CROP WATER PRODUCTIVITY OF SOME URBAN IRRIGATED VEGETABLE FARMS

Benjamin Della Dotse

B.Sc. (Hons) Agric Engineering

A Thesis submitted to the Department of Agricultural Engineering,

Kwame Nkrumah University of Science and Technology, Kumasi in

partial fulfillment of the requirements for the degree of

MASTERS OF SCIENCE IN SOIL AND WATER ENGINEERING

COLLEGE OF ENGINEERING

AUGUST 2013

DECLARATION

I, Benjamin Della Dotse, the under signed, declare that this thesis is my original work and has not been presented for a degree in any other University. All sources of material used for this thesis have been duly cited and acknowledged.

Benjamin Della Dotse	…………………	30/10/13
(Student)	Signature	Date
Certified by:		
Ing. Prof. Sampson K. Agodzo	…………………	30/10/13
Principal Supervisor	Signature	Date
Certified by:		
Dr. Emmanuel Ofori	…………………	31/10/2013
Co-Supervisor	Signature	Date
Certified by:		
Ing. Prof. Ebenezer Mensah	…………………	31/10/2013
Head of Department	Signature	Date

DEDICATION

This work is dedicated to Rev. David Fiadzo the man who provided me with spiritual support throughout my course work, my sister Mrs. Mary Esi Akummey and my brother Mr. Anthony Dotse who supported me financially..

AKNOWLEDGEMENT

I wish to acknowledge with gratitude my project supervisor, Prof. S.K. Agodzo of the Agricultural Engineering Department of the College of Engineering in the Kwame Nkrumah University of Science and Technology, for his invaluable assistance in the form suggestions, advice and inspiration throughout the research work. I also extend my appreciation to Prof. Kyei-Baffour, Prof Mensah, Dr. Ofori, Mr. Aikins and Dr. Agyare, all of the Agricultural Engineering Department for their concern about my health when I fell sick. I also wish to express my gratitude to Mrs. Abigail Yeboah and Mr. Prince Acheampong of the Agricultural Engineering Departmental Office for encouraging me to continue the course when I deferred it due to ill-health. This work will not have been completed had my wife Evelyn and children, Luther-King, Priscilla and Emmanuella not stood beside me in difficult times. I owe them a debt of gratitude for their support and encouragement. Finally, I thank the Almighty Lord God who accorded me his fatherly guidance and protection throughout my course work.

ABSTRACT

The aim of this study was to assess the crop water productivity of some urban irrigated vegetable farms with the view to: (i) assessing the irrigation water applied by farmers for vegetable production in some urban areas; (ii) comparing water applied by farmers to desired amounts required; (iii) determining the water productivity of the vegetable crops grown and propose better water management practices and (iv) assessing the economic benefits accruing to the farmer in the urban irrigated vegetable production. The study was conducted at KNUST Engineering, Ayeduase New Site and Boadi in the Kumasi metropolis. The study involved field measurements and estimates based on the interview of 50 farmers. The crops investigated were lettuce, cabbage, spring onion, green pepper and carrot. The main source of water for irrigation of crops was shallow dug wells. The main method of irrigation was the use of watering cans. Men (92 %) dominate the cultivation of irrigated vegetables in the urban areas with the women trailing behind at 8 % but produce marketing are dominated by women. The key findings from this study in line with the objectives of study include the following: (i) Quantity of water applied by farmers per season in the case study averaged at 492.2 mm, 835 mm, 520 mm, 605 mm and 745 mm for lettuce, cabbage, spring onion, green pepper and carrots respectively; (ii) There was consistent and persistent over-irrigation under farmer practices for all crops. Percentage over-irrigation ranged from 38 to 120 %. Farmers could well have saved on water, time and work done in water delivery if they were better informed; (iii) Crop water productivity values obtained in the case study were 19.2, 15.2, 21.9, 6.3 and 21.3 kg/m^3 for lettuce, cabbage, spring onion, green pepper and carrots respectively; (iv) Cost of production computed on per hectare basis has been high and could reach GH¢ 12,520 for spring onions. Computed on the basis of an average bed size of 15.75 m^2, the cost of production of spring onion was GH¢41.70 per bed. Since

the land areas cultivated were small, the farmers could afford such costs. A plot of land rented is made up of 30 beds suggesting a production cost for spring onion of about GH¢417 per plot. Similarly profits accruing for lettuce, cabbage, spring onion, green pepper and carrots were GH¢17,497, GH¢30,875, GH¢28,280, GH¢11,582 and GH¢23,830 per hectare. On the basis of a plot size of 30 beds per plot the profits were GH¢58.32, GH¢102.90 GH¢94.30 GH¢38.60 and GH¢79.43 for lettuce, cabbage, spring onion, green pepper and carrots respectively. There is the need to improve on field water management by improving savings on water, time, energy and cost of water delivery.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.1 GENERAL BACKGROUND

The consumption of exotic vegetables such as cabbage, spring onions, carrot and lettuce has increased over the years especially in the urban centers and has contributed to the increase in irrigated vegetable farming in these areas. Water for the cultivation of vegetables is not easily available so farmers normally choose sites near to drains or where wells can easily be dug for irrigation. Crop water productivity is a quantitative term used to define the relationship between crops produced and the amount of water involved in crop production. It is a useful indicator for quantifying the impact of irrigation scheduling decisions with regard to water management. Crop water productivity is defined by Kasam and Smith (2001) as "crop yield /water consumptively used in evapotranspiration (ET)".

According to Molden (1997)the productivity of water is defined as "the physical mass of production or economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water" (Kassam and Smith (2001); Molden (1997)).

Water productivity has been defined as the amount of output produced per unit of water involved in the production, or the value added to water in a given circumstance (Molden et al. (1998); Sakthivadivel et al. (1999); Tuong et al., 2000) and Bastiaanssen et al. (2003)). Water productivity can be defined with respect to the different sectors of production involving water (e.g. crop production, fishery, forestry, domestic and industrial water use). Water productivity with respect to crop production is referred to as crop water productivity (CWP), and is defined as the amount of crop produced per volume of water used. The unit of CWP is kg/m^3. CWP can also be defined in monetary terms, expressed in terms of economic return from crop produced per volume of water, with the unit expressed in equivalent of any currency (e.g. \$/m^3) (SWMRG, 2003 and Kadigi et al., 2004).

The concept of CWP has remained a subject of interest to plant, soil and irrigation scientists for almost 100 years now (Briggs and Shantz (1916); Richards (1923); De Wit (1958); Hanks et al. (1969); Hanks (1974); Augus et al. (1980);Sinclair et al. (1984);Howell et al. (1990); Musick et al. (1994) and Augus and van Herwaarden, (2001). Another terminology that has frequently been used to express the concept of CWP is water use efficiency (WUE) (e.g. Viets (1962),French and Schultz (1984); Zhang and Owie (1999) and Howell (2001).

CWP is useful for looking at potential increase in crop yield that may result from increased water availability (Burke et al., 1999). It provides a simple means of assessing whether yield is limited by water supply or other factors (Augus and van Herwaarden, 2001). In deficit irrigation scheduling, CWP is a good indicator for assessing the impact of an irrigation scheduling protocol. CWP reveals the unit increment in yield per unit of water use, from which the impact and worth of additional water supply can be assessed. Quantitative information on CWP is therefore necessary for effective planning of irrigation water management strategies in an area.

1.2 STATEMENT OF THE PROBLEM

To meet the rising food demand that will occur as a result of increasing population and changing dietary patterns, the world needs to ensure sustainable land and water productivity improvements over the coming decades (Molden et al., 2007). However, agricultural water use is facing competition from demands from industry, domestic users, and the need to allocate water to aquatic ecosystems and environmental services. The agricultural sector is projected to receive reduced water allocation despite the increasing pressure for more food production (Kline et al., 2003). Together, the increasing food demand and decreasing water allocation suggest that the agricultural sector has to produce more food with less water, that is to increase agricultural water productivity (Cai and Sharma, 2010).

1.3 OBJECTIVE OF THE STUDY

The main objective of this study was to assess the crop water productivity of some urban irrigated vegetable farms.

The specific objectives were:

- To determine the irrigation water applied by farmers for vegetable production in some urban areas.
- To compare water applied by farmers to desired amounts required.
- To determine the water productivity of the vegetable crops grown and propose better water management practices.
- To determine the economic benefits accruing to the farmer in the urban irrigated vegetable production.

CHAPTER TWO

LITERATURE REVIEW

2.1 AGRICULTURAL WATER PRODUCTIVITY

Water is the determining factor for crop yields in most areas, which, however, has to be developed in light of environmental sustainability. Irrigation is the artificial application of water to soil for the purpose of crop production. Irrigation water is supplied to supplement the water available from rainfall and this contributes to soil moisture from ground water. Irrigation is basically an attempt by man to locally alter the hydrologic cycle and to promote increased agricultural productivity (Cuenca, 1989).

Vegetables contain so much water (about 80 to 95 percent water), therefore their yield and quality suffer rapidly when subjected to drought. Thus for good yields and high quality, irrigation is essential to the production of most vegetables .If water shortages occur early in the crop development, maturity may be delayed and yields reduced. If a moisture shortage occurs late in the growing season, quality is often reduced even though total yield may not be affected (Kemble, 2000).

Urban and peri-urban agriculture can be broadly defined as the production, processing and distribution of foodstuff from crop and animal production, fish ornamentals and flowers within and around urban areas (Mougeot, 2000).

In our context, we will refer urban to "administrative city boundary" while peri-urban is used for lands outside the immediate perimeter of the city but within a radius of up to 40km of the city center (Obuobie et al., 2006).

In Ghana, urban crop farming comprises two forms:

1. open-space production for the urban market
2. back-yard gardens cultivated mostly, but not only, for home consumption.(Table 2.1)

Table 2.1 the two major categories of urban and pre-urban crop farming in Ghana

Farming Systems	Urban Areas	Peri-Urban Areas
1. Market Production (Cultivation on undeveloped urban land)	Irrigated vegetables(year-round or seasonal), flowers or ornamentals; rain-fed cereals	Irrigated vegetables (mostly seasonal),fruits: Rain-fed cereals
2. Subsistence production (cultivation at the house)	Backyard or front yard farming	Home gardens: farming around homestead

Source: Drechsel et al. (2006a; simplified)

Agricultural urban farms/open spaces are intra- urban production areas that are surrounded by residential, industrial or institutional areas. More than one farmer, not necessarily working together as a group, cultivates open spaces. It takes place on public land (hazardous lands not suitable for construction, road reserves, available land for community use etc.) as well as private land (residential, industrial or institutional plots under-utilized or awaiting development).While public land is often farmed without official permission, use of private land depends on a formal or informal agreement with the owner. The dominating crops are vegetables (Dongus, 2000).

Increasing food demands in many cities in low-income countries due to the rise in urban populations are accompanied with a shift in diets towards processed (fast) food

(CTA, 2005). In Ghana, the largely informal street food sector is responding to this phenomenon. As a small component of usually rice-based meals, raw salads consisting of leafy exotic vegetables like lettuce, cabbage and spring onions constitute one of the modern and increasingly common fast food dishes. Today, nearly all perishable vegetables consumed in Ghana's streets are produced in their urban and peri-urban areas (Obuobie et al., 2006). Leafy vegetables generally have high water requirements and need to be irrigated on daily basis; therefore, vegetable farming requires constant availability of water, especially in the climate of West Africa.

Obuobie et al (2006) reported that urban and peri-urban small holders in search of irrigation water end up using wastewater from drains and polluted streams as clean water sources are rare in the vicinity or unreliable while expensive. Since most of the farming lands are found in lowlands and along streams there is frequent flooding and water logging which leads to the deteriorating of land quality and severe problems of salinity. In addition, irrigation water is becoming increasingly scarce with growing demands due to lack of employment as a result of increasing population.

Untreated wastewater and polluted water have high levels of pathogenic microorganisms such as bacteria, viruses, parasitic worms and protozoa, and some of them can cause harm in smaller numbers (Blumenthal et al., 2001). The most affected groups are consumers of wastewater irrigated vegetables and farmers who are in contact with wastewater.

2.2 NUTRITIONAL FACTORS IN VEGETABLES

The term 'vegetable' is usually used to designate the tender edible shoots, leaves, fruits and roots of plants that are eaten whole or in part, raw or cooked, as a supplement to starchy foods and meats. Most of them are herbaceous and the definition does not include sweet dessert fruits.

Vegetables are a major source of minerals, proteins, dietary fiber, and vitamins. It plays a nutritional role as balancing agents in diets. Vitamins are complex organic substances that are required for health and are effective in small amounts. Vitamin A is synthesized in the body but its synthesis requires certain compounds (carotenes) that are obtained from many vegetable species. Red and yellow vegetables (like carrots and pumpkins) are particularly rich in carotenes. Vitamin A is essential for healthy skin and other tissues, and a lack of this vitamin may predispose the skin and epithelial tissues to infection by disease organisms. A deficiency in vitamin A also leads to poor night vision.

Vegetables are also a major source of minerals in diet .Some important minerals supplied by vegetables include iron, calcium and phosphorus. Calcium and phosphorus in the presence of vitamin D play an important role in the skeletal development of the body and the formation of strong bones and teeth. Lack of calcium in the blood leads to bone softening and fragility and to rickets in young children. Iron is an important constituent of red blood cells and a deficiency of iron causes anaemia. Proteins, carbohydrate, and dietary fibers are also supplied by vegetables. Proteins are present in leguminous and `leafy vegetables and indeed most plant organs harvested as vegetables. They are needed for the repair and maintenance of body tissues, and synthesis of enzymes, co-enzymes and hormones; (Williams, et al, 1991).

2.3 SOCIO-ECONOMIC IMPACT OF URBAN VEGETABLE PRODUCTION

Urban agriculture can be market oriented, subsistence oriented or serving both purposes. It may be practiced as a sole source of income or to supplement immediate household food requirements and is often carried out alongside other forms of employment. Open space vegetable farming is mainly for commercial purposes. Only farmers specialized in traditional (indigenous) vegetables consume a part of their produce (Obuobie et al., 2006).

Moving out of poverty: For peri-urban farmers, dry season vegetable irrigation adds 40-50% of cash to their normal income especially as significant parts of their rain-fed maize and cassava harvest are consumed by the household. Without this additional income, cash availability might actually be less than US$ 100 per year. Around Kumasi, about 60,000 people are benefiting from dry-season irrigation (Cornish and Lawrence, 2001).

However, only a minority of peri-urban farmers shift to year-round vegetable farming (e.g. tomatoes in the Akumadan area). There are three reasons for this: the importance of maize and cassava for home consumption (mentioned by 52% of the farmers interviewed); the lower price of vegetables in the rainy season (40%); and the increased risk of pest attacks (8%). But those farmers who move to urban areas and take the risk take a remarkable step to overcome poverty. As shown in Table2.2

Table 2.2 Revenue generated in different farming systems

Location	Farming System	Typical Farm size (ha)	Net revenue per actual Farm size per year (US$)
Rural/peri-urban	Rain-fed maize or maize/cassava	0.5-0.9	200-450
Peri-urban	Dry-season vegetable Irrigation only	0.4-0.6	140-170
Peri-urban	Rain-fed maize combined with dry season, irrigated vegetables	0.7-1.3	300-500
Urban	Year-round irrigated vegetable farming	0.05-0.2	400-800

Source: Cornish and Lawrence (2001)

Urban vegetable farmers can double the maize – cassava income of their rural colleagues and move over the poverty line of one US$ per capita.

Individual food supply: Open-space cultivation of vegetables is usually for the market. This is especially the case for exotic vegetables while farmers who specialize in traditional vegetables might also consume a part of their produce.

Urban food supply: At the macro level, the contribution of urban agriculture to the Gross Domestic Product will be small, but the importance for certain commodities, as lettuce, cabbage, milk and poultry products might be substantial, especially if we consider up-and downstream activities (Cofie et al., 2003; Drechsel et al., 2006b). Nugent (2000) reported that urban agriculture can meet large parts of the urban demand for certain kinds of food such as fresh vegetables, poultry, potatoes, milk, fish and eggs. The proximity of production to consumption reduces traffic,(cold) storage and packaging, Food items like tomatoes, garden eggs and cassava as well as eggs and poultry meat are derived from the peri-urban area while staples, such as cocoyam, plantain, maize and rice come from rural areas or via import to the city markets in Kumasi. Another vital part of Kumasi's urban and peri-urban agriculture is poultry production, which is practiced by people from all social sectors. Vegetable farmers in and around Kumasi benefit from this, as it offers them access to cheap but high-quality organic fertilizers (Drechsel, 1996; Drechsel et al., 2000).

2.4 SOURCE OF IRRIGATION WATER

Irrigation water mostly consists of streams, hand-dug wells and drain water highly polluted with domestic grey water. A brief overview of some key features in Accra, Kumasi and Tamale is presented here:

In **Accra**, the main source of irrigation water is urban drains. The contents of these drains vary from raw wastewater as in Korle-Bu to storm water diluted waste water as in Marine Drive, though these change with seasons. In Dzorwulu, a polluted stream (Onyasia) is used in combination with pipe-borne water. Other than using a big drain that runs through Accra's La area, a few farmers there also use partially 'treated' wastewater' from the maturation pond of the stabilization pond between treatment systems belonging to the Burma military camp. Other farmers in La use piped water.

In **Kumasi**, polluted rivers and streams are the main sources of water for 70% of the farmers. None of the farmers interviewed used (raw) effluent directly from the source or sewage treatment plant. Very few cases (n< 5) were recorded where farmers, because they have no choice, use wastewater from drains. There is an extensive use of shallow dug wells on valley bottoms (27%), especially in the urban area. Of the 70 farmers interviewed, more than 75% said they use the source of water that is accessible and reliable. Piped water is not only expensive but is unreliable and in any case inaccessible to most farmers.

In Tamale, with no perennial stream and a long dry season, water is scarce. Some farmers end up using drain water. In areas like Kamina, farmers use wastewater from a broken sewage treatment plant and others at "Waterworks" use water from water supply dam, which has been abandoned due to water pollution (Drechsel et al., 2006).

2.5 IRRIGATION METHODS AND TECHNOLOGIES USED

Watering cans, buckets, motorized pumps with hosepipe, surface and sprinkler irrigation methods, as described below are being used in the study areas.

2.5.1 Watering Cans

This is the most common irrigation method used in all the study areas (Keraita et al., 2002b, 2003a). It is also the most precise one for fragile leafy vegetables. Farmers use watering cans to fetch and manually carry water from a water source, mostly shallow dug wells, streams or dugouts, to the fields, followed by watering of crops through the spout or shower head of the can (see Figure 2.1) making it an overhead irrigation method. In many cases, farmers carry two watering cans at a time. As men dominate irrigated urban farming, it is rare to see a woman with two watering cans. In peri-urban areas, where women are more common, they seem to prefer water fetching and application with buckets, often transported as head load. One watering can as used in Ghana has a capacity of 14-17 liters of water.

Figure 2.1: Irrigation of cabbage using watering can in Ayeduase New Site

Almost all farmers in the valley bottom of urban Kumasi use watering cans. Most of them have shallow dug wells on their farms and even for those who have to fetch water from streams, the distance is usually short (10-15m). Previous studies (Keraita, 2002, Cornish et al., 2001) showed that farmers closer to water sources tend to over-irrigate in absolute crop water requirements. However, farmers are trying to keep their leafy vegetables fresh, thus irrigation is just wetting the soil surface and evaporation losses are significant.

2.5.2 Bucket Method

In this method, bowls and buckets are used to fetch water, usually from a stream/river or dugout. It is then manually carried to the fields where it is either applied directly or put in a drum to be applied later. This practice mostly involves women and children carrying buckets as 'head loads' and is commonly done in the peri-urban areas. Here male farmers can easily involve family members and take advantage of the traditional role of women and children in transporting water. Farms are comparatively further from the water source than the ones where watering cans are used, but normally are less than 50m. The manner of watering (overhead or to the roots) is determined by crop height and type. Farmers using buckets and watering cans come in contact with water mainly by stepping in it while fetching, or water splashing on them while carrying and during watering. Crop contamination is very high due to the combination of crops with large surface area and overhead application (Drechsel et al., 2006).

2.5.3 Motorized Pumps

Motorized pumps are mostly seen in peri-urban areas, but also increasingly in Accra. A small motor pump is placed temporarily near a water source, usually the bank of river or a big stream and water is pumped through rigid plastic pipes or semi-flexible pipes which are connected to a flexible hosepipe at the end. Farmers use the hose to apply water to their crops either overhead or near the roots on the surface. In other cases, pumps helped to reduce transport ways: water was pumped into a dugout from where water was fetched with cans. In many cases where motorized pumps were used in Ghana, there were massive water losses with many pipes of inappropriate size or leaking. Farmers finally end up flooding fields along the pipelines and at the point of irrigation. More than one farmer is needed for the operation (e.g. one pumping, one irrigating). Irrigators are often fully wet as they try to fix the pump, pipes and direct the hose for irrigation. The fields are usually adjacent to the water sources and the pipes could be as long as 300m.

Due to the high velocity of water from the pipes, watering can be done overhead even for tall crops like mature garden eggs. As the water pressure and the hose would damage leafy vegetables, usually only high growing and stronger vegetables are irrigated in this way. Though the total amount of water applied per season using this method was high (5litres/second), the distribution and uniformity of application was poor. Pumps are hired from the 'wealthier' farmers for a constant fee per day (US$ 3-5 day in 2000). In order to make maximum use of their money on the day of hire, farmers end up over-irrigating the area's most accessible to the feeder hose, leaving other areas of the field under – irrigated. To reduce costs on labour, farmers in certain instances irrigate once in three weeks (for a 120 – day growth period) instead of once a week. They felt that this was sufficient for the crops but in reality such long cycles could affect crop productivity (Drechsel et al., 2006).

2.5.4 Surface Irrigation

Some form of surface irrigation, mainly furrow is being practiced in La in Accra. La farming area is a comparatively wider open space with a topography that allows for furrow irrigation. The source of water is a drain that runs from the nearby military camp to its treatment plant. Farmers have constructed an open and diversion channel to irrigate their plots downstream by furrows (fruity vegetables), or they divert water into dugouts from where they can fetch with a watering can (leafy vegetables). During the dry season, farmers raise the water level in the drain with sand bags and divert the water in a main canal, which conveys the water to the plots. Furrow irrigation can reduce contamination since crops are grown on ridges, but exposure to farmers is as high as with water fetching from streams and drains (Drechsel et al., 2006).

2.5.5 Sprinkler Irrigation

This method was seen in a few sites (behind Georgia Hotel in urban Kumasi and Dzorwulu in urban Accra). In both cases, the sprinkler system is connected to a pipe borne water source. Low cost materials were used, like bamboos as sprinkler risers etc. These systems are the portable type and farmers in Dzorwulu combine them with the watering can method. The fields were reasonably large but the crops grown were the same as in the other areas. In this case, irrigation water has both on and off farm effects (aerosolized particles) on crops, farmers and the environment (Drechsel et al., 2006).

2.6 WATER AND LAND PRODUCTIVITY

Leafy vegetables, which are the most commonly grown crops in irrigated urban agriculture, have higher and more regular crop water requirements compared to more traditional crops. According to Agodzo et al. (2003) irrigation water requirements of most vegetables grown in Ghana vary between 300 and 700 mm depending on the climatic conditions and crop species. As an extension service has limited training to support informal irrigation, farmers have learnt over time when and how much water to apply to their crops. When asked a question like "how do you know the amount of water to apply?" most urban farmers indicated that it was from 'hands-on-experience' mostly using soil and weather as indicators. Generally, most farmers irrigate in the mornings and evenings, saying that "it is cooler so we can more easily carry the water-load" which corresponds well with periods of low evapotranspiration rates, allowing other jobs during normal working hours (8am to 5pm).

Not all farmers can afford to buy irrigation equipment, like motorized or electrical pumps. However, neighborhood arrangements enable farmers to hire pumps on affordable terms. At Ayeduase, in Kumasi, for instance, most farmers only pay for the fuel of a local motor pump. Payment can also be made on flexible terms such as paying after selling the crop or by providing labour for the pump owner. Some farming sites have farmers associations to exchange labour and irrigation equipment.

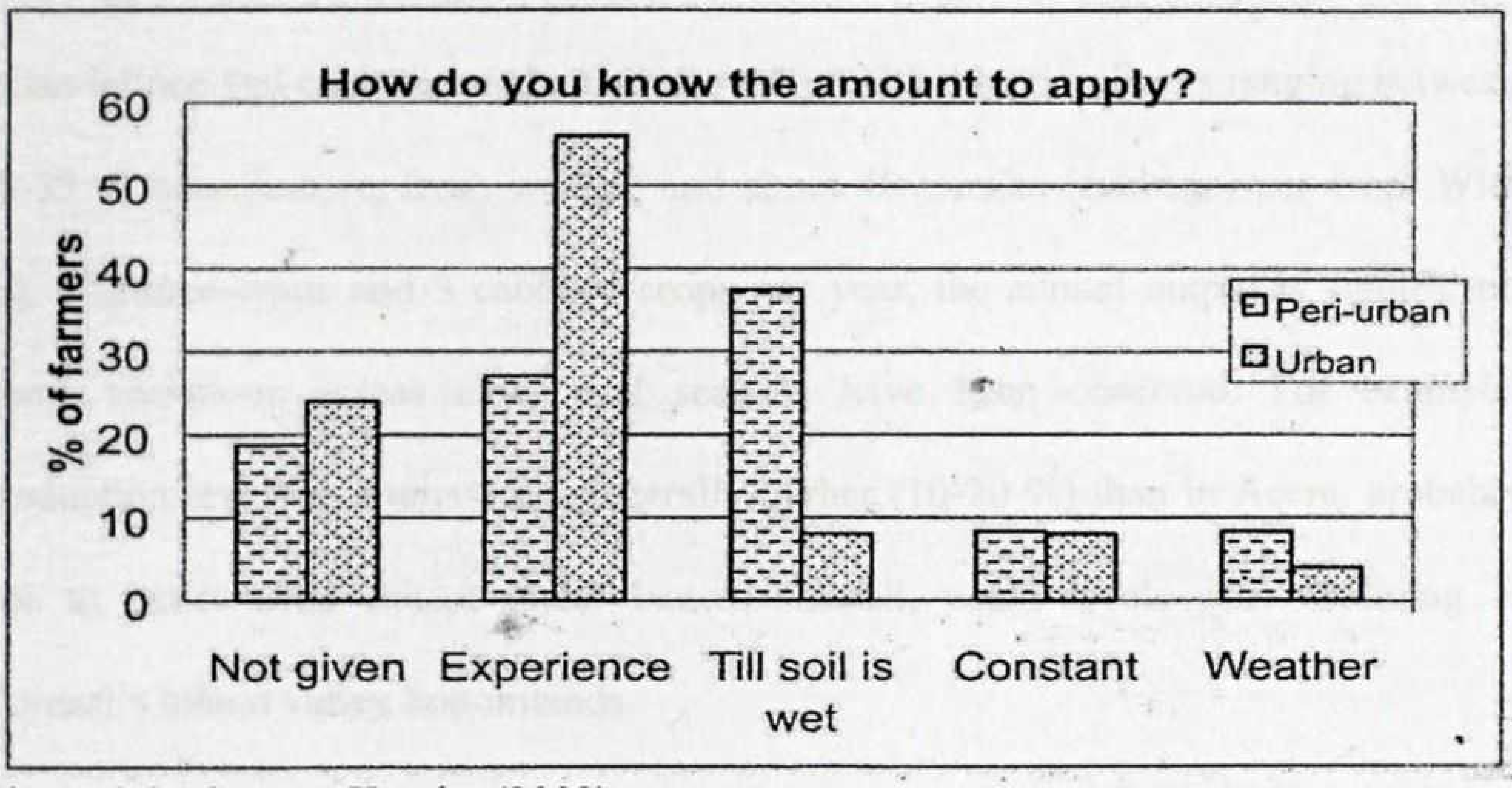


Figure 2.2: Source: Keraita (2002)

From field monitoring of water use, some farming sites in and around Kumasi showed a tendency towards over-irrigation in the urban areas by one-third of the irrigation water requirements and under-irrigation of the same magnitude in the peri-urban areas. Urban farms are much smaller (on average one-seventh) than peri-urban farms and farmers predominantly use watering cans for irrigation. Urban farmers achieve a more uniform spatial water distribution, though, because of the watering cans, and their irrigation intervals, which are regular. Peri-urban farmers use either buckets or motor pumps connected to water hoses. Peri –urban farmers have irregular irrigation intervals and poorer water distribution, especially those using hosepipes. As only a few peri-urban farmers own a pump, they wait for long periods 'queuing to hire a pump'. Subsequently it is quite common among these farmers to apply as much water as they can when the pump is available. The bucket method is laborious and depends on availability of women and children. This too contributes to irregular watering.

A good overview on tomato, garden egg, pepper, okra and onion production and yields in Ghana was provided by Nurah (1999), but few studies have been conducted on the productivity of vegetables common in Ghana's cities. Indicative studies on urban lettuce and cabbage production show typical production levels ranging between 20-35 tons/ha (lettuce, fresh weight) and about 40 tons/ha (cabbage) per crop. With e.g. 5 lettuce crops and 3 cabbage crops per year, the annual output is significant. Some variations across cities and seasons have been observed. For example, production levels in Kumasi are generally higher (10-20 %) than in Accra, probably due to better soils except under excess rainfall, when levels start declining in Kumasi's inland valley bottomlands.

2.7 THE ROLE OF IRRIGATION WATER IN AGRICULTURAL SYSTEMS

The role of irrigation water in agricultural systems is summarised as follows:

1. Sustains soil biological and chemical activity and mineralization during dry periods
2. In seasonally dry areas, irrigation water artificially extends the time period in which soil biological activity and nutrient release are elevated, creating more optimal growing conditions for cultivated crops
3. Promotes soil solution and nutrient uptake
4. Irrigation water becomes the medium in which soil nutrients are dissolved (soil solution) and through which nutrients are made available for plant uptake
5. Provides carbohydrate building block: $6CO_2 + 6\ H_2O \longrightarrow C6H_{12}O_6 + 60_2$

6. Through the process of photosynthesis, water molecules taken up by plants are broken down and their constituent atoms rearranged to form new molecules: Carbohydrates and oxygen
7. Provides plant structure/ support
8. Water molecules contained within the water-conducting vascular bundles and other tissues of plants serve to provide physical support for the plant itself
9. Promotes the maintenance of optimal temperatures within the plant
10. The loss of water through the process of evapotranspiration liberates heat from the plant, thereby regulating plant temperature (Dukes et al., 2012).

2.8 IRRIGATIONWATER REQUIREMENT

The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non-uniformity of water application. The irrigation water required takes into account the effectiveness of rainfall in the respective locations. For the vegetable crops grown, the requirement of water by the crop will range between 300 and 700mm depending on the climatic conditions and the season of the at the location .The Accra ,Kumasi and Tamale data presented in the table below are for irrigation projects at the Weija, Sata and Bontanga respectively (Agodzo, 1988).

Table 2.2 Crop Water Requirement for Accra, Kumasi and Tamale

Location	Crop	Cropping Season	Crop Water Requirements (mm)	Irrigation Water Requirements (mm)
Accra	Tomato	July – Nov/Dec	527	327
	Pepper	Sept – Dec/Jan	464	325
	Okra	March – June/July	367	23
	Aubergine	Sept – Dec/Jan	508	364
	Tinda	Apr – Jun/Jul	274	10
Kumasi	Okra	Dec – Mar/Apr	568	504
	Aubergine	Jan – Apr/Jul	521	140
	Water Melon	Dec – Febr/March	298	166
Tamale	Tomato	Oct – Jan/Febr	668	604
	Onion	Nov – Febr/March	678	581
	Okra	Nov – Febr/March	487	450
	Cabbage[a]	Oct – Jan/Febr	590	-

Source: Agodzo (1988).

For some farming activities that coincide with the major rainy season, irrigation water requirements could be next to nothing since almost all the crop water requirements could be met by rainfall. On the other hand, in the dryer months in the urban areas located in the dry savannah areas, irrigation water requirements per growing season could be as high as 600 mm as shown by the figures in Table 2.2. For farmers in the urban centers that depend on water from the drains, even though dry season farming could be more profitable, there could hardly be enough water to meet the crop water requirements. In some cases, wells are dug along the drains for a fairly constant supply of water. Some of the farmers use tap water for urban agriculture particularly those who operate home gardens.

2.9 EVAPORATION

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation (Allen et al., 1998).

2.10 TRANSPIRATION

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominantely lose their water through stomata. These are small openings on the plant leaf through which gases and water vapour pass. The water, together with some nutrients, is taken up by the roots and transported through the plant. The vaporization occurs within the leaf, namely in the intercellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant.

Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind. Hence, radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water logging and soil water salinity. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices. Different kinds of plants may have different transpiration rates. Not only the type of crop, but also the crop development, environment and management should be considered when assessing transpiration.(Allen et al., 1998).

2.11 EVAPOTRANSPIRATION (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (Allen et al., 1998).

2.12 CROP WATER REQUIREMENT

The term crop water requirement is defined as the "the amount of water required to compensate the evapotranspiration loss from the cropped field" (Allen et al.1988).The ICID (2000) describes it as the "water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield"."Although the values for crop evapotranspiration and crop water requirement are identical ,crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration"(Allen et al. 1998).The crop water requirement is also referred to as crop water need. The crop water need always refers to a crop grown under optimal conditions, i.e. a uniform crop actively growing, completely shading the ground free of diseases, and favourable soil conditions (including fertility and water).The crop thus reaches its full potential under the given environment.

The crop water need mainly depends on

1. The climate: in a sunny and hot climate need more water per day than in a cloudy and cool climate
2. The crop type: crop like maize or sugarcane need more water than crops like millet or sorghum
3. The growth stage of the crop: fully grown need more water than crops that have just been planted

2.13 IRRIGATION SCHEDULING

Irrigation scheduling consists simply of applying water to crops at the "right" time and in the "right" amount and it is considered an important Best Management Practice. The characteristics of the irrigation system, crop needs, soil properties, and atmospheric conditions must all be considered to properly schedule irrigations. Poor timing or insufficient water application can result in crop stress and reduced yields from inappropriate amounts of available water and/or nutrients. Excessive water applications may reduce yield and quality, and a waste of water, and increase the risk of nutrient leaching (Dukes et al., 2012).

2.14 SOIL MANAGEMENT

Plants depend on the soil for physical support and anchorage, nutrient and water. The degree to which the soil adequately provides these factors depends on topography, soil type and soil structure. Under cultivated conditions, soil management significantly influences the soils capacity to enhance plant growth and productivity.

Tillage is a general term for any operation that disrupts and/or moves the soil typically within254 to 305mm of the soil surface. Land preparation involves one or more tillage operations performed to make the soil more suitable for seeding and seedling (or transplant) establishment by providing the best soil structure for root growth and development. The root system development of cabbage leafy greens is influenced (and in many cases is limited) by the soil profile. If there is a hard pan, clay pan, compacted layer, or another dense formation of soil, root growth will be restricted. Cabbage and leafy greens are shallow rooted; under favourable conditions roots will grow to a depth of 457 to 610mm.Root development is severely limited by compacted soil, so proper land preparation should eliminate or significantly reduce soil compaction. Tillage with a mouldboard (bottom) plough provides the greatest soil volume conducive to vigorous root growth. This technique allows the development of more extensive root systems, which are more efficient extractors of nutrients and water from the soil (Mclaurin, Granberry, Chance, 1991).

Cabbage and leafy greens may be planted or transplanted on flat or raised beds. A raised bed will warm up more quickly and enhance earlier growth. Cabbage and leafy greens do poorly in excessively wet soils, so raise the bed to facilitate drainage and help prevent "wet" in low or poorly drained soils. However, cabbage or leafy greens planted on raised beds might require more irrigation during drought conditions .Lime fertilizer management is the application of optimal amount of lime and fertilizer (or nutrient containing material) at the most appropriate time(s and by the most effective method. Indirectly, fertilizer management is also concerned with cultural methods, tillage practices and cropping sequences that maximize usefulness (efficiency) of native soil fertility and applied plant nutrient (Mclaurin, Granberry, Chance, 1991)

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE RESEARCH AREA

Kumasi is the capital town of Ashanti Region and the second largest city in Ghana with a population of 1.3 million and an annual growth rate of 5.9% (Ghana Statistical Service, 2010). It is located 06^0 43'N and 01^0 43'W. Kumasi has a total area of 225km^2 of which about 40% is open land. Kumasi has a semi-humid tropical climate and lies in the tropical forest zone with an annual average rainfall of 1420mm with about 120 days on which it rains in the year. The rainfall pattern of the town is bimodal with the major season falling between March and July and a minor rainy season around September and October. The mean monthly temperature of the area ranges from 24^0C to 27^0C. Important streams and rivers include the Owabi River, which flows through the suburb of Anloga; Subin River, which passes through Kaasi and Ahensan; and Wiwi River, which runs through the local university campus (KNUST). Due to the hilly landscape of Kumasi, most streams run through inland valleys unsuitable for construction and of high value for urban vegetable production.

The areas which were used for the study are:

1 **Ayeduase New Site:** This farming site covers a large area and is located behind the buildings around Ayeduase New Site. It is situated in a valley and has about two female farmers. The land belongs to individuals.

2 **Boadi:** This farming site is located beside the road from Ayeduase to Boadi. There are about 20 farmers who cultivate cabbage, green pepper, spring onions and lettuce.

3 **KNUST Engineering:** The vegetable farms are located behind the main block of the College of Engineering at KNUST in an inland valley. This is the largest urban vegetable-farming site in Kumasi.

3.2 STUDY METHODS

The research was conducted by making reference to a wide range of related literature i.e, books, publications and journals at the KNUST School of Agriculture library and internet sources..

3.2.1 Methods for Data Collection

Data used in this study were collected mainly through field interview of 50 vegetable farmers on farm sites using semi-structured questionnaires on KNUST Campus (Engineering), at Ayeduase New Site and Boadi. In all 20 farmers were interviewed at Engineering, 20 farmers at Ayeduase New Site and 10 at Boadi. Field measurements and personal observations were made on the farms sites. The questionnaires involved the socio-economic and field irrigation practices on the farms. Detailed information of questionnaires can be found in the appendix 1.

3.2.2 Field data

The climatic data were taken from an existing Agro-meteorological Station at the Agricultural Engineering Department at KNUST. The following readings were taken: evaporation, amount of rainfall, wind speed, solar radiation minimum and maximum temperatures and humidity.

3.3 THE MAIN ACTIVITIES ON THE FARM

The main crops cultivated by most farmers were: lettuce, cabbage, spring onions and green pepper. Only few farmers cultivated carrots and other vegetables. The main sources of were streams and shallow wells. Majority of the farmers go to their farms as early as 6:30 a.m. and leave around 5:30 p.m. The main activities farmers engaged in are raising of beds, nursing of seedlings, transplanting of seedlings, turning of soil, weeding, application of manure or fertilizer and watering of crops.

3.4 CROP WATER REQUIREMENT

The FAO Penman-Monteith method is maintained as the sole standard method for the computation of ET_o (reference evapotranspiration) from meteorological data. This method was used to estimate values of ET_o for the selected crops from July to October 2012. Samples of this calculation are shown in the Appendix. In order to determine the water requirement for the crop the crop evapotranspiration (ETcrop), the reference crop evapotranspiration, ET_O, must be multiplied by the crop factor, Kc. The crop factor (or crop coefficient) varies according to the growth stage of the crop.

There are four growth stages to distinguish:

- The initial stage: when the crop uses little water
- The crop development stage, when the water consumption increases;
- The mid-season stage, when water consumption reaches a peak;
- The late-season stage, when the maturing crop once again requires less water.

3.4.1 Calculation of water applied by farmers

Water applied by farmers were computed as follows:

$$\text{Total Daily Irrigation} = \frac{K \times V \times N}{B} \quad \text{.......... 3.1}$$

$$\text{Net Daily Irrigation} = \frac{K \times V \times N \times AE}{B} \quad \text{.......... 3.2}$$

Where :

K = Number of cans of water per irrigation

V = Volume of can

N = Number of irrigations per day

B= Average bed size

AE = Assumed irrigation efficiency

3.4.2 Calculation of ETc

Crop evapotraspiration was computed as:

ETcrop = Kc×ETo..3.3

Since the values for ETo are normally measured or calculated on a daily basis (mm/day), an average value for the total growing season has to be determined and then multiplied with the average seasonal crop factor Kc.

3.4.3 Crop Water productivity

Crop Water productivity in terms of water applied is defined as

$$\text{CWP(water applied)} = \frac{\text{Crop yield (kg)}}{\text{water applied (m}^3\text{)}} \quad \text{.......... 3.4}$$

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 FIELD IRRIGATION PRACTICE

Data on field irrigation practices based on farmer interview and estimates are shown in Tables 4.1 and 4.2.

Table 4.1 Estimated irrigation amount based on interview with farmers (dry season)

rop	Ave bed size (m^2)	No of irr per day	Type of irrigation	Size of watering can (litres)	No. of cans of water /irr	Total irr water (litres)	Total irr water (mm/day)	Assumed irrigation efficiency	Net irr water (mm/day)	Seasonal irr Water (mm)
Lettuce	10.5×1.5	2	Watering can	14	10	280	17.8	80%	14.2	560
Cabbage	10.5×1.5	2	Watering can	14	12	336	21.3	80%	17.0	920
Spring onion	10.5×1.5	2	Watering can	14	9	252	16	80%	12.8	565
Green pepper	10.5×1.5	2	Watering can	14	8	224	14.2	80%	11.4	650
Carrot	10.5×1.5	2	Watering can	14	11	308	19.6	80%	15.7	840

Table 4.2 Estimated irrigation amount based on interview with farmers (wet season)

Crop	Ave bed size (m²)	No of irr per day	Type of irri	Size of watering can (litres)	No. of cans of water irr	Total irr water (litres)	Total irr water (mm/day)	Assumed irrigation efficiency	Net irr water (mm/day)	Seasonal irr water (mm)
Lettuce	10.5×1.5	2	Watering can	14	7	196	12.4	80%	9.9	425
Cabbage	10.5×1.5	2	Watering can	14	10	280	17.8	80%	14.2	750
Spring onion	10.5×1.5	2	Watering can	14	8	224	14.2	80%	11.4	475
Green pepper	10.5×1.5	2	Watering can	14	6	168	10.7	80%	8.6	560
Carrot	10.5×1.5	2	Watering can	14	9	252	16	80%	12.8	650

Daily irrigation amounts range between 11.4 and 17.0 mm during the dry season and between 8.6 and 14.2 mm for the wet season. From the Tables for the same average bed size cabbage requires the greatest quantity of water whilst green pepper requires the least amount of water.

4.2 IRRIGATION METHODS

Three irrigation methods were observed during the survey as practised by the farmers. The use of watering cans was very common whilst the use of motorized pumps and hoses for irrigation was the least, (Figure 4.1). From the interview with the farmers it was realized that they hire the pumps from the owners (usually fellow farmers). It was observed that during the dry season, farmers hired labour to fill drums with water and then use buckets and bowls to fetch to irrigate their crops. It must be noted that since most farmers use watering cans and buckets, field water computations were based on this method only.

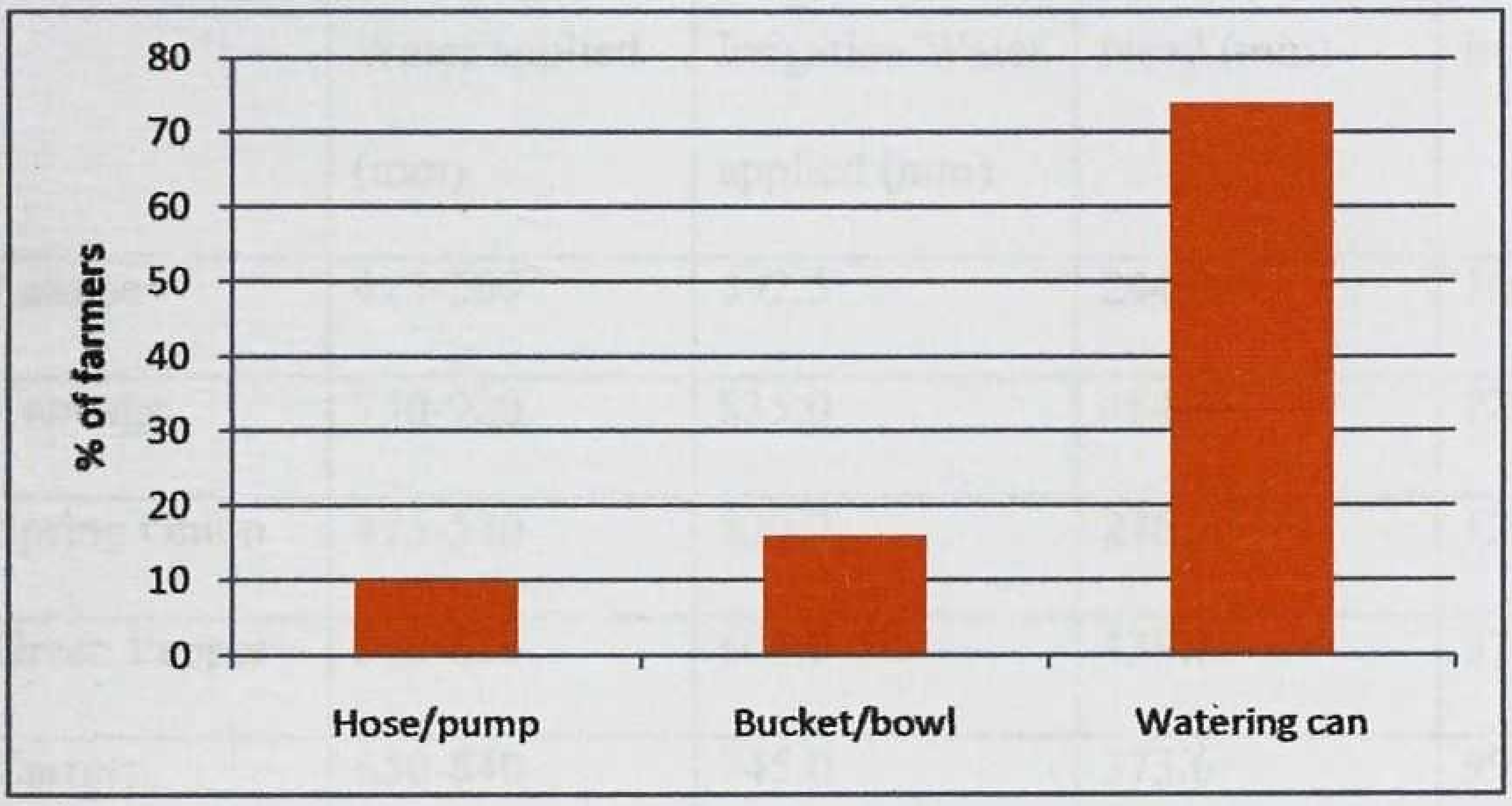


Figure 4.1: Irrigation methods used

About 74% of the farmers use watering cans to fetch water from the wells or streams which they carry to their farms for irrigation. Irrigation of crops takes a greater portion of farming activities on the farm. Farmers use the same irrigation method when applying water to different crops.

Some of the farmers at the college of Engineering use pumping machines quite often, especially in the dry season. It was observed that the farmers use about 5 litres of petrol per irrigation. There are few farmers who irrigated three times a day during the dry season due to the soil texture of the soil.

4.3 IRRIGATION WATER APPLIED AND CROP WATER NEED

Data on amount of irrigation water applied and the water requirement for the crop is presented in Table 4.3.

Table 4.3: Irrigation water applied and crop water need compared

Crop	Irrigation Water applied (mm)	Median Irrigation Water applied (mm)	Crop Water Need (mm)	Percent Over Irrigation
Lettuce	425-560	492.5	244.2	102.0
Cabbage	750-920	835.0	484.8	72.0
Spring Onion	475-530	520.0	236.4	120.0
Green Pepper	560-650	605.0	438.7	37.9
Carrots	650-840	745.0	373.6	99.4

4.3.1 Lettuce

The irrigation water applied by the farmers for lettuce ranged between 425 mm and 560 mm averaging at 492.5 mm. Compared with the computed standard values for the location studied, the irrigation water requirement should be 244.2 mm. The required irrigation water is 248.3 mm lower than what the farmers applied.

4.3.2 Cabbage

The irrigation water applied by the farmers for cabbage ranged between 750 mm and 920 mm averaging at 835 mm. Compared with the computed standard values for the location studied, the irrigation water requirement should be 484.8 mm. The required crop water need is 350.2 mm lower than what the farmers applied.

4.3.3 Spring Onion

The irrigation water applied by the farmers for onion ranged between 475 mm and 565 mm and averaging at 520 mm. Compared with the computed standard values for the location studied, the irrigation water requirement should be 236.4 mm. The required crop water need is 283.6 mm lower than what the farmers applied.

4.3.4. Green Pepper

The irrigation water applied by the farmers for cabbage ranged between 560 mm and 650 mm averaging at 605 mm. Compared with the computed standard values for the location studied, the irrigation water requirement should be 438.7 mm. The required crop water need is 166.3 mm lower than what the farmers applied.

4.3.5 Carrot

The irrigation water applied by the farmers for carrot ranged between 650 mm and 840 mm averaging at 745 mm. Compared with the computed standard values for the location studied, the irrigation water requirement should be 373.6 mm. The required crop water need is 394.8 mm lower than what the farmers applied.

From the above discussions the crop water requirement for the selected crops are far less than the irrigation water requirements. It could be concluded that there was over application of water during the observation period. According to the farmers they applied enough water to the crops to prevent crop failure. They do not have any scientific way of checking the amount of water to apply to the crop.

4.4 SOURCES OF WATER USED FOR IRRIGATION

From Figure 4.2 it is clear that majority of the farmers use shallow wells. There is also some extended use of dugout wells near the streams.

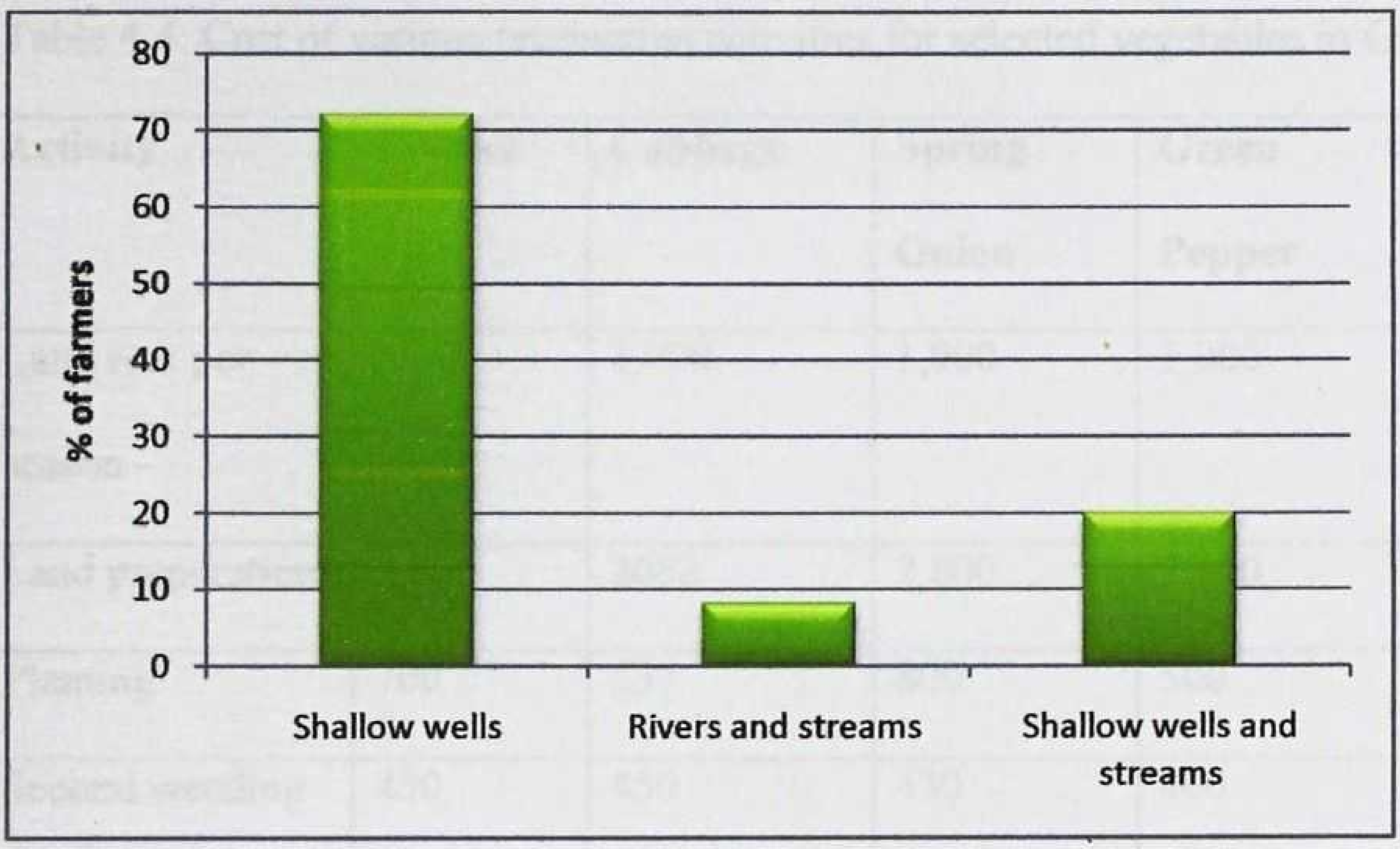


Figure 4.2 Source of water used for irrigation

More than 75 % of the farmers interviewed said that they used the source of water that accessible, available and reliable. From the table it could be observed that only 8 % of the farmers fetch water from streams and rivers using buckets and bowls. During the survey no farmer was seen using pipe-borne water because the farmers say it is not only expensive but inaccessible and unreliable.

4.5 COST OF PRODUCTION PER HECTARE OF CROP PER SEASON

The cost of production for the various activities on the farm for the selected vegetables is shown in Table 4.4

Table 4.4: Cost of various production activities for selected vegetables in GH¢

Activity	Lettuce	Cabbage	Spring Onion	Green Pepper	Carrot
Land rent per season	1,000	1,000	1,000	1,000	1,000
Land preparation	2,600	2688	2,800	2,400	2,800
Planting	700	537	800	500	600
Second weeding	430	450	430	400	470
Chemicals	1,500	1,828	1440	1,400	1,650
Seeds	538	1022	5300	268	900
Irrigation	400	600	550	450	550
Harvesting	320	300	350	300	400
Transportation	215	200	200	200	200
Total (Gh Cedis)	7,703	8,625	12,520	6,918	8,570

The cost of production for lettuce, cabbage, spring onion green pepper and carrot are shown in Figure 4.3

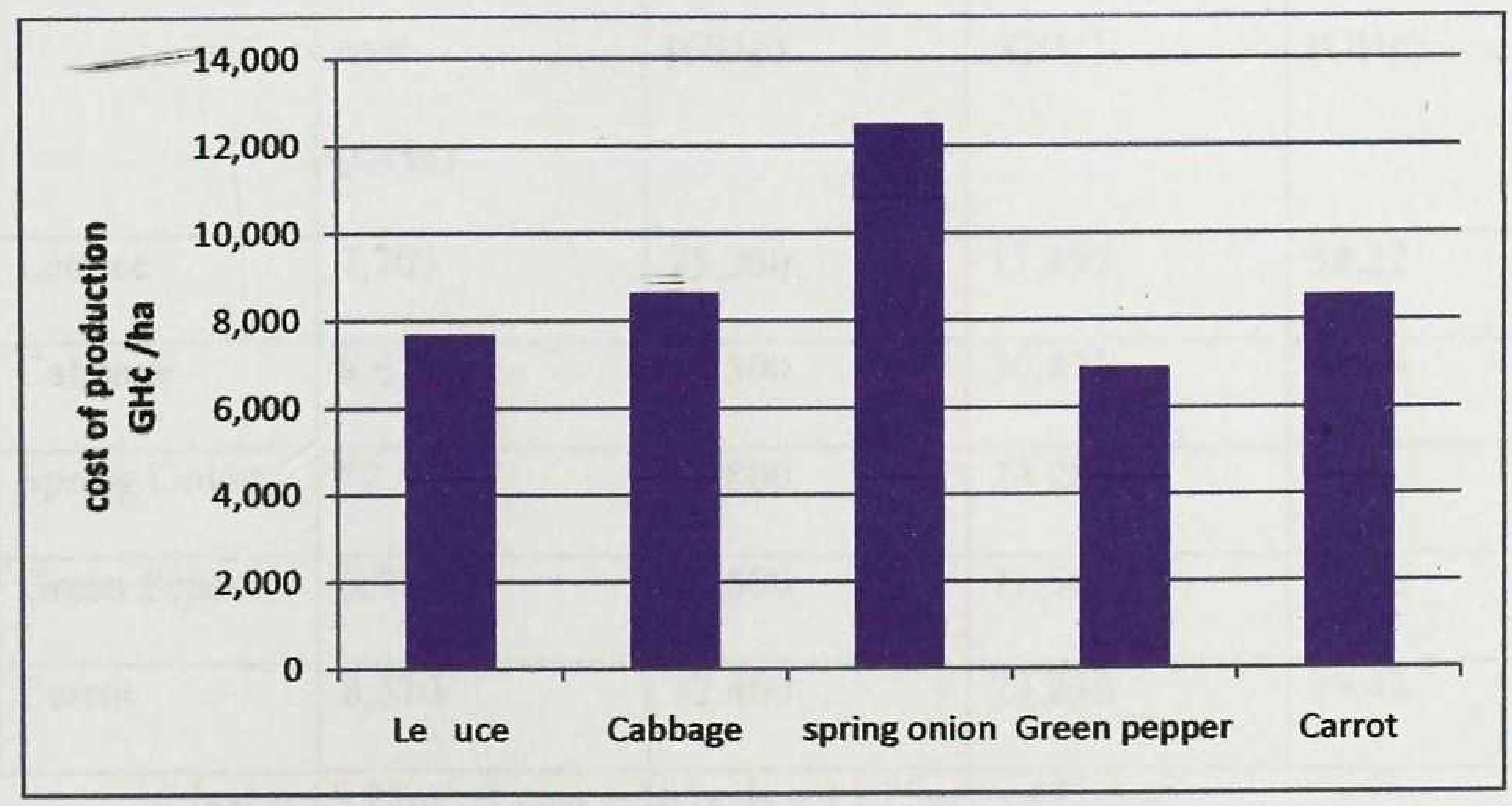


Figure 4.3: Cost of production for selected vegetables

It is clear that the cost of production of spring onions (GH¢ 12,520 /ha) has the highest amount per hectare whilst green pepper (GH¢6918/ha) takes the least. This high cost of production for spring onions is due to the high cost of spring onion seedlings. For all the crops land preparation takes the highest percentage of the total cost followed by chemicals, whilst transportation takes the least. The amount spent on land rent is about GH¢ 3000 per annum but since farmers usually cultivate the vegetables three to four times a year the amount spent on land seasonally is about GH¢ 1000 per hectare. Most of the farmers hire the land for the cultivation of vegetables on plot basis from individual land owners. It must be noted that these costs computed on per hectare basis appear substantial but considering the small patches of land use by the vegetables farmers the monies involved are relatively small and can be afforded by the farmers.

4.5 COST AND BENEFITS OF IRRIGATED VEGETABLE PRODUCTION

Data on the cost of production, revenue obtained and profit accruing from the production of the selected vegetables is presented in Table 4.5.

Table 4.5: Cost and benefits of irrigated vegetable production

Crop	Production cost (GH¢)	Revenue (GH¢)	Profit/ha (GH¢)	Profit/bed (GH¢)
Lettuce	7,703	25,200	17,497	58.32
Cabbage	8,625	39,500	30,875	102.9
Spring Onion	12,520	40,800	28,280	94.3
Green Pepper	6,918	18,500	11,582	38.60
Carrot	8,570	32.400	23,830	79.43

1 bed = $15.75m^2$; 1 plot = 30 beds × $15.75m^2$ = $472.5m^2$

From Table 4.5 the cost of production of spring onions is the highest followed by cabbage and then lettuce with the least being green pepper .Even though revenue obtained from the sale of spring onions is the highest, being GH¢40,800, the highest profit was obtained from the production of cabbages. Profit obtained from the production of green pepper is the least. Few farmers go into the production of green pepper because the profit obtained is very small. Green pepper is normally cultivated along the side of beds which are specially prepared for the other vegetables. In this survey there are about 300 beds per hectare and the area of a bed is about 15.7 m^2. It was observed during the survey that majority of the farmers cultivated either cabbages or spring onions. According to the sizes of the beds which were used for the study there are about 30 beds per plot. A farmer who cultivates only green pepper cannot make ends meet because his profit for the season of four months will be GH¢1,158 which has an average of GH¢290 per month. It will be realized that a farmer who cultivates cabbages can break even because the profit he makes during the growing season is about GH¢3,090 per plot. That means he earns about GH¢772 per month which is quite reasonable taking into consideration a family of about five.

4.6 CROP WATER PRODUCTIVITY PER HECTARE

The values of the crop water productivity of the selected vegetable crops have been presented in Table 4.6

Table 4.6Crop Water productivity of selected crops

Crop	Yield per bed (kg)	Yield per ha (kg)	Depth of water applied per bed (mm)	Volume of water applied per bed (m^3)	Computed crop water productivity (kgm^{-3})	*Expected crop water productivity (kg/m^3)
Lettuce	150	45,000	492	7.75	19.4	8.0-25.0
Cabbage	200	60,000	835	13.15	15.2	10.0-15.0
Spring onion	130	54,000	520	8.19	21.9	12.0-20.0
Green pepper	60	18,000	605	9.53	6.30	6.0-10.0
Carrot	250	75,000	745	11.73	21.31	10.0-20.0

*Sources: National Institute of Industrial Research (2011); Obeng-Ofori et al. (2007)

The computed crop water productivity for the selected vegetables are presented in the above table. Spring onion have the highest crop water productivity of 21.9 kg/m^3 followed by carrot while the least is green pepper with a value of 6.3 kg/m^3. The seasonal water applied to spring onion was 520 mm depth of water in the cropping season. It could be concluded that spring onion has the highest water use efficiency. Crop water productivity value obtained for carrot was the next higher value. It was realized that very few farmers cultivated carrots because of the difficulty in the marketing of the produce. Even though spring onion has the highest crop water productivity its cultivation is very laborious since the plant is very tender and needs a lot of care especially when watering and during the time of transplanting. The crop water productivity value obtained for green pepper is very low because the fruit is very light in weight. Here the market women buy this produce at very price from the farms but retail it high price. In this survey it was realised that no amount of money was spent on water for irrigation of the crops. Sometimes during dry seasons when there is shortage of water farmers do pay for water for irrigation.

4.7 SOCIO-ECONOMIC SURVEY

4.7.1 Gender

Fifty (50) farmers surveyed according to gender are shown in Table 4.6

Table 4.6 Gender

Gender	Frequency	Percent
Male	46	92
Female	4	8
Total	50	100

It could be seen that men dominate in vegetable farming. About 8% of the 50 farmers interviewed were female.

Women farmers usually employ labour, especially in land preparation and watering of crops. Women play a major role in the marketing of the vegetables. Traders usually go to the farms to purchase the vegetables, send them to the market centers and retail. Green peppers are sold using plastic containers or plastic buckets or fertilizer bags. Lettuce are sold on wholesale or sold per beds. Cabbages are sold per bag or per bed.

4.7.2 Age distribution of farmers

Figure 4.6 gives a summary of the age distribution of the farmers. Seventy percent (70 %) of the farmers fall within the ages of 20 and 40. This group represents those in the working class who migrate to the urban centers to look for white - collar jobs and end up in vegetable farming.

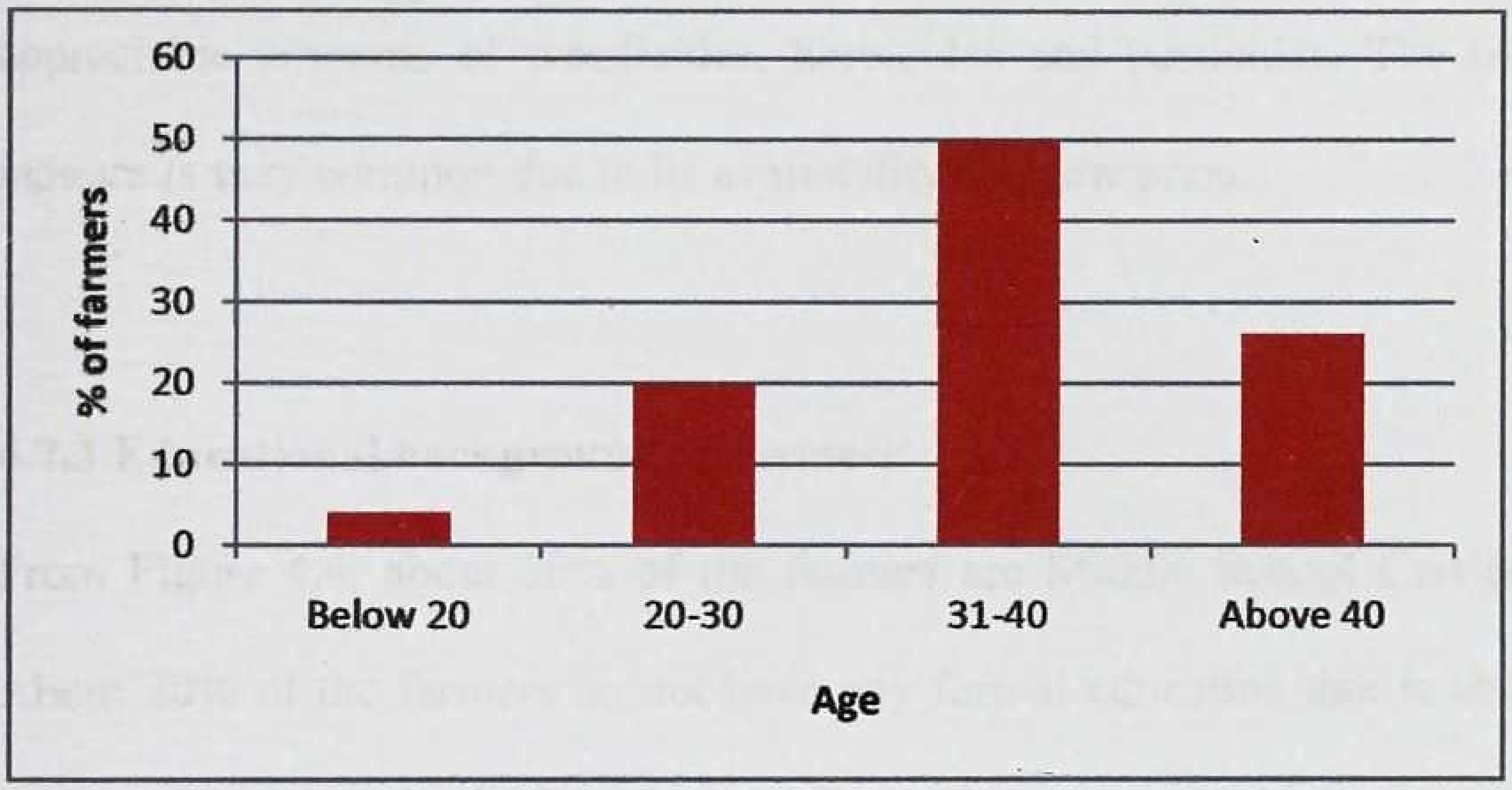


Figure 4.6 Age distribution of farmers

In the survey it was realized that farmers who cultivate vegetables in the urban areas do not have big farms. In urban areas vegetable farming is not a family business but rather an individual enterprise. In the urban centers, majority of the farmers specialize in the exotic and leafy vegetables which can provide very high revenues on the urban market. Vegetables which are mostly cultivated are cabbage, lettuce, green pepper and spring onions. The farmers cultivate all year round where most of them do manual irrigation and vary crops according to their specialization and market demand. In the KNUST Engineering area most of the farmers rent plots of land which are meant for building purposes. Formerly most of these lands were rented for free but now the lands are rented for a fee that ranges between 200 and 300 Ghana cedis. It was realised that land for vegetable farming is becoming unavailable because the rate at which buildings are being put up is high.

It was realised through interviews and observation that farmers experience water shortage during the dry season, the reason being that most of the wells are shallow and easily dry up when the rains stop. Besides water, vegetable farmers also use appreciable amounts of weedicides, herbicides and pesticides. The use of poultry manure is very common due to its availability and low price.

4.7.3 Educational background of farmers

From Figure 4.4, about 50% of the farmers are Middle School Certificate holders. About 30% of the farmers do not have any formal education that is about a third of the total. Some of the JHS graduates who could not pursue further education because their parents could not afford made up of 12%. The Senior High School certificate holders are few because most people who attended S.H.S. would like to further their education. The majority of the youth usually migrate to the urban areas to look for job opportunities.

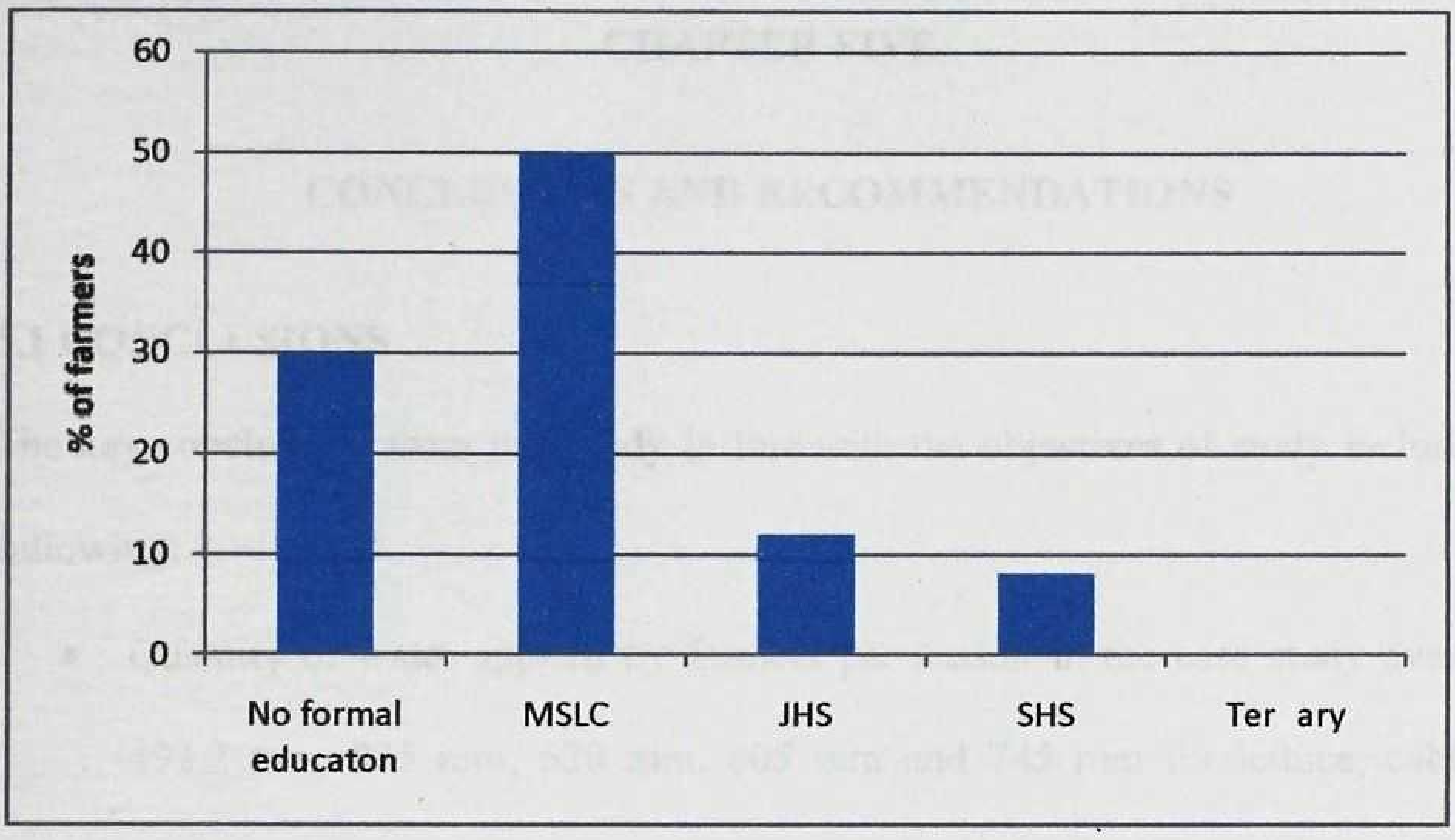


Figure 4.4: Educational background of farmers

4.7.4 Challenges in the urban vegetable farming

The farmers identified the following challenges in the urban vegetable farming:

i. Marketing of produce: Vegetable market women/sellers dictate prices of produce at harvest on the farm
ii. High cost of inputs (pesticides, farm labour, fertilizer, seeds, gum boots and watering cans)
iii. Lack of available land tenure security due to the increasing rate of urban development
iv. High labour cost of watering of vegetables
v. Non-availability of extension services
vi. Lack of capital funding for land clearing, purchase of seeds and farming implements.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The key conclusions from this study in line with the objectives of study include the following:

- Quantity of water applied by farmers per season in the case study averaged 492.2 mm, 835 mm, 520 mm, 605 mm and 745 mm for lettuce, cabbage, spring onion, green pepper and carrots respectively.
- There was consistent and persistent over-irrigation under farmer practices for all crops. Percentage over-irrigation ranged from 38 to 120%. Farmers could well have saved on water, time and work done in water delivery if they were better informed.
- Crop water productivity values obtained in the case study were 19.2, 15.2, 21.9, 6.3 and 21.3 kg/m^3 for lettuce, cabbage, spring onion, green pepper and carrots respectively.
- Cost of production computed on per hectare basis has been high and could reach GH¢ 12,520 for spring onions. Computed on the basis of an average bed size of 15.75 m^2, the cost of production of spring onion was GH¢41.70 per bed. Since the land areas cultivated were small, the farmers could afford such costs. A plot of land rented is made up of 30 beds suggesting a production cost for spring onion of about GH¢417 per plot. Similarly profits accruing for lettuce, cabbage, spring onion, green pepper and carrots were GH¢17,497, GH¢30,875, GH¢28,280, GH¢11,582 and GH¢23,830 per hectare. On the basis of a plot size of 30 beds per plot the profits were GH¢

58.320GH¢102.90, GH¢94.30 GH¢38.60 and GH¢79.43 for lettuce, cabbage, spring onion, green pepper and carrots respectively.

5.2 RECOMMENDATIONS

The urban irrigated vegetable farmers have been persistent and consistent in carrying out their vocation based on experiences accrued over a period. The study showed that there has been over-irrigation of all crops. Given that time, water and energy savings could have been made if appropriate knowledge was applied to the irrigation; it is recommended that future studies should concentrate on improving irrigation efficiencies at the farm levels.

REFERENCES

1. Agodzo, S. K. (1980). Water management study of six selected irrigation projects in Ghana .FAO-GIDA Project, KNUST, Kumasi, Ghana

2. Agodzo, S. K., Huibers, F. P., Chenini, F., van Lier, J. B. and Duran, A. 2003. Use of wastewater in irrigated agriculture. Country studies from Bolivia, Ghana and Tunisia.Volume 2: Ghana. Wageningen: WUR, 2003. (www.dow.wau.nl/iwe)

3. Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). Crop Evapotranspiration: Guidelines for Computing Crop water Requirements, FAO Irrigation and Drainage paper 56.

4. Augus, J. F. and A. F. van Herwaarden (2001). Increasing water use and water use efficiency in dry land wheat. Agron. J., 93, pp. 290-298.

5. Augus, J. F., H.A. Nix, J. S. Rusell and J. E. Kruizinga (1980). Water use, growth and yield of wheat in subtropical environment Aust. J. Agric. Res., 31,pp. 669.710

6. Bastiaassen, W., G. J. C. van Dam, P. Droogers and R. S. Malik (2003). Water productivity of irrigated crops in Sirsa District, India. Integration of Remote Sensing, Crop and soil Models and Geographical Information Systems .pp. 11-20

7. Blumenthal, U. J. D Mara, A. Peasy, G. Ruiz-Palacias and R. Scott, (2001). Reducing the health risks of using wastewater in agriculture. U.A.M, VOL, No.3. RUAF, Leusden, the Netherlands

8. Briggs, L. J. and H .L. Shantz (1916). Daily transpiration during the normal growth Period and its correlation with the weather J. Agric Res (Washington, DC), 7. pp. 155-212

9. Burke, S., M. Mulligan and J. B. Thornes (1999). Optimal Irrigation efficiency for maximum plant productivity and minimum water loss. Agric. Water Management, 40 (2/3) , pp. 377-391.

10. Cai, X. L and B. R. Sharma (2010). Integrating remote sensing, census and weather data for an assessment of rice yield, water consumption and water productivity in the Indo-Gengetic river basin. Agricultural Water Management 97(2): 309-316

11. Cofie, O.O., R. van Veenhuizen, and P. Drechsel. (2003). Contribution of urban and peri-urban agriculture to food security in Sub-Saharan Africa. Paper presented at the Africa Day of the 3rd WWF in Kyoto, 17-3-2003.

12. Cornish, G A. and P. Lawrence. (2001). Informal irrigation in peri-urban areas: A summary of findings and recommendations, DFID's Water KAR Project R7132, Report OD 144, HR Wallingford, Wallingford, UK, pp 54.

13. CTA (Technical centre for Agricultural and Rural cooperation). (2005). Feeding the town: A weighty dilemma. SPORE 117: 4-5. Wageningen: Technical centre for Agricultural and Rural Cooperation ACP-EU.

14. Cuenca, R. H. (1989).Irrigation system design (An engineering approach).Department of Agricultural Engineering, Oregon State University. Prentice Hall, Englewood Cliffs, New Jersey 07632, pp.1.

15. De Wit, C. T. (1958).Transpiration and Crop yields, Versl. Landbouwk, Onderz. 64.6 Inst. Of Biol. and Chem. Res. On field Crop and Herbage, Wageningen, The Nether lands.

16. Dongus, S. (2000). Vegetable production on open spaces in Dares Salaam-. Spatial changes from 1992-1999. City Farmer, Chanda.

17. Drechsel, P, S. Graefe, and M. Fink. Forthcoming (2006b). Rural-urban food, nutrient and water flows in West Africa. IWMI Report.

18. Drechsel, P. (1996). AFRICALAND - Applied research for peri-urban areas. IBSRAM Newsletter 42:5-7

19. Drechsel, P., R. C. Abaidoo, P. Amoah, and O.O. Cofie (2000). Increasing use of poultry manure in and around Kumasi, Ghana: Is farmers' race consumers' fate? Urban Agricultural Magazine 2:25-27.

20. Dukes, M. D., L. Zotarelli, G. D, Liu and E. H. Simmone. (2012). Principles and Practices of Irrigation Management for Vegetables.(University of Florida),pp,18

21. French, R. J. and J. E. Schultz (1984). Water use efficiency in wheat in a Mediterranean type environment: II. Some limitation to efficiency. Aust. J. Agric. Res., 35 , pp. 765–775.

22. Hanks, R. J., H. R Gardiner and R. L. Florian (1969). Plant growth evapotranspiration relations for several crops in the central Great Plains. Agron.J.61. pp . 30-34

23. Howell, J. A. (2001). Enhancing water use efficiency in irrigated agriculture. Agronomy Journal 93. pp. 281-289

24. Howell, T. A., R. H. Cuenca and K .H. Solomon (1990).Crop yield response. G. J. Hoffman (Ed.) *et al.*, Management of Farm Irrigation Systems, Am. Soc. Agric. Eng. (ASAE), St. Joseph, MI , pp. 93–122.

25. Kadigi, R. M. J., J. Kashaigilli and N. S. Mdoe (2004). The economics of irrigated paddy in Uaangu Basin in Tanzania: Water utilization, productivity in come and livelihood implications Physics, Chemistry. Earth 29 (2004), pp. 1091-1100.

26. Kasam, A. and M. Smith (2001): FAO Methodologies on Crop Water use and Crop Water Productivity.- Expert meeting on crop water productivity, Rome 3-5 December 2001 pp.18

27. Kemble, J. K. (2000).Basics of Vegetable Crop Irrigation. Auburn University: D.C. Sanders Extension Horticultural Specialist.

28. Keraita, B. N. (2002). Wastewater use in urban and peri-urban agriculture in Kumasi, Ghana: A study on the use of wastewater in vegetable farming, including

human perception, socio-cultural, legal and political factors. MSc thesis, Wageningen University, Environmental Sciences, Irrigation and Water Engineering Group, The Netherlands.

29. Keraita, B., G. Danso, and P. Drechsel (2003a). Urban irrigation methods and practices in Ghana and Togo. Urban Agriculture Magazine 10: 6-17

30. Keraita, B., P. Drechsel, F. Huibers, and L. Raschid-Sally. (2002b.) Wastewater use in informal irrigation in Urban and Peri-urban areas of Kumasi, Ghana. Urban Agriculture Magazine 8: 11-13

31. Kline, J. W; R. Barker and D. Molden (2003). Water productivity in agriculture: limits and opportunities for improvement. Wallingford UK: CABL; Colombo, Sri Lanka: LWMI. 332P.

32. Molden, D. (1997). Accounting for water use and productivity, SWIM paper1. Colombo, Sri Lanka: International Irrigation Management Institute.

33. Molden, D., C. de Fraiture and F. Rijsberman (2007). The Comprehensive Assessment of water Management in Agriculture: Water Scarcity. The food Factor. Issues on Science and Technology, 2007 Summit 39-48.

34. Molden, D., R. Sakthivadivel, C. J. Perry, C. de Fraiture and W. H. Kloezen (1998). Indicators for comparing performance of irrigated agricultural systems. Research Report 20. International water Management Instituted, Colombo, Sri Lanka.

35. Musick, J. T., O. R. Jones, B .A. Stewart and D. A. Dusek (1994). Water – yield relationships for irrigated and dry land wheat in the US Southern. Agronomy Journal 86. pp. 980-996

36. National Institute of Industrial Research (2011). Cultivation of tropical, subtropical, vegetables, spices, medicinal and aromatic plants. NIIR, 106-E, Nagar, Delhi -110007, India.

37. Nurah, G. K. (1999). Baseline study of vegetable production in Ghana. NARP Report, pp 151, KNUST, mimeo.

38. Obuobie, E., B. Keraita, G. Danso, P. Amoah, O. O. Cofie, L. Raschid-Sally, and P. Drechsel. (2006). Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. IWMI-RUAF-CPWF, Accra, Ghana: IWMI, pp.150.

39. Obeng-Ofori, D., E. Yirenkyi and J. Ofosu-Anim (2007). Vegetable and spice crop production in West-Africa. City Publishers.

40. Obuobie, E., B. Keraita, G. Danso, P, Anwah, O. O. Cofie, L. Raschid- Sally and P. Drechsel (2006). Irrigated urban vegetable production in Ghana: Characteristics, benefits and risk. IWMI-RUAF-CPWF, Accra, Ghana

41. Richards, A.E.V. (1923). The water requirements of farm crops J. Dep. Agric. Victoria Australia,21(1933) 193-212, 257-284, 321-339, 449-477

42. Sakthivadivel, R., C. de Fraiture, D. Molden, C. Perry and W. Kloezen (1999). Indicators of land and water productivity in irrigated agriculture. Int. J. Water Res. Dev., 15 (1/2) (1999), pp. 161–179

43. Sinclair, T. R., C. B. Tanner and J. M. Bennett (1984). Water use efficiency in crop production Bio Science 34. pp. 36-40

44. SWMRG (2003). Comprehensive assessment of water resources of Mkoji Sub- catchment, its current uses and productivity. FNPP-Soil Water Management Research Group Report,p.113

45. Tuong, T. P., P. P. Pablico., M. Yamauchi, R. Confessor and K. Moody (2000). Increasing water productivity and weed suppression of wet seeded rice. Effect of water management and rice genotypes Exp. Agric

46. Viets, F. G. (1962). Fertilizer and the efficient use of water .A.G. Norman (Ed.), Advances in Agronomy Journal (vol.14) .Academic Press, New York.

47. Williams, C.N., J. O. Uzo and W. T. H. Peregrine (1991).Vegetable Production in the tropics. Vinlin Press Sdn. Bhd., Sri Petalin, Kuala Lumpur, Malaysia.

48. Zhang, H and T. Owie. (1999).Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agric. Water Manage., 38 pp. 195–211

APPENDICES

APPENDIX I: SAMPLE OF QUESTIONNAIRE

INFORMATION ON FARMERS

1. Date: ……………………………………………………………………

2. Location of farm: …………………………………………………….

3. Name: ……………………………………………………………...

   Sex: (F)   (M)

4. Age of Farmer: ……………………………………………………..

5. Social status: (a) House   (b) Means of transport

   (i) Renting   (i) Motor bike

   (ii) Landlord   (ii) Bicycle

   (iii) Car

6. Occupation: ………………………………………………………

7. Level of education   (a) M.S.L.C   (b) J.H.S   (c) S.H.S   (d) Illiterate

8. What crops do you cultivate? ………………………………………….

9. Family size (number) ………………………………………………..

10. Number of children in school: ………………………………………

11. Levels of education of children

    (a) Primary   (b) Junior High School (JHS)   (c) Senior High School (SHS)

    (d) Post SHS   (e) Tertiary

	PRIMARY	J.H.S	S.H.S	POST S.H.S	TERTIARY
No. of children					

Tick as appropriate

12. Which crops do you cultivate on your farm?

CROP	DRY SEASON	WET SEASON
Lettuce		
Cabbage		
Spring onion		
Green pepper		
Carrots		
Others		

13. How many times do you water each crop per day?

CROP	DRY SEASON				WET SEASON			
Lettuce	1x	2x	3x	4x	1x	2x	3x	4x
Cabbage								
Spring onion								
Green pepper								
Carrots								
Others								

14. What is your source of water?

a. shallow well b. deep well c. stream/river d. pipe

15. Do you experience shortage of water during the dry season?

a. Yes b. No c. sometimes

16. How do you irrigate your crops? a. watering can b. sprinkler

c. pump d. other specify: ………………

17. How many cans of water do you apply to each crop?

CROP	NO. OF CANS	
	DRY SEASON	WET SEASON
Lettuce		
Cabbage		
Spring onion		
Green pepper		
Carrots		
Others		

18. How close is your farm to a source of water

a. less than 10m b. 11-50m c. 51-100m d. 100m

b. If can are used to water, what average distance is covered?

a. less than 10m b. 11m-50m c. 51m-100m d. more than 100m

19. How many cans of water do ~~you carry~~ per trip?

a. One b. two

If so, why? ....

20. FILL THE TABLE BELOW

	DRY SEASON				WET SEASON			
CROPS	Nursing period	Transplanting period	Growth period	Harvesting period	Nursing period	Transplanting period	Growth period	Harvesting period
Lettuce								
Cabbage								
Spring onions								
Green pepper								
Carrots								
Others								

21. What is the volume of your water can? (measurement) ....

22. What is the average size of the bed? (measurement) ....

23. What problems do you encounter with the kind of water you are using to irrigate you crops?

....

....

....

24. How best do you think you can manage your sources of water?

....

....

....

25. Do you receive any advice from any organization or individual?

(a) Yes (b) No If yes, what kind of advice? ……………………

26. How long have you been cultivating these crops?

Crop	Number of months/years
Lettuce	
Cabbage	
Spring onion	
Green pepper	
Carrots	
Others	

27. WET SEASON

Crops	No. of beds	Amount sold per Bed		Total cost	Yield GH¢	Profit GH¢
Lettuce						
Cabbage						
Spring onion						
Green pepper						
Carrots						
Others	—					

DRY SEASON

Crops	No. of beds	Amount sold per Bed		Total cost	Yield GH¢	Profit GH¢
Lettuce						
Cabbage						
Spring onion						
Green pepper						
Carrots						
Others						

28. What is your plot size? [Estimate]

29. Do you use pump? (a) Yes (b) No

Discharge (1/min) ....

Head (cm) ....

30. Would you like to use one? (a) Yes (b) No

If No, why? ....

If Yes, why?...

31. What are the problems encountered in operating the pump?

....

....

....

32. How long does the pump run (hour or mins) during each irrigation?

(a) Dry season (b) Wet season

33. How much fuel do you use? ....

34. How many times does it breakdown in (a) Dry season (b) Wet season

35. Where do you take it for repairs? ……………………………………………

36. How much do you spend on maintenance? ……………………………………

Grain yield (t/ha)	Crop water use (mm)	Water applied in each growth stage (mm)				Seasonal water Applied (mm) (1+2+3+4)
Lettuce						
Cabbage						
Spring onion						
Green pepper						
Carrots						
Others						

Crop	Cwp (water use) Kg/m^3	Cwp (water applied) Kg/m^3	Cwp (gross value) GH¢/m^3
Lettuce			
Cabbage			
Spring onion			
Green pepper			
Carrots			
Others			

Crop	Yield (Kg/ha)	Water use mm^{-1}	Water use efficiency WUE $Kgha^{-1}$ mm^{-1}
Lettuce			
Cabbage			
Spring onion			
Green pepper			
Carrots			
Others			

Growing season precipitation and dates of planting and first and last soil water measurements

Parameters	
Soil water balance	
Precipitation (Dry season)	
Precipitation (Wet season)	
Precipitation, mm	
September	
October	
November	
December	

Water use [WU] = Rain – [soil water 1 [soil water 2]

Water use was measured from planting to harvest

APPENDIX II: FIELD SURVEY DATA

Table A: Irrigation methods used

Irrigation equipment	Frequency	Percent
Hose/pump	5	10
Bucket/bowl	8	16
Watering can	37	74
Total	50	100

Table B: Sources of water used by farmers

Source of water	Frequency	Percent
Shallow wells	36	72
Rivers and streams	4	8
Shallow wells and streams	10	20
Total	50	100

Table C: Educational background of farmers

Educational background	Frequency	Percent
Illiterate	15	30
MSLC	25	50
JHS	6	12
SHS	4	8
Tertiary	0	0
Total	50	100

Table D: Age distribution of farmers

Age	Frequency	Percent
Below 20	2	4
20-30	10	20
31-40	25	50
Above 40	13	26
Total	50	100

Table E: Closeness of farm to source of water

Distance (meters)	Frequency	Percent
1-5	12	24
6-10	18	36
11-15	12	24
16-20	8	16
Total	50	100

Table F: No of cans of water applied to cabbage daily during dry season

No of cans of water applied	Frequency	Percent
6-10	6	12
11-15	16	32
16-20	18	36
21-25	6	12
Above 25	4	8
Total	50	100

Table G: No of cans of water applied to cabbage daily during wet season

No of cans of water applied	Frequency	Percent
1-5	24	48
6-10	16	32
11-15	4	8
16-20	3	6
Above 20	3	6
Total	50	100

Table H: No of cans of water applied to green pepper daily during dry season

No of cans of water applied	Frequency	Percent
6-10	10	20
11-15	16	32
16-20	14	28
21-25	6	12
Above 25	4	8
Total	50	100

Table I: No of cans of water applied to green pepper daily during wet season

No of cans of water	Frequency	Percent
1-5	18	36
6-10	14	28
11-15	8	16
16-20	7	14
Above 20	3	6
Total	50	100

Table J: No. Cans of Water applied to Lettuce daily during dry season

No. of cans	frequency	Percent
1-5	4	8
6-10	16	32
11-15	14	28
16-20	6	12
21-25	6	12
Above 25	4	8
Total	50	100

Table K: No of cans of water applied to lettuce daily during dry season

No of cans of water	Frequency	Percent
1-5	18	36
6-10	16	32
11-15	10	20
16-20	4	8
Above 20	2	4
Total	50	100

Table L: No of cans of water applied to spring onion daily during dry season

No of cans of water applied	Frequency	Percent
6-10	16	12
11-15	18	32
16-20	6	12
21-25	6	12
Above 25	4	8
Total	50	100

Table M: No of cans of water applied to spring onion daily during wet season

No of cans of water	Frequency	Percent
1-5	18	36
6-10	12	32
11-15	10	20
16-20	4	8
Above 20	2	4
Total	50	100

APPENDIX III: CROP WATER REQUIREMENT

1.0 CALCULATION OF CROP WATER NEED FOR CABBAGE

Crop: cabbage Planting Date: 1 /July/2012

Duration of total growing period: 120 days

Growth Stage	Days	Crop factors k_c
Initial Stage	20	0.45
Crop dev. Stage	25	0.75
Mid-season stage	60	1.05
Late season stage	15	0.90

Growth Stage	Days	Planting Date 1July
Initial Stage,	20 days	1July-20July
Crop dev. Stage	25 days	21July-15 August
Mid season,	60days	16 August-15 October
Late season,	15 days	16 October-30 October

Calculation of ET_c on Daily Basis

K_C July$=\frac{20}{30}$x0.45+$\frac{10}{30}x$0.75=0.55

K_C August$=\frac{15}{30}$x0.75+$\frac{15}{30}$x1.05=0.90

k_c October $=\frac{15}{30}$x1.05+$\frac{15}{30}\times$0.90=0.975

kc September=1.05

Calculation of ET_{crop} on Monthly Basis

$ET_{crop} = ET_O \times K_C$ (mm/day)

July: ET_{crop} =4.36 × 0.55=2.40 mm/day

August: ET_{crop} = 3.82 × 0.90=3.44 mm/day

September: ET_{crop} = 5.31×1.05 =5.58 mm/day

October: ET_{Crop} = 4.84×0.975 = 4.72 mm/day

All months are assumed to have 30 days

July: ET_{Crop}= 30×2.40 = 72 mm/month

August: ET_{crop}= 30×3.44 =103.20 mm/month

September: ET_{crop}= 30 ×5.58 =167.40 mm/month

October: ET_{crop}= 30×4.72 =141.6 mm/month

Total = 484.2 mm for the season

2.0 CALCULATION OF CROP WATER NEED FOR SPRING ONION

CROP: Spring Onion

Growth Stages	Days	K_C Values
Initial Stage	25	0.50
Crop Dev. Stage	30	0.70
Mid season Stage	10	1.00
Late season Stage	10	1.00

Initial Stage	25	1 July-July 25
Crop dev. Stage	30	26 July-25 August
Mid season stage	10	26 August-5 September
Late season	10	6 Sept-15 Sept

K_C July = $\frac{25}{30}\times 0.50 + \frac{5}{30}\times 0.70 = 0.54$

K_C August = $\frac{25}{30}\times$ 0.70+ $\frac{5}{30}\times$ 1.0 = 0.75

K_c September = $\frac{5}{30}\times 1.0 + \frac{10}{30}\times 1.0 = 0.5$

Calculation of ET_C on daily basis

July: $ET_C = 4.36\times 0.54$ =2.35mm/day

August: ET_C=3.82$\times$0.75 =2.87mm/day

September; $ET_C = 5.31\times 0.5 = 2.66$ mm/day

Calculation of ET_C on monthly basis

July : 30$\times$2.35 = 70.5 mm/month

August : 30$\times$2.87 = 86.1mm/month

September : 30$\times$2.66 = 79.8 mm/month

Total ET_C for the season = 236.4 mm

Month	ET_C (mm/day)	ET_C (mm/month)
August	2.35	70.5
September	2.87	86.1
October	2.86	79.8

3.0 CROP WATER REQUIREMENT FOR CARROT

Growth Stages	Days	Crop factors
Initial Stage	20	0.45
Crop dev .stage	30	0.75
Mid-season stage	30	1.05
Late season stage	20	0.95

Growth Stages	Days	Crop factors
Initial Stage	20	1 July-20July
Crop dev .stage	30	21 July-20August
Mid-season stage	30	21August-20 September
Late season stage	20	21September-10 October

K_C: July; $\frac{20}{30}$x0.45+$\frac{10}{30}$x0.75 = 0.55

K_c: August: $\frac{20}{30}$x0.75+$\frac{10}{30}$x1.05 = 0.85

K_C: September:$\frac{20}{30}$x1.05+$\frac{10}{30}$x0.90 =1.0

K_c: October: $\frac{10}{30}$x0.90 = 0.30

Calculation of ET_C ON daily basis

July: ETC: 4.36x0.55=2.40 mm/day

August: ET_C: 3.82x0.85=3.25mm/day

September: ET_C: 5.31x1.0=5.31mm/day

October: $ET_{c;}$:4.84×0.3mm/day=1.45

Calculation of ET_C on monthly basis

Month	ET_C(mm/day)	ET_C(mm/month)
July	2.40	72.0
August	3.25	97.50
September	5.31	159.30
October	1.45	43.50

Total Water Requirement = 372.3mm for the season

4.0 CROP WATER NEED FOR LETTUCE

Total Growth Period=80days

K_C July $=\frac{20}{30}x0.45+\frac{10}{30}x0.60=0.50$

K_C August $=\frac{20}{30}x0.60+\frac{10}{30}x1.0=0.70$

K_C September$=\frac{5}{30}x1.0+\frac{15}{30}x0.90=0.62$

Growth Stage	Days	Crop factors
Initial Stage	20	0.45
Crop dev stage	30	0.60
Mid season stage	15	1.00
Late season stage	15	0.90

Month	ET_C(mm/day)	ET_C (mm/month)
July	2.18	65.4
August	2.67	80.1
September	3.29	98.7

Total Crop Water Requirement = 244.2mm for the season

5.0 CALCULATION OF CROP WATER NEED FOR GREEN PEPPER

Growth Stage	Days	Crop factors	Date
Initial Stage	25	0.35	1 July – 25th July
Crop dev stage	35	0.70	26th – 30 August
Mid season stage	40	1.05	1 Sep – 10th Oct
Late season stage	20	0.90	11th – 30th Oct

$$K_c\ \text{July} = \frac{25}{30}\times 0.35 + \frac{5}{30}\times 0.70$$
$$= 0.292 + 0.117 = 0.41$$

K_c August = 0.7

K_c September =1.05

$$Kc\ \text{October} = \frac{10}{30}\times 1.05 + \frac{20}{30}\times 0.90$$
$$= 0.35 + 0.60$$
$$= 0.95$$

Calculation of ETc on daily basis

ETc: July $= Kc \times 4.36 = 0.41 \times 4.36 = 1.79\, mm/day$

ETc: August = $0.70 \times 3.82 = 2.67 mm/day$

ETc: September $= 1.05 \times 5.31 = 5.58\, mm/day$

ETc: October $= 0.95 \times 4.84 = 4.60\, mm/day$

Calculation of ETc on monthly basis

ETc: July = $1.7 \times 30 = 53.7$ mm/month

ETc: August = $2.67 \times 30 = 80.1$ mm/month

ETc: September = $5.58 \times 30 = 167.4$ mm/month

ETc: October = $4.6 \times 30 = 138.0$ mm/month

Total crop water need for the season for green pepper = 438.7 mm.

APPENDIX IV: FORMAT FOR CALCULATION OF ETo BY PENMAN METHOD

FORMAT FOR CALCULATION OF PENMAN METHOD

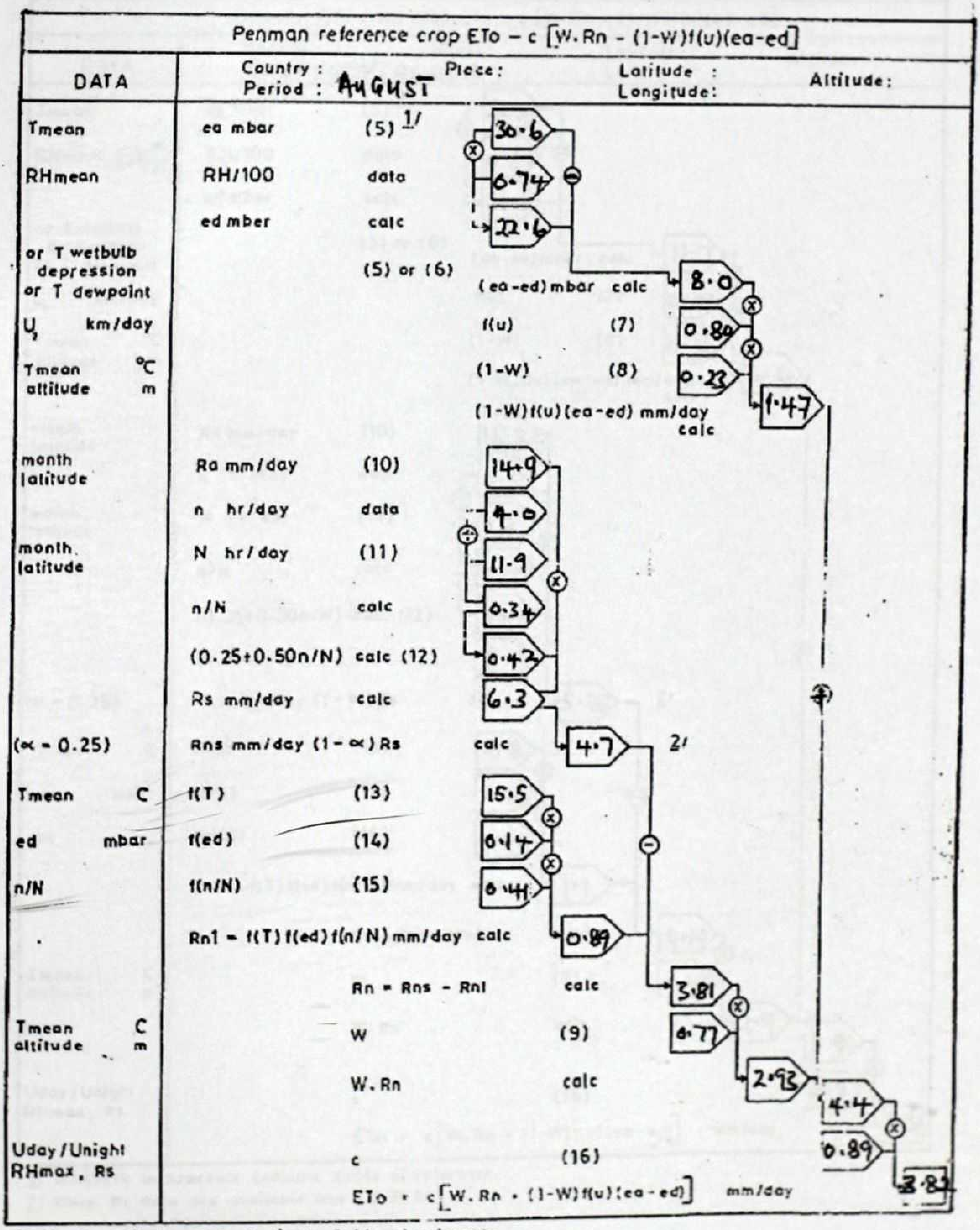
Penman reference crop ETo = c [W·Rn + (1-W)f(u)(ea-ed)]

DATA	Country: Period: JULY	Place:	Latitude: Longitude:	Altitude:
Tmean	ea mbar	(5) 1/	29.3	
RHmean 77%	RH/100	data	0.77	
	ed mbar	calc	22.6	
or T wetbulb depression or T dewpoint		(5) or (6)		
	(ea-ed) mbar	calc	6.7	
U_2 km/day	f(u)	(7)	0.93	
Tmean °C altitude m	(1-W)	(8)	0.26	
	(1-W)f(u)(ea-ed) mm/day	calc		1.74
month latitude	Ra mm/day	(10)	14.9	
	n hr/day	data	5.0	
month, latitude	N hr/day	(11)	11.7	
	n/N	calc	0.43	
	(0.25+0.50n/N)	calc (12)	0.46	
	Rs mm/day	calc	6.9	
(α = 0.25)	Rns mm/day (1-α) Rs	calc	5.18 2/	
Tmean C	f(T)	(13)	15.3	
ed mbar	f(ed)	(14)	0.14	
n/N	f(n/N)	(15)	0.48	
	Rnl = f(T) f(ed) f(n/N) mm/day	calc	1.03	
	Rn = Rns - Rnl	calc	4.15	
Tmean C altitude m	W	(9)	0.72	
	W. Rn	calc	3.0	4.74
Uday/Unight RHmax, Rs	c	(16)		0.92
	ETo = c[W. Rn + (1-W)f(u)(ea-ed)]	mm/day		4.36

1/ Numbers in brackets indicate Table of reference.

2/ When Rs data are available Rns = 0.75 Rs

FORMAT FOR CALCULATION OF PENMAN METHOD



1/ Numbers in brackets indicate Table of reference.

2/ When Rs data are available Rns = 0·75 Rs

FORMAT FOR CALCULATION OF PENMAN METHOD

Penman reference crop ETo = c [W.Rn + (1-W)f(u)(ea-ed)]

DATA	Country : Period : SEPTEMBER	Place:	Latitude : Longitude:	Altitude:
Tmean	ea mbar	(5) 1/	32.5	
RHmean 64%	RH/100	data	0.64	
	ed mbar	calc	20.8	
or T wetbulb depression or T dewpoint		(5) or (6)		
	(ea-ed) mbar	calc	11.7	
U_2 km/day	f(u)	(7)	0.84	
Tmean °C altitude m	(1-W)	(8)	0.31	
	(1-W)f(u)(ea-ed) mm/day	calc	3.0	
month latitude	Ra mm/day	(10)	15.2	
	n hr/day	data	5.0	
month latitude	N hr/day	(11)	12	
	n/N	calc	0.42	
	(0.25+0.50n/N)	calc (12)	0.46	
	Rs mm/day	calc	7.0	
(α = 0.25)	Rns mm/day (1-α)Rs	calc 2/	5.25	
Tmean C	f(T)	(13)	15.8	
ed mbar	f(ed)	(14)	0.14	
n/N	f(n/N)	(15)	0.48	
	Rnl = f(T) f(ed) f(n/N) mm/day	calc	1.7	
	Rn = Rns - Rnl	calc	4.19	
Tmean C altitude m	W	(9)	0.69	
	W.Rn	calc	2.9	5.9
Uday/Unight RHmax, Rs	c	(16)	0.9	
	ETo = c[W.Rn + (1-W)f(u)(ea-ed)]	mm/day	5.31	

1/ Numbers in brackets indicate Table of reference.

2/ When Rs data are available Rns = 0.75 Rs

FORMAT FOR CALCULATION OF PENMAN METHOD

Penman reference crop $ETo = c\,[W.Rn + (1-W) f(u)(ea-ed)]$

DATA	Country: / Period: OCTOBER	Place:	Latitude: / Longitude:	Altitude:
				Value
Tmean	ea mbar	(5) 1/		33
RHmean 60%	RH/100	data		0.60
	ed mbar	calc		19.8
or T wetbulb depression or T dewpoint		(5) or (6)		
	(ea-ed) mbar	calc		13.2
U_2 km/day	f(u)	(7)		0.8
Tmean °C altitude m	(1-W)	(8)		0.24
	(1-W) f(u) (ea-ed) mm/day	calc		2.5
month latitude	Ra mm/day	(10)		15
	n hr/day	data		5.2
month latitude	N hr/day	(11)		12
	n/N	calc		0.43
	(0.25+0.50n/N)	calc (12)		0.47
	Rs mm/day	calc		7.1
(α = 0.25)	Rns mm/day (1-α) Rs	calc 2/		5.3
Tmean C	f(T)	(13)		15.8
ed mbar	f(ed)	(14)		0.15
n/N	f(n/N)	(15)		0.35
	Rnl = f(T) f(ed) f(n/N) mm/day	calc		0.83
	Rn = Rns - Rnl	calc		4.47
Tmean C altitude m	W	(9)		0.76
	W.Rn	calc		3.4
				5.19
Uday/Unight RHmax, Rs	c	(16)		0.87
	ETo = c [W.Rn + (1-W) f(u) (ea-ed)] mm/day			4.84

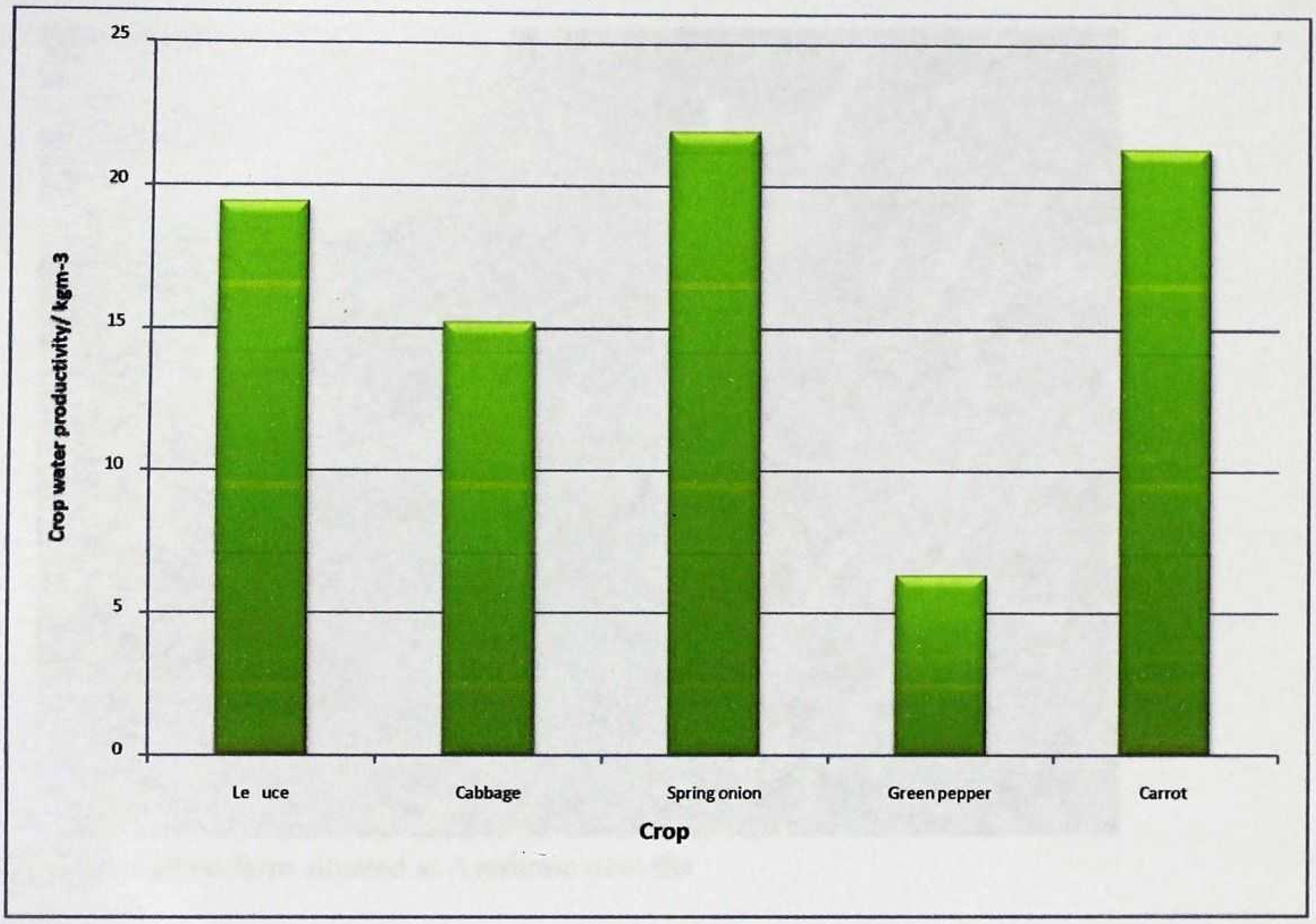
1/ Numbers in brackets indicate Table of reference.

2/ When Rs data are available Rns = 0.75 Rs

APPENDIX V: METEOROLOGICAL DATA

Month	Max. Temp˚C	Min. Temp˚C	Hum %	Dew Pt.˚C	Wind Speed m/s	Pressure Bar kPa	Total Rain mm	Solar Rad. W/m²	Total ET mm
Jul 2012	24.6	26.3	80.4	20.4	0.332	983.6	0.4	85.1	86.89
Aug 2012	24.7	23.9	78.6	20.3	0.412	984.0	5.0	110.9	64.33
Sep 2012	25.9	24.9	76.0	20.9	0.246	983.3	85.4	128.0	25.69
Oct 2012	26.1	25.1	76.7	21.2	0.172	981.5	93.4	169.2	88.76
Nov 2012	27.3	26.2	74.3	21.8	0.180	980.7	32.4	187.0	81.75
Dec 2012	26.8	25.8	70.9	20.4	0.124	980.5	36.6	171.9	91.89
Jan 2013	27.2	25.8	57.1	16.1	0.227	981.0	0.0	177.9	101.51
Feb 2013	29.6	28.4	59.3	19.4	0.278	979.6	16.6	191.2	93.40

APPENDIX VI: CROP WATER PRODUCTIVITY



PHOTOS

Dug-out well on farm situated at Ayeduase new site

Vegetable Farm at Ayeduase new site