined as the value derived per unit of water used. Water productivity is also sometimes measured specifically for crops as crop water productivity and for livestock as livestock water productivity (Steduto *et al.*, 2007). Thus the physical crop water productivity (kg/m^3) is the ratio of crop yield (t/ha) to the amount of water used (m^3/ha). The economic water productivity ($/m^3) relates the economic benefits per unit of water used.

Kijne *et al.*, (2003) expressed Crop water productivity or water use efficiency in kg/m^3 as an efficiency term, thus, expressing the amount of marketable product (e.g. kilograms of grain) in relation to the amount of input needed to produce that output (cubic meters of water). The water used for crop production is referred to as crop evapotranspiration. This is a combination of water lost by evaporation from the soil surface and transpiration by the plant, occurring simultaneously. Except by modeling, distinguishing between the two processes is difficult.

Areas where water resources are restrictive, it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land (Fereres and Soriano, 2007). This is to say, the saved water can be used for other purposes or to irrigate extra units of land (Kipkorir *et al.*, 2001). An experiment conducted by Ganiyu *et al.*, (2012) on water use efficiency and productivity for rice (oryza sativa) in the Bontanga irrigation scheme of northern region of Ghana showed that, 939.9 mm of water was required for its growth, development and maturity. However the average yield of paddy rice was 3.6 tons/ha whiles the average water productivity in the scheme were 0.43 kg/m^3. It was then established that, application of proper irrigation schedule by the management would bring about better water use efficiency for improved rice yield. Abdul-Ganiyu *et al.*, (2012) also reported in a similar experiment that the water productivity of onion crop was 2.19 kg/m^3 with an average crop yield of 11.3 t/ha in the Bontanga irrigation scheme.

Henry *et al.*, (2012) established that the crop water use of onion decreased with increase in irrigation deficit. Regulated deficit irrigation of 20 and 40% deficit saved 19.2 and 41.7% water and resulted in 20 and 32% reduction in yield, respectively as reported by Patel and Rajput (2013). Further report also indicated that in deficit irrigation, 20% water deficit in the growth stages of 2nd, 3rd and 4th saved 2.1, 13.2 and 4.6% of water with 19.8, 18.3 and 11.2% reduction in yield, respectively in comparison to full irrigation water application (Patel and Rajput, 2013). Also in an experiment conducted at Lay Bir farm, in Jabitehnan woreda, West Gojam Zone of Amhara Region with three (full, three-quarter, and half of) irrigation application levels, the variability among the three treatments was not statistically significant (Arega and Tena, 2012). In order to study the effect of different irrigation schedules on yield and water use of onion, a field experiment was conducted on the calcareous chernozem soil in the Institute of Field and Vegetable Crops, Novi Sad in Serbia during 2005, 2006 and 2007 growing seasons where three irrigation treatments according to available soil water depletion (T1 30, T2 50 and T3 70%) and a rainfed treatment (T0) were included. The highest and lowest water use efficiency (WUE) of 91.35 kg and 34.80 kg ha^{-1} mm^{-1} was obtained in irrigation and rainfed conditions in 2007, respectively. The highest irrigation water use efficiency (IWUE) of 280.54 kg ha^{-1} mm^{-1} was obtained from T1 treatment in 2007, while the lowest value of 45.83 kg ha^{-1} mm^{-1} was obtained from T1 treatment during the rainy period of 2005 (Borivoj *et al.*, (2010).

2.8 Crop Water Productivity Models

Improving onion water use efficiency in the Northern Region of Ghana is essential in the light of current irrigation water shortages. Anac *et al.*, (1999), Molden, (2003) and Jin *et al.*, (2014) agreed that well-timed irrigation can substantially improve water use efficiency, providing an optimal growth environment throughout the season. Crop water productivity models are important tools in evaluating the effects of different irrigation regimes on crop yield. The relationship between water and crop yield has been described with both empirical and mechanistic models since the mid-1960s (Jensen, 1968) and (Penning de Vries *et al.*, 1989). Examples include, De Wit, (1970) proposal of the existence of a linear relationship between yield and water consumption whereas, Downey, (1972), suggestion that there exists a nonlinear relationship between water and yield. The above studies however resulted in the development of the Minhas model (Minhas, *et al.*, 1974), Rao model (Rao, *et al.*, 1988), Blank model (Blank, 1975), and the Stewart model (Stewart *et al.*, 1976). Wang and Sun, (2001) however also showed the existence of a quadratic relationship between crop yield and crop water consumption. Following the above work, Kang et al., (2004) proposed a multiple and synergistic model (developed under deficit irrigation conditions). Presently, the simulation of the soil-plant-atmosphere continuum remains an important part of such research, especially with regard to expansion of the application range of resulting models to a wider array of cropping systems (Jin *et al.*, 2014).

The Food and Agricultural Organization (FAO) then developed the AquaCrop model in an effort to meet this need in 2009 which originated from the “yield response to water” data of Doorenbos and Kassam, (1979), and evolved to a normalized crop water productivity concept (Steduto *et al.*, 2009). Comparatively, AquaCrop model is relatively simple to operate, and allows for simulation of crop performance in multiple scenarios, exhibiting a high level of accuracy, this robust model requires a limited set of input parameters, most of which are relatively easy to acquire (Hsiao *et al.*, 2009).

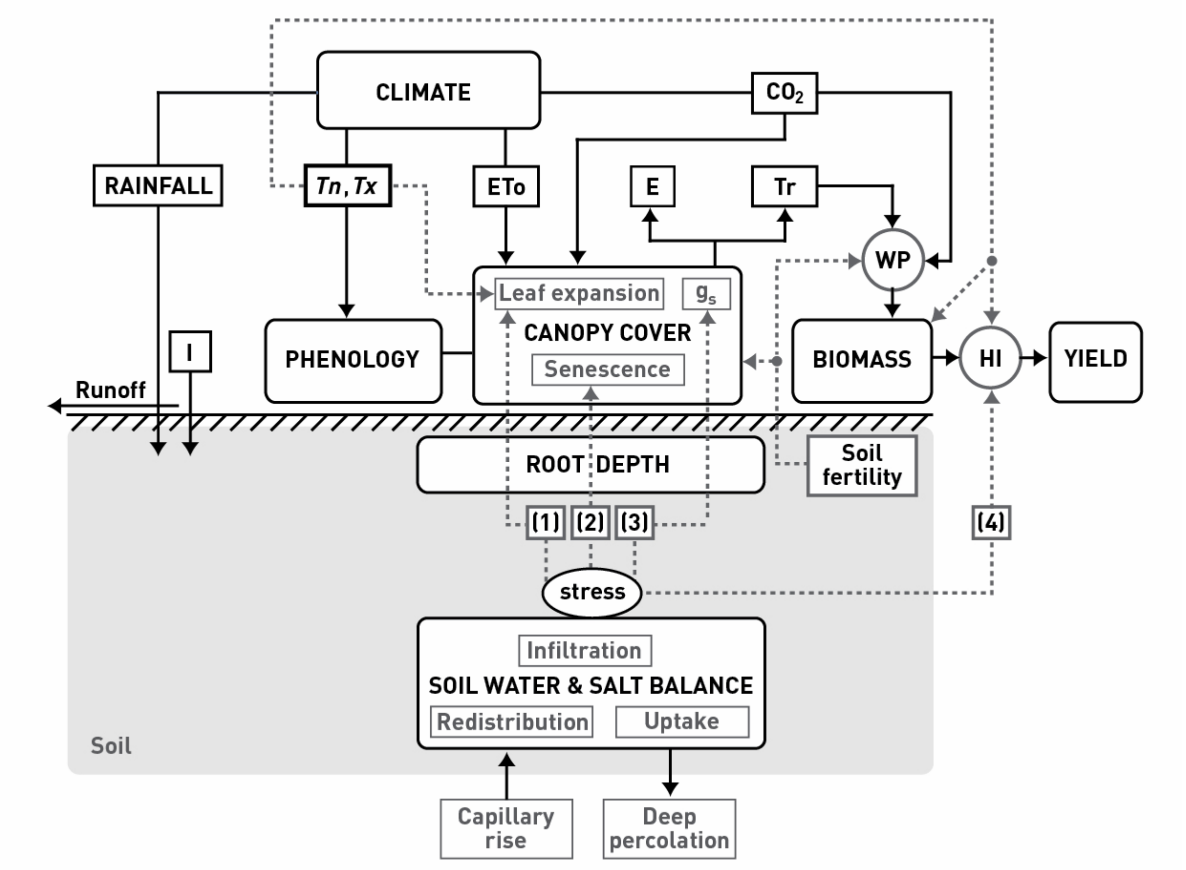
2.9 The AquaCrop Model

AquaCrop model was developed upon reflection by Food and Agriculture Organization (FAO) on the importance of predicting yield response to water and how to cope with the world wide water scarcity. This was carried out in consultation with experts from major scientific and academic institutions, and governmental organizations worldwide. AquaCrop replaces the approach developed by Doorenbos and Kassam (1979) (FAO Irrigation & Drainage Paper no. 33) (Berk *et al.*, 2001), as it is a revised framework that treats separately field crops from tree crops. It separates the evapotranspiration into soil evaporation and crop transpiration and also the final yield into biomass and harvest index. The separation of evapotranspiration into evaporation and transpiration avoids the confounding effect of the non-productive consumptive use of water and is however important especially during incomplete ground cover (Raes *et al.*, 2009). Separation of yield into biomass and harvest index differentiates the basic functional relations between environment and biomass from those between environment and harvest index. The AquaCrop growth engine is therefore given by the Equation 2.2:

$$B = WP.\sum Tr \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

Where; B is the biomass, Tr is the crop transpiration (in mm) and WP is the water productivity parameter (kg of biomass per m^2 and per mm of cumulated water transpired over the time period in which the biomass is produced). These relations are fundamentally different and their use avoids the confounding effects of water stress on biomass and on harvest index.

As indicated by Raes *et al.*, (2009), AquaCrop has a structure that overarches the soil-plant-atmosphere continuum. It includes the soil, with its water balance; the plant, with its development, growth and yield processes; and the atmosphere, with its thermal regime, rainfall, evaporative demand and carbon dioxide concentration. In addition, some management aspects are explicitly considered such as the irrigation and fertility as they will affect the soil water balance, crop development and therefore final yield. Pests, diseases, and weeds are however not considered. The functional relationships between the different model components are depicted in the flow chart (Figure 2.1).



Source: Raes *et al.*, (2009)

Figure 2.1: Flowchart of AquaCrop indicating the main components of the soil-plant-atmosphere continuum.

2.9.1 Simulation with AquaCrop Model

Atmosphere

As illustrated in Figure 2.1, the temperature (T) plays a role in influencing the crop development (phenology); the rainfall and ETo are inputs for water balance of the soil root zone; and the CO_2 concentration of the bulk atmosphere influences the crop growth rate and the water productivity.

Daily maximum and minimum air temperatures (T), daily rainfall, daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo), and the mean annual carbon dioxide concentration in the bulk atmosphere are the climatic variables required to run the AquaCrop model.

Temperature (min and max), rainfall and ETo may be provided at different time scales, thus, daily, 10-day, and monthly data. However, when running, AquaCrop processes the 10-day and monthly records into daily values. The flexibility for different time scales of climatic input variables is required to use AquaCrop in areas of limited climatic data (Raes *et al.*, 2009).

Crop

AquaCrop distinguishes four major crop types on the basis of their harvestable yields: fruit or grain producing crops, root and tuber producing crops, leafy vegetable producing crops and forage crops. Each of these crop types has its own corresponding developmental stages.

Like the parameters for atmosphere, the crop system also has five major components and associated dynamic responses, thus, phenology, aerial canopy, rooting depth, biomass production and harvestable yield. Crop responses to possible water stress, which can occur at any time during the crop cycle, occur through three major feedbacks, thus;

- reduction of the canopy expansion rate (typically during initial growth),

- acceleration of senescence (typically during completed and late growth), and
- closure of stomata (typically during completed growth).

Water stress of particular relevance may also affect the water productivity parameter and the harvest index. The canopy, thus, represents the source for actual transpiration that gets translated in a proportional amount of biomass produced through the water productivity parameter. The harvestable portion of such biomass (yield) is then determined through the harvest index (HI), based on Equation 2.3.

$$Y = B.HI \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

Soil

The soil component of AquaCrop allows up to 5 horizons of different texture composition along the profile. For each texture class, the model associates a few hydraulic characteristics which include the hydraulic conductivity at saturation, and the volumetric water content at saturation, field capacity, and wilting point.

According to Raes *et al.,* (2009), for the soil profile explored by the root system, the model performs a water balance that includes the processes of runoff (through the curve number), infiltration, redistribution or internal drainage, deep percolation, capillary rise, uptake, evaporation, and transpiration. A distinctive feature of the water balance in AquaCrop is the ability to separate soil evaporation from crop transpiration based on a modification of the Ritchie's approach (Ritchie, 1972). The effects of mulches, withered canopy cover, partial wetting by localised irrigation, and the shading of the ground by the canopy are also parameters included in the simulation of evaporation.

Field Management

Fertility level or regime to be adopted during the crop simulation and field-surface practices such as mulching to reduce soil evaporation, or the use of soil bunds to control surface runoff and infiltration are factors considered in this section. Fertility levels are considered include, non-limiting, near-optimal, medium, and poor fertility. These levels influence the water productivity parameter (WP), the canopy growth development and its maximum canopy cover and the rate of decline in green canopy during senescence (Raes *et al.*, 2009).

Irrigation Management

Irrigation management considers options related to rainfed-agriculture with no irrigation, and irrigation for which after selecting the method such as sprinkler, drip, or surface, either by furrow or flood irrigation, a schedule on the basis of depth or timing criteria is defined, or the model automatically generate the scheduling on the basis of fixed interval, fixed depth, or fixed percentage of soil water content criteria where allowed. The irrigation option is particularly suited for simulating the crop response under supplemental or deficit irrigation (Raes *et al.*, 2009).

AquaCrop is a water-driven simulation model that requires a relatively low number of parameters and input data to simulate the yield response to water under supplemental or deficit, of most of the major field and vegetable crops cultivated worldwide. Its parameters are explicit and mostly intuitive and the model maintains sufficient balance between accuracy, simplicity and robustness (Raes *et al.*, 2009).

2.9.2 Application of AquaCrop Model

AquaCrop model may be appled in various areas including:

- assessing water-limited, attainable crop yields at a given geographical location
- as a benchmarking tool, comparing the attainable yields against actual yields of a field, farm, or region, to identify the yield gap and the constraints limiting crop production

- assessing rainfed crop production on the long term
- developing irrigation schedules for maximum production (seasonal strategies and operational decision-making), and for different climate scenarios
- scheduling deficit and supplemental irrigation
- evaluating the impact of fixed delivery irrigation schedules on attainable yields
- simulating crop sequences
- carrying out future climate scenario analyses
- optimizing limited amount of available water (economic, equitability, and sustainability criteria)
- evaluating the impact of low fertility and of water-fertility interactions on yields
- assessing actual water productivity (biological and/or economic) at the field and higher scales, up to regions
- supporting decision making on water allocation and other water policy actions appraising the role of various water-related crop responses in yield determination for ideotype design (FAO, 2013)

2.9.3 Calibration and Validation of AquaCrop Model

Various works have been undertaken to test the performance of AquaCrop for several crops with very satisfactory results. Studies recommend on the model's ability to satisfactorily simulate crop yield and water use efficiency under rainfed conditions, supplementary and deficit irrigation, and on-farm water management strategies. Also in cases of limited input data, the AquaCrop could be a promising model for estimating crop productivity under deficit irrigation conditions (Hussein *et al.*, 2011).

Result reported by Kiptum *et al.*, 2013, showed that AquaCrop model overestimated the biomass of cabbages even as it provided excellent simulation of canopy and yield. 17g/cm^2

and 76% were reported to be the water productivity and harvest index for cabbages respectively in this study.

Also, AquaCrop model was used to determine the effect of three irrigation levels thus, 100, 75 and 50 percent plant water requirement on the performance and water use efficiency of potato in VakilAbad of Jiroft in 2010. The results of the study suggested that the amount of water requirement, behaviour and water use efficiency simulated by AquaCrop model had well adaptation and correlation with field measures (Atefeh and Ali, 2013).

In a tropical humid coastal savanna zone in south-central Ghana (Cape Coast), AquaCrop was calibrated and tested for hot pepper grown under full and deficit irrigation. Four treatments were investigated, thus, 100%, 90%, 80% and 70% crop water requirement. The model was able to simulate the seasonal water requirements to an appreciable degree but could not simulate accurately the yield of hot pepper for all the treatments with the exception of Treatment 90% water requirement which was simulated with the lowest deviation of 4% as reported by Sam-Amoah, (2013). Hamid *et al.*, (2007), indicated that variations in crop water use (ranging from 400 to 900 mm per season) and water stress across the irrigation regimes were adequately captured by the model, which translated to sound predictions of biomass and yield. Also results were particularly promising considering the simplicity of the model and the limited parameterization as indicated. However, parameterized inputs for cotton performed satisfactorily at Tel Hadya, but need to be further tested under a wider range of climate and soil variability.

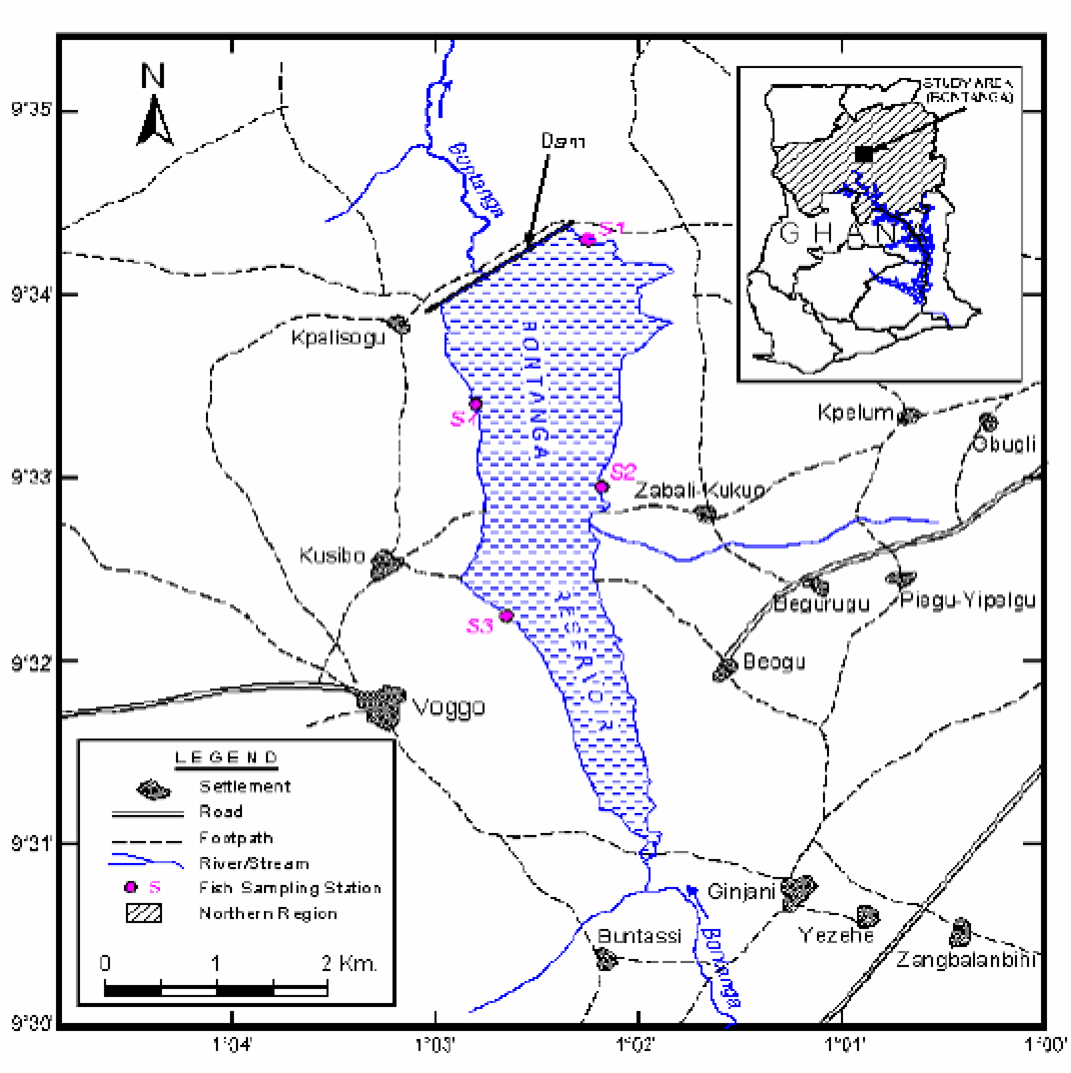
Also in an experiment carried out by Jin *et al.*, (2014), to calibrate, and validate winter wheat crop performance under various planting dates and irrigation application rates using AquaCrop model, which was conducted at the Xiaotangshan experimental site in Beijing, China, during seasons of 2008/2009, 2009/2010, 2010/2011 and 2011/2012, the results showed that the simulated canopy cover, biomass yield and grain yield were consistent with the measured canopy cover, biomass yield and grain yield, with corresponding coefficients of determination (R^2) of 0.93, 0.91 and 0.93, respectively. In addition, relationships between biomass yield, grain yield and transpiration, (R^2 = 0.57 and 0.71, respectively) was observed. These results suggested that frequent irrigation with a small amount of water significantly improved biomass yield and grain yield. In Agricultural Research Institute (ARI) Tarnab, Peshawar, Pakistan, during 2011 however, using onion as a test crop to evaluate its' performance, an experimental field was laid down. Four different irrigation treatments of 100, 80, 60 and 40% of crop water requirements (CWR) were applied on each growth stage. Results indicated that the biomass and yield estimated through AquaCrop model showed overestimation for all irrigation treatments, similarly underestimation was observed for water productivity without any discrimination among full and sever water stress conditions. The performance of the model to estimate biomass, yield and water productivity was not satisfactory, confirmed by performance indicators (Muhammad and Hussain, 2012). Muhammad and Hussain, (2012) further established that the unreliability and differences in results may be due to other factors including crop structure and phenology, rather than climatic, soil and water supply parameters.

CHAPTER THREE

METHODOLOGY

3.1 Study Area

The Bontanga Irrigation Scheme is located in the Northern Region of Ghana, in the Kumbungu district, 34 kilometres northwest of Tamale, the regional capital. It lies between latitude 9° 30” and 9° 35”N and longitude 1° 20”and 1° 04”W.



Source: Abdul-Ganiyu *et al.*, (2012)

Figure 3.1 Map of the Bontanga irrigation scheme

The scheme has a potential area of 800 ha with 495 ha as present irrigable land, of which 240 ha is used for lowland rice cultivation and 255 ha for upland vegetable production such as okra, pepper, onion and maize. The vegetables are produced mainly in the dry season, October to April and rice produced both in the dry and wet seasons. The upland is free draining soil and plots are designed for furrow irrigation while the lowland soil is heavily textured and irrigated by flooding. The system works under gravity from the dam through the canals, laterals and to the various farms. The maximum, life and dead storage of the reservoir are 25 million m^3, 20 million m^3 and 5 million m^3, respectively. Two (2) main canals and twenty eight (28) laterals aid the distribution of water to the farms. Thirteen (13) villages benefit from the dam, including Tibung, Kumbungu, Kpasogu, Dalun, Wuba, Kukuo, Kpong, Saakuba, Yiplegu, Voggu, Kushibo, Zangbalwe and Bagli. Figure 3.2 shows is the layout of the Bontanga Irrigation Scheme.

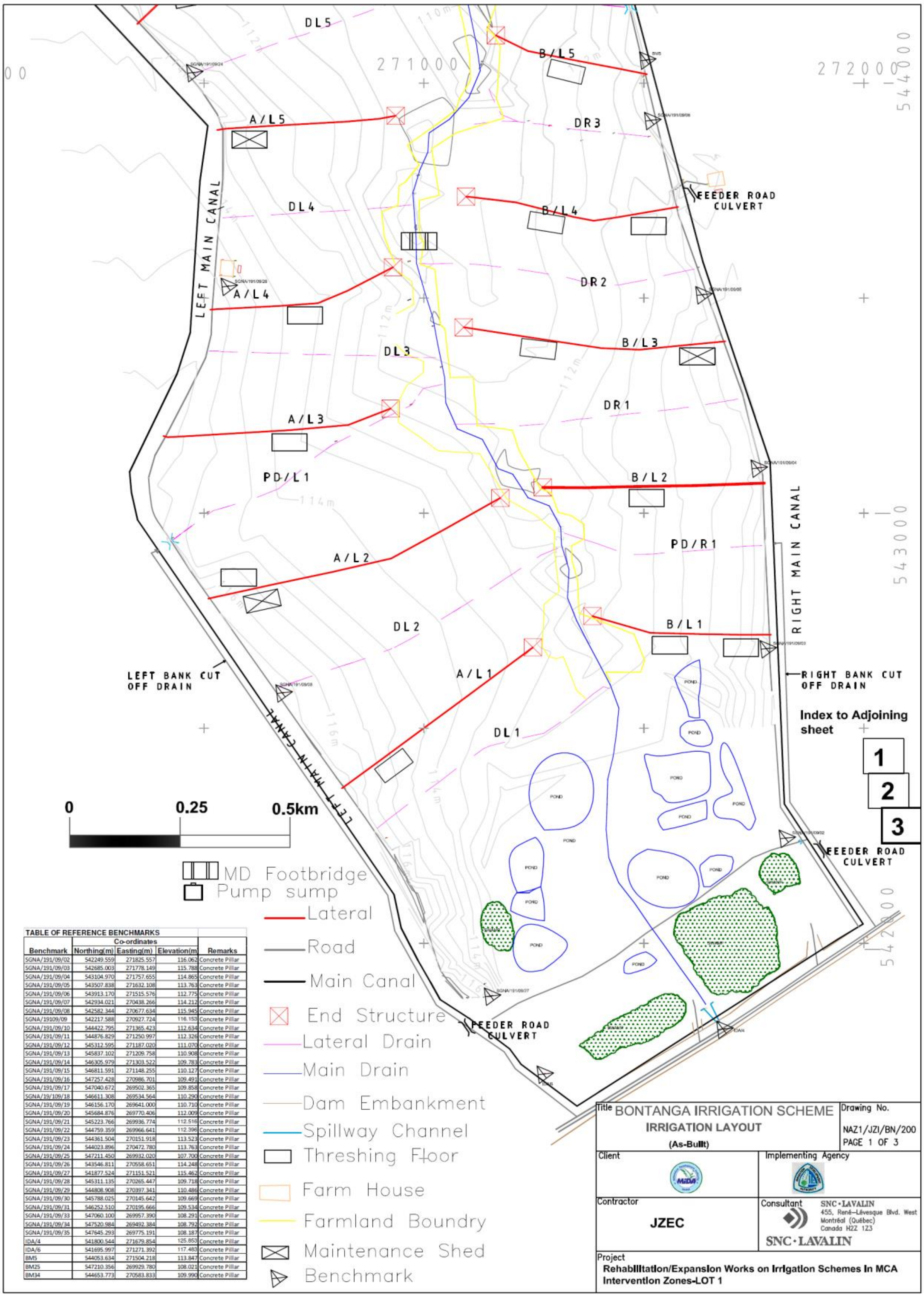


TABLE OF REFERENCE BENCHMARKS

Benchmark	Co-ordinates			Remarks
	Northing(m)	Easting(m)	Elevation(m)	
SGNA/191/09/02	542249.559	271825.557	116.062	Concrete Pillar
SGNA/191/09/03	542685.003	271778.149	115.788	Concrete Pillar
SGNA/191/09/04	543104.970	271757.655	114.865	Concrete Pillar
SGNA/191/09/05	543507.838	271632.108	113.763	Concrete Pillar
SGNA/191/09/06	543913.170	271515.576	112.775	Concrete Pillar
SGNA/191/09/07	542934.021	270438.266	114.212	Concrete Pillar
SGNA/191/09/08	542582.344	270677.634	115.945	Concrete Pillar
SGNA/19109/09	542217.588	270927.724	116.153	Concrete Pillar
SGNA/191/09/10	544422.795	271365.423	112.634	Concrete Pillar
SGNA/191/09/11	544876.829	271250.997	112.326	Concrete Pillar
SGNA/191/09/12	545312.595	271187.020	111.070	Concrete Pillar
SGNA/191/09/13	545837.102	271209.758	110.908	Concrete Pillar
SGNA/191/09/14	546305.979	271303.522	109.783	Concrete Pillar
SGNA/191/09/15	546811.591	271148.255	110.127	Concrete Pillar
SGNA/191/09/16	547257.428	270986.701	109.491	Concrete Pillar
SGNA/191/09/17	547040.672	269502.365	109.858	Concrete Pillar
SGNA/19/109/18	546611.308	269534.564	110.290	Concrete Pillar
SGNA/191/09/19	546156.170	269641.000	110.710	Concrete Pillar
SGNA/191/09/20	545684.876	269770.406	112.009	Concrete Pillar
SGNA/191/09/21	545223.766	269936.774	112.516	Concrete Pillar
SGNA/191/09/22	544759.359	269966.641	112.396	Concrete Pillar
SGNA/191/09/23	544361.504	270151.918	113.523	Concrete Pillar
SGNA/191/09/24	544023.896	270472.780	113.763	Concrete Pillar
SGNA/191/09/25	547211.450	269932.020	107.700	Concrete Pillar
SGNA/191/09/26	543546.811	270558.651	114.248	Concrete Pillar
SGNA/191/09/27	541877.524	271151.521	115.462	Concrete Pillar
SGNA/191/09/28	545311.135	270265.447	109.718	Concrete Pillar
SGNA/191/09/29	544808.908	270397.341	110.486	Concrete Pillar
SGNA/191/09/30	545788.025	270145.642	109.669	Concrete Pillar
SGNA/191/09/31	546252.510	270195.666	109.534	Concrete Pillar
SGNA/191/09/33	547060.100	269957.390	108.291	Concrete Pillar
SGNA/191/09/34	547520.984	269492.384	108.792	Concrete Pillar
SGNA/191/09/35	547645.293	269775.191	108.187	Concrete Pillar
IDA/4	541800.544	271679.854	125.853	Concrete Pillar
IDA/6	541695.997	271271.392	117.483	Concrete Pillar
BM5	544053.634	271504.218	113.847	Concrete Pillar
BM25	547210.356	269929.780	108.021	Concrete Pillar
BM34	544653.773	270583.833	109.990	Concrete Pillar

Title BONTANGA IRRIGATION SCHEME
IRRIGATION LAYOUT
(As-Built)

Drawing No.
NAZ1/JZI/BN/200
PAGE 1 OF 3

Client

Implementing Agency

Contractor
JZEC

Consultant
SNC·LAVALIN
455, René–Lévesque Blvd. West
Montréal (Québec)
Canada H2Z 1Z3
SNC·LAVALIN

Project
Rehabilitation/Expansion Works on Irrigation Schemes In MCA Intervention Zones-LOT 1

Figure 3.2 Layout of the Bontanga Irrigation Scheme

(Bontanga Irrigation Scheme, 2014)

A global positioning system (GPS) was used to take the coordinates of the study area and a map was extracted from the Google earth. Table 3.1 shows the GPS coordinates of various locations in the study area. Figure 3.3 and 3.4 show maps of the experimental unit.

Table 3.1: GPS Coordinates of the Study Area

Location	Latitude (W)	Longitude (N)	Altitude (m)
Dam wall	1°01'42.92"	9°33'59.11"	122.2248
	1°01'23.52"	9°34'12.39"	121.0056
	1°01'08.47"	9°34'22.74"	123.1392
Lateral 5	1°01'21.75"	9°34'33.36"	117.348
	1°01'31.38"	9°35'23.45"	113.6904
Canal	1°01'31.90"	9°35'23.56"	113.9952
	1°01'32.90"	9°35'23.75"	113.9952
Experimental Plot	1°01'31.52"	9°35'19.77"	115.2144
Plot Demarcations			
Point A	1°01'31.90"	9°35'20.37"	115.2144
Point B	1°01'31.23"	9°35'20.43"	115.2144
Point C	1°01'31.12"	9°35'19.24"	115.5192
Point D	1°01'31.77"	9°35'19.18"	115.2144

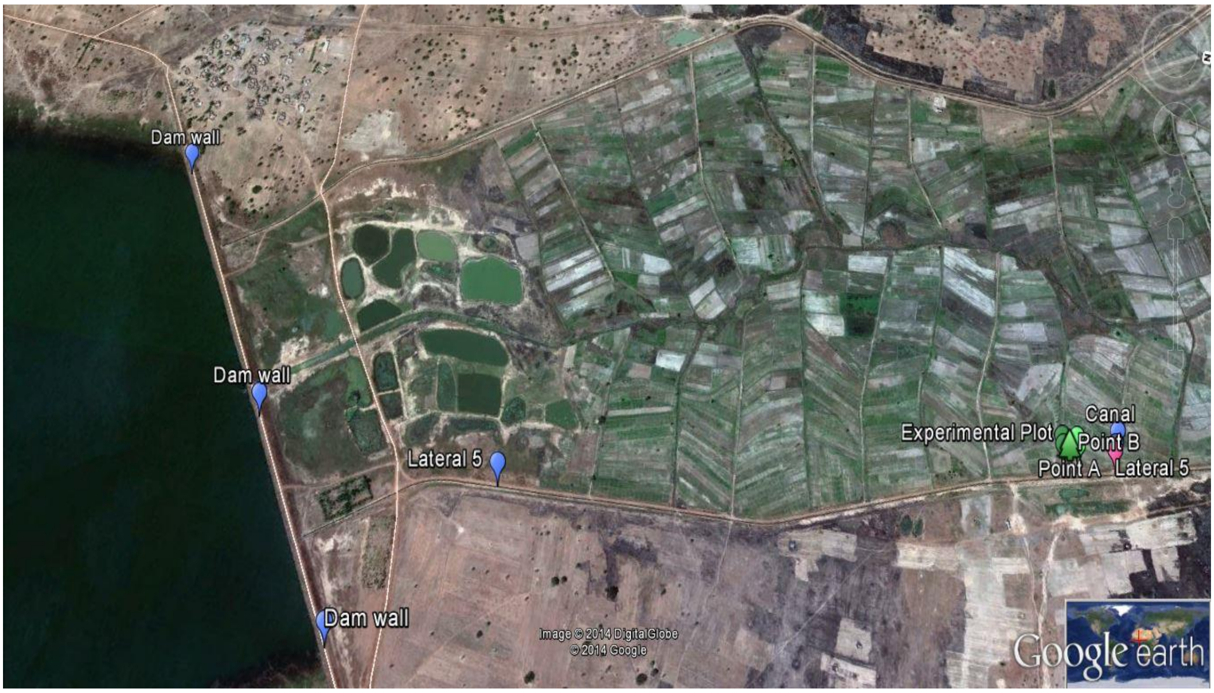


Figure 3.3: A Google Earth Map of the Bontanga Irrigation Scheme

(Google Earth, 2010)

Figure 3.4: A Google Earth Map of the Experimental Plot

(Google Earth, 2010)

3.2 Materials

Data was collected using electronic balance, oven, measuring rule, soil core sampler and soil moisture meter.

3.2.1 Cultural Practices

Weeding, ploughing and bed laying were under taken to prepare the cropping field. Pre-emergence weedicide (active ingredient; 500g/Lt Pendimethalin) was then sprayed on the field. After land preparation, onion seedlings were transplanted 42 days after nursing on the field. Transplanting was then done at crop spacing of 20 cm × 15 cm, resulting in a crop density of 160 plants per plot. A total of 450 kg/ha NPK (15:15:15) fertilizer was applied by split application at two weeks and twelve weeks after transplanting. Hoes were used to control weed growth during the crop growth. Insecticide (active ingredient; emamectin benzoate) and fungicide (active ingredient; 80% w/w mangozeb) were also sprayed across the field at two and eight weeks after transplanting. After transplanting, 117%, 100%, 80% and 60% of the water required by crops (ETc) was applied as treatments for 95 days duration. Water application was done in the morning.

3.2.3 Experimental Design

The experiment was arranged in a Randomised Complete Block Design (RCBD) with four treatments in five replicate blocks. The treatments included 117% (practice by farmers), 100%, 80%, and 60% of ETc irrigation regimes on a total land area of 226.2 m^2. The plot area of 6 m^2, thus (1.2 m × 5 m) and a block size of 7.8 m^2 was used. Both row and block spacing were 1 m.

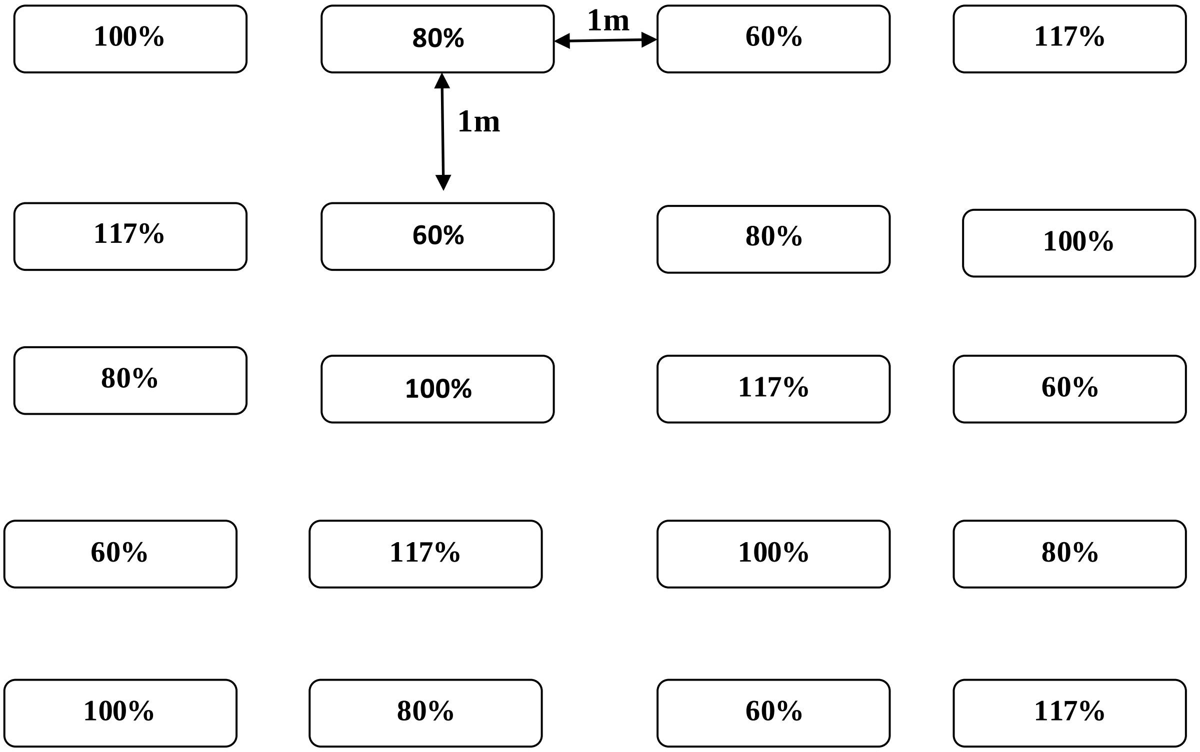


Figure 3.5 Layout of experiment at Bontanga Irrigation Scheme

3.3 Data Collection

Primary data were collected from observations and measurements on the farmland. Semi-structured questionnaires were administered to the management of the Bontanga Irrigation Scheme.

3.3.1 Climatic data

Climatic records, consisting of monthly averages of minimum and maximum temperature, relative humidity, sunshine, wind speed, rainfall and geographic coordinates (altitude, latitude, longitude) for the period of 1976–2012 were obtained from Ghana Meteorological Services.

3.3.2 Soil data

Soil samples were randomly taken from the upper, middle and lower portion of the experimental plot before planting and after harvest from the experimental field. They were taken from each block before planting and again from each plot after harvesting. Soil samples were taken using soil auger at a depth of 0-15cm. A total of twenty five (25) soil samples were collected and air dried. Soil aggregates were crushed in a mortar and sieved with a 2 mm sieve. The following soil parameters were then analysed for in the Savannah Agricultural Research Institute laboratory.

Soil pH

A 10 g of air- dried soil was weighed into a 100 ml beaker to which 25ml of distilled water was added. The resulting soil-water suspension was then stirred vigorously for the next 20 minutes and allowed to stand for 30 minutes, by which time most of the suspended clay had settled out from the suspension. A pH meter was calibrated with blank at pH of 4 and 7 respectively. The electrode of the pH meter was inserted into the partly settled suspension and pH value was recorded (IITA, 1982). This process was repeated for each sample.

Nitrogen (N)

The total Nitrogen N was analysed using micro Kjeldahl method (Novozamsky *et al.*, 1983). A 0.5 g of air dried soil was weighed into a 100ml long – necked kjeldahl flask. A 3 ml of digestion mixture, made up of (3.5 g selenium powder, 72 g salicylic acid in 1L H_2SO_4). A 1 × 2 ml of hydrogen peroxide was added and placed on a block digester pre-heated to 320°C. After sample was clear (2 hrs), it was cooled and topped up to 100 m. After which it was left to settle overnight. An aliquot of 10 ml of digest was transferred into the kjeldahl distillation flask and placed in the vapodest, to which 20 ml of 40 % NaOH was added. The vapodest was programmed to run for 5 minutes. The distillate was collected of over a 10 ml 4% Boric acid in a mixed indicator of bromocrystal green and methyl red. A light blue colour indicated the presence of nitrogen. The distillate was titrated with 0.1 N HCl till blue colour changed to grey and suddenly flashed to pink. A blank determination was however carried out without the soil sample. Nitrogen content was then calculated as;

Weight of N in the soil $= 14 \times (A - B) \times N$ .... (3.0)

Where; 14 g of N contained in one equivalent weight of NH_3, A is the volume of standard HCl used in the sample titration, B is the volume of standard HCl used in the blank titration and N is the normality of standard HCl. However, weight of soil sample used considering the dilution and the aliquot taken for distillation

Thus, the percentage of nitrogen in the soil sample is;

$N\% = 14 \times (A - B) \times N$ .... (3.1)

- **Phosphorus (P)**

To determine phosphorus content of soil, 5.0 g of the air dried soil samples were weighed into a 50 ml shaking bottle. A 35 ml of Bray P1 extracting solution (Extractant) was added and was shook on a mechanical shaker for 10 minute. Using a whatman (42) filter paper, the solution was then filtered into a 100 ml conical flask. A 10 ml of the filtrate was then pipette into a 25 ml volumetric flask. A 3 ml of molybdate reagent was added followed by 1.0 ml of the dilute reducing agent (ascorbic acid). Solution then developed a blue colour, and distilled water was added to make up 25 ml. The solution was again shook vigorously and allowed to stand for 15 minutes. The percent transmission at 600 nm wavelength was measured on a colorimeter or UV-Spectrophotometer and recorded. Percentage transmittance (% T) values were converted to 2 – Log T. Using P standard solutions to obtain actual concentration of P, a graph was plotted. The concentration of P in the % T or 2 – Log T (Absorbance) extract is obtained by comparing the results with a standard curve plotted (Bray and Kurtz, 1945).

Exchangeable Cations (Potassium (K), Calcium (Ca) and Magnesium (Mg))

To determine the exchangeable cation content, 5 g of air dried soil sample was weighed into a shaking bottle. A 50 ml ammonium acetate solution was then added and shook for 5 minutes. Solution was then filtered through no. 42 Whatman filter paper. Determination of the concentration of potassium in the soil extract was done using the flame photometer (Toth and Prince, 1949). Calcium and Magnesium were also determined from the soil extract, using the Atomic Absorption Spectrophotometer (AAS).

Organic Carbon (OC)

To determine the organic carbon content, 0.5 g of soil sample was weighed into a 500 ml Erlenmeyer flask. Exactly 10 ml of 1.0 N Potassium dichromate solution was then added from a burette, followed by 20 ml of concentrated H_2SO_4. The mixture was then swirled ensuring that the solution was in contact with all the particles of the soil. The flask and content was then allowed to cool on an asbestos sheet for 30 minutes. A 100 ml distilled water was added, followed by 5 ml orthophosphoric acid. It was left to cool after which 5 ml of diphenylamine indicator was also added. Titration was done with 5N ferrous sulphate solution until the colour changed to blue and then to a green endpoint. The titre values were then recorded. A sample blank was also determined in a similar manner and the endpoint determined (> 10.5).

Percentage organic carbon was calculated as;

$$\frac{S\,(B-T)\times 0.39}{weight\ of\ sample}\times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where; S refers to molarity of ferrous sulphate, B is the titre value for blank and T is the titre value for the sample (Nelson and Sommers, 1996).

Cation Exchange Capacity (CEC)

To determine the cation exchangeable capacity, 5 g of each soil sample was weighed and transferred into a 50-ml centrifuge tube. 25 ml of 1.0 M sodium acetate solution was added to the tube. A stopper was then inserted and shook in a mechanical shaker for 5 minutes. It was then placed in a centrifuge at 2000 rpm for 5 minutes, thus till the supernatant liquid was clear. Liquid was then decanted completely and extraction was repeated for three more times. Decant was discarded. While repeating the process, ethanol was added before shaking in the mechanical shaker. This was done till the electrical conductivity (EC) of the decant read less than 40 ms/cm. To displace adsorbed sodium (Na), ammonium acetate solution was added before shaking in a shaking machine. Decant was collected in a 100 ml volumetric flask fitted with a funnel and filter paper. Ammonium acetate solution was added to make up the volume. Series of sodium standard solutions were prepared in the range of 0 – 10 me/liter of sodium. This was in order to determine sodium concentration by flame photometry. A standard curve with Na concentration on the x-axis and flamephotometric reading on the y-axis was also prepared. An unknown sample extract was then fed onto the flamephotometer for which reading was taken corresponding to which the concentration of sodium is read from the standard curve. Lithium chloride (LiCl) was added in each standard to yield a final concentration of about 5 me/liter of LiCl. Cation exchangeable capacity of the soil was then measured as the displaced sodium. Therefore the milli equivalent Na/100 g soil actually referred to the milli equivalent exchangeable cation (Ca, Mg, Na and K)/100 g soil.

Soil Moisture Content

Using a digital soil moisture meter, soil moisture content was determined and recorded for various treatment at 4, 6, 8 and 10 weeks after transplanting, after an initial soil moisture content was taken. Each plot was divided into three sections and data was taken within each section. The resultant average on each plot was then recorded as the moisture content for the plot.

3.3.3 Agronomic data

Leaf Length

Each plot was divided into four sections, out of which one onion plant was randomly selected, making four plants in total in each plot. Selected plants were then tagged within each plot. The leaf length was taken 2, 4, 6, 8, 10 weeks after transplanting (WAT). Leaf length was taken by measuring the height from the level of the stem to the tip. For each plant, an average leaf length was estimated for the bottom, middle and top leaf in each experimental unit.

Number of Leaves per Plant

Number of leaves per plants were taken by counting all leaves on each tagged plant in each experimental unit. The number of leaves per plant was taken 2, 4, 6, 8, 10 weeks after transplanting (WAT).

Leaf Area Index

To estimate leaf area index, leaf area was first determined, on the tagged sample of four plants per plot : during 2, 4, 6, 8 and 10 weeks after transplanting, the leaf length (l) and the maximum width (w) of each leaf blade were measured and leaf areas (LA) were estimated from these measurements, considering leaf shape as a cone.

Thus;

$$\pi r^2 + \pi rl = LA \quad \ldots\ldots (3.3)$$

Where; LA is the leaf area; l is the height or length; r is the radius and π is pie (22/7) (Tei *et al.*, 1996).

Leaf area index (LAI) was then calculated for each plot using the Equation 3.4;

$$LAI = \frac{(LA_m.N)}{A} \qquad (3.4)$$

Where; LA_m is the average or mean leaf area; N is the average number of leaves and A is the area occupied by plant (Allen *et al.,* 1998).

Canopy Cover

Canopy cover (CC) for each plot was estimated using the Equation 3.5;

$$CC = \frac{LAm.N}{A} \times 100 \qquad (3.5)$$

With all terms same as for Equation 3.4.

Above Ground and Bulb Biomass

A 1m^2 area of plants was uprooted from each plot randomly. Leaves together with onion stem from individual plots were weighed distinctively to estimate the above ground biomass. To estimate the leaf biomass, leaves from individual plots was harvested labelled, put into paper bags, and the fresh weights of each taken as leaf biomass. It was then oven dried at 80^{0}C for 48 hours, after which the dry weights were taken. The total dry leaf biomass under each treatment was then estimated.

To estimate the bulb biomass, bulbs from individual plots were put in paper bags distinctively after which fresh weights of each were taken as bulb biomass and labelled. Samples were then oven dried at 80^0C for 48 hours, after which the dry weights were taken. The total dry bulb biomass under each treatment was then estimated.

Total biomass was then estimated as;

$$Total\quad Biomass = Bulb\quad Biomass + Above\quad Ground\quad Biomass \qquad (3.6)$$

Onion Yield Harvest Index (HI)

Yield was estimated by harvesting crops on each plot distinctively and weighing them separately. The harvest index was estimated using the equation;

$$HI = \frac{Yield(t/ha)}{Biomass(t/ha)} \times 100 \qquad (3.7)$$

3.4 Evapotranspiration Water Productivity Crop Water Productivity and Economic Water Productivity

The CROPWAT 8.0 software was used to calculate crop water requirements (maximum evapotranspiration – ETM), effective rainfall, reference evapotranspiration (ETo), and irrigation needs of crops. Table 3.2 presents the crop water requirement for onion which was calculated using CROPWAT model. Appendix A11 also shows the average irrigation water used per plot during the experiment.

Table 3.2: Crop Water Requirement for Onion at Bontanga Irrigation Scheme

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Feb	1	Initial	0.7	2.66	16	1.3	14.9
Feb	2	Initial	0.7	2.7	27	2.8	24.2
Feb	3	Development	0.71	2.77	22.2	5.2	16.9
Mar	1	Development	0.75	2.99	29.9	7.3	22.6
Mar	2	Development	0.81	3.26	32.6	9.4	23.2
Mar	3	Development	0.86	3.5	38.5	13.9	24.7
Apr	1	Development	0.92	3.75	37.5	19.1	18.4
Apr	2	Mid	0.94	3.87	38.7	23.5	15.1
Apr	3	Mid	0.94	3.73	37.3	26	11.2
May	1	Late	0.94	3.57	35.7	28.5	7.2
					315.4	137	178.7

(Field survey, 2014)

The evapotranspiration water productivity was estimated based on Equation 3.8 (Molden, 1997; Ahmad *et al*., 2004):

$$ETWP(kg/m^3) = \frac{Y}{ETact} \quad \ldots\ldots (3.8)$$

Where; $ETWP$ is the evapotranspiration water productivity (kg/m^3), Y is the actual yield (kg/ha) and $ETact$ is the actual evapotranspiration (m^3/ha).

Crop water productivity (CWP) was calculated using Equation 3.9 as follows:

$$CWP(kg/m^3) = \frac{Yield(kg/ha)}{TWU(m^3/ha)} \quad \ldots\ldots (3.9)$$

Where; TWU is total water used (m^3/ha) from planting to harvest (Steduto *et al.*, 2007).

Economic water productivity (EWP) was calculated using Equation 3.10 as follows:

$$EWP = \frac{Value}{TWU} \quad \text{...} \quad (3.10)$$

Where; TWU (\$/m^3) is total water used (m^3) from planting to harvest and value (\$) is the total cost of crops harvested (Steduto *et al.*, 2007).

3.5 Calibration and Validation of AquaCrop model

AquaCrop model simulation was done using climatic data, thus, daily maximum and minimum air temperatures (T), daily rainfall and daily evaporative demand of the atmosphere expressed as reference evapotranspiration (ETo) acquired from the Ghana Meteorological Services and a default mean annual carbon dioxide concentration for the climatic file. To create the crop file, type of crop was selected; AquaCrop was then used to generate the complete set of required crop parameters. Four growth stages were considered, namely: the initial stage, the development stage, the mid-season stage, and the late season stage. Irrigation files were also created for each of the treatments in the experiment. With this, the time and the application depth of the irrigation events were specified. Soil file was created out of the type of soil (soil texture), depth of soil and other few parameters. Estimated and conservative parameters used are as given in Appendix A9 and Appendix A10. Crop yield, crop biomass and evapotranspiration water productivity were generated for each treatment and validated by comparing actual results to the AquaCrop modelled results.

3.6 Data Analysis

Agronomic and soil data collected on various parameters were entered into Microsoft excel spreadsheet for treatment mean and statistically analysed using analysis of variance

(ANOVA) with GenStat 12.1. Least significant difference (LSD) of $p \leq 0.05$ was used to separate means.

The model performance was then assessed using statistical tools such as correlation and regression (R^2), standard deviation, Nash-Sutcliffe model efficiency (E) by Nash and Sutcliffe (1970), expressed using Equation 3.11 – 3.13,

$$E = 1 - \frac{\sum_{i=1}^{n} (s_i - o_i)^2}{\sum_{i=1}^{n} \left(o_i - \overline{o}\right)^2} \quad \ldots\ldots (3.11)$$

Root Mean Square Error (RMSE) expressed as,

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (s_i - o_i)^2}{n}} \quad \ldots\ldots (3.12)$$

and the Index of Agreement (d) by Willmot (1981, 1982) also expressed as

$$d = 1 - \frac{\sum_{i=1}^{n} (o_i - s_i)^2}{\sum_{i=1}^{n} \left(\left(o_i - \overline{o}\right) + \left(s_i - \overline{o}\right)\right)^2} \quad \ldots\ldots (3.13)$$

Where s_i and o_i are predicted, and observed data, respectively with, $\overline{o}$ is the mean value of O_i, and n is the number of observations.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the effect of different irrigation regimes on soil moisture content and soil chemical properties. It also discusses the yield results of onion, obtained under the various irrigation regimes (thus, 117%, 100%, 80% and 60% of ETc irrigation regimes). Correlation analysis is done between soil moisture content, soil chemical properties and crop yield. Furthermore, crop and economic water productivity of the various irrigation regimes are discussed. Results from calibration of AquaCrop model are compared to observed data to assess the performance of the AquaCrop model.

4.2 Effects of Different Irrigation Regimes on Soil Properties (Nutrients)

4.2.1 Effects of Different Irrigation Regimes on Soil Moisture Content

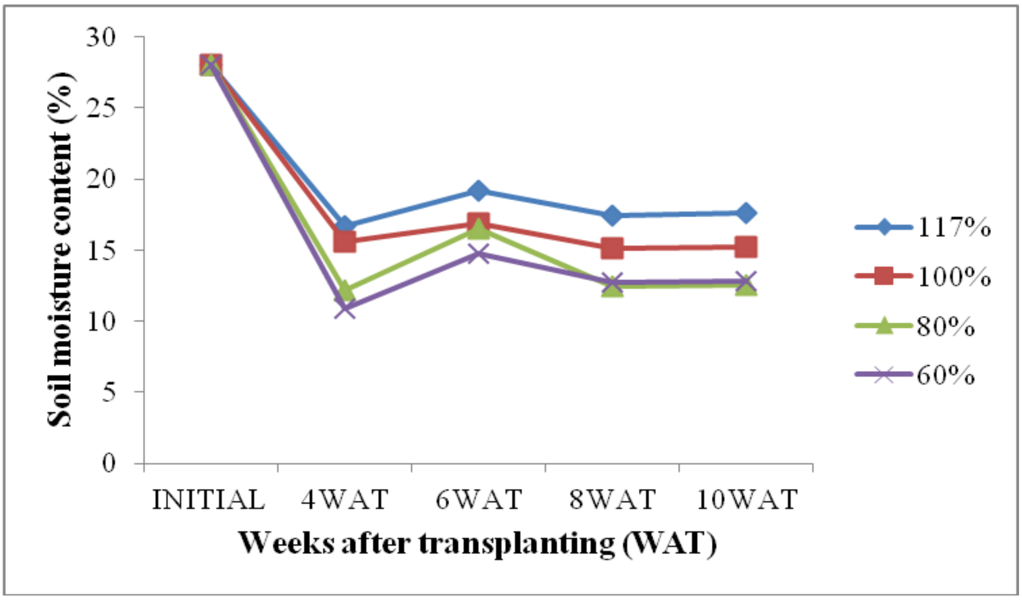


Figure 4.1: Soil moisture content as affected by different irrigation regimes (Field survey, 2014)

Soil moisture content as influenced by different irrigation regimes is represented in Figure 4.1. There were significant differences between the soil moisture content at different weeks after transplanting for the various treatments. Soil moisture content reduced from the initial soil moisture content (28%) with respect to all irrigation regimes. Irrigation regime of 117% had the highest mean soil moisture content of 19.78%, whereas 60% irrigation regime recorded the least 15.83%. According to FAO (2013), onion, like most vegetable crops, is sensitive to water deficit and for high yield, soil water depletion should not exceed 25 percent of available soil water. When the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. From the results, soil moisture content of all the irrigation regimes was in line with findings of FAO, (2013).

4.2.2 Effects of Different Irrigation Regimes on Soil pH

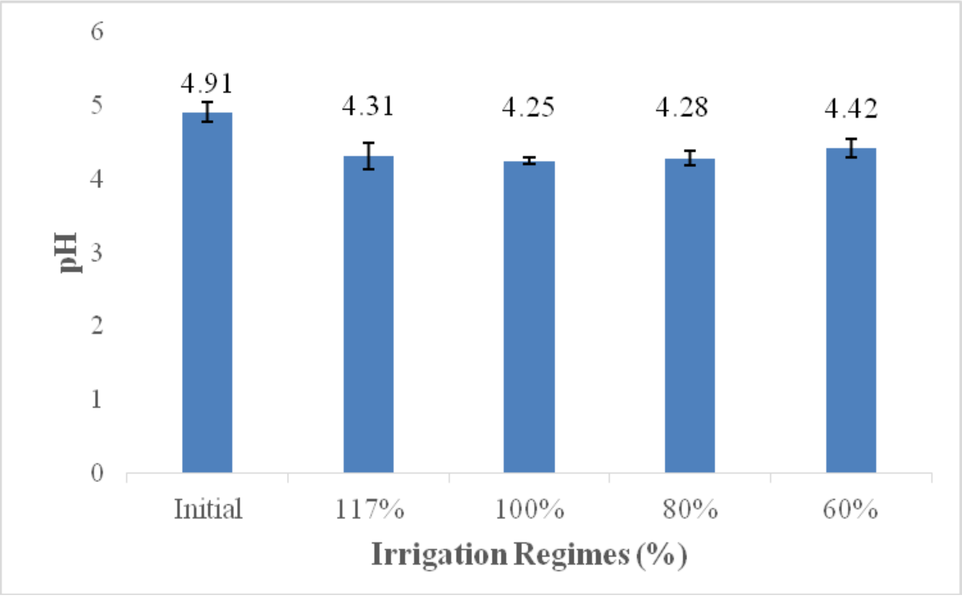


Figure 4.2: Soil pH as affected by different irrigation regimes

(Field survey, 2014)

The average soil pH as recorded before treatment application was 4.91. There was no significant difference among treatments. There was a decline in soil pH level to a range of 4.3 – 4.4 lower than range in northern Ghana (4.5-6.7) as reported by MoFA (2010) as a result of different irrigation regimes (Figure 4.2). FAO (1976) classified tropical soil pH ranging from 4.5-5.5 and 7.5-7.8 as a medium and that ranging from 4.0-4.5 as low. FAO (2013) and Raemaekers, (2001), established that onion has average tolerance to soil acidity ranging from 6 to 7. The increase soil acidity due to the treatment may affect onion yield. It is then evident that soil pH is affected by irrigation.

4.2.3 Effects of Different Irrigation Regimes on Soil Nitrogen, Phosphorus and Potassium Content

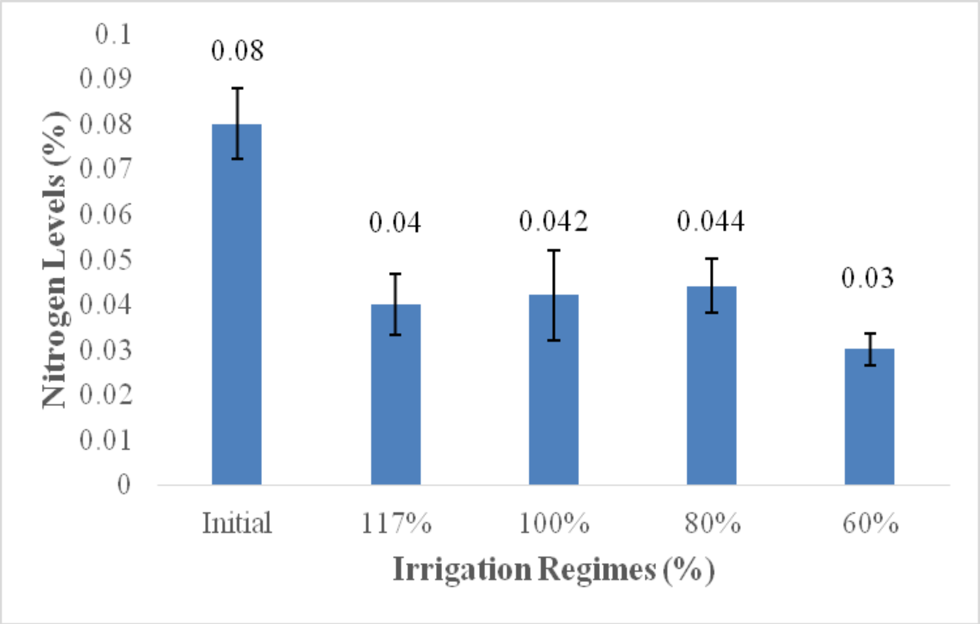


Figure 4.3: Soil nitrogen content as affected by different irrigation regimes (Field survey, 2014)

The average Nitrogen content of the soil recorded before treatment application was 0.08%. After application of irrigation treatments, there was a significant decrease between each treatment and the initial value. Irrigation treatments recorded soil nitrogen contents ranging from 0.030 – 0.044%, as illustrated in Figure 4.3. Irrigation regime of 60% recorded the least soil nitrogen content of 0.030%, whereas 0.044% was recorded by the irrigation regime of 80% as the highest nitrogen content among treatments.

The average initial Potassium and Phosphorus content of the soil were, 81.6 ppm and 10.3 ppm respectively. There was an increase in both soil nutrient parameters after treatment application. There was a significant increase in soil Potassium content between initial and after irrigation regimes of 60 and 117%. Soil Phosphorus content also increased significantly between initial and after the irrigation regime of 117%. Irrigation regimes of 117% and 80% recorded 20.5 ppm and 14.8 ppm, respectively as the highest and least soil Phosphorus content. Also, irrigation regimes of 117% and 80% recorded 160.0 ppm and 122.5 ppm, respectively as the highest and least soil Potassium content. These are indicated in Table 4.1.

Table 4.1 Soil Potassium and Phosphorus content as affected by different irrigation regimes

Parameters	**Treatments**					**Grand Mean**	**LSD**	**CV (%)**	**F.Pr Values**
	Initial	**117%**	**100%**	**80%**	**60%**				
K(ppm)	81.6	144.0	122.5	154.0	160.0	132.4	65.89	37.7	0.129
Bray1 P(ppm)	10.3	16.0	14.8	17.2	20.5	15.8	9.15	44.0	0.263

(Field survey, 2014)

According to Metson (1961), the tropical soil nitrogen content of less than 0.1 is very low. FAO (1976), also classified tropical soil Phosphorus content greater than 10 mg/kg as high and Potassium content also greater than 0.4 as Cmol/kg as high. By these standards, the soil Nitrogen content is very low whereas that of Phosphorus and Potassium are both high. They as well fall within the range recorded by MoFA (2010) (Nitrogen = 0.02-0.05% and Phosphorus = 2.5-10 mg/kg) for the Northern Region of Ghana. According to Shakoor *et al.*, (2012), Fiuczek (1976), Bhalarao *et al.*, (2001) and Treder *et al.*, (1997) higher doses of NPK and better soil moisture conditions under the drip irrigation/ fertigation systems maintained higher levels of available nutrients in the soil. Results are in line with these findings in exception of soil nitrogen content which is contrary to the findings.

4.2.4 Effects of Different Irrigation Regimes on Soil Organic Carbon

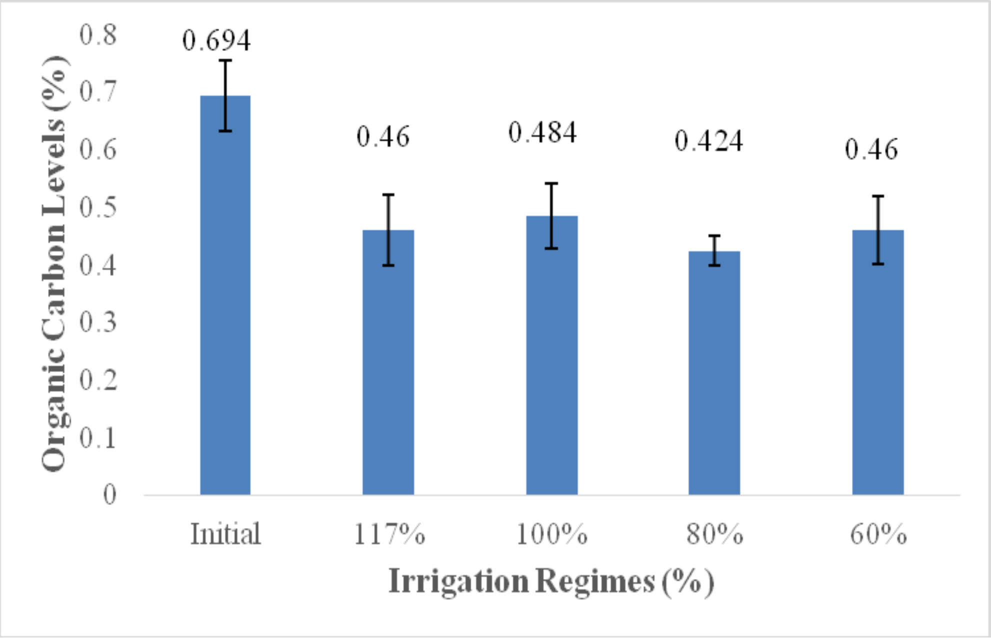


Figure 4.4: Soil organic carbon content as affected by different irrigation regimes (Field survey, 2014)

The results of soil organic carbon content as influenced by the different irrigation regimes are presented in Figure 4.4. The organic carbon content of the soil as recorded before treatment application was 0.694%. However, after application of treatments, there was a significant decrease in soil organic carbon content with respect to the initial organic carbon content of soil. There was no significant difference among treatments. As such, organic carbon content ranged from 0.484% being the highest mean recorded by 100% irrigation treatment to 0.424%, also being the least mean recorded by 80% irrigation treatment. By FAO (1976), standards, the soil organic carbon content recorded was very low (< 2%) with respect to tropical soils for crop production. Abu and Malgwi (2014), also reported that the application of water depths of 85 % TAW and 8 days frequency significantly enhanced soil organic carbon (OC) content, and consequently, promoted macroaggregate stability measured by mean weight diameter and microaggregate stability measured by aggregating silt and clay and clay flocculation index as well as infiltration rate.

4.2.5 Effects of Different Irrigation Regimes on Soil Magnesium, Calcium and Cation Exchange Capacity

The results of soil magnesium content as influenced by the different irrigation regimes are presented in Figure 4.5. Initial soil magnesium content was 36 ppm. After application of the various irrigation treatments, there was a significant increase in soil magnesium content. As such, magnesium content ranged from 222 ppm being the highest recorded by 100% irrigation treatment to 167 ppm, also being the least recorded by 80% irrigation treatment.

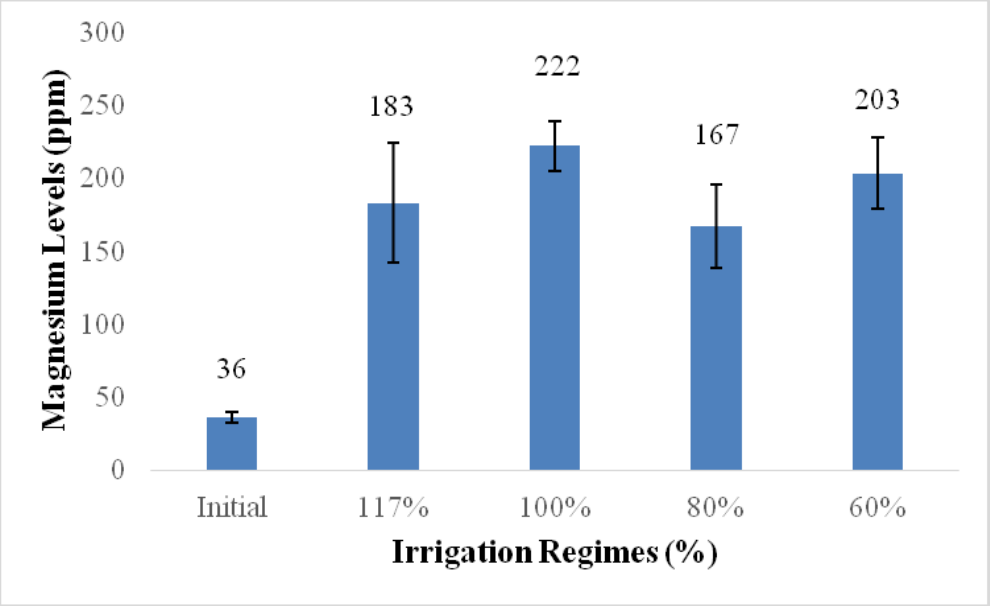


Figure 4.5: Soil magnesium content as affected by different irrigation regimes (Field survey, 2014)

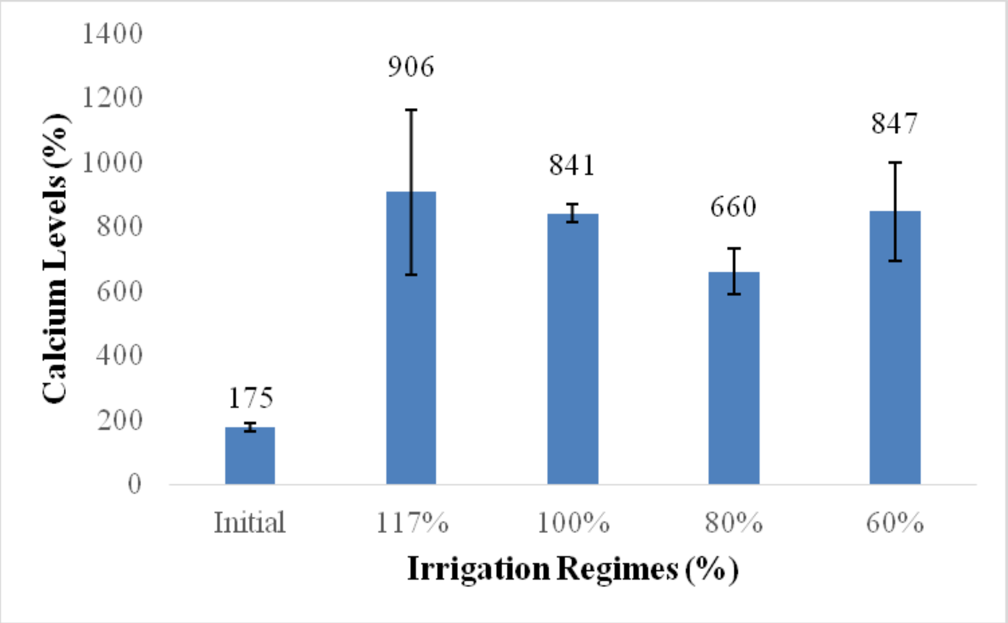


Figure 4.6: Soil calcium content as affected by different irrigation regimes (Field survey, 2014)

The results of calcium content of the soil as influenced by the different irrigation regimes are presented in Figure 4.6. Calcium content of soil as recorded before treatment application was 175 ppm. However, after application of treatments, there was a significant increase in soil calcium content with respect to the initial calcium content of the soil. There was no significant difference among treatments. As such, calcium content ranged from 906 ppm being the highest mean recorded by 117% irrigation treatment to 660 ppm, also being the least mean recorded by 80% irrigation treatment. The calcium content however, was within the range recorded by MoFA (2010) (45-90 mg/kg) after irrigation treatments were applied. Petterson *et al*, (1983) reported an increased content of Mg, Ca and S under fertigation and are mainly ascribed to the positive interactions of the nutrients and moisture and also their greater availability due to increased organic inputs.

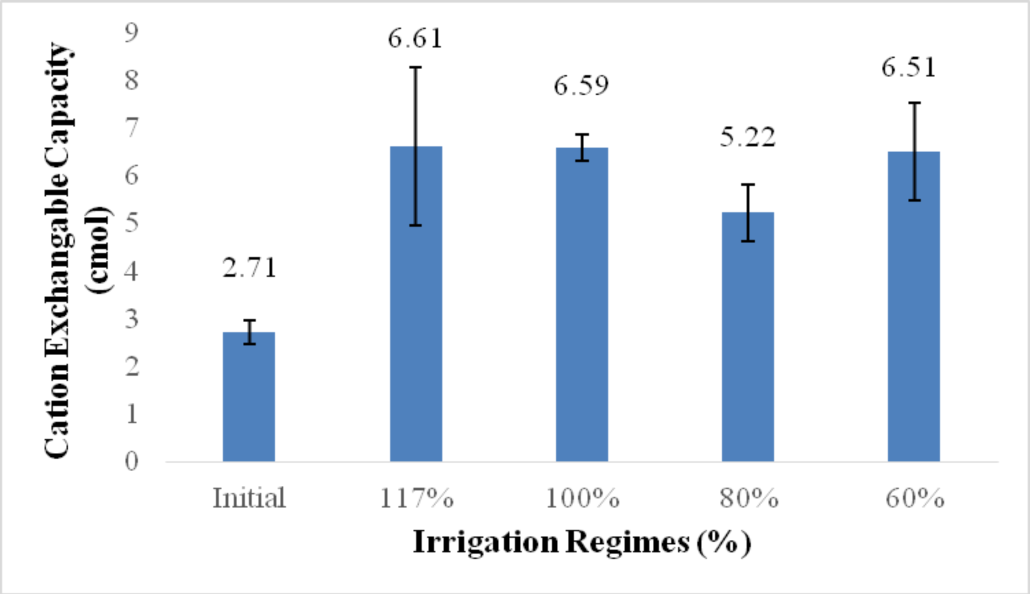


Figure 4.7: Soil cation exchange capacity as affected by different irrigation regimes (Field survey, 2014)

There was a general increase in the cation exchange capacity of the soils after application of each treatment. There was a significant difference between each treatment and the initial cation exchange capacity of the soil except for irrigation regime of 80%. Cation exchange capacity of soils per treatments ranged from, 5.22 – 6.61 cmol at the end of the experiment, whereas the initial cation exchange capacity of the soil was 2.71 cmol (Figure 4.7). By FAO (1976) standards, the resultant cation exchange capacity is low, in that they are all less than 8 (cmol/kg). Drip irrigation treatments sustains soil CEC and organic carbon of the soil as compared to the conventional methods of irrigation (Dubey *et al.*, 2003). Contrary to the results, Shakoor *et al.*, (2012) reported that flood irrigation caused a reduction in soil CEC in both top and subsoil.

4.3 Effects of Irrigation Regimes on Onion Growth and Yield

4.3.1 Effects of Different Irrigation Regimes on Number of Leaves

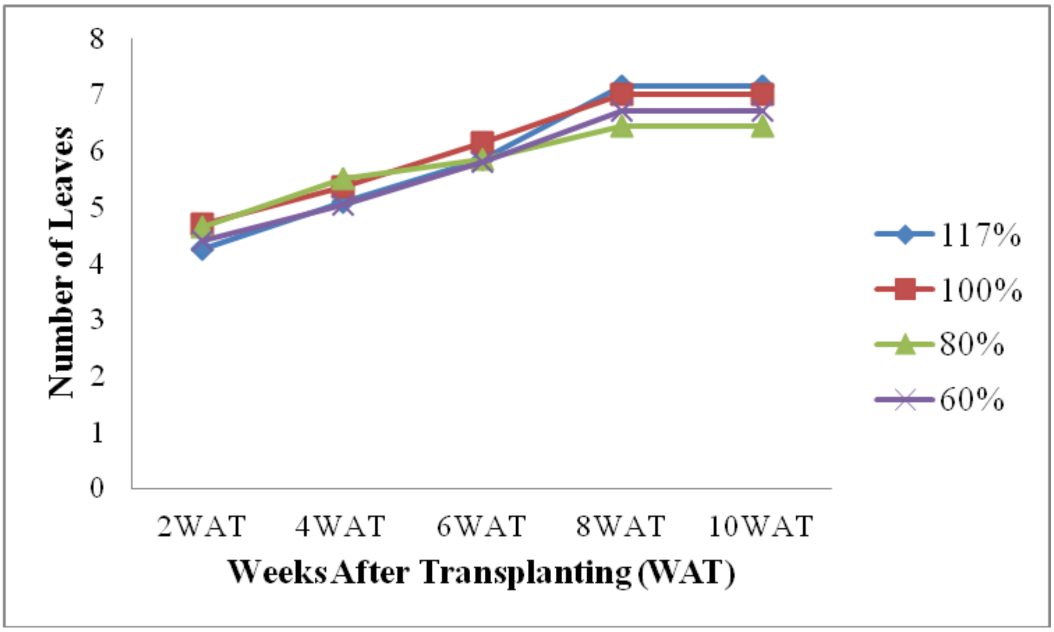


Figure 4.8: Number of leaves as affected by irrigation regimes at different weeks after transplanting

(Field survey, 2014)

The effect of different irrigation regimes on the number of leaves during the cropping season is as presented in Figure 4.8. The highest number of leaves is 6.04 whereas the least is 5.73. These were recorded for 100% and 60% respectively. This however is in line with a report by Addai *et al.*, (2014), which indicated that drought stress does not significantly affect vegetative growth of onion with respect to the number of tillers. The results, however, contradicts a report by Biswas *et al.*, (2010), that indicated that the number of leaves per plant varied significantly at 5% significance level for different irrigation treatments.

4.3.2 Effects of Different Irrigation Regimes on Leaf Height

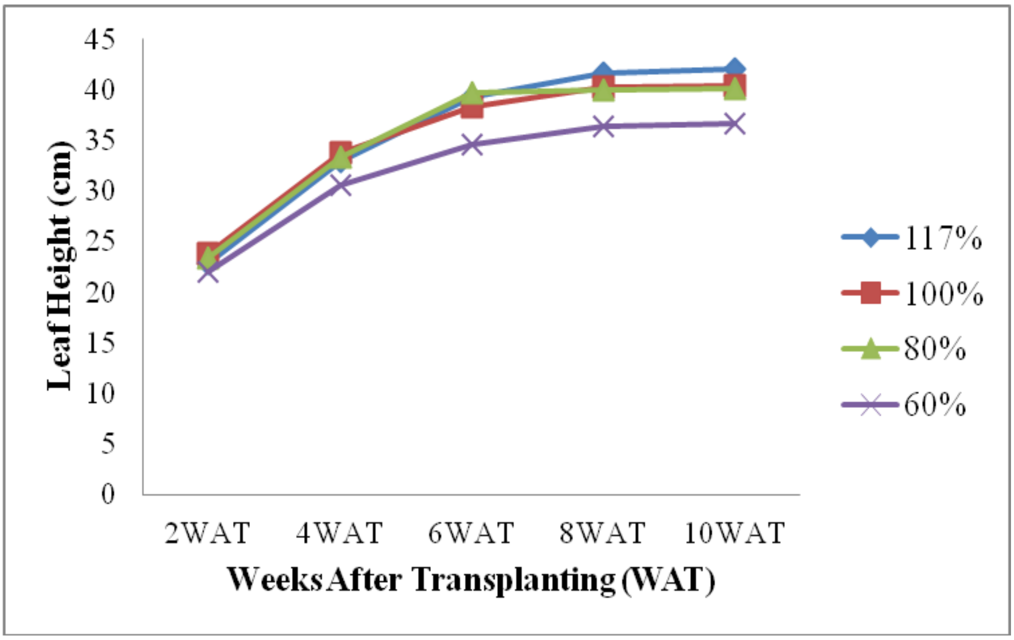


Figure 4.9: Leaf height as affected by irrigation regimes and at different weeks after transplanting

(Field survey, 2014)

The effect of different irrigation regimes on leaf height during the cropping season is as shown in Figure 4.9. There was no significant difference among treatments, except for eight and ten weeks after transplanting where 60% and 117% irrigation regimes exhibited significant difference. The greatest leaf height was 35.7 cm, whereas the least leaf height was 32.0 cm. These were recorded by 117% and 60% respectively. As proved by Pelter *et al.*, (2004), onions are more sensitive to water stress during bulb elongation than they do in the vegetative stage. Addai *et al.*, (2014) also indicated that drought stress, did not significantly affect vegetative growth of onion.

4.3.3 Effects of Different Irrigation Regimes on Canopy Cover

Table 4.2: Canopy Cover as Affected by Different Irrigation Regimes

Parameters	Treatments (%)				Grand Means	LSD	CV (%)	F.pr Values
	117%	100%	80%	60%				
2WAT	12.70	14.03	14.55	13.08	13.59	3.277	38.3	0.660
4WAT	27.2	29.9	30.7	23.8	27.9	6.00	34.1	0.103
6WAT	42.0	45.9	43.7	35.0	41.7	6.75	25.7	0.012
8WAT	63.8	59.8	56.8	51.4	58.0	11.58	31.7	0.192
10WAT	64.4	60.0	56.9	51.7	58.2	11.58	31.6	0.178

(Field survey, 2014)

Crop canopy cover for irrigation regimes of 60%, 80%, 100% and 117% varied significantly during 4, 6 and 8 weeks after transplanting whereas there was no significant variation among treatments for the remaining weeks after transplanting as can be seen in Table 4.2. Also, crop canopy cover varied significantly between 2, 4, 6 and 8 weeks after transplanting during crop growth. Irrigation regime of 117% recorded the highest mean of 64.4%, whereas 51.7% was recorded by the irrigation regime of 60% as the least canopy cover. This, however, contradicts the findings of Addai *et al.*, (2014) which indicated that drought stress, did not significantly affect vegetative growth of onion. However, Al-Kaisi and Broner (2005) established that the effect of water stress alone cannot show significant difference in tiller production of onion, as other factors, may have an important influence during the stress period. The duration of drought and the variety of onion can also have influence over onion growth. However, results are in line with the report from FAO (2013) which indicated that onion is sensitive to water deficit. Pelter *et al.*, (2004), further clarifies that, onions are more sensitive to water stress during bulb elongation than they do in the vegetative stage.

4.3.4 Effects of Different Irrigation Regimes on Yield

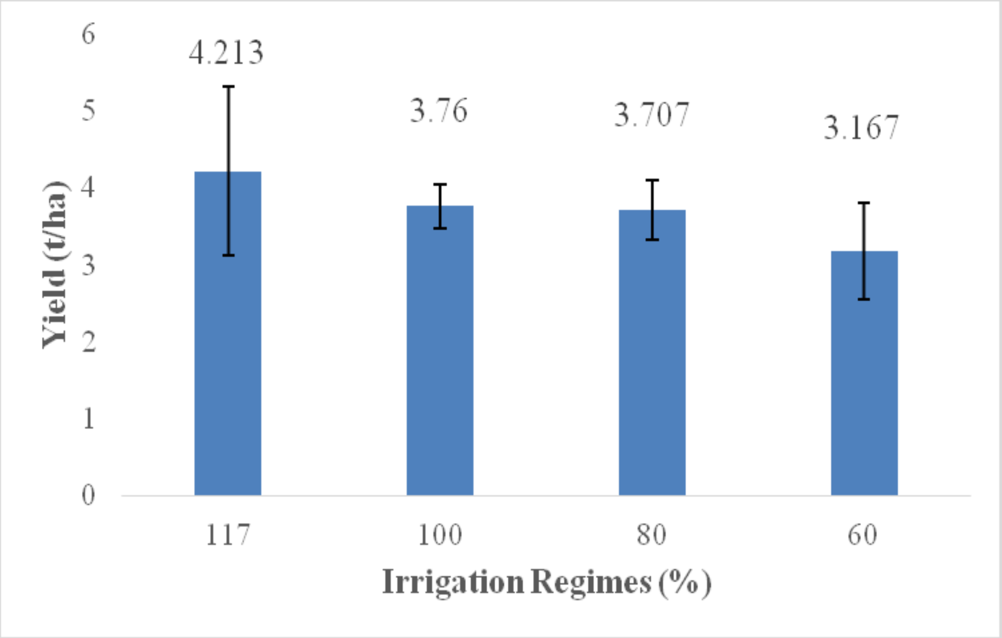


Figure 4.10: Crop yield as affected by different irrigation regimes

(Field survey, 2014)

The effect of different irrigation regimes on the weight of the harvested bulb after cropping is as shown in Figure 4.10. The mean bulb weight per hectare ranged from 3.167 to 4.213 t/ha. No significant difference was observed among the various treatments ($P > 0.05$). However, the irrigation regime of 117% recorded the highest weight of yield, with the yield decreasing with water application rate. This is in line with findings of Addai *et al.*, (2014), which indicated that there is no significant difference between yields based on irrigation rate. Reports from Borivoj *et al.*, (2010), Nagaz *et al.*, (2012) and Biswas *et al.*, (2010) on the other hand illustrated that onion yield was significantly affected by irrigation. FAO (2013) indicated that when the soil is kept relatively wet, root growth is reduced and this favours bulb enlargement. Adding to this Al-Kaisi, (2005) also established that the most critical growth period of onions to water stress is the bulb formation and development stage.

4.3.5 Effects of Different Irrigation Regimes on Onion Grade

The results of weight of graded bulbs as influenced by the different irrigation regimes are presented in Table 4.3. Weight of small graded bulb ranged from 1.113 – 1.869 t/ha, 1.659 – 2.09 t/ha for the medium and for large, 0 – 1.284 t/ha. There was however no significant difference among the various irrigation regimes.

Table 4.3: Grading as Affected by Different Irrigation Regimes

Parameters	**Treatments (t/ha)**				**Grand Mean**	**LSD**	**CV (%)**	**F.pr (>0.05)**
	117%	**100%**	**80%**	**60%**				
Small (0 - 3.0)	1.113	1.67	1.869	1.221	1.468	0.7799	39.6	0.168
Medium(3.0 - 5.0)	1.817	2.09	1.838	0.89	1.659	1.7774	79.9	0.517
Large (>5.0)	1.284	0	0	1.055	0.585	2.2935	292.5	0.515

(Field survey, 2014)

Irrigation regime of 80% recorded the highest small bulb weight of 1.869 t/ha, as the 100% irrigation regime produced 2.09 t/ha being the highest medium bulb weight. Irrigation regime of 117% gave 1.284 t/ha as the highest large bulb weight. The 117% and 60% irrigation regimes produced the least small and medium bulb weight respectively. However, 100% and 80% irrigation regimes had the lowest bulb weight of 0 t/ha. Sen *et al.*, (2006), showed in an experiment that all other parameters used on onion such as bulb diameter, bulb length, bulb weight per plant and yield/ha increases with the increase of soil moisture. His assertion was confirmed by the result from this research.

4.3.6 Effects of Different Irrigation Regimes on Biomass

The effect of different irrigation regimes on biomass is as presented in Tables 4.4 and 4.5. Irrigation regime of 80% recorded 4.78 t/ha and 8.482 t/ha being the highest above ground biomass and total biomass respectively. A 4.26 t/ha and 7.487 t/ha were recorded by irrigation regimes of 117% and 60% as the least above ground biomass and total biomass respectively.

Table 4.4: Biomass as Affected by Different Irrigation Regimes

Parameters	Treatments (t/ha)				Grand Mean	LSD	CV (%)	F.pr (>0.05)
	117%	100%	80%	60%				
Bulb Biomass	4.213	3.760	3.707	3.167	3.712	2.0212	40.6	0.752
Above Ground Biomass	4.26	4.55	4.78	4.32	4.48	1.034	17.2	0.715
Total Biomass	8.477	8.308	8.482	7.487	8.188	3.3069	30.1	0.905

(Field survey, 2014)

Table 4.5: Dry Biomass as Affected by Different Irrigation Regimes

Parameters	Treatments (t/ha)				Grand Mean	LSD	CV (%)	F.pr Values
	117%	100%	80%	60%				
Dry Bulb Biomass	2.88	2.68	4.24	2.80	3.15	1.954	46.3	0.322
Dry Leaf Biomass	1.504	1.932	2.515	2.748	2.175	0.1974	6.8	<.001

(Field survey, 2014)

There was however no significant difference among the various treatments for total biomass, above ground biomass, bulb biomass and dry bulb biomass. Dry leaf biomass on the other hand showed a highly significant variation among treatments. A 4.24 t/ha was the highest dry bulb biomass recorded by 80% irrigation regime, whereas 2.68 t/ha was the least dry bulb biomass recorded by 100% irrigation regime. The 117% irrigation regime recorded the least dry leaf biomass of 1.504 t/ha as the 60% irrigation regime recorded the highest dry leaf biomass of 2.748 t/ha. This is similar to work by Singh and Bilas (2009) who established that varying water stress regimes affected both biomass and yield production in *Dalbergia sissoo*.

4.4 Correlation Analysis

4.4.1 Correlation Between Soil Properties (Nutrients)

Correlation analysis was run to determine the relationship between various soil nutrients after irrigation treatments. At a significance level of <0.001, soil nitrogen content positively correlated with soil pH and soil organic carbon content, but negatively correlated with soil phosphorus, cation exchange capacity, calcium, potassium and magnesium content. Soil organic carbon negatively correlated with soil cation exchange capacity, calcium, potassium and magnesium content, but positively correlated with phosphorus and soil pH. The phosphorus content of soil correlated negatively with soil pH, but positively correlated with soil magnesium, potassium, calcium and cation exchange capacity. Soil pH then correlated negatively with soil calcium, cation exchange capacity, potassium and magnesium content. There was a positive significant correlation between soil cation exchange capacity and magnesium, potassium and calcium content. A positive significant correlation as well existed between soil calcium content and soil potassium and magnesium content. At a significant level of <0.001 there was a positive correlation between soil potassium content and soil magnesium content. These results are indicated in Table 4.6.

Table 4.6: Correlation Analysis of Various Soil Nutrients Showing a Two-sided Test of Correlations Different from Zero

Nutrients		**Correlation**							
%_N_kjeldahl	1	-							
		-							
%_O_C_Walkley_Black	2	0.8518	-						
		(<0.001)	-						
Bray1_P_ppm	3	-0.1503	0.0005	-					
		(0.4734)	(0.9980)	-					
CEC_cmol_kg	4	-0.3780	-0.1934	0.6247	-				
		(0.0624)	(0.3542)	(<0.001)	-				
Ca_ppm	5	-0.4689	-0.2967	0.6120	0.9852	-			
		(0.0180)	(0.1498)	(0.0011)	(<0.001)	-			
K_ppm	6	-0.2952	-0.1295	0.6588	0.9577	0.9361	-		
		(0.1520)	(0.5373)	(<0.001)	(<0.001)	(<0.001)	-		
Mg_ppm	7	-0.4744	-0.2963	0.5154	0.8646	0.8388	0.8040	-	
		(0.0166)	(0.1503)	(0.0084)	(<0.001)	(<0.001)	(<0.001)	-	
pH_1_5_H2O	8	0.7247	0.7803	-0.1195	-0.2991	-0.4025	-0.1784	-0.3670	-
		(<0.001)	(<0.001)	(0.5695)	(0.1464)	(0.0461)	(0.3936)	(0.0711)	-
		1	2	3	4	5	6	7	8

(Field survey, 2014)

4.4.2 Correlation Between Soil Properties (Nutrients), Soil Moisture Content and Crop Yield

Correlation analysis was run to know the relationship between various soil nutrients, soil moisture content and crop yield after irrigation treatments. At a significance level of <0.001, soil moisture content negatively correlated with soil pH, organic carbon content, potassium, calcium, magnesium, cation exchangeable capacity and crop yield. Crop yield as well positively correlated with soil pH, organic carbon content, nitrogen, potassium, calcium and the cation exchangeable capacity of the soil. These results are indicated in Table 4.7.

Table 4.7: Correlation Analysis of Various Soil Nutrients, Soil Moisture Content and Crop Yield Showing a Two-sided Test of Correlations Different from Zero

Variable		**Correlation**									
pH(1:2.5 H2O)	1	-									
		-									
% O.C(Walkley-Black)	2	0.5890	-								
		(0.0063)	-								
% N(kjeldahl)	3	0.3122	0.7533	-							
		(0.1803)	(<0.001)	-							
Bray1 P(ppm)	4	0.0277	0.2976	0.0181	-						
		(0.9076)	(0.2025)	(0.9396)	-						
K(ppm)	5	0.2271	0.3582	0.0808	0.6137	-					
		(0.3356)	(0.1210)	(0.7347)	(0.0040)	-					
Ca(ppm)	6	0.1035	0.2761	0.0552	0.5791	0.9643	-				
		(0.6641)	(0.2386)	(0.8171)	(0.0075)	(<0.001)	-				
Mg(ppm)	7	0.3432	0.4642	0.2226	0.4149	0.7795	0.6884	-			
		(0.1385)	(0.0392)	(0.3455)	(0.0689)	(<0.001)	(<0.001)	-			
CEC(cmol/kg)	8	0.1751	0.3331	0.0914	0.5669	0.9780	0.9861	0.7943	-		
		(0.4604)	(0.1513)	(0.7016)	(0.0092)	(<0.001)	(<0.001)	(<0.001)	-		
Yield(kg/ha)	9	0.5074	0.5642	0.5281	0.2494	0.5168	0.5143	0.3278	0.5080	-	
		(0.0224)	(0.0096)	(0.0167)	(0.2890)	(0.0197)	(0.0203)	(0.1583)	(0.0222)	-	
Soil moisture content	10	-0.1865	-0.0724	0.0273	0.1540	-0.1061	-0.0719	-0.1255	-0.1132	-0.0417	-
		(0.4310)	(0.7618)	(0.9090)	(0.5169)	(0.6563)	(0.7631)	(0.5980)	(0.6346)	(0.8613)	-
		1	2	3	4	5	6	7	8	9	10

(Field survey, 2014)

4.5 Water Productivity

4.5.1 Evapotranspiration Water Productivity

Evapotranspiration water productivity was estimated based on actual evapotranspiration of 3154 m^3. Evapotranspiration water productivity of onion produced in Bontanga under the various irrigation regimes thus, 117%, 100%, 80% and 60% were 1.33587 Kg/m^3, 1.19214 Kg/m^3, 1.17523 Kg/m^3 and 1.00402 Kg/m^3 respectively. The 117% irrigation regime recorded the highest evapotranspiration water productivity, followed by 100% irrigation regime. Irrigation regime at 60%, however, turned out with the least evapotranspiration water productivity. This then implies that evapotranspiration water productivity decreases with decreasing irrigation water regime. Abdul-Ganiyu *et al.*, (2012), reported the average yield of onion to be 11.3 t/ha and crop water productivity also to be 2.19 kg/m^3 in the Bontanga Irrigation Scheme which are both higher than results stated above. This could be due to the difference in season of cultivation and poor pH condition of the soil on which this study was done. As established by GIDA-JICA-SSIPP, (2004), for optimum yield, cool temperature and abundant soil moisture during the early stages of growth before bulbing, higher temperatures of over 35 ^{O}C and the long days during the dry season favour good bulbing in the dry savannah areas.

4.5.2 Crop Water Productivity

The total water used during irrigation was 3647.242 m^3/ha, 3117.3 m^3/ha, 2493.84 m^3/ha, and 1870.38 m^3/ha respectively, for 117%, 100%, 80%, and 60% irrigation regimes. Irrigation regime of 117% recorded the least crop water productivity of 1.155 kg/m^3, whereas, 60% recorded the highest crop water productivity of 1.693 kg/m^3, followed by 80% also recording 1.486 kg/m^3 of crop water productivity. Irrigation regimes of 60% and 80%, in turn saved 40% and 20% of water used respectively. This however shows that onion, water productivity increases with decreasing irrigation regimes which is similar to a report by Henry *et al.*, (2012) which showed that crop water use of the onion crop decreased with increase in irrigation deficit. Patel and Rajput (2013) also reported that, regulated deficit irrigation by 20 and 40% saved 19.2 and 41.7% water and resulted in 20 and 32% reduction in yield, respectively. Further report also indicated that in deficit irrigation, 20% water deficit in the growth stages of 2nd, 3rd and 4th saved 2.1, 13.2 and 4.6% of water with 19.8, 18.3 and 11.2% reduction in yield, respectively in comparison to the full irrigation water application (Patel and Rajput, 2013).

4.5.3 Economic Water Productivity

The value per kilogram for onion as obtained from the Tamale market was approximately 3GH₵ which was equivalent to 1.0161$ (exchange for May, 2014). The total water used during irrigation was 3647.24 m^3/ha, 3117.3 m^3/ha, 2493.84 m^3/ha and 1870.38 m^3/ha respectively, for 117%, 100%, 80% and 60% irrigation regimes. However, the economic water productivity of the various irrigation regimes as recorded in an ascending order were, 1.17, 1.23, 1.51 and 1.72 $/$m^3$ for 117%, 100%, 80% and 60% respectively. This also showed that economic water productivity of onion increases with decreasing irrigation water regime.

4.6 AquaCrop Model Analysis

4.6.1 Calibration and Simulation of AquaCrop Model

The calibrated AquaCrop model was assessed for its performance to predict crop yield, crop biomass and evapotranspiration water productivity (ETWP). The simulated onion yield, biomass and the evapotranspiration water productivity of the different irrigation water regimes were compared with the measured values from the experiment as indicated in Tables 4.8 and 4.9. Crop yield and biomass were overestimated for 100% irrigation water regime and underestimated for irrigation regimes of 80%, 60% and 117%. The deviation in actual crop yield and biomass as compared to the simulated crop yield and biomass were 4.149% to -2.810% and 4.742% to -2.257% respectively. The 100% irrigation water regime recorded the highest, whereas 60% irrigation regime recorded the least in both cases. On the other hand, evapotranspiration water productivity as simulated by the AquaCrop model were underestimated. This ranged from a deviation as low as -10.235% to -13.192%.

Table 4.8: Comparison between simulated and actual values of yield and biomass of onion for different irrigation regimes

Irrigation Regimes	Yield (t/ha)				Biomass (t/ha)			
	Actual	Simulated	Standard Deviation	Deviation (%)	Actual	Simulated	Standard Deviation	Deviation (%)
117%	4.213	4.177	± 0.03	-0.855	8.477	8.354	± 0.09	-1.451
100%	3.760	3.916	± 0.11	4.149	8.308	8.702	± 0.28	4.742
80%	3.707	3.662	± 0.03	-1.214	8.482	8.324	± 0.11	-1.863
60%	3.167	3.078	± 0.06	-2.810	7.487	7.318	± 0.12	-2.257

(Field survey, 2014)

Table 4.9: Comparison between simulated and actual values of Evapotranspiration water productivity of onion for different irrigation regimes

Irrigation Regimes	Evapotranspiration Water Productivity (kg/m^3)			
	Actual	Simulated	Standard Deviation	Deviation (%)
117%	1.335	1.19	± 0.10	-10.861
100%	1.192	1.07	± 0.09	-10.235
80%	1.175	1.02	± 0.11	-13.192
60%	1.004	0.88	± 0.09	-12.351

(Field survey, 2014)

Regression analysis showed that there was a significant linear relation between simulated and measured crop yield (y = 1.0694x – 0.261), biomass (y = 1.124x – 1.0292) and evapotranspiration water productivity (y = 0.941x – 0.0671). The correlation factors on yield, biomass and evapotranspiration water productivity were $R^2=0.95$, $R^2=0.80$ and $R^2=0.99$ respectively. This is in line with a report by Atefeh and Ali, (2013) which suggested that the amount of water required, behaviour and water use efficiency, simulated by the AquaCrop computer model had well adapted and correlation with field measures.

Deviations recorded under this study are also in line with work by Muhammad and Hussain (2012) who reported that the performance of the model to estimate biomass, yield and water productivity was satisfactory. The deviations in results could be due to factors including crop structure and phenology, rather than climatic, soil and water supply parameters.

4.6.2 Validation of AquaCrop Model

Validation of the AquaCrop model by Nash-Sutcliffe efficiency (E), Root mean square errors (RMSE) and index of agreement (d) statistical tools are as shown in Table 4.10.

Table 4.10: Validation of AquaCrop Model

Parameters	**Efficiency Criteria**		
	Nash Coefficient	**RMSE**	**Index Agreement**
Yield (t/ha)	0.96	0.09	0.99
Biomass (t/ha)	0.67	0.24	0.93
Evapotranspiration Water Productivity (Kg/m^3)	-0.37	0.14	0.73

(Field survey, 2014)

The results as obtained for the Nash-Sutcliffe efficiency (E) for yield, biomass and evapotranspiration water productivity were 0.96, 0.67 and -0.37 respectively. Root mean square errors recorded were 0.09, 0.24 and 0.14 for yield, biomass and evapotranspiration water productivity respectively. As well, the index of agreement was 0.99, 0.93 and 0.73 for yield, biomass and evapotranspiration water productivity respectively. These results, however, showed that AquaCrop model satisfactorily simulated all parameters considered in the research.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Results from soil nutrients analysis showed that Cation Exchange Capacity of the soil increased significantly after application of various irrigation water regimes except for irrigation regime of 80%. There was no significant difference in soil pH levels among treatments, but a significant decrease after application of treatments. After application of irrigation treatments, there was a significant decrease in the soil Nitrogen content from the initial value. There was also a significant increase in soil Potassium content after irrigation regimes of 60 and 117%. Soil Phosphorus content also increased significantly after water irrigation regime of 117%. There was a significant increase in soil Organic Carbon, Magnesium and Calcium content from the initial compared to that after various irrigation regimes.

The study showed that production of onion in dry season (February to May) under deficit irrigation of 20 and 40% and over irrigation of 17% did not significantly affect the number of leaves, yield, grading, dry bulb biomass and total biomass of onion crop. Dry leaf biomass varied significantly between 60%, 80%, 100% and 117% irrigation water regimes. However, Leaf length showed no significant difference among treatments, except for eight and ten weeks after transplanting where 60% and 117% irrigation regimes varied significantly. Crop canopy cover for irrigation water regimes of 60%, 80%, 100% and 117% varied significantly during 4, 6 and 8 weeks after transplanting.

Evapotranspiration water productivity increased with increase in irrigation water regime, whereas crop water productivity and economic water productivity increased with decreasing irrigation regime. In light of this, in areas of water scarcity, it may be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land. The saved water can then be used for other purposes or to irrigate extra units of land.

The AquaCrop model was able to simulate the crop yield, biomass and evapotranspiration water productivity of onion. There was a strong correlation and a significant linear relation between the simulated and measured crop yield, biomass and evapotranspiration water productivity. Validation of the AquaCrop model by Nash-Sutcliffe efficiency (E), Root mean square errors (RMSE) and index of agreement (d) showed that, AquaCrop model satisfactorily simulated all parameters considered in the research. However, the differences in results may be due to factors including crop structure and phenology, rather than climatic, soil and water supply parameters.

5.2 Recommendations

The following are recommendations for further studies;

1. In the event of water deficit, farmers should adopt 60% irrigation regime in order to save water, while increasing yield.
2. Considering the low pH level of the soil, liming should be done to increase the soil pH.
3. For better performance of water productivity model adopted for global agriculture purposes, below grounds stems and bulb like crops should be considered along with cereals and cash crops to obtain more realistic results.
4. The study should be repeated over space and time taking into consideration various soil conservation measures, such as mulching and application of organic manure.

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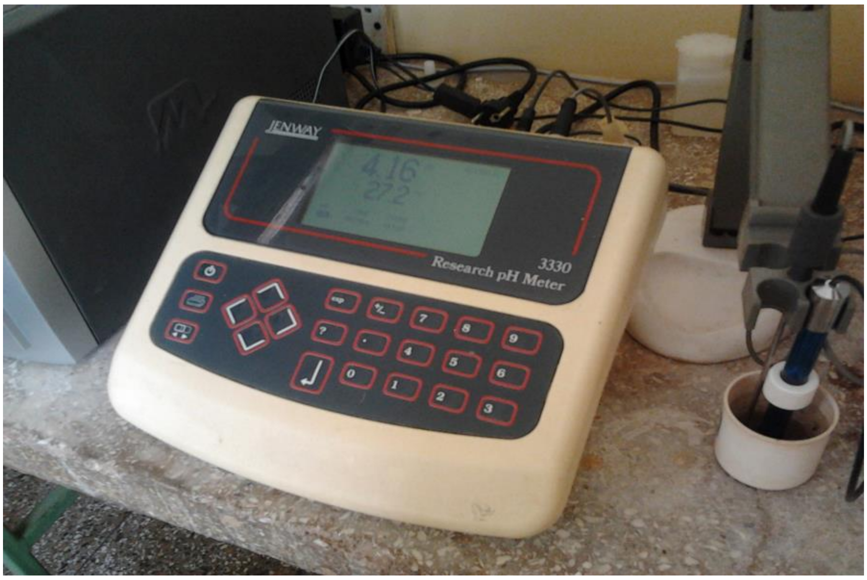
APPENDIX A

Appendix A1: Experimental plot at the Bontanga Irrigation Scheme



Appendix A2: Reading soil pH level with the pH meter

Appendix A3: Weighing of soil samples for chemical analysis

Appendix A4: Filtration of soil solution into a conical flask

Appendix A5: Mechanically shaking soil solution

Appendix A6: Bagged fresh leaves and bulbs to be oven dried

Appendix A7: Oven dried onion leaves

Appendix A8: Oven dried onion bulb

Appendix A9: User-Specific parameters used in simulation

Parameter	Unit	Measured or calibrated
Soil surface covered by an individual seedling at (90%) recover	(cm^2/plant)	50
Number of plants per hectare	Ha^{-1}	266,667
Time from transplanting to recover	Days	20
Maximum canopy cover, CCx	%	
Irrigation regime (100%)	%	60.0
Irrigation regime (80%)	%	56.9
Irrigation regime (60%)	%	51.7
Irrigation regime (117%)	%	64.4
Time from transplanting to start senescence	Days	50
Time from transplanting to maturity, i.e. length of crop cycle	Days	95
Time from transplanting to flowering	Days	75
Length of flowering stage	Days	20
Maximum effective rooting depth	(m)	0.35
Time from sowing to maximum rooting depth	Days	86
Reference Harvest Index (HIO)	%	
Irrigation regime (100%)	%	45.2
Irrigation regime (80%)	%	43.70%
Irrigation regime (60%)	%	42.30%
Irrigation regime (117%)	%	49.70%
Water productivity (WP*)	g/m^2	17
Soil texture		Sandy loam

Appendix A10: Conservative parameters of aqua crop used in simulation

Description	**Units/Meaning**	**Value**
Base temperature	^0C	10
Upper temperature	^0C	30
Soil H_2O depletion factor, canopy expansion	Upper threshold (p-exp)	0.20
Soil H_2O depletion factor, canopy expansion	Lower threshold (p-exp)	0.55
H_20 productivity normalized for ETo and CO_2	gram/m^2 (WP*)	17

Appendix A11: The Average Irrigation Water Used Per Plot during the Experiment

Growth Stages	**Average Irrigation Requirements (mm/ day)**	**Treatments (Irrigation Regimes) (mm^3/plot)**			
		117%	**100%**	**80%**	**60%**
Initial (20 days)	2.68	376.272	321.6	257.28	192.96
Development (45 days)	3.254	1027.9387	878.58	702.864	527.148
Mid (20 days)	3.8	533.52	456.0	364.8	273.6
Late (10 days)	3.57	250.614	214.2	171.36	128.52
Total Irrigation Water Used		2188.345	1870.38	1496.304	1122.228

(Field survey, 2014)

APPENDIX B

Appendix B1: Soil Chemical Properties as Affected by Different Irrigation Regimes

Parameters	Treatments					Grand Mean	LSD	CV (%)	F.pr Values
	Initial	117%	100%	80%	60%				
pH(1:2.5 H_2O)	4.91	4.31	4.25	4.28	4.42	4.43	0.366	6.3	0.007
%O.C (Walkley-Black)	0.694	0.460	0.484	0.424	0.460	0.504	0.160	24.1	0.016
% N(kjeldahl)	0.080	0.040	0.042	0.044	0.030	0.047	0.021	34.2	0.001
Bray1 P(ppm)	10.3	20.5	16.0	14.8	17.2	15.8	9.15	44.0	0.263
K(ppm)	81.6	160.0	144.0	122.5	154.0	132.4	65.89	37.7	0.129
Ca(ppm)	175.0	906.0	841.0	660.0	847.0	686.0	406.1	44.9	0.007
Mg(ppm)	36.0	183.0	222.0	167.0	203.0	162.0	76.7	35.9	<.001
CEC(cmol/kg)	2.71	6.61	6.59	5.22	6.51	5.53	2.736	37.5	0.032

(Field survey, 2014)

Appendix B2: Leaf Number as Affected by Different Irrigation Regimes

Parameters	Treatments				Grand Mean	LSD	CV (%)	F.pr (>0.05)
	117%	100%	80%	60%				
2WAT	4.25	4.70	4.65	4.40	4.500	0.5274	18.6	0.286
4WAT	5.10	5.35	5.50	5.05	5.25	0.597	18.1	0.397
6WAT	5.85	6.15	5.85	5.80	5.91	0.599	16.1	0.639
8WAT	7.15	7.00	6.45	6.70	6.83	0.930	21.6	0.448
10WAT	7.15	7.00	6.45	6.70	6.83	0.930	21.6	0.448

(Field survey, 2014)

Appendix B3: Leaf Number as Affected by Different Irrigation Regimes and Weeks after Transplanting

Parameters	Treatments					Grand Mean	LSD	CV (%)	Fpr (<0.05)
	2WAT	4WAT	6WAT	8WAT	10WAT				
117%	4.25	5.10	5.85	7.15	7.15	5.90	0.867	23.4	<.001
100%	4.70	5.35	6.15	7.00	7.00	6.04	0.5125	13.5	<.001
80%	4.65	5.50	5.85	6.45	6.45	5.78	0.631	17.4	<.001
60%	4.40	5.05	5.80	6.70	6.70	5.73	0.867	24.1	<.001

(Field survey, 2014)

Appendix B4: Leaf Height as Affected by Different Irrigation Regimes

Parameters	Treatments (cm)				Grand Mean	LSD	CV (%)	F.pr (>0.05)
	117%	100%	80%	60%				
2WAT	22.77	23.81	23.36	21.96	22.97	3.550	24.5	0.753
4WAT	32.86	33.81	33.28	30.54	32.62	4.399	21.4	0.467
6WAT	39.23	38.36	39.64	34.62	37.97	4.072	17.0	0.065
8WAT	41.69	40.31	40.02	36.34	39.59	4.548	18.2	0.121
10WAT	41.98	40.38	40.17	36.65	39.80	4.497	17.9	0.124

(Field survey, 2014)

Appendix B5: Leaf Height as Affected by Different Irrigation Regimes and Weeks after Transplanting

Parameters	Treatments Mean (cm)					Grand Mean	LSD	CV (%)	F.pr (<0.05)
	2WAT	4WAT	6WAT	8WAT	10WAT				
117%	22.77	32.86	39.23	41.69	41.98	35.71	4.784	21.3	<.001
100%	23.81	33.81	38.36	40.31	40.38	35.34	3.576	16.1	<.001
80%	23.36	33.28	39.65	40.02	40.17	35.30	3.586	16.2	<.001
60%	21.96	30.54	34.62	36.34	36.65	32.02	4.751	23.6	<.001

(Field survey, 2014)

Appendix B6: Canopy Cover as Affected by Different Irrigation Regimes and Weeks after Transplanting

Parameters	Treatment Mean (%)					Grand Mean	LSD	CV (%)	F.pr (<0.05)
	2WAT	4WAT	6WAT	8WAT	10WAT				
117%	12.7	27.2	42.0	63.8	64.4	42.0	9.97	37.8	<.001
100%	14.0	29.9	45.9	59.8	60.0	41.9	6.46	24.5	<.001
80%	14.5	30.7	43.7	56.8	56.9	40.5	7.45	29.3	<.001
60%	13.1	23.8	35.0	51.4	51.7	35.0	9.48	43.1	<.001

(Field survey, 2014)

Appendix B7: Yield by weight as Affected by Different Irrigation Regimes

Parameters	**Treatments (t/ha)**				**Grand Mean**	**LSD**	**CV (%)**	**F.pr (>0.05)**
	117%	**100%**	**80%**	**60%**				
Yield	4.213	3.760	3.707	3.167	3.712	2.0212	40.6	0.752

(Field survey, 2014)

Appendix B8: Soil Moisture Content as Affected by Different Irrigation Regimes and Weeks after Transplanting

Parameters	**Treatments Mean (100%)**					**Grand Mean**	**LSD**	**C.V (%)**	**F.pr (<0.05)**
	Initial	**4WAT**	**6WAT**	**8WAT**	**10WAT**				
117%	28.00	16.68	19.22	17.38	17.64	19.78	3.364	12.9	<.001
100%	28.00	15.60	16.86	15.10	15.24	18.16	1.832	7.6	<.001
80%	28.00	12.16	16.46	12.40	12.56	16.32	2.106	9.8	<.001
60%	28.00	10.92	14.76	12.68	12.78	15.83	2.108	10.1	<.001

(Field survey, 2014)

Appendix B9: Evapotranspiration Water Productivity of Onion as Affected by Different Irrigation Regimes

Irrigation Regime (%)	**Yield (kg/ha)**	**ETact (m^3)**	**ETWP (kg/m^3)**
117%	4213.33	3154	1.34
100%	3760.00	3154	1.19
80%	3706.67	3154	1.18
60%	3166.67	3154	1.00

(Field survey, 2014)

Appendix B10: Crop Water Productivity of Onion as Affected by Different Irrigation Regimes

Irrigation Regime (%)	Yield (kg/ha)	TWR (m^3/ha)	kg/m^3
117%	4213.33	3647.242	1.155
100%	3760	3117.3	1.206
80%	3706.67	2493.84	1.486
60%	3166.67	1870.38	1.693

(Field survey, 2014)

Appendix B11: Economic Water Productivity of Onion as Affected by Different Irrigation Regimes

Irrigation Regime (%)	Yield (kg/ha)	Value (¢)	Value ($)	TWU(m^3/ha)	EWP ($/$m^3$)
117%	4213.33	12638.4	4280.63	3647.24	1.173663
100%	3760	11278.6	3820.06	3117.3	1.225438
80%	3706.67	11118.6	3765.87	2493.84	1.51007
60%	3166.67	9498.81	3217.25	1870.38	1.720104

(Field survey, 2014)