ECONOMIC EVALUATION OF IRRIGATION SYSTEMS USED IN VEGETABLE PRODUCTION IN KOULIKORO AND MOPTI REGIONS, MALI

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in any University or other institution of learning for any awards.

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DEDICATION

This work is dedicated to all my family members for their prayers, constant encouragement and understanding. They endured hard times while they stood by me as I laboured on this work.

ABSTRACT

Majority of households in Mali depend on rain-fed agriculture for their food production. Overreliance on rain-fed agriculture limits the production output due to unreliable rainfall in the country. To mitigate this, the government has invested in rehabilitation of irrigation schemes. Due to increasing problem of water shortage as a result of climate change, irrigation water input in vegetable production must be economically efficient. Although the Malian government has promoted different types of irrigation systems, it is unclear if these technologies are economically efficient and viable for vegetables production. This study determined the contribution of different irrigation systems to produce vegetables on household welfare in rural communities. The objectives of the study were to characterize the production systems and small scale irrigation technologies, to evaluate the economic efficiency of water use in the small scale irrigation systems, to determine the economic viability of the alternative small scale irrigation systems and to determine the technical efficiency of small scale vegetables production under different irrigation systems among smallholder farming households in Koulikoro and Mopti regions. This study was guided by the production theory. Primary data was collected from 273 farmers selected from four wards (Fanafiecoura and Tieman, in Koulikoro region and Mopti and Dialango, in Mopti region) using face-to-face interviews. Secondary data from literature reviews was also used. Statistical analysis such as Data Envelopment Analysis (DEA), Benefit Cost Ratio analysis and Stochastic Frontier production functions were used. This study found that the irrigation systems as used in production of the three main crops were characterized by 24% inefficiency. With respect to the vegetable production of potatoes, shallots and tomatoes, the technical efficiency scores were higher in drip irrigation (91.68%) and sprinkling irrigation (90.56%) than in Californian irrigation system (76.87%). This means that drip and sprinkling irrigation systems were relatively more economically efficient as compared with the Californian system. The excess benefits (compared to costs) was realized more with drip irrigation system (BCR = 2.579) with the second best being sprinkler (BCR = 2.118) and the third being California (1.890). With respect to the production of potatoes, shallots and tomatoes, technical efficiency scores were highest in drip (91.68%) and sprinkling (90.56) and lowest in Californian (76.87) irrigation systems. This study recommends more training and capacity building to the farmers with an aim of reducing their levels of inefficiencies in production of potatoes, shallots and tomatoes. Drip, sprinkling and Californian irrigation systems presents a good opportunity for superior technical efficiency in vegetable production and should be promoted.

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ACRONYMS AND ABBREVIATIONS

ADPs	:	Agricultural Development Projects
CCR	:	Charnes, Cooper and Rhodes
CRS	:	Constant Returns to Scale
CSCRP	:	Strategic Framework for Growth and Poverty Reduction
DEA	:	Data Envelopment Analysis
[illegible]	:	Competiveness and Agricultural diversification Irrigation Program
DMU	:	Decision Making Unit
DNSI	:	National Direction of Statistic and Informatics
DP	:	Diagnostic Participative
FAO	:	Food and Agriculture Organization of the United Nations
GL	:	Generalized Leontief
HYV	:	High Yield of Vegetables
ICBA	:	International Center of Bio-saline Agricultural
ICID	:	International Commission on Irrigation and Drainage
IER	:	Institut d'Economie Rurale (Rural Economic Institute)
[illegible]	:	Impact of Climate Change
IWMI	:	International Water Management Institute
KfW	:	German Development Bank
MOA	:	Ministry of Agriculture
OED	:	Overall efficiency values used for Bank-supported projects in India
PAFASP	:	Initiative for the development of the small irrigation
PCDA	:	Programme de Compétitivité et Diversification Agricole (Competiveness and Agricultural diversification Program)
PDF	:	Local Plan of Financial Development
PDSI	:	Palmer Drought Severity Index
PIP2S	:	Proximity Irrigation Project Second
PNSAS	:	National Food Security Plan
PNIP	:	Programme National d'Irrigation de Proximité
PPIP	:	Small Irrigated Area Project
PPIV	:	Small Irrigated Area of Village

PRIW	:	Property Right of Irrigation Water
SSA	:	Sub Saharan Africa
SPSS	:	Statistical Package for Social Scientists
UN	:	United Nations
USAID	:	United States Agency for International Development
VRS	:	Variable Returns to Scale
WUE	:	Water Use Efficiency
WFFRD	:	Water for Food and Rural Development
WUA	:	Water Users Association

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Irrigation is one of the means by which agricultural productivity can be improved to meet the growing food demand (Awulachew *et al.*, 2005). International agencies like the FAO and the World Bank, as well as national governments of low and middle income countries point at irrigation as an important tool to overcome food security. Such countries make huge investments in the construction, improvement and maintenance of physical infrastructure for efficient capture, distribution and use of water for irrigation. African people face numerous challenges as they struggle to feed themselves and to generate sufficient income to meet their basic needs. These difficulties are often compounded as people are forced to farm on lands which have been degraded due to population pressures.

According to FAO (2005) irrigation in Africa as compared to what is happening in Asia has remained limited especially in Sub-Saharan Africa with a few medium and large scale commercial schemes developed during the colonial period and modest small irrigation sub-sector. At the continental level, it is apparent that Africa has not been able to intensify agricultural production and generate intracontinental trade to feed its growing towns and cities, and buffer the volatility of rainfed production Most irrigation in Africa involves non-pressurized irrigation systems (Sirte, 2008).

More than 80% of Malian population is engaged in agricultural activities (either directly or indirectly). Agriculture is the backbone of Mali's economy. The sector has a huge potential for improving economic growth. Agricultural activities represent around 33% of GDP. Mali has important and underexploited agricultural potentialities, especially in the south and center of the country. Malian government dedicates 15% of its budget to the agricultural sector. Despite investment opportunities, Malian agriculture depends strongly on erratic rainfalls and is vulnerable to fluctuating commodity prices. Climate change is adding greater stress on natural resource management and has caused decreased production yields (USAID, 2018).

Mali is one of the world's poorest countries, with a Gross Domestic Product (GDP) worth 14.05 billion US dollars in 2017. The GDP value of Mali represents 0.02 percent of the world economy. Since the year 2000, Mali had continuously succeeded in reducing poverty, due mainly to increased agricultural production and better functioning value chains. Due to persistent drought and conflict, poverty levels have remained consistently high. Life expectancy is low (57 years of age); malnutrition levels are high (28 percent of under five children are stunted); and most of the 17.1 million population is illiterate (69 percent of adults). The economy of this landlocked country is predominantly rural and informal: 64 percent of the population resides in rural areas, and 80 percent of the jobs are in the informal sector. Improving human well-being through sustainable increases in production, employment and food security is a key goal of development policy in all countries especially in poor developing countries.

According to Swift and Hamilton (2003), the naturally most food insecure environments in Africa are the arid and semi-arid zones, where drought is a major recurring risk. The arid and semi-arid areas of Mali cover more than half of the land area. Most Sub- Saharan African countries are characterized by low agricultural productivity. One of the reasons for poor production is that African agriculture is predominantly rain- fed, which is in most cases unreliable resulting in poor yields and the changing weather conditions would further exacerbate the situation, exposing smallholders to negative impact of climate change (Todaro, 2012). It is becoming increasingly evident that required food supplies cannot be met by rain fed conditions alone (PCDA, 2009). In Mali, the economy dependents on agriculture, that contribute to 36 percent of income derived from cereal, vegetable, cotton, and sugarcane (National Report Ministry of Agricultural, 2013).

Though the agricultural productivity in sub-saharan African countries has improved over the last decades, it is evident that the full potential has not yet been realized. Low size of land holdings is a major contributor to low agricultural productivity. Due to low land holding, no scientific cultivation with improved techniques and seeds can take place. Small sized holdings lead to great waste of time, labour, difficulty in proper utilization of irrigation facilities and irrigation among farmers. Poor techniques of production also contribute to low productivity.

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Due to sinking water levels, the use of manual pumps in deep wells in some areas is no longer sustainable. It has been argued that one strategy which would be used to mitigate water scarcity and dependence on rain fall is irrigation. Indeed (Pinstrup and Derill, 2011, Hussain, 2004), revealed that investing in small scale irrigation schemes is one of the strategies to improve production levels especially for small holder farmers. The general belief is that irrigated agriculture limits crops failure, external shocks and increases yield thus leading to better food security (Nokuphiwa *et al.*, 2014) (FAO, 2010).

In Mali, farmers face many challenges as they try to grow and sell enough crops to support their families. Uncertain rainfall, potential crop failure due to natural disasters or disease, unpredictable crop prices, and shaky land tenure all contribute to the difficulties and risks inherent in farming. Improvements in the production processes and productivity of farmland could help many poor families achieve a better life. Use of irrigation technology seeks to reduce poverty through economic growth. Increasing production and productivity, farmer's income, improving land tenure security, modernizing irrigated production systems and mitigating the uncertainty from subsistence rain-fed agriculture can be a good avenue to profitable agriculture. Success of irrigation systems in Mali has the potential of creating additional arable land for farming (IPA, 2018).

In Mali, half of its 1.24 million square kilometers of land is arid, with average annual rainfall of less than 200 millimeters. This implies that agricultural activities in the country cannot support its growing population without irrigation farming. With the lagging efforts of the government in its support for irrigation technologies in farming, food insecurity is a big challenges and hence Mali is also one of the world's poorest countries, with many people living below the poverty line; life expectancy at birth is also extremely low (World Bank, 2010).

Half of Mali's rural population lives below the poverty line and suffers from undernourishment or malnutrition. Due to climate change and rapid population growth, the traditional methods of rain-fed farming are unable to guarantee sufficient income and food for the population. However, Mali possesses large water reserves and these can be used in small-scale irrigation schemes to develop and diversify agricultural production and to improve nutrition (GIZ, 2018).

Despite the Government efforts, agricultural productive capacity in Mali is only slowly improving and much arable and irrigable land remains underdeveloped. Only a small proportion of potential crop yields is exploited, limiting the potential to achieve poverty reduction results. Changing climate conditions is one of the determinants of low agricultural productivity as most agricultural land is rain-fed and droughts severely increase the risk for agricultural producers. Price uncertainty in the market also limits Malian farmers' private investment in agriculture. Moreover, access to finance for agriculture is low, particularly for women farmers.

The Malian government has over the years endeavored to expand the country's irrigation infrastructure in order to improve agricultural production and enhance food security. The aim was to bring about a large expansion of the total irrigated area. Before the year 2008, Dougabougou and Siribala sugar cane plantations were the only irrigated large scale land in Mali. Currently the government of Mali is implementing food sustainability for smallholder farmers through a long term national program for food security by 2025. This may be attained by targeting small scale irrigation systems to increase production (Kelly, 2008).

The types of irrigation technologies that are practiced in Mali are: drip irrigation, Californian system, sprinkling system and gravity system. The Drip irrigation technology consists of bringing water under pressure in a system of pipelines. This water is then distributed in drops in the field by a large number of gutters distributed all along rows of plants. This irrigation system is used to grow tomato, onion, shallot (Allium fistulosum), banana, papaya and oranges (Vandersypen *et al.*, 2006).

The Californian irrigation system is a network of PVC pipelines buried that permits to decrease losses by infiltration. It routes water on a parcel moved away of the source of pumping or having an irregular topography, and follow the level of triage and of row without addition or manipulation of hoses. Water is lifted from the surface or the underground water source and distributed to plants into furrows. With this system, crops are arranged on ridges. This system is mainly used for vegetable crops such as shallot and onion (Asawa, 1999).

The Sprinkling irrigation system; the technique of irrigation by aspersion is conceived on the model of the natural rain. Water is driven back under pressure in a network of conducts and then it is distributed by the rotary aspersers under the form of artificial rain. It is practiced on commercial farms on high value crops such as fruit trees, coffee, sugar cane and horticultural crop, the potato (Adetola, 2009).

Koulikoro and Mopti regions of Mali carries numerous irrigation activities as majorly supported by two main rivers (River Niger and River Senegal). The Niger River draws its source from the small mountains of Guinea and flows in a broad eastern arc across Mali, passing through the capital Bamako and past the legendary city of Timbuktu before continuing through Niger, and curving to the south to its Atlantic Ocean mouth in Nigeria. The Senegal River also has its source in Guinea and flows slightly to the northeast before turning back east and merging with the Bafing River, then passing through the city of Kayes and continuing to form the border of Mauritania and Senegal before flowing to the Atlantic Ocean. The climate in Koulikoro and Mopti regions is typical of the Sudano-Sahelian zone. Average long-term annual rainfall is about 1073 mm ± 187. The rainy season extends from May to October and the seasonal average temperature is 29°C. During the dry season (November to April) the temperature and saturation vapour deficit increase and crop production is impossible without irrigation (Sivakumar, 1988).

1.2 Statement of the Problem

Although the Malian government has promoted different types of irrigation systems, it is unclear if these technologies are economically efficient and viable for the production of vegetables such as shallots (Allium fistulosum), tomatoes and potatoes. Due to the escalating problem of water shortage compounded by climate change, water utilization as an input in vegetable production must be economically efficient; it can affect the production and profitability of the smallholders. For sustainability, the returns must be commensurate with the cost of inputs incurred. Since most studies on irrigation systems are in the domain of engineering, analysis of crop enterprise combinations, gross margins and economic efficiency are not commonly done. Further, empirical information on institutional factors affecting the irrigators are rarely available. This current study establishes the economic efficiency of irrigated vegetables in Mali.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was to contribute to improved livelihood of smallholder farmers in rural areas through enhanced efficiency of irrigation systems in vegetable production in Koulikoro and Mopti regions, Mali.

1.3.2 Specific Objectives

The specific objectives of the study were:

i. To characterize the production systems and small scale irrigation technologies among smallholder farming households in Koulikoro and Mopti regions.
ii. To evaluate the economic efficiency of water use in the small scale irrigation systems.
iii. To determine the economic viability of the alternative small scale irrigation systems.
iv. To determine the technical efficiency of small scale vegetables production under different irrigation systems.

1.4 Research Questions

i. What are the production system in smallholder farming household and the characteristic of irrigation technologies?
ii. How efficient are the small scale irrigation systems used with respect to the water use efficiency?
iii. What is the economic viability of the alternative small scale irrigation systems?
iv. What is the technical efficiency of small scale vegetables production under different irrigation systems?

1.5 Justification of the Study

The world population is growing rapidly. By mid of this century, it will be home to over 3 billion more people (UN, 2011). Food availability is however not keeping pace with population growth. By mid-century, world will need 100% more food than that produced today (ICID, 2011). In meeting this objective, future agricultural production systems have to make use of limited water resources in sustaining profitable production systems. This study is expected to make a contribution in determining whether the small scale production system under irrigation is efficient in terms of technical and water use efficiency.

This study is of great significance to a number of stakeholders. First, the study is key to smallholder irrigation farmers who rely on irrigation systems in their production as well as the government in its effort to design appropriate policies to improve the livelihood of the farming households that depend on small scale irrigation systems. Some of the other stakeholders whom this study is expected to benefit include the various NGOs in the region whose efforts are geared towards improving the livelihoods of the farming households.

1.6 Scope and Limitations of the Study

The scope of the information in this study related to the period between the year 2014 to 2016 and the area of coverage was Koulikoro and Mopti regions in Mali. The sample for the study comprised of households that had integrated vegetable crops under irrigation systems. Though irrigation systems entail many crops, the study was limited to tomatoes, potatoes and shallots (*Allium fistulosum*).

Although there are other factors that may influence irrigation systems used in vegetables production, such were outside the scope of this study. The limitations of this study included the fact that Koulikoro and Mopti are a small geographical area of the country, and therefore the results may only be generalized to others areas with similar characteristics.

1.7 Definition of Key Terms

Benefit-Cost Ratio: Benefit-Cost Ratio criterion for judging the economic soundness of projects is globally accepted method. Irrigation projects with B.C. ratio greater than 1.5 are generally considered acceptable from economic point of view. B.C. Ratio is obtained by dividing the annual benefits by the annual cost.

Crop Production - Crop production is a branch of agriculture that deals with growing crops for use as food and for sale. This study considers crop production as the growing of selected vegetable crops, under irrigation technologies.

Economic efficiency – Economic efficiency is a broader term than technical efficiency. It covers an optimal choice of the level and structure of inputs and outputs based on reactions to market prices. Being economically efficient means to choose a certain volume and structure of inputs and outputs in order to minimize cost or maximize profit. Economic efficiency requires both technical efficiency and efficient allocation. While technical efficiency only requires input and output data, economic efficiency requires price data as well. This study used DEA, a nonparametric linear programming model, assuming no random mistakes to measure economic efficiency. This study considered efficient firms are those that produce a certain amount of or more outputs while spending a given amount of inputs or using the same amount of or less inputs to produce a given amount of outputs, as compared with their inefficient counterparts.

Economic evaluation: is the process of systematic identification, measurement, valuation and comparative analysis of the inputs and output of two alternative activities. It is basically an evaluation of the project is basically an investment decision guided by cost estimate of the project on one side and the benefits expected to flow by such investments on the other. Different policy decisions adopted by various countries/agencies govern criteria to be used for assessing the economic viability of the projects.

Economic viability – This is the ability of an economic system to achieve higher returns per unit of input used. This study considers economic viability as the ability of an irrigation system to give a better return and the general prosperity of farmer though the yield of selected vegetable crops (potatoes, shallots and tomatoes) as assessed by Cost Benefit Analysis.

Household – Sheffrin (2003) defined a household as a *single* dwelling with persons sharing either meals or living space. It is a basic unit of analysis in many social, microeconomic and government models. This study refers a household as a group of people related by blood, living together under one roof and/or one homestead and sharing resources within one land holding. Members of a homestead have one head.

Irrigation - Irrigation is the art of applying water artificially to the field in accordance to the crop requirement throughout the cropping period for the full fledge nourishment of the plant for better yield ability (NARC, 2011).

Irrigation Systems – This study considers irrigation systems as the different technologies that smallholder farmers in Mali use in supporting their vegetable crops against seasonal moisture/drought. Such technologies includes Californian system, sprinkling system, drip irrigation and manual watering.

Irrigation management - This is a process by which institutions or individuals set objectives for irrigation systems, establish appropriate conditions and identify, mobilize and use resources so as to attain these objectives while ensuring that all activities are performed without causing adverse effects.

Livelihood – Acharya (2006) defined the term 'livelihoods' as a wide range of people's activities and assets in considering how they support themselves. Livelihoods focuses on economic, income-generating or formal activities. This study considers livelihood as a set of activities, in farming undertaken to meet the requirements of smallholder farming household in the study area.

Smallholder farmers - Small-holder farmers are defined as those marginal and sub-marginal farm households that own or/and cultivate less than 2.0 hectare of land. Small-holders owns less of the total cultivated land although their contribution to national production is often higher in any farming economy. Their contribution to household food security and poverty alleviation is thus dis-proportionately high - and constantly increasing. As the national population increases, so does the number of small-holdings. Smallholder farmers are defined in various ways depending on the context, country and even ecological zone. Often the term 'smallholder' is interchangeably used with 'small-scale', 'resource poor' and sometimes 'peasant farmer'. In general terms smallholder only refers to their limited resource endowment relative to other farmers in the sector. This study considers smallholder farmers as those farmers owning small-based plots of land on which they grow vegetable crops (potatoes, shallots and tomatoes) either as one or as multiples of these, relying almost exclusively on family labour.

Technical efficiency - Technical efficiency is the physical component of the production system which deals with the maximization of output from the physical combination of inputs. A technically efficient producer avoids as much waste by producing as much output as input use will allow or by using as little inputs as output production will allow. A farmer is more efficient than the other if he/she can produce the same output using less of at least one input or can produce more of at least one output using the same inputs (Kebede, 2001).

Vegetable crops – This study considers vegetable crops as high value crops such as potatoes, shallots and tomatoes grown by small holder farmers for food (subsistence) or sale (commercial).

Vegetables Production: This refers to the growing of potatoes, shallots and tomatoes.

CHAPTER TWO

LITTERATURE REVIEW

This section details the past documented literature on economic evaluation of irrigation systems used in vegetable production. The section gives an overview of irrigation practice in the world, water resources in Mali, irrigation and irrigation management, irrigation potential in Sub-Saharan African (SSA) countries, small scale irrigation technologies in Sub-Saharan African (SSA) countries, advantages and disadvantages of irrigation in Mali, importance of irrigation to agriculture, irrigation schemes in Mali, vegetables production in Mali, efficiency and its estimation methods, economic efficiency of water use in the small scale irrigation systems in Mali, economic viability of small scale irrigation systems in Mali and technical efficiency of small scale vegetables production under different irrigation systems. Some theoretical paradigm that guided this study is provided at the end of the section together with a conceptual.

2.1 Irrigation Practice in the World

According to UNESCO (2018), rainfed agriculture covers 80% of the world's cultivated land, and is responsible for about 60% of crop production. Today, irrigated agriculture covers 279 million hectares – about 20% of cultivated land – and accounts for 40% of global food production. With rapid population growth, water withdrawals have tripled over the last 50 years. This trend is explained largely by the rapid increase in irrigation development stimulated by food demand in the 1970s and by the continued growth of agriculture-based economies.

UNEP (2001) argued that among other natural resources available in the world, water resources have a unique position. Water is the main extensively distributed substance across the world. It contributes to a key role in the human life and surrounding environment. Fresh water is the most important among them, which is essential for human beings' life and activity. About 1.4 billion km^3 water is available on earth. Among them, approximately 35 million km^3 freshwater resources are present (nearly 2.5% of total volume).

Most of the irrigated area locates in Asia (68%) where in America the irrigated area is approximately 17%. In Europe the total irrigated area is about 9%, in Africa approximately 5% and in Oceania about 1% of total cultivated area. About 18 % of the world's cropland is irrigated, producing 40 % of all food grown. Irrigation uses globally some 70% of all waters in the groundwater and rivers. (Siebert *et al.*, 2000). Figure 1 shows the distribution of cultivated areas equipped for irrigation as verified in the year 2009.

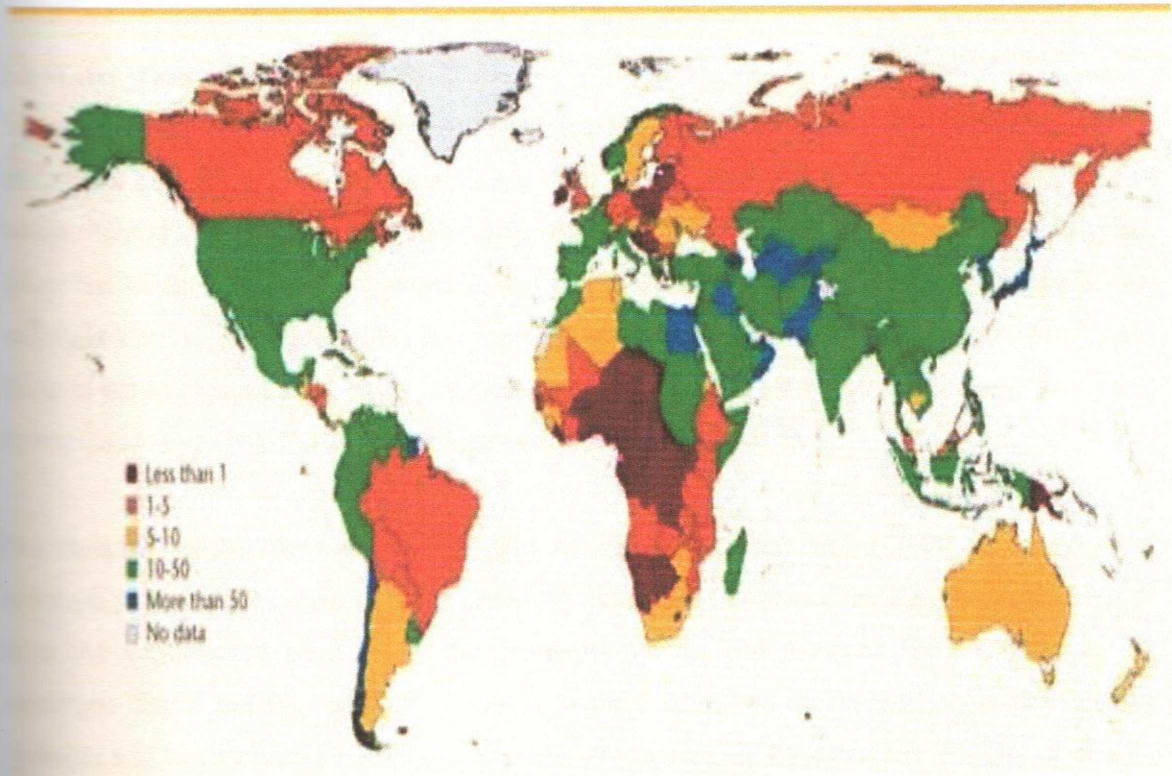

Figure 1: Percentage of world cultivated areas equipped for irrigation

Source: UN-Water (2018)

According to UN-Water (2018), the global demand for water has been increasing at a rate of about 1% per year over the past decades as a function of population growth, economic development and changing consumption patterns, among other factors, and it will continue to grow significantly over the foreseeable future.

The United Nations World Water Development Report asserted that industrial and domestic demand for water will increase much faster than agricultural demand, although agriculture will remain the largest user overall. The vast majority of the growth in demand for water will occur in countries with developing or emerging economies. At the same time, the global water cycle is intensifying due to climate change, with wetter regions generally becoming wetter and drier regions becoming even drier. Other global changes (e.g., urbanization, deforestation, intensification of agriculture) add to these challenges (UN-Water, 2018).

2.2 Water Resources in Mali

Water resources in Mali can be classified as surface and underground water. Surface water can either be perennial or non-perennial. Mali has numerous rivers draining to different basins. Sénégal River is the only main river with Atlantic Ocean as its drainage basin. Sénégal River has tributaries such as Falémé River, Karakoro River, Kolinbiné River, Bafing River and Bakoy River. Gulf of Guinea is a drainage basin for Volta River and Niger River. Niger River is fed by tributaries such as Dallol Bosso (Niger), Vallée du Tilemsi, Diaka River, Bani River, Canal du Sahel, Faya River, Sankarani River and Fié River.

The capacities of the rivers are: 70 billion m^3 of water in average year, 110 billion m^3 of water in humid year and 30 billion m^3 of water in dry year. The South and the Centre of the country have the majority of watersheds; the Northern part is characterized by the presence of numerous fossil valleys. Surface water is mainly from the rivers and their dependents (Senegal and Niger rivers). Underground water is estimated to be 2 to 5 times lesser. It is also important to know that surface water contributes about 10 to 15% of the total volume of water consumed by populations, the balance of the demand is covered by underground water. Non-perennial water is the volume collected in water reservoirs by constructing infrastructures or natural ponds and kept for few months. This type of collected water exists all over Mali and is estimated to be about 15 billion m^3 yearly. Usually, non-perennial water is sued by populations living in remote areas from the river bank (DNH, 2006).

The volume of static underground water reserve in Mali is estimated at 2700 billion m^3 with an annual renewable rate of 66 billion m^3 representing the main source of water consumed by populations. The level of mobilization of this water resource is very low. Its mining is made possible through 15100 drills and 9400 modern wells with large diameter (DNH, 2003). Generally, underground water tables are not polluted by human activities. Only few cases of poor contamination are observed in urban areas where agriculture occurs using fertilizers and pesticides. For example, water controls in Bamako city revealed that nitrate content was higher than indicated norms for pure water (ENI, 1991). It has been proved that the contamination of underground water in Bamako city is chemical and bacterial. Table 1 shows precipitation and renewable water sources in Mali. The total renewable water resource is found to be 137 billion m^3 corresponding to 11 417 m^3 per inhabitant and per year. Today, annual water needs are evaluated to about 6 billion m3 distributed as followed: pure water for drinking (1 %), livestock (1%) and agricultural and others usages (98%).

Table 1: Precipitation and renewable water in Mali

Precipitation and renewable water resource	Volume (billion m^3)
Volume of precipitation	415
Perennial water of surface	56
Non-perennial water of surface	15
Renewable underground water	66
Total renewable water resource	137
Average per person per year	11417

2.3 Irrigation and Irrigation Management

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 the contribution to soil moisture from ground water (Michael, 1997). Irrigation management is defined as a process by which institutions or individuals set objectives for irrigation systems, establish appropriate conditions and identify, mobilize and use resources so as to attain these objectives while ensuring that all activities are performed without causing adverse effects (IIMI, 1992).

In irrigated crop production a number of interrelated activities ranging from designing and constructing of the irrigation infrastructure to water acquisition and watering crops are carried out (Wodeab, 2003). There are three categories of irrigation management activities and organizational activities. The first involves water acquisition, distribution and drainage. The second focus on design, construction, operation and maintenance. The third focuses on conflict management, communication, resource mobilization and decision making (Wodeab, 2003). The management aspect of irrigation is often neglected while priories are giving to the construction of irrigation infrastructure, although both the human and physical aspects interact in an irrigation domain.

Byrnes (1992) conjointly classified irrigation management activities in to a few dimensions. These are water use activities, management structure activities and organizational activities. Water use activities: are management activities that are focusing on the provision of water to crops in an adequate and timely manner include acquisition, allocation, distribution and drainage. Acquisition is the first management activity concerned with the acquisition of water from surface or subsurface sources, either by creating and operating physical structure such as dams' weirs or wells or by actions to obtain some share of an existing supply. Allocation on the other hand is heavily refers to the assignment of rights to users thereby determining who shall have access to water. Distribution refers to the physical process of taking the water from a source and dividing it among users at certain places, in certain amounts, and at certain times. Drainage is important where excess water must be removed.

Control structure activities: are management activities that are focusing on the structures required for water control include design, construction, operation and maintenance. Design involves the design of dams' diversions or well to acquire water, of systems of rules to allocate it, of channels and gates to distribute it and of drains to remove it. Construction involves the construction of the structures to acquire, distribute and remove water, or implementation of rules that allocate it. Operation refers to the operation of the structures that acquire, allocate, distribute or remove water according to some determined plan of allocation. Maintenances are the final control structure activity. This provides for the continued and efficient acquisition, allocation, distribution and drainage.

Organizational activities: are management activities focusing on the organization of efforts to manage the structures that control irrigation water includes resource mobilization conflict resolution communication and decision-making. The activity of resource mobilization entails marshalling management and utilization of funds manpower, materials, information or other inputs needed to control water through structures or to undertake various organizational tasks.

The activity of communication entails conveying information about decisions made, resource requirements etc. to farmer or any other persons involved in irrigation managements. The activity of decision making entails the processes including planning involved in making decision about the design, construction, operation or maintenance of structures; acquisition, allocation, distribution or drainage of water or the organization deals with these activities.

2.3.1 Irrigation Water as a Common Pool Resource (CPR)

Common pool resources are products where, like public product, it is pricey or troublesome to exclude potential users, that are subtractable (rival in consumption), like that of personal product. Two characteristics distinguish public product from personal product. First, is the excludability that refers to the flexibility of provision of a decent or service to exclude or limit potential beneficiaries from consuming and secondly, rivalry that refers as to whether or not one person's use or consumption of a decent or services reduce its availability to a different. Thus, CPRs create each the issues of provision and also the risk of depletion. CPRs do not fulfill the pure public product characteristics of non-subtractability. Thus, they are vulnerable to the chance of over extraction (Bedru, 2007). As shown in the following table, private goods are characterized by both high excludability and high rivalry, while public goods are characterized by low excludability and low rivalry.

Table 2: Types of Goods, Rights and Owners

Type of goods	Goods	Rights	Owners
Private	- Excludable - Substractable	- Specifies clearly what the rightsholder is entitled to do - Is secure so that the holder of the right is protected from confiscation by others - Is exclusively vested in the holder of the right and definitely not in no holders of the right	- Represents only itself
Public	- Non-excludable - Non-substractable	- Rights of access and use that do not include the right to exclude others from such use	- Represents the general population and not just a single individual
CPR	- Non-excludable - Substractable	- Group of individuals share private property rights - Systems of shared private rights owned by private entities	- Group of individuals (shared, joint or collective) ownership - Community ownership

Source: Adopted from Bedru (2007)

Water falls within the variety of rain, and flows and evaporates no matter any boundary. However, Water is subject to rivalry in consumption and as a result of this it cannot be grouped under public product rather it is a common pool resource that there is a restricted quantity that has got to be shared in common over a range of uses.

However, Bromley (1992) viewed resources controlled and managed as common property, state property, personal property or resources over that no property rights are given. Irrigation systems represent the essence of a standard property regime. There is a well-defined cluster whose membership is restricted, there is an asset to be managed (the physical distribution system), there is an annual steam of advantages (the water that constitutes a valuable agricultural input), and there is a requirement for cluster management of each the capital stock and also the annual flow (necessary maintenance of the system and method for allocating the water among members of the cluster of irrigators) to form certain that the system continues to yield advantages to the cluster.

Ostrom (1990) in her seminal book "Governing the Commons", too complains concerning the misleading understanding when definitions do not seem to be clearly created. Failure to differentiate between subtractability of the 'resource units' (water unfold on one farmer's field cannot be unfold onto the sphere of somebody else) and also the jointness of the resource system (all appropriators advantages from maintenance of an irrigation canal) ends up in confusion concerning the link of common pool resources to public resources (or collective resources). Typical for a common pool resource is that the subtractability of the resource unit that ends up in the likelihood of approaching the boundaries of the amount of resources units made.

Hardin (1968) states that degradation of the atmosphere to be expected when several people use commonly a restricted resource. He explains the logic behind this model explaining it by the accepted example of a pasture with open access to any or all. The essence is that every herder is motivated to feature additional and additional animals and bears solely a share of the prices ensuing from overgrazing. Since users are probably to ignore the results of their actions on the pool when pursuing their self-interest, it should be concluded that the majority of the resources bear the danger of a tragedy of the commons.

Ostrom (1990) criticizes the approaches to unravel tragedy of the commons social dilemma as insufficient. It is neither sufficient to form a system of personal property rights, neither is it the sole answer that the central government stay management over common resources. Significantly, the theory of self-organization and self-governance can also be used to explain issues relating to the common pool resource (Ostrom, 1990). The implication is that collective action may be a way by that societies will hold common property resources and use the resources in a very sustainable manner. Collective action is action by over one person directed towards the achievement of a typical goal or the satisfaction of a typical interest (that is, a goal or interest that cannot be obtained by a private working on his own). If the common goal or common interest is characterized by infinite edges and non-exclusion, the achievement of that common goal or interest implies that a public or collective sensible has been provided. Thus, the collective action may be formulation of a rule of restrained access to a common-pool resource and observance of that rule and also the public sensible may be the case of sustainable exploitation that results (Wade, 1987).

2.3.2 Irrigation System as a Sociotechnical System

Different approaches have been employed in the analysis of irrigation by different scholars. Woldeab (2003) identify three approaches: the technocratic approach, the organizational approach and the social force approach. The technical infrastructure of the irrigation system is the main focus of the 'technocratic approach'. Importance is given to large scale construction and rehabilitation work. Irrigation management is confined to the operation and maintenance of the irrigation infrastructure. The 'organizational approach' mainly focuses on the management of irrigation systems. Organizational problems with respect to water distribution in large scale irrigation systems are studied. The 'social force approach' considers irrigation as a way of producing, a social activity, shaped by the dialectical interaction of social force and, in that process, becoming a social force in itself and influencing further development in society. Problems in irrigation systems are examined as an ongoing struggle between different interest groups over water. These approaches have attempted to examine irrigation in a non-comprehensive way using individual disciplines such as engineering, management, anthropology and economics.

Woldeab (2003) criticizes past management and economics literature on irrigation and current approaches to irrigation studies for having three conceptual problems: lack of appreciation of the social dimension of technology, simplified concept of the human agency and little interest in social relations of power and the institutional forms through which purposes of irrigation are achieved. He argues that an interdisciplinary investigation of irrigation requires insights into its technical, organizational or institutional and socio-economic and political aspects. Woldeab (2003) outlines the social dimension of the irrigation system in terms of three basic concepts: social construction, social requirements for use and social effects.

2.3.2.1. Social Construction

Irrigation technologies are socially constructed. This means that technology development and design are social processes in which different stakeholders interact (communicate, negotiate, take decisions) and the nature of that process and the different perceptions and interests of the stakeholders shape the technical characteristics of the technologies.

2.3.2.2 Social Requirements for Use

Woldeab (2003) defines an 'irrigation system' as the physical infrastructure needed to capture, transport, and distribute to farms. To a considerable degree the source of water (river, dam or ground water) and the canal system in use determine the type of organizations needed in an irrigation system. Difference in the sources of water may require different forms of management. In an irrigation system where dam technology is used as the water harvesting technique, the water allocation (scheduling) practice is dependant on the volume of water stored in the dam. Accurate measurement of the available water on a regular basis is important to determine the irrigable land size in the irrigation system and irrigators could also decide the type of crop to plant. The transport of water from a dam to the farms needs an efficient canal networks to tackle problems such as water logging and soil salinity. Hence, farmers may need training in techniques of water management, irrigated agriculture, and conservation of resources.

2.3.2.3 Social Effects

The third way in which irrigation technologies are socially relevant is in their social effects. It is very important in irrigation that farmers get water on time with required quantity. The canal structure conveys the water to the fields. An ill-designed canal or dam limits farmer's access to water. Furthermore, unreliable water supply may have a negative effect on the management of an irrigation system. If farmers consider that the arrival of water in the canal is unreliable and quite unpredictable, or if they have not had any for a long time, their participation in water management could be curtailed.

[illegible] Water Users Association and Collective Action

A water users' association, or WUA, is a non-government, non-profit organization initiated and managed by a group of farmers and other water users along one or more hydrological subsystems or watercourses. By organizing themselves, water users can exert their financial, material, technical and human resources needed to manage, operate and maintain an efficient irrigation and drainage system in their locality (USAID, 2006). According to the report of USAID on water users association in Afghanistan in 2006, the major benefits and functions of having a WUA includes creation and enforcement of a unified set of water use rules within the area it serves; a more responsive, better understood and well-respected water management system for farmers and other water users; a more equitable distribution of water among farmers regardless of their location, type and size of farm and status (whether a WUA member or not); a much more reliable water supply for particular crops and other needs; more efficient use of water that will minimize waste and prevent erosion, water logging and over-watering of irrigated lands; prevention of illegal water theft; faster and more efficient resolution of disputes between and among WUA members and non-members over the distribution and use of water, the management of irrigation and drainage infrastructure and the operation and maintenance of equipment; better maintenance of irrigation canals, drainage and other infrastructure, operating and maintenance equipment and other properties owned by the WUA and better protection of the environment.

According to Van Koppen (2002), irrigation institutions are defined as the collective arrangements at scheme level for water control and use which include water distribution, construction of infrastructure, maintenance and rehabilitation. Water is derived from streams, dam, river diversion or groundwater, then allocated and distributed. Identifying factors that make sustainable and effective of collective action for the event of irrigation will facilitate to spot where collective action will be established simply and effectively and it is necessary to spot conjointly where efforts are required for the institution and effectiveness of collective action. The thematic analysis areas concerning collective action for irrigation management embody how individuals organize themselves with respect to irrigation water, what consistent policies and different instruments will be utilized to rework stakeholder's manner and the way common property management be used to facilitate and initiate native organizations for water management. Individuals will learn from the success of traditional irrigation systems, particularly from the institutional, managerial and legal facet of water administration and management. Understanding the evolution, development and functioning of ancient water uses associations ought to provide necessary insights on a way to organize and develop trendy irrigation associations (Gebremedhin *et al*., 2003).

International expertise with farmer irrigation management suggests that, for a successful community management of irrigation schemes, the economic and money prices of sustainable self-management should be a little proportion of improved income. Also the transaction price of the organization should be low and irrigation should be central to the development of livelihoods for a major range of members. Developing native leadership skills for irrigation management conjointly seems to be a key issue for successful collective irrigation management (Gebremedhin *et al*., 2003).

2.4 Irrigation Potential in Sub-Saharan African (SSA) Countries

According to Hillel (2000) and Reuben et al. (2012), the key to maximizing crop yields per unit of supplied water in dry lands irrigated areas is by ensuring that the available moisture is used through plant transpiration and little is lost through soil evaporation, deep filtration and transpiration from weeds. In recent years, there has been increasing concern at the performance of conventional irrigation systems in sub-Saharan Africa.

Poor development in irrigation technologies have resulted in under-utilization of the agricultural potential in reducing food insecurity. This has been one of the reasons irrigation has lost its appeal as an investment strategy. Good performance in irrigation systems is judged on its ability to result in high output and efficient use of available water resources. For irrigation systems to be effective and efficient it must ensure that maintenance of soil fertility, drainage and salinity-control measures are employed (Hillel, 2000).

Mali has a vast area with irrigation potential out of which less than 20% is actually irrigated. (Keita *et al*,. 2011). USAID (2018) confirms that it is only seven percent of 43.7 million arable hectares of land which is currently cultivated while it only 14 percent of 2.2 million potential irrigable hectares which are currently irrigated.

Majority of the irrigation practices in the country is small scale. A number of small scale projects under donor-to-donor agreement between USAID and the German Development Bank (KfW) exist. Most of these projects and programmes aims to support the Malian government's National Program for Small-Scale Irrigaiton, 2012-2021 (Programme National d'Irrigation de Proximité, PNIP). By the year 2021, Malian government aims to develop 26,000 hectares of irrigated land that can benefit potentially 3 million people with an estimated cost of 396 billion FCFA which is approximately $792 million USD (USAID, 2018). During the development period between year 2016 and 2021, the PNIP plans to develop 48,000 hectares of land under improved irrigation for an estimated cost of 118 billion FCFA ($236.2 million USD) (USAID, 2018). Numerous government and international development agencies in partnership with the Government of Mali has promised and effected their contribution. These include USAID, Germany, Canada and the European Union (USAID, 2018).

2.5 Small Scale Irrigation Technologies in Sub-Saharan African (SSA) Countries

Since 1980s, there has been a growing shift in attention to small scale irrigation systems mainly because small informal systems continued to play significant role especially in the production of vegetables (tomatoes, pepper, okra and others) when the large formal systems were unsuccessful. Various economic and investment analyses point to the profitability and viability of small scale irrigation systems (Dittoh, 1991b). For instance, You (2008) showed that although some large scale schemes in Sub-Saharan Africa may result in much higher profits, the potential for profitable small-scale irrigation is about 10 times greater than that for large-scale irrigation.

Water is a basic need for human beings and animals. It is essential for their metabolic processes. It is used to build healthy workforce, ensuring food security, provision of clean energy for agriculture, industry and service maintenance of healthy ecosystem, recreation (aesthetic value), transportation, hedge against climate change and variability catalyst (MOWE, 2013).The most essential use of water in agriculture is for irrigation to produce enough food. Agriculture is the largest user of water in all regions of the world except Europe and North America (FAO, 2003). About 90% of water withdrawn is taken by irrigation in some developing countries and significant proportions in more economically developed countries (Awulachew, 2005). About one fifth of the world (about 1.2 billion people) live in areas of water scarcity, which is not enough water available to meet their daily, needs (World Bank, 2010).

According FAO (1996), irrigated agriculture can be defined as the supply of water increased by artificial means, involving the use of water controls technology and including drainage to arrange excess water. Irrigation has been practiced in Egypt, China, India and other parts of Asia for a long period of time. Irrigation enables farmers to increase crop production and achieve higher yields, food availability and affordability for non-irrigators and reduces the risk of crop failure if rain fails (Hussein and Hanjra, 2004). India and Far East have grown rice using irrigation nearly for 5000 years (Zewdie *et al.*, 2007). Analysis in Asia indicates that irrigation contributes to increase yields per area, for most crops by between 100%–400%. This has contributed to a reduction in food prices. Irrigation contributes to agricultural productivity through solving the rainfall shortage, motivates farmers to use more of modern inputs and harvest throughout the year and creates employment to members of the households especially to wife and children (FAO, 2011).

According to Fuad (2002) irrigation can be classified in to three: Small-scale irrigation which are often community based and traditional methods covering less than 200hectares, medium scale irrigation which is community based or publicly sponsored, covering 200 to 3000 hectares and large scale irrigation covering more than 3000 hectares, which is typically commercially or publicly sponsored.

Small-scale irrigations are type of irrigations that defined as schemes that are controlled and managed by the users. Small-scale schemes developed, operated and maintained by individuals, families, communities, or local rules and landowners, independently of government (Bart, 1996). Small-scale irrigation is a type of irrigation defined as irrigation, on small plots, in which farmers have the controlling influence and must be involved in the design process and decisions about boundaries (Tafesse, 2007).

Irrigation technology is a system of improving natural production by increasing the productivity and expanding the total area under agricultural production especially in the arid and semi-arid regions of the world (Bhattarai & Narayanamoortht, 2003). According to Knowler and Bradshaw (2007), irrigation is the artificial application of water to land for the purpose of enhancing plant production. It reduces or removes water deficits as a limiting factor in plant growth and makes it possible to grow crops where the climate is too dry for this purpose and to increase crop yields where plant-available soil water is a yield-limiting factor during parts or all of the growing season.

Irrigation is therefore, a technique that involves artificial provision of crops with water to facilitate their growth. This technique is used in farming to enable plants to grow when there is not enough rain, particularly in arid areas. It is also used in less arid regions to provide plants with the water they need when seed setting. When using irrigation due to insufficiency of rainfall to allow crop growing, irrigation is said to be supplementary; which is the process of distribution of additional water to the crop with the objective of stabilizing and increasing yield, in environments where the given crop is usually grown under rainfed agriculture. In arid and semi-arid areas, irrigation is used for production during the dry season in the absence of rain (Water report 22: Deficit Irrigation Practices, FAO).

There are many technologies used in small scale irrigation in Mali. These technologies comprise manual drilling and mechanical drilling including pedal pumps (popularly known as *Nafasoro*), Aeolian pump, electric pump and motor pump. For the manual drilling, water is lifted from wells, rivers or other water source of the surface by human force using rope and a container (Keita *et al.*, 2011). These devices are mainly used by poor resource farmers. In the mechanical drilling, water is shifted by manual or motor pumping systems. This method is used for small and great irrigation by average and wealthy farmers. With both methods water is distributed to plots through the gravity irrigation, Californian system, sprinkling system, drip irrigation and manual watering.

Use of small scale irrigation technologies requires prudent management. Irrigation management is important since it helps determine future irrigation expectations. Irrigation is the artificial exploitation and distribution of water at project level aiming at application of water at field level to agricultural crops in dry areas or in periods of scarce rainfall to assure or improve crop production. The goal of irrigation management is to use water in the most profitable way at sustainable production levels. For production agriculture this generally means supplementing precipitation with irrigation. In recent years there has been significant decline in groundwater levels, almost all over the world. In most places, there is pumping restrictions for irrigation water. Additionally, increases in fuel prices means that pumping extra irrigation water increases irrigation expenses without increasing income.

2.5.1 Drip Irrigation

Drip irrigation, also known as trickle irrigation, functions as its name suggests. Water is delivered at or near the root zone of plants, drop by drop. This method can be the most water efficient method of irrigation, if managed properly, since evaporation and runoff are minimized. In modern agriculture, drip irrigation is often combined with plastic mulch, further reducing evaporation and is also the means of delivery of fertilizer.

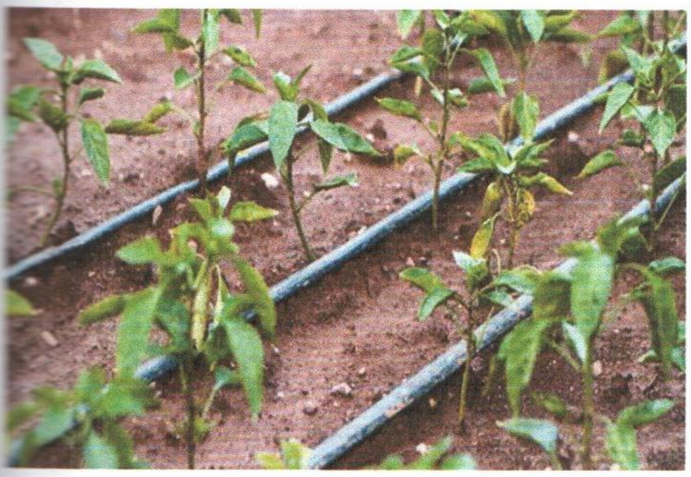

Plate 1: Drip irrigation system

Drip irrigation has many advantages over sprinkler or flood irrigation, including application uniformity, the ability to apply water exactly where it is needed, and the potential reduction of disease and weed incidence in irrigated systems. Drip irrigation refers to both rigid ½ inch poly tubing with inline emitters and the thin wall tubing commonly referred to as "drip tape." Drip tape is available in an assortment of wall thicknesses and emitter spacing and is relatively low cost, but also much less durable compared to the rigid poly tubing. Drip tape is commonly used in small-scale vegetable production systems as a means of conserving water and minimizing weed and disease pressure. Depending on the water source, drip tape and tubing often require filtration to limit clogging of emitters. Drip tape and poly tubing with inline emitters require pressure regulation to optimize application uniformity. Drip tape and poly tubing with inline emitters require a grade of 2% or less and runs of no more than 300 feet for optimum distribution uniformity. Careful consideration must be given to design when setting up a drip irrigation system to optimize distribution uniformity and system function.

Drip irrigation has the potential to use scarce water resources most efficiently to produce vegetables (Locascio, 2005). The major benefits of drip irrigation are the ability to apply low volumes of water to plant roots, reduce evaporation losses and improve irrigation uniformity (Schwankl *et al.*, 1996).

Use of drip irrigation can result in high nutrient use efficiency (Thompson *et al.*, 2002). Saline irrigation water can be used with drip irrigation, while maintaining yields and improving water use efficiency compared to surface irrigation (Cahn & Ajwa, 2005; Tingwu *et al.*, 2003).

In drip irrigation, the efficiency of water use is high since evaporation, surface runoff and deep percolation are greatly reduced or eliminated. In addition, the risk of aquifer contamination is reduced since the movement of fertilizers chemical compound by deep percolation is reduced. The use of degraded and subsurface wastewater application can reduce pathogen drift and reduce human and animal contact with such water.

The efficiency in water application is improved since fertilizers and pesticides can be applied with accuracy. In widely spaced crops, a smaller fraction of soil volume can be wetted, thus further reducing unnecessary irrigation water losses. Reductions in weed germination and weed growth often occur in drier regions.

Hand laborers benefit from drier soils by having reduced manual exertion and injuries. Likewise, double cropping opportunities are improved. Crop timing may be enhanced since the system need not be removed at harvesting nor reinstalled prior to planting the second crop. On the other hand, laterals and submains can experience less damage and the potential for vandalism is also reduced. Operating pressures are often less, thus, reducing energy costs.

Drip irrigation is the most energy and water efficient of all the irrigation systems. Water savings of up to 50% compared to sprinkler irrigation are common (Lamont *et al.*, 2002). Ideally, water is applied in the proper amount to the root ball of the plant, minimizing water leaching from the root zone and minimizing evaporation of water since the water isn't sprayed into the air (Shock, 2006; Lamont *et al.*, 2002; Haman & Smajstria, 2010; Schultheis, 2005). The water can be emitted at uniform distances along a pipe or a tube with an emitter that directs water to one plant volume of soil. The drip hose can be placed above ground or buried in the ground, which is called sub-surface drip irrigation (Lamm *et al.*, 2003). Sub-surface irrigation has the advantage of nearly zero evaporation, but it is difficult to diagnose if an emitter becomes plugged or damaged.

Drip irrigation operates at low pressures, 10 to 20 psi at the emitter. The system pressure will need to be higher to overcome pressure loss in filters, valves, backflow preventers, pressure regulator and tubing. Typically, about 40 psi is needed at the pump outlet. Drip irrigation can be designed to fit any situation or field. It can also reduce disease problems, because it doesn't get the plant wet. It does require some experience to learn how much water to apply, but a soil water sensor in the row or next to the plant can provide feedback to aid in determining the correct amount of water. Drip irrigation requires understanding of the system to assure good management and maintenance.

Drip method of irrigation helps to reduce the over-exploitation of groundwater that partly occurs because of inefficient use of water under surface method of irrigation. Environmental problems associated with the surface method of irrigation like waterlogging and salinity are also completely absent under drip method of irrigation (Narayanamoorthy, 1997). Drip method helps in achieving saving in irrigation water, increased water-use efficiency, decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer-use efficiency (Qureshi *et al.*, 2001; Sivanappan, 2002 Namara *et al.*, 2005).

The classical 'leaching requirement' approach for salinity management does not work well with subsurface drip irrigation (SDI), because irrigation with SDI results in no leaching above the depth of the drip tape, and salts will accumulate throughout the growing season. Irrigation with SDI can maintain suitable root-zone salinity, but surface salt accumulation will occur unless there is adequate leaching due to rainfall or supplemental surface irrigation. Facilitating crop establishment with SDI will help to improve the long-term economic sustainability of SDI (Thomas *et al.*, 2010).

Accumulation of salts in concentrations detrimental to plant growth is a constant threat in irrigated crop production. With surface irrigation, leaching adequate amounts of water through the soil profile (e.g. the 'leaching requirement') is the desired method for maintaining suitable soil salinity (Dasberg & Or, 1999; Hanson & Bendixen, 1995; Oron *et al.*, 1999). By applying saline water with appropriate irrigation management techniques, long-term sustainability in agricultural systems can be achieved Rhoades *et al.* 1992). One such irrigation technique is drip-irrigation, which has been successfully used in combination with saline waters (Shalhevet, 1994).

Surface drip irrigation provides solutions to wastewater recycling problems. By recycling used water, fresh water is "freed up" for domestic needs, which is less expensive than developing new water resources. Additionally, water recycling solves waste disposal problems and reduces fertilizer requirements (Radke, 2006).

sustainable development and reducing environmental hazards through sub-surface drip irrigation (SDI) is more suitable for treated wastewater and results in even more efficient water use and crop growth than surface drip irrigation methods. However, continued research is required to ensure the success of recycled water in agricultural production.

Water management is undoubtedly the foundation of Israel's success in agriculture in arid, semi-arid and dry sub-humid zones. The most conspicuous technology in this regard is the ubiquitous surface drip irrigation developed in Israel during the 1960s that enabled farmers to increase crop yield and quality while using less water and fertilizers. This result in even higher levels of water use efficiency through reduced runoff, evaporation and other parameters, and provides nutrients to plants while maintaining a dry soil surface. Drip emitters in SDI systems are positioned within the soil in attempts to conserve water, control weeds, minimize runoff and evaporation, increase longevity of laterals and emitters, permit heavy equipment to move easier in the field and prevent human contact with low-quality water. Additional motivation for SDI comes in the form of savings of the extensive labor involved with seasonal installation and collection of surface drip system laterals (Mekala *et al.*, 2008).

Wastewater reuse (untreated) is a common practice in developing countries of Asia and Africa and wastewater (treated) recycling is common in water scarce regions of the developed countries such as the Australia, Middle East, south west of US, and in regions with severe restrictions on disposal of treated wastewater effluents, such as Florida, coastal or inland areas of France and Italy, and densely populated European countries such as England and Germany (Marsalek *et al.*, 2002). Utilization of SDI systems is particularly beneficial when using recycled wastewater systems, making them particularly relevant to Israeli agriculture in drylands. Whether for simple soil-based waste disposal or for agricultural utilization, regulated flow and prevention of surface exposure are extremely important when irrigation systems rely on effluents. SDI is a potential tool for alleviating problems of health hazards, odor, contamination of groundwater, and runoff into surface water. SDI particularly augments opportunities for treated wastewater in landscape and ground cover as well as in edible crops. SDI presents a unique opportunity to manipulate root distribution and soil conditions in drylands in order to better manage environmental variables including nutrients, salinity, oxygen and temperature.

The widening gap between supply and demand is often made up with marginal resources, especially reclaimed municipal wastewater, which is becoming an increasingly important source of water for agricultural in water-short countries. Drip irrigation may however pose some drawbacks. Water applications may be largely unseen and it is more difficult to evaluate system operation and water application uniformity. System mismanagement can lead to under irrigation, less crop yield quality reductions, over irrigation. It may also result to poor soil aeration and deep percolation problems. If emitter discharge exceeds soil a soil infiltration, a soil overpressure develops around emitter outlet, enhancing surfacing and causing undesirable wet spots in the field. Timely and consistent maintenance and repairs are a requirement. Leaks caused by rodents can be more difficult to locate and repair, particularly for deeper systems.

There is one disadvantage of surface irrigation that confronts every designer and irrigator. The soil which must be used to convey the water over the field has properties that are highly varied both spatially and temporally. They become almost undefinable except immediately preceding the watering or during it. This creates an engineering problem in which at least two of the primary design variables, discharge and time of application, must be estimated not only at the field layout stage but also judged by the irrigator prior to the initiation of every surface irrigation event. Thus while it is possible for the new generation of surface irrigation methods to be attractive alternatives to sprinkler and trickle systems, their associated design and management practices are much more difficult to define and implement. Drip irrigation systems tend to be labour-intensive. This labour need not be overly skilled. But to achieve high efficiencies the irrigation practices imposed by the irrigator must be carefully implemented. The progress of the water over the field must be monitored in larger fields and good judgement is required to terminate the inflow at the appropriate time. A consequence of poor judgement or design is poor efficiency. One sometimes important disadvantage of surface irrigation methods is the difficulty in applying light, frequent irrigations early and late in the growing season of several crops. For example, in heavy calcareous soils where crust formation after the first irrigation and prior to the germination of crops, a light irrigation to soften the crust would improve yields substantially. Under surface irrigation systems this may be unfeasible or impractical as either the supply to the field is not readily available or the minimum depths applied would be too great.

2.5.2 Sprinkler Irrigation

In this method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. According to Dupriez and De Leener (2002), Sprinkler irrigation imitates rainfall. It is also called overhead irrigation. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. In contrast to surface irrigation, sprinkler systems are designed to deliver water to the field without depending on the soil surface for water conveyance or distribution. This type of irrigation is beneficial for uniform distribution of water and highly efficient use of water, water application at controlled rate and used for cooling crops during high temperatures and frost control during freezing temperatures. But it needs high initial costs and more maintenance, and there is high loss of water by evaporation.

In sprinkler or overhead irrigation, water is piped to one or more central locations within the field and distributed by overhead high-pressure sprinklers or guns, A system utilizing sprinklers, sprays, or guns mounted overhead on permanently installed risers is often referred to as a solid-set irrigation system. Higher pressure sprinklers that rotate are called rotors and are driven by a ball drive, gear drive or impact mechanism. Guns are used not only for irrigation, but also for industrial applications such as dust suppression and logging. Sprinklers can also be mounted on moving platforms connected to the water source by a hose. Automatically moving wheeled systems known as traveling sprinklers may irrigate areas such as small farms unattended (Dahigaonkar, 2008).

Plate 2: Sprinkler irrigation system

Using a system of pipes through pumping, water is distributed to the target crops. Through the sprinklers, water is sprayed into the air so that it breaks up into small water drops which fall to the ground. This method is best for ensuring uniform application of water. Sprinkler irrigation is good for most row, field and tree crops and water can be sprayed over or under the crop canopy. Not all sprinklers are good for all crops irrigation. Some produce large water drops that may damage the crop. Unlike some types of irrigation systems, sprinkler irrigation can be applied to any form of land in relation to its slope, whether flat or otherwise. It is advisable that the lateral pipes supplying water to the sprinklers to be laid out along the land contour whenever possible. This minimizes the pressure changes at the sprinklers, thereby providing a uniform irrigation. Although sprinkler irrigation is best suited to sandy soils with high infiltration rates, it is also adaptable to most other types of soils. It is however not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used. Large sprinklers that produce larger water droplets should be avoided. To avoid problems of sprinkler nozzle blockage, good clean supply of water, free of suspended sediments is required. This also avoids spoiling of crop through sediment coating (Michael, 1978).

Sprinkle irrigation is used on approximately 5 percent of irrigated land throughout the world, the majority of which is in developed countries. It is unlikely to replace the large areas under surface irrigation, (essentially the remaining 95 percent, except for a small amount of trickle). Sprinkle irrigation has a distinct advantage, because good water management practices are built into the technology. Sprinkler irrigation technology can provide the flexibility and simplicity required for successful operation, independent of the variable soil and topographic conditions. Pumps, pipes and on-farm equipment can all be carefully selected to produce uniform irrigation at a controlled water application rate and provided simple operating procedures are followed, the irrigation management skills required of the operator are minimal. This puts the responsibility for successful irrigation in the hands of the designer rather than leaving it entirely to the farmer. Sprinkle can be much simpler to operate and requires fewer water management skills. However, it requires sophisticated design skills and on-farm support in terms of maintenance and the supply of spare parts (Fuad, 2002).

Sprinkler is potentially less wasteful of water and uses less labour than surface irrigation. It can be adapted more easily to sandy soils subject to erosion on undulating ground, which may be costly to re-grade for surface methods. There are many types of sprinkle systems available to suit a wide variety of operating conditions. The most common for smallholders is a system using portable pipes (aluminum or plastic) supplying small rotary impact sprinklers. Because of the portability of sprinkle systems they are ideal for supplementary as well as total irrigation (Adewumi et al., 2005).

There are many different sprinkler irrigation systems. Solid set system is the commonest where the sprinkler irrigation system is in fixed position. Other sprinkler systems are hose-reel, hose-bull and travelling guns where depth ranging of irrigation can be applied from 15 mm to 40 mm.

2.5.3 Manual Irrigation

Manual irrigation systems are not only cheap but simple and require no technical equipment. The system is easy to handle and therefore generally cheap (in contrast to other irrigation systems such as sprinkler and drip irrigation. They however suffer a major disadvantage of high labour requirement. A common and very simple technique for manual irrigation is for instance the use of watering cans as it can be found in peri-urban agriculture around large cities in some African countries. There are many methods for manual irrigation, which are easy to install and simple to use. In general, all of these methods have high self-help compatibility and a relatively high performance (FAO 1997).

Plate 3: Manual irrigation system

Most smallholder farmers in developing countries irrigate their field with watering cans. The rose on the top of the outlet creates a sprinkler effect (FAO, 2011). Irrigation by watering cans is a very basic way but is still widely used. This creates a lot of work for the labours especially if this technique is used for large fields. A common way to make this work easier is a carry-pole across the shoulders. With watering cans, the field worker is able to irrigate very specific and only where it is necessary.

2.5.4 Gravity Irrigation Systems (Canal IP)

A gravity fed irrigation system is a cheap effective way to provide water for a smaller sized crop area. It would be especially cost effective if the climate of the area can provide enough precipitation to consistently keep a reservoir filled using rain water harvesting techniques. The basic system is very simple consisting of an elevated reservoir with a pipe coming out the bottom that feeds water into a basic drip irrigation system that is all controlled either by hand or with a very efficient battery powered timer that controls the rate at which the crop is watered (Asawa, 1999).

Plate 4: Gravity Irrigation Systems (Canal IP)

This involves diverting water into a farm field. There are two primary ways of diverting surface and ground waters: gravity diversions and pumping plants. When water surface elevations or heads at the water source are sufficient, gravity diversions are used. A pumping plant is used to lift and/or offer pressure for conveying and/or applying irrigation water (Awulachew et al., 2005).

A gravity diversion is the most common type of gravity diversion. It uses a turnout to admit water from an open water source into farm canals and pipelines. A turnout consists of an inlet, a conduit or other means of conveying water through the bank of the supply canal and where required, an outlet transition. Turnouts normally include a means of regulating and measuring inflow to the farm such as weirs, sluice gates or valves (Asawa, 1999).

On farms that obtain water from pressurized pipelines, a valve is used in lieu of a turnout to admit water into the farm pipeline. A pumping plant is necessary only when the delivery pressure (from the off-farm pipeline) is not sufficient to provide the head needed to operate the farm irrigation system. The inflow rate to the farm is controlled by regulating the delivery pressure and valve opening (BADC, 2012).

Pumping plants are used when water must be lifted from the water source and/or when sufficient head (pressure) is not available to operate the farm irrigation system. Pumping plants normally have one or more horizontal or vertical centrifugal pumps powered by either electric motors or internal combustion engines (Dahigaonkar, 2008).

Gravity irrigation system, also called surface irrigation system is the oldest methods of irrigation, which convey water from the survey to the fields in lined or unlined channels. Surface irrigation is the introduction and distribution of water in a field by the gravity flow of water over the soil surface. The primary methods of applying water are basins irrigation, borders irrigation, flood irrigation and furrows irrigation (Widtose, 2001). One can choose these irrigation methods depending on the nature of the soil, the form of the land, the head of the water stream, the quantity of water available and the nature of the crop.

Basin irrigation - Basin irrigation is the most common form of surface irrigation, particularly in regions with layouts of small fields. A basin is a piece of land, small or large, surrounded by earth bunds in which water is pounded. The field to be irrigated is divided in two units surrounded by levels or dams. Gated outlets, siphon tubes, spiels, and hydrants conduct water from delivery channels in to each basin. This type of irrigation is suitable for all types of soil and efficient use of water but it needs high initial cost for leveling land (Dahigaonkar, 2008).

Furrow irrigation - Furrow irrigation is accomplished by running water in small channels that are constructed with or across the slope of a field. Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using 'furrows,' 'creases,' or 'corrugations. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. Water is diverted in to furrows from open ditches or pipes. The advantage of this type of irrigation are Uniform application of water, less evaporation loses, less intercultural operations but it needs high cost for preparing furrows. Because it requires more and require more labor (Dittoh et al., 2010).

Border irrigation - Border irrigation is an open-field method viewed as an extension of basin irrigation to sloping, long rectangular or contoured field shapes, with free draining conditions at the lower end. Here a field is divided into sloping borders. Water is applied to individual borders from small hand-dug checks from the field head ditch. Soils can be efficiently irrigated which have moderately low to moderately high intake rates but, as with basins, should not form dense crusts unless provisions are made to furrow or construct raised borders for the crops. The benefits of this type of irrigation are uniform application of water, uniform application of water, efficient use of water but it requires repairing of ridges and supervision during irrigation and land needs to be graded uniformly (Dupriez & Leener, 2002).

Flood irrigation - Flood irrigation is an ancient method of irrigating crops. It was likely the first form of irrigation used by humans as they began cultivating crops and is still one of the most commonly used methods of irrigation used today. Water is delivered to the field by ditch, pipe, or some other means and simply flows over the ground through the crop. This type of irrigation is least cost method and does not require any skill but it is inefficient method, result in uniform stand of crops and low yield, and more wastage water due to run off, deep seepage and evaporation (FAO, 1997).

2.5.5 Californian Irrigation Systems

Compared to surface irrigation (flood and furrow), Californian irrigation reduce water loss to evaporation, deep percolation, and completely eliminate surface runoff (Phene, 1990), it also increase crop marketable yield and quality (Ayers *et al.* 1999). Just like in drip irrigation, use of Californian irrigation can result in high nutrient use efficiency (Thompson *et al.*, 2002). Saline irrigation water can be used with drip irrigation, while maintaining yields and improving water use efficiency compared to surface irrigation (Cahn and Ajwa, 2005; Tingwu *et al.*, 2003). Californian irrigation system application of water below the soil surface, using buried drip tapes has many benefits over conventional drip irrigation (Singh and Rajput, 2007). The biophysical advantages are the lower canopy humidity and fewer diseases and weeds as drip irrigation (Camp & Lamm, 2003).

Plate 5: Californian irrigation system

Karlinsky (2005), explains that Californian irrigation system is a network of PVC pipelines put underneath the soil to permit and to reduce water loss by infiltration. The term "California irrigation method," was derived to mean the irrigation system used in the citrus industry in California. It implies the underground installation of water tubes meant for distribution by means of spigots. This irrigation system is suitable for use in tree irrigation where spacing is about six to seven meters. This provides adequate room for burying of tubes as well as further space for cultivation between the rows by a variety of means such as animals or tractors. A furrow system was used to irrigate the roots themselves, instead of ditches. Spigots that are attached to the underlying water tubes are used to bring water to the surface while discharging it into dirt furrows, ploughed in the orchards by mechanical means. The roots are served by water through percolating from the furrows, precluding the need for basins.

2.6 Advantages and Disadvantages of Irrigation in Mali

Increase in agricultural production and productivity depends, to a large extent, on the availability of water. Increased supplies of irrigation water have been instrumental in feeding irrigation can make possible the growing of two or three crops in a year in most places. This can considerably enhance agricultural production and productivity.

There is evidence in many regions that employment opportunities are often created with the implementation and development of irrigation systems. This can occur either because labour is needed for new land brought into production or for land that is being double cropped and therefore requires additional labour in planting and harvesting (Picazo-Tadeo & Reig-Martínez, 2005).

The construction of a water storage and conveyance system decreases the risk associated with stochastic rainfall. Farmers are better able to plan their cropping patterns when they can predict the supply of water available. The planting of certain crops, requires the assurance of a sufficient water supply. Irrigation also allows farmers to apply water at the times that are most beneficial for the crop, instead of being subject to the variation in rainfall (Schoengold & Zilberman, 2007).

The expansion of agriculture is a primary cause of deforestation in developing countries (Namara, Nagar & Upadhyay, 2007). Increasing food production in a region requires either more intensive use of existing cropland or an expansion of agriculture onto new cropland. Irrigation is a necessary input into high-intensity crops production. One major outcome is that irrigation can reduce the need for new agricultural land development. This could lead to a decrease in deforestation and the resulting environmental problems such as soil erosion. If an area lacks irrigation systems, increase in food demand is achieved through the use of more land.

Insufficient, uncertain and irregular rain causes uncertainty in agriculture. In most parts of sub-saharan countries, rains are experienced only about four months in a year. The remaining eight months are dry. Even during the rainy seasons, the rainfall is scanty and undependable in many countries. Sometimes the rainy season is delayed considerably while sometimes the rains cease prematurely. This pushes many farming households into drought conditions. With the help of irrigation, droughts and famines can be effectively controlled (Vandersypen *et al.*, 2006).

Irrigation helps in stabilizing the output and yield levels. It also plays a protective role during drought years. Since both income and employment are positively and closely related to output, prevention of fall in output during drought is an important instrument for achieving stability of income and employment in rural areas. Irrigation has ability to make many developing countries to acquire 'partial immunity' from drought (Smith-Laurence, 2004).

Irrigation confers indirect benefits through increased agricultural production. Employment potential of irrigated lands, increased production, helps in developing allied activities, means of water transport etc. are improved income of government from agriculture. Availability of regular water supply increase the income of farmers imparting a sense of security and stability in agriculture (Oad & Kullman, 2006).

Irrigation investment can help farmers to increase diversification of crops, and use of more chemical inputs like pesticides, fertilizers or improved seed varieties (Bhattarai *et al.*, 2007; Bhattarai *et al.*, 2007) and switched from low-value subsistence production to high-value market-oriented production (Huang *et al.*, 2006). Farmers in rural areas who suffer from persistent poverty and food insecurity due to climatic changes and dependence on variable rainfall can benefit from irrigation. Over-reliance on rainfed agriculture leads to low agricultural productivity and persistent rural poverty and which in turn, through increasing population pressure often result in a vicious circle of poverty and environmental degradation (Von Braun, 2008). Irrigation development is recognized as a backbone of agricultural productivity, enhancing food security, earning higher incomes and increasing crop diversification (Smith, 2004). In many developing countries, small scale irrigation schemes are consider as a means to increase production, reduce the risk of unpredictable rainfall and provide food security and employment to poor farmers (Burrow, 1987). Small-scale irrigation should be a policy priority in developing countries for rural poverty alleviation, food security and growth. It enables households to generate more income, increase their resilience, and in some cases transform their livelihoods (MOFED, 2006). Small-scale irrigation plays a significant role in diversification of production to new types of marketable crops like fruits, cash crops and vegetables (Eshetu, 2010). According to G/egziabher (2008), farm production in irrigation and rainfall-based areas has big difference in their productivity. Farm production based on irrigation is often high due to post harvest storage facilities, and doubling or tripling effects of irrigation while the rain-fed areas produce subsistence crops and makes farmers to encounter chronic food deficit. Hagos *et al.* (2009) indicated that irrigation in Ethiopia increased yields per hectare, income, consumption and food security.

Despite large-scale investment and expansion of irrigation facilities, it is a matter of serious concern that about 60 per cent of the total cropped area is still dependent on rain. There are a number of problems related to irrigation and they have to be solved. The biggest problem in the irrigation has been the tendency to start more and more new projects resulting in excessive proliferation of projects. There is also delay in utilisation of potentials already present. In most of the projects, there have been delays in construction of field channels and water courses, land leveling and land shaping. Irrigation make use of water resource which is public and often planned by the government. However, some rivers are inter-state in character. As a result, differences with regard to storage, priorities and use of water arise between different countries. This can contribute to inter-countries rivalries over distribution of water supply. Introduction of irrigation has led to the problem of waterlogging and salinity in some parts of the country. The cost of providing irrigation has been increasing over the years. Most irrigation equipment are expensive to smallholder farmers (Ghosh, Singh & Kundu 2005).

2.7 Importance of Irrigation to Agriculture

Increased supplies of irrigation water have been instrumental in feeding the populations of developing countries in the last 50 years. Irrigation has increased food security and improved living standards in many parts of the world. With a rapidly growing world population and a limited food supply, irrigation could be the only way out. In many developing countries, irrigation is credited with the expansion of food supply, stabilization of water supply, the improved welfare of farming households and a relative decrease in deforestation of land for agriculture (Bright Hub, 2018).

One clear benefit of irrigation is its expansion in the feasible land base for agricultural production. A region might have high quality soil for growing crops, but if it doesn't receive enough rainfall at the right times of the year, it can't be used for crop production. For areas that receive rainfall during the wrong season, the development of reservoirs allows water to be stored during the rainy time of the year, and then used for farming during a dry part of the year. For those areas that don't receive enough water for growing crops, a system of pipes or canals allow water to be transported from a water-rich area to an arid area (Schoengold & Zilberman, 2007).

There is indisputable evidence that irrigating land leads to increased productivity. Irrigation is a necessary input into sustainable and commercial agriculture. One acre of irrigated cropland is worth multiple acres of rain-fed cropland. Globally, 40% of food is produced on irrigated land, which makes up only 17% of the land being cultivated. Irrigation allows farmers to apply water at the most beneficial times for the crop, instead of being subject to the timing of rainfall. (Smith-Laurence, 2004)

It has been pointed out by several previous studies that the contribution of irrigated agriculture to food and nutrition security, increased employment and poverty alleviation is very significant in many parts of Asia (Postel et al., 2001; Bhuttarai & Narayanmoorthy, 2003; Hussain & Hanjra, 2004) and also in several parts of Africa (Dittoh, 1997; Ojo et al., 2011). It has even been stated that there is need to invest to double the irrigated area in Sub-Saharan Africa, if the first Millennium Development Goal of halving poverty and hunger (MDG l) is to be achieved (Commission for Africa, 2005). The performance of irrigation systems in Sub-Saharan Africa and especially in West Africa has however continued to be very disappointing.

Another benefit of irrigation is that through its reservoirs, stored water can be used for double cropping of fields. There are many tropical areas that are warm throughout the year, but have seasonal rains for a portion of the year while remaining dry and arid for the other part. The ability to store water during the rainy season for use in the dry season could allow a farmer to move from one annual crop to two or three (Schoengold & Zilberman, 2007).

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2.8 Irrigation Schemes in Mali

Office du Niger (OdN) is the largest irrigation scheme in West Africa. Established in 1932 to develop a vast area of 2.8 million hectares using the waters of the Niger river diverted at Markala dam. OdN has since then built and managed a hydraulic system delivering water to close to 120,000 ha mostly cropped with rice and sugarcane and the potential for expansion of irrigable area up to 450,000 hectares. OdN is mandated by the Government to undertake irrigation development using public funding from national budget or from projects and has the responsibility to operate and maintain the irrigation systems in partnership with the users who irrigation service fee. OdN also provides extension services. OdN also the land on the Government and distribute it to smallholder farmers holding a land use permit on plots developed at the Government's cost and to investors holding a land lease on plots developed at their own cost.

High demographic growth rates and declining soil fertility have made the OdN area a particularly prized area for land ownership / occupation. The demand for land with irrigation facilities is much higher than their supply (approximately 4,000 ha are built annually in the OdN). While large producers can finance part or the totality of these facilities, smallholder farmers are dependent on the extension of irrigation schemes financed by the Government. Farmers settled on existing schemes have very few if any opportunity to expand their farms. Population growth means these farms get divided among the heirs and their size reduces constantly (from an average of 7 hectares in the eighties to less than 2 hectares presently). As the availability of fertile, irrigable land diminishes and demand for access to OdN land increases, the opportunities for profiteering and rent-seeking in the publicly managed land and irrigation scheme have grown. Concerns over 'land-grabbing' and speculative land acquisitions by politically well-connected elites and investors have emerged and point to the significance of the area for the consolidation of political legitimacy or control. These pressures have been counterbalanced by the emergence of grassroot farmer organizations and syndicates with strong leadership and real political weight (Rosegrant *et al*. 2002).

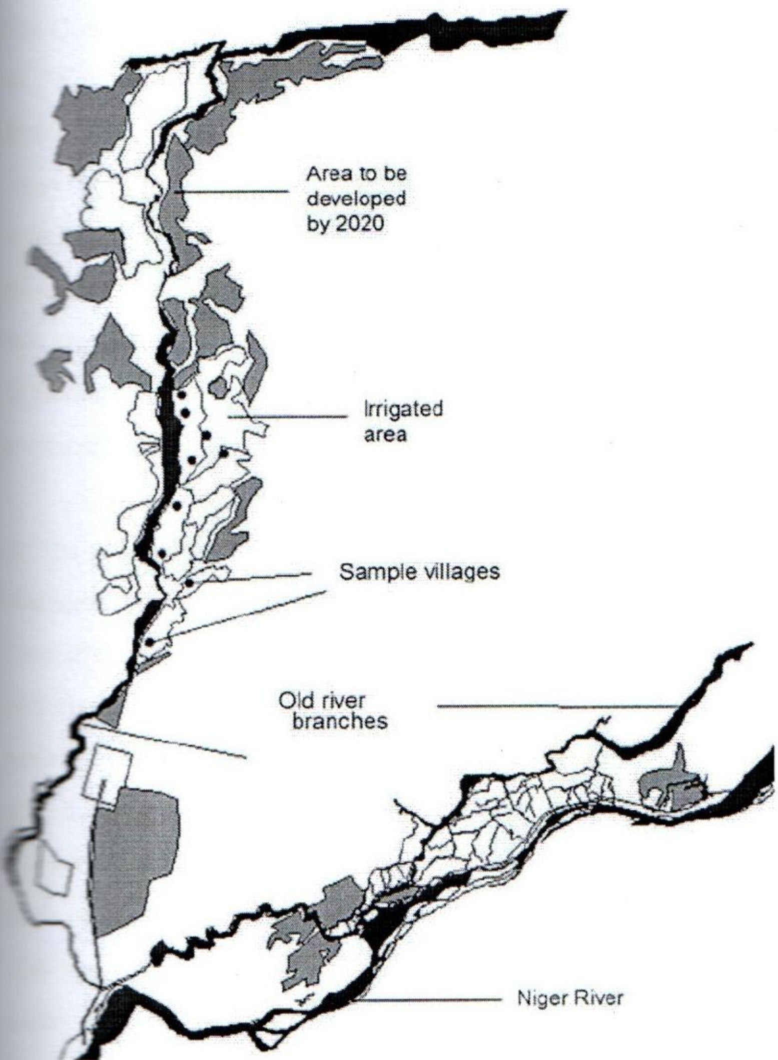


Figure 2: Map of the Office du Niger irrigation scheme, indicating the currently irrigated area and areas to be developed by 2020

Source: Office du Niger (2016).

Based on a water balance for Niger basin, a paradigm shift from the current model of irrigation development which is based essentially on rice cultivation with gravity-fed, low efficiency irrigation systems and full public financing, the government is laying and setting priorities for the sustainable development additional irrigable land. Importantly, measures are being set to improve water efficiency and drainage, to develop fish farming and high value crops, to increase the synergy between irrigated agriculture and livestock production and to enhance land tenure security and management in OdN area (Moustafa, 2004).

The Government has established an *Agence pour l'Aménagement des Terres et la Fourniture de l'Eau d'Irrigation* (ATI) with a mandate to help finance irrigation development using innovative financing mechanisms to leverage private sector financing. ATI is an autonomous entity entrusted with the mission to accelerate the pace of investment in irrigation and drainage throughout Mali. Its main functions are to (i) negotiate and mobilize public and private funding for irrigation development; (ii) avail irrigated land for producers and ensure the provision of adequate irrigation service; (iii) support the Government services in implementing strategic studies and (iv) recover part of the investment costs from the producers for use in future investments.

In the context of structural adjustment, international donors have pushed Irrigation Management Transfer (IMT) in state-led irrigation schemes all over the developing world (Svendsen and Meinzen-Dick, 1997). It was assumed that, having a direct stake in the success of their irrigation scheme, farmers would be better managers than the bureaucracies that they replaced had been (Larson & Ribot 2004; Agrawal & Gupta 2005). International donors not only hoped that the schemes would become financially self- sustainable. They also aimed at water conservation. The latter gained importance as it became clear that the pending food crisis, triggered by fast population growth is in fact a water crisis (Rosegrant *et al.*, 2002). This water conservation agenda was (and sometimes still is) based on the naïve paradigm that water conservation is good for all stakeholders. Often, it was not realized that some conservation practices are neutral or can even go against the interests of participating farmers, who generally carry the largest burden of conservation activities but not necessarily reap the rewards. In addition, when the resource is a common property, as is the case for irrigation schemes, its management demands collective action. Collective action is not always sure to arise spontaneously and heavily depends on the available social capital (Ostrom 1994; Berger *et al.* 2007). Furthermore, the availability of water influences greatly farmers' incentives to use water efficiently. It has been shown that both water shortage, especially when unpredictable, as abundance can lead to over-consumption (Perry & Narayanamurthy 1998; Chad & Kullman 2006). As a consequence, not all transfer programs have led to the desired results (Cleaver, 1999; Moustafa, 2004; Blaikie, 2006). In fact, the different stakeholders take decisions based on their own objectives and a mental model of how actions will influence results (van Noordwijk *et al.*, 2002).

2.9 Vegetables Production in Mali

Vegetables are a complex group of a wide variety of different types of plants. Some species grow from year to year; other--grow and die within one or two years. They have diverse forms of propagation: by seeds or vegetative parts. They may be herbaceous, viny, shrubby, or tree in growth habit. They differ in growth requirements. Many vegetables can be grown under a wide range of conditions; while others have more exacting requirements for water, temperature, and light. Different parts of a plant may be used as a vegetable, depending on localities and culture. In general, developing countries utilize more parts of a particular plant as a vegetable than developed countries. Most vegetables are high in water which makes them bulky and highly perishable, particularly the leafy ones (Locascio, 2005).

Considering their diverse nature, it is very difficult to come up with a single, acceptable, all-encompassing definition of vegetables. Definitions of the word "vegetable" are generally based on their use. A vegetable could thus be defined as an edible, usually a succulent plant or a portion of it eaten with staples as main course or as supplementary food in cooked or raw form. Since any definition of vegetable generally centers on its use, a plant may be a vegetable in one country but a fruit, a weed, an ornamental, or a medicinal plant in another country, depending on the crop. In some cases, a plant could be a vegetable only at a certain growth stage. The bamboo is a crop used for its wood but bamboo shoot is a vegetable. Some of the legumes can be used at various stages of development: the sprouted seeds, the tender shoots, the immature tender pods, and the mature seeds. Some fruits, such as papaya and jackfruit, are used as vegetables (NARC, 2011).

The economy of developing countries is usually agriculture-based. The majority of the rural populace depend on farming for livelihood; and a substantial number of farmers grow vegetables as a secondary, if not a primary crop. Vegetable production has the potential, therefore, of improving the lives of people. Vegetable production is labor intensive. Production of vegetables creates a number of job opportunities in the rural and suburban areas and in the complementary fields of business that arise, such as marketing, processing, and transportation. Vegetable growers tend to earn higher income than most other farmers because of the relatively higher yield and value of the crops (Sanchez et al., 2003).

Women in developing countries play a major role in vegetable production. They produce vegetables to meet their household's needs in addition to their primary responsibility to their family. Data on the extent of vegetable production are only estimates and generally not very reliable because of the difficulty of accounting for all crops produced in small farms or home gardens. Moreover, plant species considered to be vegetables vary from place to place. Yields are higher in developed countries than in developing countries although total production in the former may be lesser (Sudha et al., 2006).

Since the yield potential of vegetables revolves around photosynthesis and respiration, directly or indirectly, all the environmental factors that affect the efficiency of these processes must be at optimum level. The factors can be grouped into two: abiotic and biotic, referring to nonliving and living components of the environment, respectively. The abiotic factors include the climate and the soil. The biotic factors include beneficial and harmful insects and microorganisms and higher plants and animals. A knowledge of the environmental factors affecting vegetable production will make it easier for the grower to modify the environment or adjust his practices to attain the same result (Ntow et al., 2006).

Vegetables, being succulent products by definition, are generally more than 90% water. Thus, water determines the weight and yield of vegetables. The quality of vegetable products is also determined by the quality of water management. Many defects of vegetable products may be traced directly or indirectly to mismanagement of water supply in the production field (Sanchez et al., 2003).

A good proportion of investment in vegetable growing is allocated for water management, whether it is in a traditional farm where water is applied by manual labor or in an automated drip-irrigation system. Unlike field crops which can be grown under rain fed conditions, vegetables with few exceptions are always irrigated, at least partially. It is every grower's utmost concern to use irrigation water in the most efficient way. It is equally important to provide adequate drainage facilities in the field because most vegetables cannot tolerate prolonged waterlogged conditions. In the humid tropics, vegetable crops may be classified according to adaptation to the wet or dry seasons roughly corresponding to their adaptation to excess or deficiency of moisture. The dry season, taking all environmental factors into consideration, is generally more favorable for growing vegetables than the wet season. Hence, all tropically adapted vegetables can be grown successfully during this season, provided that irrigation water is available. Without irrigation, less vegetable crops can be grown (Locascio, 2005).

Rain fed dry-season crops are normally limited to those that are early maturing (i.e., they can be harvested in 60 days or less) and relatively tolerant to excess moisture during the early stage and drought at a later stage. These crops must be sown towards the end of the wet season; so that, enough residual moisture is available for germination and crop establishment. With adequate drainage, some crops perform even better during the wet season than during the dry season. These are yard-long bean, winged bean, and leafy vegetables. However, these are exceptions. As a rule, irrigated dry-season crops provide the bulk of vegetable supply in the tropical environment (Sudha et al., 2006).

The most common vegetables in Mali include onions, tomatoes, okra, potatoes and eggplant. Vegetable crop production is largely dependent on rainfall and households cultivate relatively small land areas, of about half hectare to two hectares on average (Drechsel et al., 2004; Eastwood et al., 2006). The rainy season is relatively short and rainfall is very erratic, thus droughts and floods, even within the same year, are common. There is considerable disguised unemployment especially in the long dry season which is a major reason for the persistent food insecurity and poverty in the country.

Majority of Mali is located in arid and semi-arid West Africa with a Sudano-Sahelian climate which is very conducive to horticultural production (than the humid areas). Vegetable production is extremely suitable during the dry season because of higher solar radiation, cooler nights and less pest and disease pressure (Pastemak *et al.*, 2006). The humid areas of

Mali, on the other hand, experience cooler weather and high sunshine, a period that is suitable for vegetable production in those areas.

Over 75% of the irrigated area in Mali is under vegetables since almost all the informal irrigation is for vegetable production and a considerable proportion of the formal small scale irrigation systems are for vegetable production. Vegetables are cultivated mainly because of their high agro-climatic suitability, high value added (income) per unit of land, and high nutritional and medicinal importance. They are however very sensitive to water stress or dry spell in the growing period. They are also easily perishable. Therefore, farmers produce vegetables under high risks in terms of production as well as marketing-reflected by high fluctuation of market prices.

Irrigation is the means to reduce the risks in farming, ensure high yields as well as make production possible all year round. That means vegetable production needs to be managed competently; in a business-like manner. Several past studies have demonstrated higher economic profitability of vegetable production, under both rain fed and irrigated conditions, than cereals and other staple crops (Weinburger and Lumpkin, 2007; Amisah et al., 2002; Adewuml et al., 2005). Also it has been shown that the irrigated vegetable systems are more profitable than rainfed vegetable systems (Dittoh, 1992). The findings imply that vegetable production is responsive to market forces and prospects for commercialization are high. All these findings point to a very good agribusiness potential of irrigated vegetable production in Mali and the West African region.

Many different types of vegetables are cultivated across the sub-region. The main ones include onions, tomatoes, peppers (hot and sweet), several types of melon, eggplants and leafy vegetables (exotic, such as lettuce and cabbage, and local such as kenaf, hibiscus and roselle), green beans and okra. Almost all vegetables produced under irrigation are mainly for the market. However, the indigenous leafy vegetables are also consumed in relatively large quantities by the people and serve as "hunger gap fillers" during crop failures and during the long dry seasons in the arid and semi-arid areas of West Africa (Amisah et al., 2002).

Vegetables production in the arid and semi-arid parts of West Africa may be categorized into four types as follows:

Rainy season production: Production is undertaken around family houses (home gardens) by women. Indeed vegetable production is traditionally women's activity. Mainly indigenous vegetables such as local leafy vegetables, okra, pumpkin and roselle are produced by women in the households mainly for home consumption but some can be sold.

Small scale production under irrigation: These are produced using almost all the types of irrigation systems but particularly along rivers and on small dam sites in relatively rural and remote areas. Mainly onions, tomatoes, pepper and exotic leafy vegetables (cabbages, lettuce and others) are produced for sale in local market.

Urban and peri-urban production: This production takes place along the banks of rivers and streams running through cities and towns. Deep wells, boreholes and taps are also sources of water for urban and peri-urban small-scale vegetable production. Mainly exotic leafy vegetables are produced for the urban markets; people living in fenced bungalows also cultivate vegetables in home gardens mainly for home consumption. Wastewater and sludge are commonly used for farming around large towns and cities. The main vegetables grown under the urban and peri-urban irrigation system include lettuce, spring onions, spinach, and cabbage. Others include carrots, onions, amaranth, eggplant, tomatoes, okra, hot pepper, green beans, and cucumber. Dreschel *et al.* (2006) noted that though peri-urban agriculture covers a small percentage of the total irrigated area, it accounts for between 60 and 100 percent of the consumed leafy vegetables in cities like Dakar, Bamako, Accra, Kumasi and Tamale, depending on crop and season.

Large-scale production for markets in cities and for export: This production takes place mainly under drip irrigation. The production involves relatively large investments in modem and large-scale drip irrigation equipment. Some of the examples of this kind of production include green beans and sweet pepper.

Most of the vegetables produced in Mali are sold and/or consumed without any industrial processing and/or any form of proper packaging. Thus Malian vegetable value chains are quite short. The agribusiness potential becomes greater if vegetable value chains are systematically developed, and improved post-harvest management and technologies are introduced. The development of vegetable value chains will result in increased income due to value addition and employment, since several sections of the expanded value chains will employ labour; and the resultant effect will be the increase in food and nutrition security of all actors along the chains.

2.10 Efficiency and its Estimation Methods

The measure of the efficiency first appeared in Koopmans (1951) and Debreu (1951) whom in their separate studies were interested in the production analysis and resources utilization coefficient, respectively. Wu, Yang and Liang (2006) argued that the firm's efficiency can be calculated empirically using an innovation method of efficiency frontier estimation from real situations of production observations.

A production unit is effective technically if, from the inputs it possesses, it produces the maximum of possible outputs or if, to produce an outputs given quantity, it uses the smallest possible quantities of outputs. According to Briec, Comes and Kersten (2006), technical efficiency degree measure of a production unit permits to surround if this last one can increase its production without consuming, at the same time, more resources or reduce the use of at least one input by conserving at the same time, the same level of production.

Rodriguez-Alves, Tovar and Trujillo (2007) considered that allocative efficiency puts in relation the inputs utilizations by the enterprise according to the current prices on the market. The allocative efficiency is necessary if the firm maximizes its profits or minimizes its costs at a given level of production. These two hypotheses of behavior permit to define an optimum inputs combination and the allocative efficiency measure is got by comparing the minimum cost of outputs quantity production at the cost incurred effectively by the firm.

The economic efficiency is measured by the global economic performance of the firm, that is, by its ability to make its operations profitable. Guzman and Estrázulas (2012) defined economic efficiency by the product of technical efficiency and the allocative efficiency. Accordingly, a firm cannot be 100% efficient economically if it is not 100% efficient technically and at the same time 100% efficient allocativelly. The economic efficiency can be separated into two distinct criteria and is therefore only the result of those two measures. As it is shown by Coelli *et al.* (2005), this definition seems to be accepted universally.

The frontier estimation methods can be classified according to the frontier planned form, according to the estimation technique used to get it and according to the nature and the supposed properties of the gap between the observed production and the optimal production. The classification according to the frontier form permits to distinguish between the parametric approaches and the nonparametric approaches. The parametric approach presents a function including explicit parameters (Cobb-Douglass, CES, Translog, etc.). Nuama (2006) indicates that the parametric approach is the one which presents a function including explicit parameters. In the case of a parametric function, many econometrical techniques and non-econometrical ones permit to estimate the production or the cost frontiers parameters: the least squares method or the maximum likelihood method. The nonparametric frontiers have the particularity not to impose any pre-established form to the frontier (Murillo-Zamorano, 2004). The nonparametric approach is then used when the production process cannot be identified by a functional form. The convexity of the production is the only differentiation element of the non-parametric approaches. It makes it possible to distinguish the convex nonparametric approach from that non convex. Data Envelopment Analysis help to estimate the parametric approach of the production frontier. DEA estimates a convex envelop, so as to estimate a frontier. The mathematical program planning helps to estimate the nonparametric approach frontiers. It is about some descriptive methods which use as support the linear program planning or the quadratic program planning (Leleu, 2006). The nature of the gaps between the observed production and the maximum production distinguishes the stochastic frontiers from the deterministic frontiers. In fact, if we suppose that the gaps are only explained by the inefficiency of the producer, we qualify the frontier of having a deterministic nature. If, on the contrary, we estimate that the gaps are explained at the same time by the inefficiency of the producer and by some random elements which do not depend on the producer, we say that the frontier has a stochastic nature (Kumbhakar & Lovell, 2000).

A firm efficiency can be measured through some parametric and non-parametric approaches which differ primarily by the assumptions concerning the residues. A production or a cost frontier will be parametric if we impose a deterministic functional form (Cobb-Douglass, Translog, etc.) of we suppose that any gap between the estimated function and the observations is considered as coming from the producer's inefficiency and stochastic if, the gaps are explained by both the producer's inefficiency and some random elements which are not under the owner's control. The parametric approaches impose a functional form that presuppose the frontier form, whereas the nonparametric approaches impose less structure to the frontier but they suppose the absence of random errors.

[illegible] Economic Efficiency of Water Use in the Small Scale Irrigation Systems in Mali.

Water use efficiency is a term commonly used to describe the relationship between water (input) and agriculture product (output). When used in this way the term is, strictly speaking, a water use index. Water use efficiency is also often used to express the effectiveness of irrigation water delivery and use. Barrett Purcell & Associates (1999) correctly point out that efficiency is in fact a dimensionless term obtained by dividing figures with the same units such as volume of water used (output) divided by a volume of water supplied (input). Consequently, the ton of produce per mega liter of water used is an index, not efficiency. This common misuse of the term "water use efficiency" has created great confusion. Water use efficiency (WUE) concepts have evolved over a century of irrigation development (Bos & Walters, 2000; Solomon, 2000; Clemmens & Solomon, 2007). Economic efficiency is related to the value (rather than the physical amounts) of all inputs used in producing a given output. The production of a given output is economically efficient if there are no other ways of producing the output that use a smaller total value of inputs. For example, a firm may have several alternative production methods that it could use. One may require a lot of labour but only a little capital whereas another requires a lot of capital and only a little labour. A third production method may require a lot of land but relatively little of both labour and capital. In order to maximize its profits, the firm should choose the production method that costs the least (Barrett-Purcell & Associates, 1999).

Sub-Saharan Africa has vast untapped water resources. Expansion of the irrigated area has the potential to make a substantial contribution to agricultural development and address the problem of food insecurity. Many irrigation schemes in the past failed due to a combination of factors, including high investment costs, poor planning and a lack of maintenance. It is recommended that new irrigation schemes are initiated in response to demand from farmers, increasing the chances of local management and maintenance of the schemes. Irrigation cannot be treated in isolation and must be considered alongside other elements of agricultural development, including improved markets (proximity, information), institutional and legal transparency, clarity of land rights, efficient use of inputs (seeds, fertilizer, pesticides), extension services for farmers, research and development and environmental management (Reuben *et al.*, 2012).

In Sub-Saharan Africa the available groundwater resources are 100 times those of renewable surface water. But farmers often hold back from investing in groundwater irrigation because of the high drilling costs of tube wells and lack of information about groundwater availability. Furthermore, the evidence suggests that the region has significant groundwater resources but that in most cases the hydrology is suited for low yielding boreholes that can only be operated by hand-pumps. Newer technologies such as drip and sprinkle systems have the potential to increase productivity but are really only accessible to those farmers who can afford to buy them and who are growing cash crops such as vegetables, fruits and flowers (Reuben *et al.*, 2012).

The original work by Charnes, Cooper and Rhodes (1978) is attributed to have coined the term Data Envelopment Analysis (DEA) and the development of the dual pair of linear programming method into the equivalent ratio form (popularly known as the CCR model). This development provided a basis for analysing efficiency (Cooper *et al.*, 2011; Ding *et al.*, 2015).

Economic Viability of Small Scale Irrigation Systems in Mali

Irrigation is the art of applying water artificially to the field in accordance to the crop requirement throughout the cropping period for the full fledge nourishment of the plant for better yield ability (NARC, 2011). Policy makers are usually interested in achieving higher yield for a unit of water applied and consequently interested in more economic return. It is obvious that water used in certain irrigation systems is more than that used in others, but the question is how much of water in excess. A good irrigation system should give a better return, and the general prosperity of farmer is based on the yield of crops.

For the farms to remain viable they do not necessarily need to increase their efficiency since successful farming may depend on the farmer's ability to choose a farming activity that fits the size of the farm in order to maintain the farm economic viability in the long term.

Assessment of economic viability can serve as a crisis management tool. Typically scientists (Scott, 2001; Adelaja, 2005; Scott *et al.*, 2008) use financial indicators and statistical methods to measure the economic viability of agricultural holdings. It is evident that research does not devote sufficient attention to the assessment of farm economic viability through a relevant choice and use of assessment methodologies.

In assessing the economic viability it is important to make a distinction between the financial costs and benefits, and the economic costs and benefits, because the latter encompasses a much broader range of factors (including non-monetary factors) than the former. In agriculture, there are many 'values', both financial and non-financial to be taken into account.

Benefit cost ratio is an important tool for assessing economic viability of agricultural technologies. Economic valuation of irrigation technologies benefits and costs involves converting their financial values into economic values, also known as "shadow pricing." This conversion requires economic prices of project outputs and inputs to be estimated. Economic prices reflect values of enterprises supported by the irrigation technologies. When considering benefits in the Cost–Benefit analysis, benefits have to be considered in the broad sense of the term: direct or indirect, internal and external. In order to estimate direct benefits, the first step would be to research whether there is available market data regarding the specific benefit. In cases in which benefits appear as cost savings, the quantification of a benefit is implicit in the cost estimate of the alternatives under analysis. When valuing project costs and benefits, a quantification problem can arise. Most of the costs are direct costs, but the project may have other indirect costs and benefits as well as positive and negative "externalities" (Yates, 2009).

Prices should reflect the best alternative use of the goods (opportunity cost) to the extent to which it is possible (Guzman & Estrázulas, 2012). Although market prices are the best way to reflect the opportunity cost, in some circumstances they may not do so accurately (distortions in the specific market for the good or service due to monopolies or other market imperfections) and there is a need to discount the effect of taxes in the prices/costs, as they are part of the nominal value of the cost (in terms of cash flows), but do not imply a cost in terms of society (but in fact are a revenue for the government). Dealing with benefits is especially challenging since all benefits have to be quantified. Benefits often relate to the "opportunity cost" concept. Time savings are a clear example (in the field of transportation projects).

Determining the unit of analysis and its monetary value is not an easy exercise for many intangible variables. One alternative to determine its monetary value is to assess the highest price an individual is willing to agree to pay for a good or a service (Breidert, 2005). How much a person is willing to pay depends on the perceived economic value and on the utility of the good. These two values determine whether the price a person is willing to accept is the reservation price or the maximum price. If a person believes that there is no alternative offering, the highest amount of money he or she is willing to pay equals the utility of the good and is the reservation price. If a person perceives an alternative offering with an economic value below utility, the highest price he or she would accept equals the economic value of the product and is the maximum price. Where it is difficult to determine the monetary value of a benefit, it can be useful to consider values from studies in other countries, although care is necessary in interpreting these as the value (for example, willingness to pay) in one country may be different from another.

not to quantify a specific benefit, the benefit should be treated qualitatively and or included in the analysis in addition to the quantitative results. In this case, even not possible to express all of the benefits or costs in quantitative terms, it is possible important aspects for decision-makers.

economic terms, it may be said that there is a need to demonstrate that a project's and economic benefits are higher than its costs. The first act is to demonstrate social economic benefits in quantitative terms. When this is not possible, it may be handled through a qualitative analysis, describing the main advantages and the value added by the project to the society in terms of relevant magnitudes, defined in accordance with the authority's strategic plan and global strategic objectives.

According to the World Bank (2011), most research studies carried out on performance of irrigation schemes have targeted to monitor the performance over time, for example to evaluate the impact of change in management or to examine the performance of similar projects. Mostly these evaluations focus on analysis of inputs and outputs of irrigation projects that is water, land, labor, value of production, cost of operation and maintenance. These indicators are often referred to as external indicators. These indicators do not provide significant information when comparing projects. Obviously projects producing fruit and vegetables have a better productivity than single-crop rice projects. The use of internal indicators as a tool for the diagnosis of irrigation projects need to be defined and discussed.

The concept of viability can be defined at different levels and in various contexts. In a general context, it includes the ability of the scheme to generate sufficient income to satisfy the household income expectations of the irrigators and to cover basic operational and maintenance (O+M) costs of the irrigation infrastructure, while not mining the natural resources (soil and water). Though income expectations may differ widely across cultures and among individuals, it is much related to the relative role irrigation plays in the income functions of individual irrigators (Kamara, Van Koppen & Magingxa, 2001). Further considerations include the ability of the scheme to maintain cash flows and consistency of income generation over time, and management of risks and shocks associated with small-scale farming.

Technical Efficiency of Small Scale Vegetables Production under Different Irrigation Systems

The economic efficiency of a production system is made up of two components, technical and allocative efficiency. Crudely defined, technical efficiency is the physical component of the production system which deals with the maximization of output from the physical combination of inputs, and allocative efficiency is the optimization of the production process which takes into consideration input-output price relationships. It is possible to estimate technical efficiency alone. A technically efficient producer avoids as much waste by producing as much output as input use will allow or by using as little inputs as output production will allow. Thus, comparing two producers, one producer is more efficient than the other if the producer can produce the same output using less of at least one input or can produce more of at least one output using the same inputs (Kebede, 2001).

Graphically, we can illustrate technical efficiency as shown in Figure 3. In Figure 3, land and water are inputs that can be used to produce output, say maize. Curve A is a production possibility frontier. This frontier is a plot of the maximum amount of maize that can be produced from all the possible combinations of the inputs land and water given a certain technology. Assume that a farmer uses these inputs but only manages to produce at F in Figure 3. This particular farmer's technical efficiency is given by the distance OF expressed as a percentage of the distance OA. This is a measure of how close to the frontier the farmer manages to get. The farmer's technical inefficiency is measured by the distance FA expressed as a percentage of the distance OA. This is a measure of how much the farmer falls short of getting onto the frontier. From Figure 3 we can observe that the relationship between technical efficiency and technical inefficiency can be represented as: Technical inefficiency = 1 – technical efficiency.

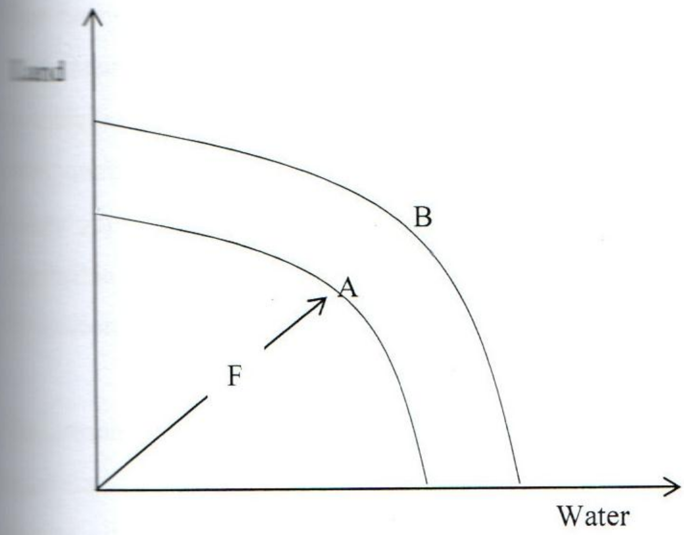


Figure 3: Simplified illustration of technical efficiency

Different methods can be used to estimate technical efficiency or technical inefficiency. If one collects farm-level data that can be used in linear programming, then one can use DEA to estimate technical efficiency. If one collects data that can be used for regression analysis, then one can use the stochastic frontier production function and use the residuals to estimate technical inefficiency as explained later in the methodology. Usually, the choice of method is made before data is collected. Continuing with the example, different farmers will have different levels of efficiency or inefficiency in the land-water space bounded by curve A in Figure 4. If a farmer is 100% efficient, that farmer is producing on the frontier. Given the technology available to the farmer, that farmer has achieved the maximum possible efficiency or has an inefficiency of zero. Most farmers produce with some degree of technical inefficiency. Assume that those farmers with the frontier defined by curve A are using land and saline groundwater for irrigation. However, the extension agent advises them that if they use the groundwater conjunctively with better quality surface water, they can produce more maize from the same quantities of land and water. The new plot of the maximum possible maize output from all possible combinations of land and water might be represented by frontier B in Figure 4. Frontier B is said to be higher than frontier A. The change in irrigation water quality shifted the production possibility frontier from curve A to curve B for the same farmers. If we assume that the farmers with the production possibility frontier curve A (call them farmer population A) are different from those farmers with the production possibility frontier curve B (call them farmer population B), then farmer population B is producing maize on a higher production possibility frontier than farmer population A. If the knowledge about better quality water that helped farmer population B to achieve a higher frontier is shared with farmer population A, either by contact with population B or through extension advice, then it is possible that farmer population A could shift its production possibility frontier towards the production possibility frontier achieved by farmer population B.

The presentation above simplifies the concept of technical efficiency. In reality farmers use more than two inputs, for instance, they use land, labor, fertilizer, irrigation water, oxen and a host of other inputs to produce one output, for example, maize. This makes the production possibility frontier a multidimensional surface instead of a two dimensional one, as represented in Figure 4. We can usually estimate only portions of the production possibility frontier from a sample of farmers. Fortunately, we have statistical tools that enable us to test whether one portion of a frontier that we have estimated is higher or lower than another.

In Figure 4, assume that curve A is a part of farmer population A's production possibility frontier that we have estimated from a sample of five farmers, and curve B is the frontier estimated from five farmers for farmer population B. In Figure 4 farmer population A is represented by the black dots and farmer population B by the circles. It is still the case that curve B represents a higher production possibility frontier for maize than curve A. Figure 4 shows the distributions for both populations of farmers.

If we assume that our two samples of five farmers are representative of their respective populations, then this distribution of the five farmers closely represents the distribution of their populations. We can observe that population A is very close to the frontier A. This means population A has a low level of inefficiency or a high level of efficiency, given the technology they are using. We can also observe that population B, although on a higher frontier, has a low level of efficiency, or has a high level of inefficiency, given the technology they are using. A desirable transformation for population A would be to shift to frontier B while still maintaining the high level of efficiency, while a desirable transformation for population B would be to try and have the same level of efficiency as population A while still maintaining frontier B. The relevance of this discussion becomes obvious as we explain the methodology and interpret the results of the technical efficiency analysis. For a comprehensive treatment of the concept of efficiency (Coelli *et al*., 2005).

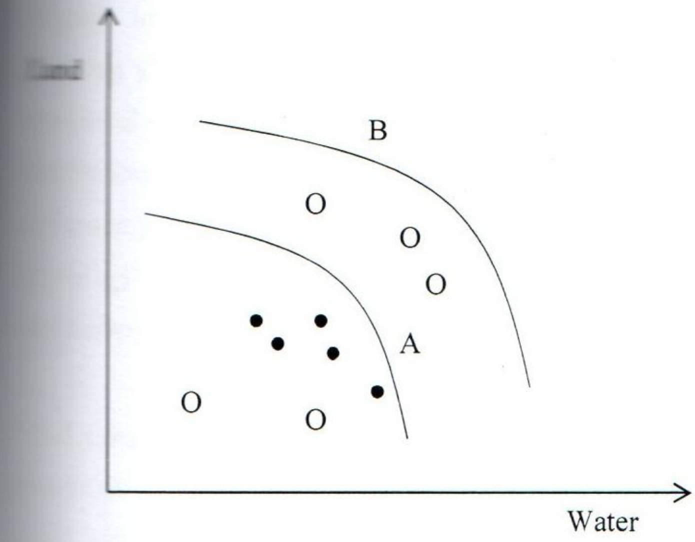


Figure 4: Simplified illustration of technical efficiency of two types of farmers

In Mali, the case study from ICBA-SSA confirms that improving irrigation technologies can significantly contribute towards improving the rural economy and livelihoods. A well-defined scientific framework is needed for successful expansion of this technology to SSA. This framework has to be developed based on studies of the efficient utilization and management of available water resources. The extent and scope of the challenges facing small farmers in SSA can be identified through studies to develop and test suitable technologies for increasing agricultural productivity through more effective utilization of soil and water resources, improved cropping systems and strengthening the institutions serving farmers (including the private sector). Such efforts will assist in sustaining water resources development, leading to improvements in agricultural productivity and farm income (Coelli *et al*., 2005).

Socio-economic and institutional issues will be addressed while evaluating sustainability concerns for on-farm management. In this context, possible scenarios of agricultural and livestock production systems will be assessed. The scenarios will include, but are not limited to (i) public/private/community based irrigation development and management; (ii) investment in irrigation technology/water harvesting; and (iii) better integration of crops and and/or livestock production systems (Coelli *et al*., 2005).

The main impact of irrigation expansion is to increase the value of agricultural output via increasing yields per ha per year (cropping intensity) and through changing the structure of agricultural output towards crops that have a yield per hectare. The increased productivity (and profitability) and incomes/welfare of households as related to improved water, irrigation, crop management and labor will be assessed. This will determine the best combination of technology and/or crop diversification that will help in improving the overall livelihood of rural farmers (Coelli *et al*., 2005).

[illegible] Empirical Comparative Studies on Technical Efficiency

Several efficiency studies have been conducted by other researchers worldwide. Battese and Coelli (1995), in their study of Technical Inefficiency Effects in a Stochastic Frontier Production Function using panel data concluded that the inefficiency effects were stochastic and depended on the farmer specific variables as well as the time of observation. Farmer-specific variables herein refer to inputs used in the production process such as labour and capital which are associated with each firm. They used a linearised version of the logarithm of Cobb-Douglas production function where different input variables accounted for different effects. For instance, they used age, schooling, years in production, among others, to account for technical change and time varying effects.

Similarly, Battese and Coelli (1992) effectively demonstrated the importance of frontier production function in predicting technical inefficiency of individual firms in an industry. They demonstrated this using panel data of 38 farms in India for which firm effects were an exponential function of time, and concluded that technical inefficiencies of the farmers were not time invariant when the year of observation was excluded from the stochastic frontier. The opposite was true when year of observation was included in the stochastic frontier.

Comparisons have also been made between the traditional (average) Cobb Douglas function and the generalized frontier model and the results have shown that generalized frontier models are more suitable models in the study of technical inefficiencies. For example, a study by Battese and Coelli (1988) on the prediction of firm level technical efficiencies revealed that the traditional Cobb-Douglas production function was not a suitable model for prediction. They applied a stochastic frontier production function to the dairy industry of New South Wales and Victoria. They further observed that a more generalized model for describing firm effects in frontier production functions accounted for the situations in which there was high probability of firms not being in the neighborhood of full technical efficiency.

Bravo-Ureta and Pinheiro, (1997), analyzed technical, economic, and allocative efficiency in peasant farming in the Dominican Republic. They used maximum likelihood techniques to estimate a Cobb-Douglas production frontier which was then used to derive its corresponding dual cost frontier. These two frontiers formed the basis for deriving farm-level efficiency measures. The results of their study revealed average levels of technical, allocative, and economic efficiency of 70 per cent, 44 per cent, and 31 per cent, respectively. These results suggest that substantial gains in output and/or decreases in cost could be attained given existing technology. The results also point out to the importance of examining not only TE, but also AE and EE when measuring productivity. In their second stage regression where they used Tobit to regress TE, AE, and EE, on various socio-economic attributes of the farm and farmer (contract farming, agrarian reform status, farm size, schooling, producer's age, and household size), the results showed that younger, more educated farmers exhibited higher levels of TE, AE and EE their older counterparts. Additionally, the study also showed that contract farming, medium-size farms, and being an agrarian reform beneficiary had a statistically positive association with EE and AE. On the contrary, the study also revealed that the number of people in the household had a negative association with AE. In conclusion, the researchers observed that for the peasant farmers in the Dominican Republic AE appeared to be more significant than TE as a source of gains in EE which from the policy point of view, contract production, farm size, and agrarian reform status were the variables found to be most promising for action (Kabwe, 2012).

[illegible]a (2000) estimated a translog production function to determine technical efficiency differential between small and medium scale tobacco farmers in Uganda who did and did not adopt new technologies. Results showed that credit accessibility, extension service access and farm assets contributed positively to technical efficiency. The differences in efficiency between farmer groups were explained with only socio-economic and demographic factors.

[illegible]ga (2003) assessed the impact of new maize production technology and efficiency of smallholder farmers in Ethiopia using the stochastic efficiency decomposition technique to analyze technical, allocative and economic efficiency of farmers in different agro-climatic zones. Although the study revealed positive result for improved production technology and production efficiency, inefficiencies were observed under both the traditional and improved method. That is, the study revealed production inefficiency under the traditional maize production as being attributed to technical inefficiency while inefficiency under the improved system was as a result of both technical and allocative efficiencies. The implication of this was that both technical and allocative efficiencies needed to be raised under the improved technology.

Tchale (2009) studied the efficiency of smallholder agriculture in Malawi using a nationally representative sample survey of rural households undertaken by the National Statistical Office in 2004/2005. The aim of the study was to inform agricultural policy about the level and key determinants of inefficiency in the smallholder farming system that need to be addressed to raise productivity. The researcher used a parametric frontier approach because of the many variations that underlie smallholder production in developing countries. This was so because the stochastic frontier attributes part of the deviation to random errors (reflecting measurement errors and statistical noise) and farm specific inefficiency (Coelli *et al.*, 1998). The results revealed that allocative or cost inefficiency is higher than technical inefficiency, and that the low economic efficiency level could largely be explained by the low level of allocative efficiency relative to technical efficiency. High levels of cost inefficiency were probably attributable to the low profitability that resulted from inadequate agricultural market development.

Factors Affecting Technical Efficiency of Farms

Empirical literature on farmer efficiency is vast especially for Asia and the developed economies (Coelli, 1995). There are only a few studies that have focused on efficiency of African smallholder agriculture. Seyoum *et al.* (1998) examined technical efficiency and productivity of Ethiopian maize farmers, comparing the performance of farmers within technology demonstration programme and those without. They found the farmers within the programme more technically efficient. Another study in Ethiopia, Weir (1999), examined the effect of education on the productivity of cereal farmers. It used average and stochastic production functions and found positive correlation between schooling and farmer efficiency. The study further observed that a farmer needed to have a minimum of four years of schooling for education to have a significant effect on technical efficiency. Weir and Knight (2000) further explored the impact of education externality on the technical efficiency of the Ethiopian rural farmers. They noted that average schooling at village level improved technical efficiency of the farmers. An additional year of schooling was found to increase technical efficiency by 2.1 percentage points. Education externality occurs through adoption and diffusion of technologies that shift the production frontier to the right. Weir (1999) and Weir and Knight (2000) focused on schooling as the only source of technical efficiency which is a great weakness.

Townsend, Kirsten and Vink (1998) analyzed the efficiency of wine producers in Western Cape of South Africa. The objective of the study was to test the relationship among farm size, returns to scale and efficiency. They used DEA approach for panel data and found that most of the farmers experienced constant returns to scale. On average, farms experiencing increasing returns to scale were smaller than those experiencing constant returns to scale. The relationship between farm size and returns to scale was, however, not consistent. The inverse relationship between farm size and efficiency was found to be weak and not consistent across the wine producing regions. One limitation of this study is that wine producers are more specialized and profit motivated. The results may, therefore, not be generalized for the smallholder subsistence agriculture.

Mochebelele and Winter-Nelson (2000) studied the effect of labour migration on technical efficiency of farms in Lesotho using stochastic frontier analysis, both translog and Cobb-Douglas specifications. They found that households that had some of their members working in the mines in South Africa were more efficient. They attributed this relationship to remittances. The study also found no evidence of relationship between both farm size and age of household head, and farmer efficiency. The main weakness of this study is that it did not take into account the many other factors such as farmer education and experience, access to credit and extension services, and the level of remittances received by the households. While it may be true that migrant labour remits money to the exporting households, it is the amount remitted that would be important in influencing the kind of farm investments that the households may undertake.

Sherlund, Barrett and Adesina (2002) used panel data and controlled for environmental factors to investigate the technical efficiency of the smallholder rice farmers in Côte d'Ivoire. They used both stochastic and DEA frontiers in the analysis and observed that controlling for environmental factors improved both estimation of technical efficiency and precision with which one may explain the sources of technical efficiency. Farmers without formal education who cultivated three or more rice plots and those who specialized in rice production were found to be more efficient. They attributed this to the view that those with formal education may not pursue farming as a primary occupation. Instead they would focus on off-farm employment opportunities which promise superior income stream (Barrett *et al.*, 2001). Conversely, farmers who had more land planted in modern rice varieties were less efficient, possibly because of their unfamiliarity with correct management practices for these varieties. Like most of the previous studies on technical efficiency of the smallholder farms, this study focused on a mono crop. This restricts its applicability to multiple crop farms which dominate smallholder agriculture.

Binam *et al.* (2004) simultaneously estimated stochastic frontier and sources of efficiency for Cameroonian maize and groundnut farmers using survey data. They concluded that farmers with more than four years of formal education, access to credit, located in regions with fertile soils and those who participate in farmers' clubs were more efficient. Farmers whose plots [illegible] from access roads were found to be less efficient. Agricultural extension was found [illegible] influence on farm efficiency. In Malawi, Chirwa (2007) used the same approach on smallholder maize farmers and found similar results for extension and membership to farmer club. The study also found adoption of hybrid seeds to enhance farm efficiency, and formal education and adoption of inorganic fertilizer to have no effect on the same.

Kibaara (2005), using joint estimation of stochastic frontier and inefficiency models, identified use of improved seed varieties, mechanized cultivation, farmer education, male gender of the farmer, off-farm income, access to credit and high agricultural credit as the factors that increase the technical efficiency of farms. Owuor and Ouma (2009) and Nyagaka et al. (2010) made similar observations but identified additional factors as social capital and proximity to market. While Kibaara (2005) and Owuor and Ouma (2009) used the one-step approach (Battese and Coelli, 1995), Nyagaka *et al.* (2010) applied a two-step approach. This involved estimating technical efficiency by SFA in the first step and then applying Tobit model on the efficiency coefficients to establish the determinants.

[illegible] Theoretical Framework

This study was guided by numerous economic theories with conceptual links on economic analysis of efficiency. These include neoclassical, managerial, behavioural and X-efficiency theories of the firm. The study was also based on production theory where farmers were assumed to be maximizing their revenues by trying to attain the highest profits possible given certain constraints. The random utility theory guided the empirical estimation of the farmers' choices of irrigation technologies. In the interpretation of Data Envelopment Analysis (DEA) results, this study was guided by the theory of returns to scale and variable proportions.

2.4.1 Economic Theories of Efficiency

There are numerous economic theories that have conceptual links on economic analysis of efficiency. These include neoclassical, managerial, behavioural and X-efficiency theories of the firm.

Neoclassical Theory of the Firm

The microeconomic theory of the firm provides the foundation for the concepts related to efficiency. The neo-classical theory of the firm stems from the static equilibrium framework. The conventional neoclassical theory treats the firm as a production unit that transforms resources into commercially viable goods. This transformation of inputs into outputs is described by a production function or production possibilities set. The conventional neoclassical theory of the firm assumes that the firm is operating in a perfectly competitive market where all firms seek to maximize their profit.

This is accomplished by putting in a strategy of maximizing revenues and minimizing costs. Consequently, a competitive general equilibrium is achieved by equating the marginal rates of substitution for all firms between any two economic variables (inputs or outputs). The competitive equilibrium leads all firms to earn normal profits. In other words, firms cannot earn revenues than is necessary to cover their economic costs. In the short run however, it is possible for some individual firms to make abnormal profits and this phenomena will attract other firms to enter the market and compete with incumbent firms. Competition between firms will drive the market price down until all firms are earning a normal profit in the long run. If any firm is not able to make normal profits due to inefficient operations, then in the long run, more efficient firms will either acquire these inefficient firms or the latter will have to exit the market. Thus, according to the conventional neoclassical theory of the firm, the efficient firm, which allocate resources to produce the maximum level of output for given input, will survive and the inefficient firm will exit the market. However, empirical research suggests that not all firms operate on the efficient frontier (Avkiran, 2009). Also a large number of firms do not produce at the point where long run average costs are minimised but still survive in the market. Thus, the traditional neoclassical theory fails to explain why inefficient firms survive in the market, and because of this some alternative theories have been developed to supplement the conventional theory of the firm.

Demsetz (1997) noted that the firm in neoclassical theory reflects the imperatives of the price system. If the price system works well, resources are allocated well. However, the traditional theory is not well geared to explain the internal workings of the firm and provides no analysis the decision-making process or clear explanation of the factors that determines business success or failure. Therefore, the neo-classical theory of the firm has been challenged by alternatives such as managerial, behavioural and X-efficiency theories (Dobbs, 2000). These alternative theories explain why firms may not always operate efficiently.

2.4.1.2 Alternatives Theories (Managerial, Behavioural and X-efficiency Theories)

i) Managerial Theory of the Firm

The criticism met by conventional theory of the profit-maximizing firm is largely attributed to factors such as separation of ownership and control in large firms in a modern economy. The managerial theory of the firm provides a better explanation of this reality, by arguing that the group who controls management of the firm are likely to pursuing their own interests and utility, rather than maximizing the profit of the firm. Managers of firms are most likely to seek those objectives from which they obtain prestige, power and greater personal monetary reward. This might prevent from costs being minimized and building a level of organizational slack into the system (Rogalska, 2013). There is indeed a high degree of correlation between the managerial objectives such as income, power, prestige etc. with sales revenue. This implies that the primary goal of management would be to maximize sales revenue after achieving a minimum level of profit necessary to satisfy shareholders. A dynamic model of the firm assumes that the managerial objectives are to maximize firm growth over a long time-period. Managers are also known to maximize their own utility by spending some of the firm's potential profits for unnecessary purposes thereby increasing managerial satisfaction or utility.

The principal-agent problem as conceptualized in managerial theories explains the analysis of the problems of arranging contracts with imperfect and asymmetric information and "agency theory" (Roberts, 2005). In principal-agent analysis the firm is considered as a nexus of contracts between owners of a firm (i.e. the principal) and its subcontractor/ manager (i.e. the agent). The principal/ owners (shareholders) hire the agents (managers) to increase performance and maximize the value of the firm. The owners usually do not have full knowledge and information about the firm's operation and performance capabilities whereas the managers have more information or knowledge than the owners. Thus, asymmetric information and uncertainty between the principal (owners) and the agents (managers) leads to a problem of "hidden action" or "moral hazard" where the latter are inclined to pursuing their own interests such as high salaries, better working conditions, on-the-job leisure, job security etc. The former not being able to monitor these actions.

The owners (principal) then consider implementation of two complementing tactics; first, invest in monitoring the actions of managers leading to agency costs and, second, motivate the manager's (agent) behaviour in their own interests by creating additional incentives such as a compatible reward structure and remuneration package. Overall, however, the principal-agent problem reduces firm's profit and induces inefficiency in the firms' operations.

ii) Behavioural Theory of the Firm

The behavioural theory of the firm argues that, in practice, the firm's ability, need or even desire to optimize (maximize) the objectives may be questionable. This is attributed to uncertainty and the absence of complete information faced by firms in real time. Managers emphasize on bounded rationality in the decision-making process instead of pursuing pure maximization objectives (Giovanni *et al.*, 2012). Individuals or groups in the firm therefore may want to act rationally, but they are unable to do so because they possess cognitive limitations in solving complex problems and in processing information. Thus, bounded rationality exists in the process of decision making and decision-makers exhibit 'satisficing' behaviour which is set in terms of some aspiration level, rather than optimizing behaviour. In summary, a firm operating in this manner will not prevent in cost-minimization and this results in productive inefficiency.

The firm as an organization is not a unified structure but a coalition of various participants such as owners, managers, employees, customers, suppliers and so forth. It is generally acknowledged that each of these groups will have varying interests and objectives. Moreover, the firm itself has its own objectives that might come in conflict with each other. As a result decision-making within the firm is a continual process of bargaining and aspiration levels, in which side payments are made to ensure compliance or to entice individuals into subgrouping.

However, disparities exist between the resources available to the firms' managers and the payments required to keep problematic factors at bay.

[illegible]anni *et al.* (2012) defines organizational slack as the difference between total resources and total costs and increases unnecessary costs and reduce the overall efficiency of the firm. In a stable environment, the payments may converge towards aspiration levels thereby leading organizational slack to be close to zero. But in practice it is clear that the environment is not stationary. The evolution of business cycles as well as technological infrastructure ensures that firms must strive to maintain themselves on a best-practice frontier. Given this flux, it is possible for some inefficient firms to survive in the market, as long as they are not too removed from the frontier (Dobbs, 2000).

iii) X-efficiency Theory of the Firm

The X-efficiency theory links behavioural theory and managerial utility theory (Frantz, 1988). X-efficiency describes the general efficiency of a firm (given the resources it uses and the best technology available) in transforming inputs into outputs. Firms are not well geared to maximize profits and many of them maximize managerial-utility instead (Davis, 2010).

In rejecting the neo-classical theory, Leibenstein (1978) identified two possible sources of inefficiency. The first source is a divergence between price and marginal cost, better known as allocative inefficiency. This may be caused by monopoly, tariffs and other impediments to competitive output rates. The second source is known as X-inefficiency, which stems from failure of firms to achieve the lowest possible cost functions for producing their goods and which leads to wastage of resources. Inefficiencies deriving from X-inefficiency is more significant in comparison to inefficiencies deriving from allocative inefficiency.

The concept of non-maximizing behaviour is a key idea of X-efficiency (Zelenyuk & Zheka, 2006) and that the problem of principal–agent relationships is an important source of X-inefficiency. Moreover, due to the feature of incomplete contingent contracts between principals and agents, the latter can evade the consequences of cost overruns and have lesser motivation to keep costs down. In this case, firms will be more X-inefficient (Taylor & Taylor [illegible]).

Production Theory

The study was based on production theory. In this theory, farmers were assumed to be maximizing their revenues by trying to attain the highest profits possible given certain constraints. This can be expressed as:

$Max\ \pi = p_a q_a - p_x x - wl$, profit .... (1)

Where:

q_a is the product which in this case it is vegetable that the farmer gets from the farm.

p_a product price in this case the price of vegetables.

Two variable factors: x with price p_x. These factors will include inputs and maintenance expenses, vegetables transportation costs and costs of signing contracts. On the other hand, l (labour) multiplied with price w (wage rate) forms a major cost in the equation.

In this case the farmers' revenue is income derived from the sale of vegetables at the given market price. The inputs p_x is a vector of a number of inputs like seeds, maintenance costs, costs of transporting vegetables, binding costs in a contract and labour. These inputs valued at their different market prices are the costs incurred.

$Max\ \pi = (p_a q_a - p_x x - wl)$

Subject to: $g(q_a, x, l; z^q) = 0$, production function

Supply function:

$q_a = q_a(p_a, p_x, w, z^q)$ .... (2)

Factor demands:

$x = x(p_a, p_x, w, z^q)$ .... (3)

$l = l(p_a, p_x, w, z^q)$ .... (4)

z^q (fixed capital, farm size)= Fixed factors and farm characteristics.

Thus, the farmers will be maximizing profits from sale of the farm products subject to the constraints being faced which may be management, institutional and financial constraints (Sadoulet and Janvry, 2005). This can be represented as

Max. Profit: $\pi^* = \pi^*(p_a, x, y, z,)$ ....(5)

Where:

p_a - price of vegetables and its products

x - Institutional constraints and these include information availability, customer search costs, length of supply chain, cost of contracts, groups, opportunity cost of time and standards of measurement

y - Financial constraints which include Debt, Debt asset ratio, Asset base, financial records

z - Managerial constraints include farm size, farmer characteristics, production system and vegetable type

$\pi = \beta_i x_i + \beta_j x_j + \beta_k x_k + \varepsilon$ ....(6)

Where:

π - Profitability

x_i - institutional constraints for the i^{th} farmer

x_j - financial constraints for the j^{th} farmer

x_k - managerial constraints for the k^{th} farmer

2.4.3 Random Utility Theory

The random utility model would guide the empirical estimation of the farmers' choices of irrigation technologies. Most theoretical developments assume that individuals behave deterministically. Decision-makers are assumed to be all knowing with perfect discriminatory power, able to process information, choose the best choice, and repeat this identical choice under identical circumstances. This is implied by the assumed properties of the preferences, such as completeness, transitivity, and continuity. However, in reality such assumptions may not be fully consistent with real behavior. Actually, there are numerous examples both in laboratory experiments and in the field in which it appears that decision-makers do not behave as such. As Tversky (1969) points out, "when faced with repeated choices between x and y, often choose x in some instances and y in others." Inspired by the need to explain experimental observations of inconsistent preferences, probabilistic choice theory was developed.

In probabilistic choice theory, rather than assuming there is a deterministic process that can be used to establish the choice outcome, it is recognized that the best that can be done is to determine the probability of different choice outcomes given a particular choice situation and decision-maker.

There are several ways of modeling probabilistic choice. Assume that the source of the stochasticity is due to errors made by the analyst in developing the model. Here the assumption is that while humans are deterministic and rational utility maximizers, analysts are unable to understand and model fully all of the relevant factors that affect human behavior. The individual is assumed to be all knowing and rational and select the alternative with the highest utility. However, the utilities are not known to the analyst with certainty and are therefore treated by the analyst as random variables. This is called the random utility approach. The value of the random utility approach is that it provides a link with behavioral theory from microeconomics and therefore a link to the concepts and methods that are useful for both developing model specifications and using the models for analysis.

A decision maker *i* who must choose from a set of mutually exclusive alternatives, n = 1…, n would be assumed.

The decision maker *i* obtains utility U_{in} from each choice made. In general, given a set of alternatives as stated above, a rational individual will choose an alternative that provides the highest utility.

The model is constructed on the premise that the decision maker chooses the choice that maximizes utility. The utility is not directly observed, but instead only attributes of the available alternatives are observed. Thus, the random utility function may be expressed as follows:

$$U_{in} = V_{in} + \varepsilon_{in} + \forall n \qquad (7)$$

Where; V_{in} is the deterministic component which can be calculated based on observed characteristics and $\mathcal{E}_{in}$ is the unobserved random or stochastic error component. The error component is never observed which makes it difficult to have enough information that would allow prediction of a specific individual's choice at each occasion. Regression analysis can be used to make predictions about the patterns of choices over many individuals and many choice occasions. The probability of a decision maker i choosing alternative k among n alternatives is expressed as follows;

$$P_{ik} = Pr(U_{ik} > U_{in} \forall n \neq k$$

$$= Pr(V_{ik} + \mathcal{E}_{in} > V_{in} + \mathcal{E}_{in} \forall n \neq k \quad \text{-----} (8)$$

The utility specified above under a random utility modeling framework can be extended as follows:

$$V_{ik} + \mathcal{E}_{ik} = \chi_{ik}\beta + \mathcal{E}_{ik} \quad \text{-----} (9)$$

Where; χ_{ik} is a vector of characteristics which influence the choice of irrigation strategy, β is the coefficient vector and $\mathcal{E}_{ik}$ is the term for random disturbances with an extreme value distribution.

2.4.4 Theory of Returns to Scale and Variable Proportions

In the interpretation of Data Envelopment Analysis (DEA) results, this study was guided by the theory of returns to scale and variable proportions. The laws of production describe the technically possible ways of increasing the level of production. Output may increase in various ways. Output can be increased by changing all factors of production. Clearly this is possible only in the long run. Thus the laws of returns to scale refer to the long-run analysis of production.

In the long run expansion of output may be achieved by varying all factors. In the long run all factors are variable. The laws of returns to scale refer to the effects of scale relationships. In the long run output may be increased by changing all factors by the same proportion or by different proportions. Traditional theory of production concentrates on the first case, that is, the study of output as all inputs change by the same proportion. The term 'returns to scale' refers to the changes in output as all factors change by the same proportion.

Suppose we start from an initial level of inputs and output, $X_0 = f(L, K)$ and we increase all the factors by the same proportion k. We will clearly obtain a new level of output X*, higher than the original level X_0, that is, $X = f(kL, kK)$

If X* increases by the same proportion k as the inputs, we say that there are constant returns to scale. If X* increases less than proportionally with the increase in the factors, we have decreasing returns to scale. If X* increases more than proportionally with the increase in the factors, we have increasing returns to scale.

Suppose we increase both factors of the function, $X_0 = f(L, K)$, by the same proportion k and we observe the resulting new level of output X as illustrated below:

$X^* = f\,(kL, kK)$ --(10)

If k can be factored out (that is, may be taken out of the brackets as a common factor), then the new level of output X* can be expressed as a function of k (to any power v) and the initial level of output as shown below:

$X^* = K^v f\,(L, K)$ or $X^* = k^v X_0$ --(11)

This type of production function is called homogeneous. If k cannot be factored out, the production function is non-homogeneous. Thus A homogeneous function is a function such that if each of the inputs is multiplied by k, then k can be completely factored out of the function. The power v of k is called the degree of homogeneity of the function and is a measure of the returns to scale. If $v = 1$ we have constant returns to scale. This production function is sometimes called linear homogeneous. If $v < 1$ we have decreasing returns to scale and if $v > 1$ we have increasing returns to scale.

Returns to scale are measured mathematically by the coefficients of the production function. For example, in a Cobb-Douglas function, $X = b_0 L^{b1} K^{b2}$ the returns to scale are measured by the sum $(b_1 + b_2) = v$.

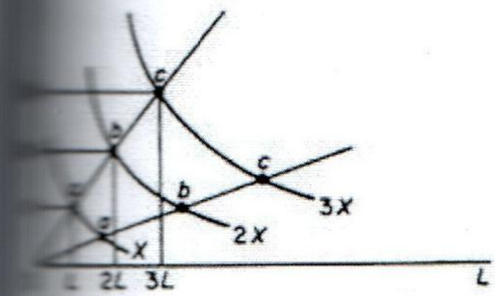
For a homogeneous production function the returns to scale may be represented graphically in an easy way. Before explaining the graphical presentation of the returns to scale it is useful to introduce the concepts of product line and isocline.

To analyze the expansion of output we need a third dimension, since along the two-dimensional diagram we can depict only the isoquant along which the level of output is output. Instead of introducing a third dimension it is easier to show the change of output by means of the isoquant and use the concept of product lines to describe the expansion of output. A product line shows the (physical) movement from one isoquant to another as we change all factors and a single factor. A product curve is drawn independently of the prices of factors of production. It does not imply any actual choice of expansion, which is based on the prices of factors and is shown by the expansion path. The product line describes the technically possible alternative paths of expanding output. What path will actually be chosen by the firm will depend on the prices of factors.

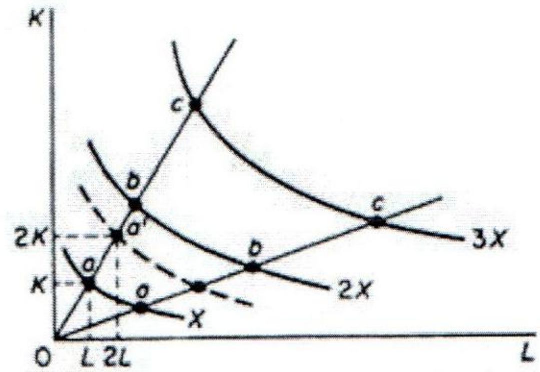
The product curve passes through the origin if all factors are variable. If only one factor is variable (the other being kept constant) the product line is a straight line parallel to the axis of the variable factor. The K/L ratio diminishes along the product line.

Among all possible product lines of particular interest are the so-called isoclines. An isocline is the locus of points of different isoquants at which the MRS of factors is constant. If the production function is homogeneous the isoclines are straight lines through the origin. Along any one isocline the K/L ratio is constant (as is the MRS of the factors). The K/L ratio (and the MRS) is different for different isoclines. If the production function is non-homogeneous the isoclines will not be straight lines, but their shape will be twiddly. In this case, the K/L ratio changes along each isocline (as well as on different isoclines).

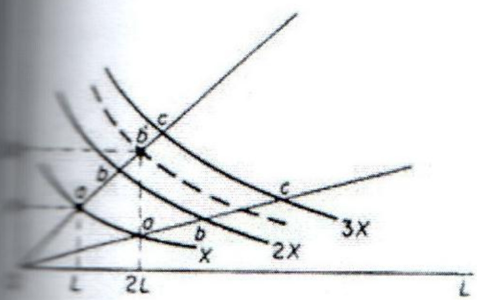
The returns to scale may be shown graphically by the distance (on an isocline) between successive 'multiple-level-of-output' isoquants, that is, isoquants that show levels of output which are multiples of some base level of output, e.g., X, 2X, 3X, etc. For constant returns to scale, the distance between successive multiple- isoquants is constant along any isocline. Doubling the factor inputs achieves double the level of the initial output; trebling inputs achieves treble output, and so on (Figure 5).



i: Constant returns to scale: Oa=ab=bc



ii: Decreasing returns to scale: Oa<ab<bc



iii: Increasing returns to scale: Oa>ab>bc

Figure 5: Illustration of constant, decreasing and increasing returns to scale

For decreasing returns to scale, the distance between consecutive multiple-isoquants increases. By doubling the inputs, output increases by less than twice its original level. In Figure 5 (ii) the point a', defined by 2K and 2L, lies on an isoquant below the one showing 2X.

For increasing returns to scale, the distance between consecutive multiple-isoquants decreases. By doubling the inputs, output is more than doubled. In Figure 5 (iii) doubling K and L leads to point b' which lies on an isoquant above the one denoting 2X.

Returns to scale are usually assumed to be the same everywhere on the production surface, that is, the same along all the expansion-product lines. All processes are assumed to show the returns over all ranges of output either constant returns everywhere, decreasing returns everywhere, or increasing returns everywhere. However, the technological conditions of production may be such that returns to scale may vary over different ranges of output. Over one range we may have constant returns to scale, while over another range we may have increasing or decreasing returns to scale. Production functions with varying returns to scale are difficult to handle and economists usually ignore them for the analysis of production.

With a non-homogeneous production function returns to scale may be increasing, constant or decreasing, but their measurement and graphical presentation is not as straightforward as in the case of the homogeneous production function. The isoclines will be curves over the production surface and along each one of them the K/L ratio varies. In most empirical studies of the laws of returns homogeneity is assumed in order to simplify the statistical work. However, homogeneity is a special assumption, in some cases a very restrictive one. When the technology shows increasing or decreasing returns to scale it may or may not imply a homogeneous production function.

The increasing returns to scale are due to technical and/or managerial indivisibilities. Usually most processes can be duplicated, but it may not be possible to halve them. The larger-scale processes are technically more productive than the smaller-scale processes. Clearly if the larger-scale processes were equally productive as the smaller-scale methods, no firm would use them: the firm would prefer to duplicate the smaller scale already used, with which it is already familiar. Although each process shows, taken by itself, constant returns to scale, the indivisibilities will tend to lead to increasing returns to scale.

The most common causes of decreasing returns to scale is 'diminishing returns to management'. The 'management' is responsible for the co-ordination of the activities of the various sections of the firm. Even when authority is delegated to individual managers (production manager, sales manager, etc.) the final decisions have to be taken from the final 'centre of top management' (Board of Directors). As the output grows, top management becomes eventually overburdened and hence less efficient in its role as coordinator and ultimate decision-maker. Although advances in management science have developed of management techniques, it is still a commonly observed fact that as firms grows beyond the appropriate optimal 'plateaux', management diseconomies creep in. Another source of decreasing returns may be found in the exhaustible natural resources: doubling the fishing fleet may not lead to a doubling of the catch of fish; or doubling the plant in mining or in an oil-extraction field may not lead to a doubling of output.

Conceptual Framework

Smallholder vegetables farmers use different irrigation technologies in terms of drip system, sprinkling and Californian system. Farmers are faced with an institutional environment which includes issues like the policy on water use in term of environmental protection and efficiency use of natural resources. These irrigation systems, institutional and efficiency in use of water interact with each other and together they influence the efficiency and high yield of vegetables. The interaction of the different variables in this study is conceptualized as shown in Figure 6. In a bid to use irrigation technologies in their farming systems, smallholder farmers aim at achieving Water Use Efficiency (WUE) and realize High Yield of Vegetables (HYV).

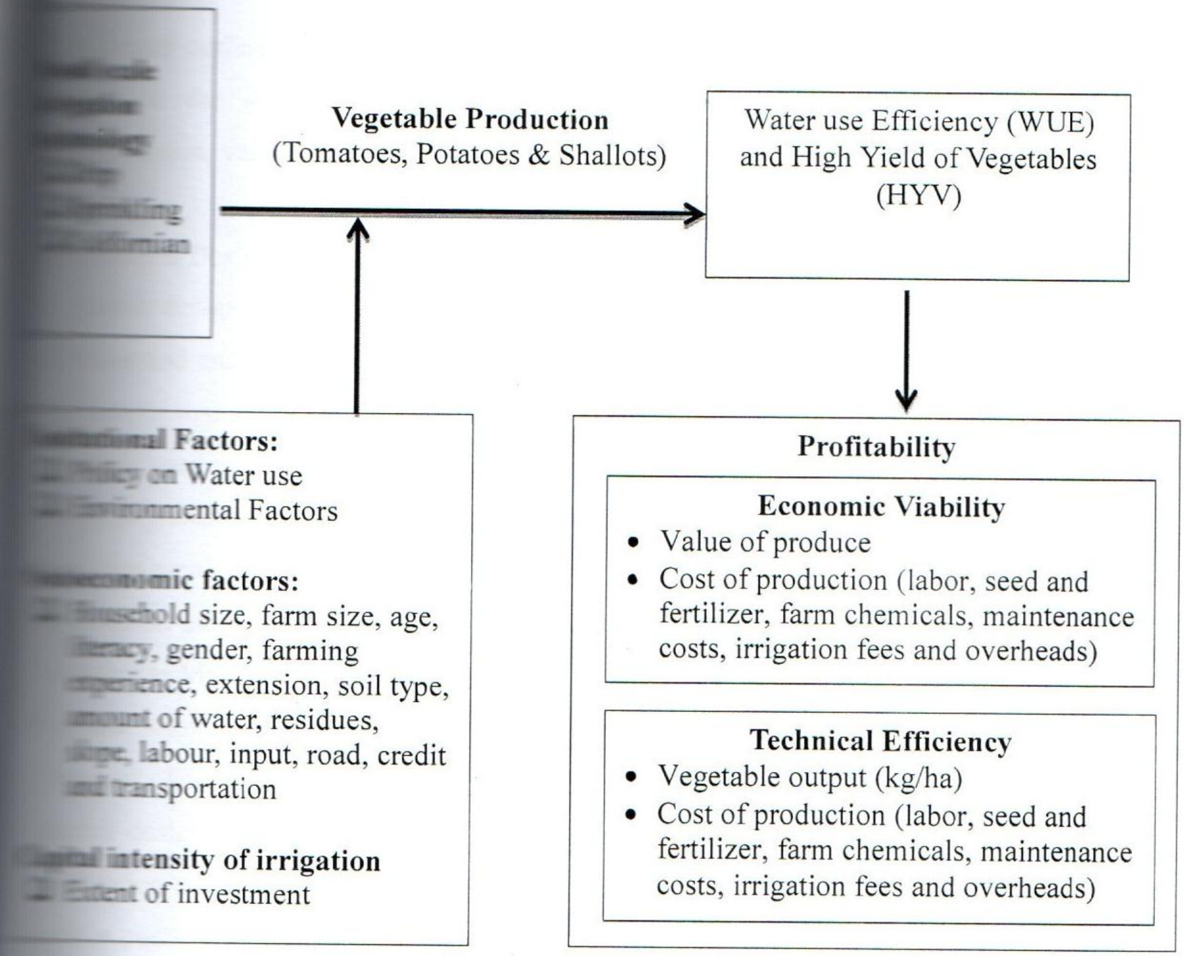


Figure 6: Conceptual Framework

Source: Author (2018)

CHAPTER THREE

METHODOLOGY

This chapter outlines the research methodology used. It describes the research design, the location of the study, the target population, sampling procedure and sample size, instrumentation, validity, reliability, data collection and data analysis.

3.1 Research Design

A research design is purely and simply the framework or plan for a study that guides the collection and analysis of the data. It is a blueprint that is followed in completing the study. This ensures that study remains relevant to the problem and employs economical procedures. This study used exploratory research design. In essence exploratory studies are undertaken to better comprehend the nature of the problem where very few studies have been considered in the chosen area (Yin, 2003). Extensive interviews with many people are undertaken to get a handle on the situation and understand the phenomena. More rigorous research then proceeds. According to Marshall & Rossman (2006), exploratory studies are also necessary when some facts are known but more information is needed for developing a viable theoretical framework. To a certain extent design has also been built around descriptive research. This research design helped the researcher in enhancing familiarity with the problem under investigation and to clarify the concepts. It also helped in finding out the new hypotheses that could be pursued by future researchers.

3.2 The Study Area

This study was carried out in three regions; Fanafiecoura, Tieman and Dialango. These regions were chosen owning to their great importance in the country's food security through their practice of small scale irrigation technologies. Mali is a landlocked country in West Africa, lying between latitudes 10°34'N and 25 N and longitudes 4°E and 160 19''W. It is the eighth largest country in Africa, with an area of just over 1,240,000 square kilometers. The population of Mali is 18 million (UNDESA (2017). The country's economy centers on agriculture and fishing.

The climate in the study sites is typical of the Sudano-Sahelian zone. Average long-term annual rainfall is about 1073 mm ± 187. The rainy season extends from May to October and the seasonal average temperature is 29°C. During the dry season (November to April) the temperature and saturation vapour deficit increase and crop production is impossible without irrigation (Sivakumar, 1988).

Mali economy is mainly based on the primary sector (agriculture, livestock, fisheries and forestry), which accounts for nearly 36% of GDP and is the main source of income for at least 80% of the population. In addition, the sector contributes about 40% of export earnings.

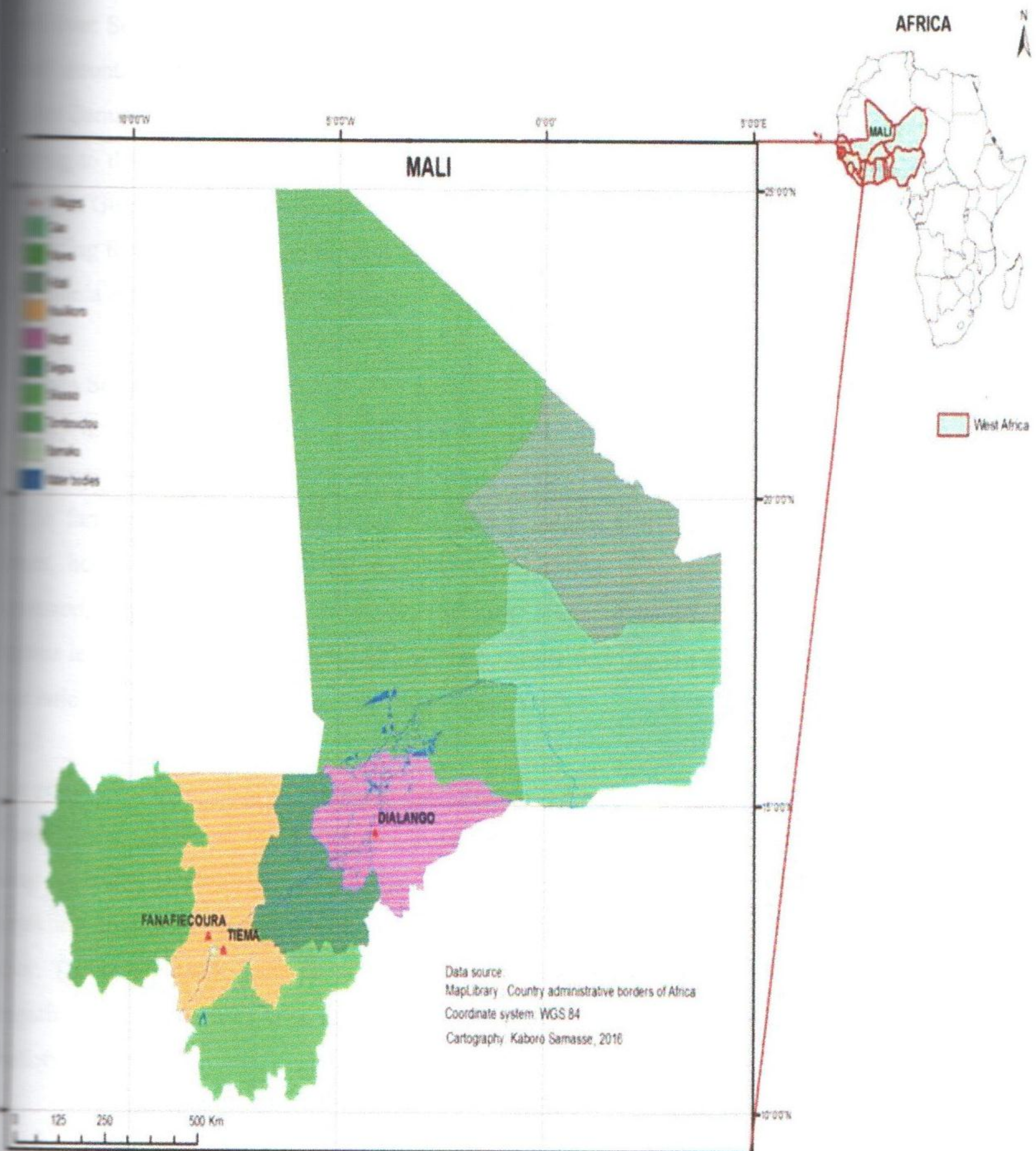


Figure 7: Maps showing location of the Study Area: (Source: Annual report PIB, 2011).

Irrigation activities in the study area are majorly supported by two main rivers (River Niger and River Senegal) which dissect the country. The Niger River draws its source from the mountains of Guinea and flows in a broad eastern arc across Mali, passing through the capital Bamako and past the legendary city of Timbuktu before continuing through Niger, and turning to the south to its Atlantic Ocean mouth in Nigeria. The Senegal River also has its source in Guinea and flows slightly to the northeast before turning back east and merging with the Bafing River, then passing through the city of Kayes and continuing to form the border of Mauritania and Senegal before flowing to the Atlantic Ocean.

3.3 Data Sources

Primary and secondary data was collected for the study. Structured open ended and close ended questionnaires were used to collect primary data. The questionnaires were administered to the farmers by enumerators. Data collected included: irrigation technologies, gender issues, household size, farm size, age, literacy, farming experience, livestock ownership, extension, soil type, amount of water, residues, slope, distance from Homestead, labor, income levels and the off farm income. Secondary data was used in the calculation of benefit-cost ratio.

The population comprised of small holder farmers in Koulikoro and Mopti regions in Mali. Manual irrigation is the most common practice used by farmers to distribute water to crops using watering devices such as watering cans, calabashes and buckets. The introduction of sprinkling irrigation system has facilitated crop production and reduced irrigation time and labour. The respondents were farmers who held at most 1 hectare of land using small scale irrigation systems such as drip, sprinkling and Californian to produce potatoes, tomatoes and millets.

3.4 Sample Size Determination

The sampling technique employed was multistage sampling. Data was collected using a structured questionnaire. A total of 273 respondents were interviewed as derived from the equation below.

$$n = \frac{Z^2 P(1-P)}{D^2}$$ (Kothari *et al.*, 2004)

Where: confidence level (K) (Z-value) 95% (2-tail) = 1.96; Expected proportion in population P (50% most conservative); Acceptable margin of error in percent (D) which is 9.5%, hence

$$n = \frac{1.96^2 0.5(1-0.5)}{0.095^2} = 273$$

Sampling procedure

A Multistage sampling procedure was used to select 273 farming households of local irrigation scheme in the three regions. The first stage was to purposely select three regions; Fanafiecoura, Tieman and Dialango on the basis of the fact that they are within the area mapped for vegetable crops and the incidence of irrigation systems. The second stage involved the use of stratified sampling where the strata included the different irrigation technologies engaged by vegetable farmers. Random sampling was used to select respondents distributed as shown in Table 3. The different irrigation technologies were: T_1 (Drip irrigation system), T_2 (Sprinkling) and T_3 (Californian irrigation system).

Table 3: Distribution of respondents

Enterprises	Different Irrigation Technologies			Population	Sample size	Proportion (%)	Location
	T_1	T_2	T_3				
[illegible]	31	31	31	3923	93	34.0	Tiema
[illegible]	30	30	30	2727	90	33.0	Fanafiecoura
[illegible]	30	30	30	3549	90	33.0	Dialango
Total	91	91	91	10,200	273	100.0	

Instrumentation

A self-administered structured questionnaire was used to collect data from the respondents. The items of the instrument were constructed based on the research objectives. The instrument (structured questionnaire) was chosen because of its ease in administering besides the results being readily analyzed.

Validity

Validity is the degree to which results obtained from the analysis of data actually represent the phenomenon under study (Marshall & Rossman, 2006). Validity ensures that the instrument used to collect data actually measures what it is intended to measure. To ensure the items of the structured questionnaire measured what it was intended for, the instrument was subjected to scrutiny by the three experts in agricultural economics, who assisted in reviewing the instrument to address its face and content validity. The university supervisors reviewed the face validity of the instrument. Face validity addressed the format of the instrument and aspects such as clarity of printing, font size and shape, adequacy of workspace and appropriateness of language. Content validity dwelt with the representativeness and adequateness of items designed to measure the various variables of the study (Lee & Greene, 2007). This procedure assisted in developing items that covered all the objectives in the study.

Reliability

Pre-testing the data collection instrument enabled the researcher to assess the reliability of the instrument and its use. Yin (2003) explain that pre-testing allows errors to be discovered before the actual collection of data. This involved administering the questionnaire to 20 farmers who were not part of the study group. According to Mugenda and Mugenda (2003), the pilot test sample should range from 1% to 10% of the calculated sample, depending on the sample size. The calculated sample size for this study was 217; hence the pilot testing with 20 farmers falls within the acceptable range. The collected data was cleaned, coded, entered into computer and analyzed using Statistical Package for Social Sciences (SPSS) Version 22 for windows. According to Fraenkel and wallen, (2000) a reliability co-efficient threshold of above 0.70 is recommended for survey research.

The reliability of the data will be computed using the Cronbach alpha coefficient. According to Creswell (2008), the coefficient provides a good measure of reliability because holding other factors constant, the more similar the test content and situations of administration are, the greater the internal consistency.

Data Collection Procedure

Prior to data collection, approval from relevant authority was sought. Pre-study visits were made to the study areas to meet the respective farmers' leaders and the frontline extension staff who assisted to draw schedule of visits to the respondents' homes. Where the expected household respondent was not present, the planned date for data collection was rescheduled to an appropriate time. The researcher visited and interviewed the respondents at their home. Secondary data was collected to supplement the primary data through review of publications, books, academic journals and official reports kept at the Ministry of Agriculture offices; both national and regional level. Internet search method was also employed to access data stored on websites.

Analytical techniques

Objective 1: To characterize production systems and small scale irrigation technologies among smallholder farming households

This specific objective described the farmers' household and technologies of irrigation. It was done using descriptive statistics such as mean, mode, percentages, standard deviations, graphs and also pie charts.

Objective 2: To evaluate the economic efficiency of water use in the small scale irrigation systems.

The use of Data Envelopment Analysis (DEA) was employed in analyzing water use efficiency in production and profitability. The DEA analysis was used to determine the efficiency rate of three irrigation technologies (drip, sprinkler and Californian) as used in three vegetable crops (potatoes, shallots and tomatoes). DEA is a non-parametric approach that generates an envelopment frontier using well positioned data points. DEA model helps in the analysis relative efficiency of production units. DEA is preferred over other methods of efficiency analysis due to its ability to include multiple inputs and outputs in its calculations. Unlike many stochastic frontier analyses, DEA generates a single scalar value in its measure of efficiency and does not require any specification of functional forms.

The DEA input-oriented constant returns to scale (CRS) and variable returns to scale (VRS) models are used to obtain the technical efficiency scores. The efficiency scores obtained from the first stage of the DEA are taken as the dependent variables in the subsequent stage of the Tobit model. Tobit regression models handle dependent variables that are constrained at particular limits (Cooper *et al*, 2010; Macdonald & Moffitt, 2009). In statistics literature, the Tobit model is an extension of profit analysis developed by Tobin in 1958 and is also referred to as a censored normal regression model (Yu *et al*., 2012).

This procedure allows for the evaluation of economic water use efficiency, economic viability and technical efficiency irrigation technologies. The Tobit model is defined as follows:

$$y = \begin{cases} y^* & \text{if } y^* > 0 \\ 0 & \text{if } y^* \leq 0 \end{cases}$$

$$y^* = \beta x_i + \varepsilon_i, \varepsilon_i \sim N(0, \quad \sigma^2)$$

Where, y is the dependent variable (the DEA efficiency score), y* is the latent variable, β is a vector of unknown coefficients which determine the relationship between the independent variables and the latent variable and X_i is a vector of independent variables. The model assumes that there is an underlying stochastic index equal to $\beta X_i + \varepsilon_i$ observable only when it is positive (Macdonald & Moffitt, 2009).

The data envelopment analysis (DEA) method is used in analyzing production and profitability efficiencies. The model is a mathematical programming method that has the ability to analyze dual output scenario. This method of analysis however does not consider influence of errors in measurement and other noise in the data (Coeli, 1995). The method is preferred due to its ability to simplify the functional form of the frontier and the distributional form of u_i (Coeli, 1995). The efficiency in production within one firm is measured relative to the efficiency of all the other firms.

$$\text{Min}\theta_j$$

$$\theta x_{jm} \geq \sum_{k=1}^{k} x_{km}\lambda_{jk} \text{ for all m}$$

$\lambda_{jk} \geq \mu_{ji}$ for all i

≥ 0

Where m represents the resources used so that x_{jm} is the amount of productive resources m used by DMU j and x_{km} is the amount of productive resources m used by each of the other DMU k. Within the proceeding equation, i represents outputs so that y_{ji} represents the amount of output i produced by DMU j and y_{ki} is the amount of output i produced by each of the other DMU k. Linear programming technique provides an optimal set of weights denoted by λ_{jk} that satisfy the m × i constraints and give an efficiency coefficient denoted by $0 \geq \theta j \geq 1$. The model weight provides an indication about extent of inefficiency for each DMU (Coeli, 1995).

Charnes, Cooper and Rhodes (1978) and Sarkar (2014) have used the model with an orientation of inputs, assuming constant returns to scale (CRS). Banker *et al.* (2009) used the model with an orientation on variable return to scale. The CRS is the most commonly used method among the two.

Profitability efficiency may also be analyzed with the use of Generalized Leontief (GL) as well as the Translog functional forms. These models have been designed to overcome the shortcoming arising from restrictive nature of the Cobb-Douglas model. These models have a disadvantage of inability to control high levels of multicollinearity and low levels of degrees of freedom. The GL model is not popular in the estimation of efficiency frontiers despite its great popularity in the estimation of cost functions and input demands (Mbaga *et al.*, 2010).

The input oriented Data Envelopment Analysis (DEA) model based on Variable Returns to Scale (VRS) assumption was used as outlined by Cinemre *et al.*, (2009). The model generates optimal input/output scenarios that minimize input for each production process, thus helping estimate efficiency (Coelli 1998). The efficiency of a firm consists of two components technical efficiency, and allocative efficiency, which gives an implication of the firm's ability to use the inputs in optimal proportions). These two measures (combined) provide a measure of cost efficiency or economic efficiency. According to Farrell (2000) the most efficient firm should have a measure of one (1) on the frontier. The lower the efficiency the lower the coefficient measure. For each household, a measure of the ratio of all inputs, uy_i/vx_i will be computed, where u is an M×1 vector of output weights and v is a K×1 vector of input weights. To select optimal weights, the mathematical linear programming problem is specified as:

$$\max_{u,v}(uy_i/vx_i),$$

subject to:

$$\frac{uy_i}{vx_i} \leq 1, i = 1,2, \dots, N,$$

$$u,v \geq 0.$$

This entailed finding the values of u and v such that the efficiency measure of the i-th household is maximized, given the constraint that all efficiency measures must at most be equal to unity. The above model, however, gives an infinite number of solutions and an additional constraint $vx_i = 1$ is necessary to address the problem. The linear programming model will thus be modified as below:

$$\max_{\mu,\vartheta}(\mu y_i/\vartheta x_i),$$

Subject to:

$$\vartheta x_i = 1$$

$$\frac{\mu y_i}{\vartheta x_i} \leq 1, i = 1,2, \dots, N,$$

$$\mu,\vartheta \geq 0,$$

Where the notation for the weights have changed to reflect the transformation giving rise to multiplier form of the linear programming model. Duality in linear programming can subsequently be employed to derive an equivalent envelopment form of the LP problem as below:

$$\min_{\theta,\lambda}\theta,$$

Subject to:

$-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$\lambda \geq 0,$

Where θ is a scalar and λ is an N×1 vector of constants. The value, θ represent the household's efficiency score. The efficiency score is less or equal to unity, with unity indicating a point on the frontier and hence a technically efficient household (Farrell, 1957). Efficiency score for each of the household in the sample will be determined by solving the LP problem N times. The efficiency score so computed will be on a constant return to scale (CRS) assumption. To incorporate the variable return to scale (VRS) assumption, an additional convexity constraint $N1'\lambda = 1$ will be added to the above LP model. The ultimate LP model that will be estimated will be as below:

$\min_{\theta,\lambda} \theta,$

Subject to:

$-y_i + Y\lambda \geq 0,$

$\theta x_i - X\lambda \geq 0,$

$N1'\lambda = 1$

$\lambda \geq 0,$

Where N1 is an N×1 vector of ones.

Objective 3: To determine the economic viability of the alternative small scale irrigation systems

The Benefit-Cost Analysis (BCA) was used for judging the economic soundness of irrigation projects. From an economic point of view, an irrigation projects with benefit-cost ratio (BCR) greater than 1.5 is generally accepted (Guzman & Estrázulas, 2012). BCR is obtained by dividing the annual total benefits by the annual total cost. The net annual benefit is computed as a difference between the value of produce and total running costs incurred in production. Running cost may include expenditure on seeds, manure/fertilizers, pesticides, hired labor/equipment, government taxes/ levies among others.

The interest on capital cost of the project at the prevailing rate is included in the denominator. BCR is thus a division of the total benefits by the total costs. In calculating the simple Benefit-cost ratio, the following formula is used:

$$\frac{\Sigma(B_i)}{\Sigma(C_i)} \qquad \text{(Yong \& MCDonagh, 2011)}$$

Where:
Bi = the benefits of the irrigation technology
Ci = the costs of the irrigation technology
d = the discount rate

BCR analysis has numerous merits. The cost benefit analysis may be applicable for both the new as well as old projects. The cost benefit analysis is based of accepted social principle that is on individual preference. This method encourages development for new techniques for the evaluation of social benefits.

Cost Benefit Analysis poses some disadvantages in its application. There is potential inaccuracies in identifying and quantifying costs and benefits. A cost benefit analysis requires that all costs and benefits be identified and appropriately quantified. Unfortunately, human error often results in common cost benefit analysis errors such as accidentally omitting certain costs and benefits due to the inability to forecast indirect causal relationships. Additionally, the ambiguity and uncertainty involved in quantifying and assigning a monetary value to intangible items leads to an inaccurate cost benefit analysis. These two tendencies lead to inaccurate analyses, which can lead to increased risk and inefficient decision-making.

Another disadvantage of the cost benefit analysis is the amount of subjectivity involved when identifying, quantifying, and estimating different costs and benefits. Since some costs and benefits are non-monetary in nature, such as increases in farmers' satisfaction, they often require one to subjectively assign a monetary value for purposes of weighing the total costs compared to overall financial benefits of a particular endeavor. This estimation and forecasting is often based on past experiences and expectations, which can often be biased. These subjective measures further result in an inaccurate and misleading cost benefit analysis.

Since this evaluation method estimates the costs and benefits for a project over a period of time, it is necessary to calculate the present value. This equalizes all present and future costs and benefits by evaluating all items in terms of present-day values, which eliminates the need to account for inflation or speculative financial gains. Unfortunately, this poses a significant disadvantage because, even if one can accurately calculate the present value, there is no guarantee that the discount rate used in the calculation is realistic. Some people use carefully developed cost benefit analysis template to help reduce the likelihood of incorrectly calculating the present value of costs and benefits.

Another disadvantage seen when utilizing a cost benefit analysis is the possibility that the evaluative mechanism turns in to a proposed budget. When cost benefit analysis is presented to most people (including leadership team), there is tendency of viewing the expected costs as actual rather than estimation, which may lead to misappropriating costs and setting unrealistic goals when approving and implementing a project budget. This can put a project manager in an unfavorable situation when he or she attempts to control costs in order to maintain the expected profit margin.

Objective 4: To determine the technical efficiency of small scale vegetables production under different irrigation systems

Technical efficiency (TE) is a measure of the effectiveness of a farmer in the use of inputs. A farmer is considered technically efficient if he/she is able to either produce the maximum possible output from a given level of inputs (output-oriented approach) or use as little input as possible for a given level of output (input-oriented approach). It may not be a suitable measure of farmer efficiency because, in agriculture, prices of inputs and outputs are heavily distorted through such government interventions as subsidies and price legislations. TE can be measured even without price data and without having to impose behavioural objective on the farmers (Kumbhakar and Lovell, 2000).

Estimation approaches to productive efficiency are broadly grouped into parametric (stochastic) and non-parametric (deterministic) frontiers. Parametric frontiers impose functional form on the production function and make assumptions about the error term while non-parametric frontiers do not. Furthermore, parametric frontiers can decompose deviations from the frontier into the statistical noise and farm-specific inefficiency whereas non-parametric frontiers assume that all the deviations from the frontier are due to the farm's inefficiency (Battese & Coelli, 1992; Coelli, Rao & Battese, 1998).

The Cobb-Douglas functional form (Mbaga *et al.*, 2009; Coeli, 1995) and Stochastic Frontier Production Function (Battese, 1993 & Coelli, 1995) are important tools that may be used in the efficiency analysis. The Cobb-Douglas function as a logarithmic transformation technique simplifies the estimation of econometric models. Except for its weaknesses in restrictiveness with respect to returns to scale (which is assumed to be equal across all firms in the sample) as well as the assumption that the elasticity of substitution equal to unity, Cobb-Douglas is the most widespread tool in efficiency analysis (Mbaga *et al.*, 2009; Coeli, 1995).

Stochastic Frontier Production Functions is mostly used in the identification of the best practice technology against which the efficiency of other firms within the industry can be measured. Frontier models also provide firm specific efficiency measures.
The model is specified as:

$$Y_i = f(X_i\beta) + \varepsilon_i = \exp(x_i\beta + \varepsilon_i)$$

Where ε_i is an error term with

$$\varepsilon_i = v_i - u_i$$

Where:

Y_i denotes the output of production of the i-th farmer,

x_i represents a (1x k) vector of functions of inputs quantities applied by the i-th farmer,

β is a (k x 1) vector of unknown parameters to be estimated

ε_i is two economically distinguishable random disturbances.

The errors v_i are random variables assumed to be independently and identically distributed $N(0, \delta_v^2)$.

The component u_i is assumed to be distributed independently of v_i and to satisfy $u_i \leq 0$ and half normal distribution $N(0, \delta_u^2)$ and non-negative variables associated with technical inefficiency in production.

Following Battese and Coelli (1995), the technical efficient (TE) and technical inefficiency of the *i-th* farmer are given as:

$$TE_i = \frac{Y_i}{Y_i^*} = \frac{Y_i}{\exp(x_i\beta + v_i)} = \frac{\exp(x_i\beta + v_i - u_i)}{\exp(x_i\beta + v_i)} = \exp(-u_i)$$

$$u_i = z_i\delta + w_i)$$

Where $Y_i^* = f(\exp(x_i\beta + v_i))$ is the farm-specific stochastic frontier and if Y_i is equal to Y_i^* then $TE_i = 1$ expresses 100% efficiency.

For technical inefficiency, z_i is a (1xm) vector of farmer specific variables associated with technical inefficiency and δ is a (m x1) vector of unknown parameters to be estimated, w_i are random variables, defined by the normal distribution with zero mean and δ_v^2 variance. If $u_i = 0$ indicating that the production lies on the stochastic frontier, the farmer obtains maximum achievable output given the set of inputs.

If $u_i < 0$ suggesting that the production lies below the frontier hence farmer operates on inefficiency. The inefficiencies are estimated using a predictor that is based on the conditional expectation of $\exp(-u_i)$ (Battese and Coelli, 1995). The maximum likelihood function is expressed in terms of The variance parameters as:

$$\delta^2 = \delta_v^2 + \delta_u^2 \; and \; \gamma = \frac{\delta_u^2}{\delta^2}$$

Where the value of γ must lie between zero and one, with values close to one indicating that random component of inefficiency makes a significant contribution and zone indicating the deviations from the frontier are due to the noise.

DEA has gained popularity in productivity and efficiency analysis especially in circumstances where multi-output production is relevant and where price data are lacking. Parametric frontiers, unlike non-parametric frontiers, are sensitive to misspecification, omitted variables and measurement errors (Jacob, Smith and Street, 2006). Nonetheless, results of the two approaches do not differ significantly (Abdourahmane, Bravo-Ureta & Teodoro, 2001; Coelli, Sandura & Colin, 2002). However, if the functional form of the production technology is clearly known, stochastic frontier analysis (SFA) performs better than DEA but when the knowledge about the underlying technology is weak, DEA outperforms SFA (Banker *et al.*, 1985; Gong & Sickles, 1992; Sharam *et al.*, 1999).

Definition, measurement and A-Priori expectation of variables

Table 4 show the definition, measurement and a-priori expectation of variables used in Cobb Douglas production function. Variables used in the analysis include: production (yield), seeds, manure, fertilizer, pesticides, labour, transportation, energy and water as they are also the inputs which are used in this study.

Production/output is the quantity of potatoes, shallots and tomatoes produced by each household in the 2017 cropping season measured in kilograms. Seed is the cost in FcFa of planting materials that was used in the selected horticultural crops farming by each of the smallholder farmer per hectare of land during the 2017 cropping season. Manure was the cost of organic matter that was purchased and applied per hectare of land by smallholder horticultural farmers during the period under review and was measured in FcFa. Fertilizer was assumed to be the cost of inorganic fertilizer that was purchased and applied per hectare of land by smallholder horticultural farmers during the period under review and was measured in FcFa. Pesticides was the cost of agrochemicals that was purchased and applied per hectare of land by smallholder horticultural farmers for control of pests during the period under review and was measured in FcFa.

Table 4: Description of variables used in Cobb Douglas production function

Variable Name	Variable Description	Measurement	Expected Sign
Yieldi	Yield of selected horticultural crops (tomatoes, potatoes and shallots)	Kg	+/-
Irrigate_techi	Selected technology of irrigation (drip, sprinkling and Californian)	1= Drip 2= Sprinkling 3=Californian	+/-
Seeds	Cost of seed in the production of selected horticultural crop	FcFa	+
Manure	Cost of manure in the production of selected horticultural crop	FcFa	+
Fertilizers	Cost of fertilizer in the production of selected horticultural crop	FcFa	+
Pesticides	Cost of pesticides in the production of selected horticultural crop	FcFa	+
Labour	Cost of labour in the production of selected horticultural crop	FcFa	+
Transportation	Cost of transport in the production of selected horticultural crop	FcFa	+
Energycost	Cost of energy in the production of selected horticultural crop	FcFa	+
Watercost	Cost of water in the production of selected horticultural crop	FcFa	+

Labour is measured as cost of man-days used in selected crop production including family labour that was used during the 2017 cropping season. Transportation is measured as cost of movements of products and inputs for use in selected crop production as applied during the 2017 cropping season. Energy and water costs were the indirect costs that were assumed to be incurred by each smallholder farmer in the production of potatoes, tomatoes and shallots and was measured in FcFa. Irrigation technologies included the selected technology of irrigation used in production of potatoes, shallots and tomatoes (drip, sprinkling and Californian).

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results and discussion of the findings of the study. A total of 273 questionnaires were distributed as per the sampling technique employed. However, 270 questionnaires were returned (98.9% response rate). According to Mugenda and Mugenda (2003), a response rate of 80% and above implies a good representation of the sample to the population.

4.1 Descriptive and Inferential Statistics

Descriptive statistics form the basis of every quantitative analysis of data. They were used to describe the basic features of the sample where summaries and other measures are provided. The household characteristics considered were sex, age, level of education, household size, income from non-farming activities, housing, use of irrigation in crop production, period used for irrigation , difficulties in using irrigation, proposed solutions, sources of irrigation water, mode of access of irrigation water, membership and functionality to Water Users Association (WUA), major type of irrigation systems practiced, size of irrigated land, area per household, access to institutional support, information, education and training, farmers training programmes, farmers' visit of extension demonstration site, road conditions in the region and farmers' extension service providers.

4.1.1 Gender of the Household Heads

The results of gender of the household heads are presented in Table 5.

Table 5: Gender of the household heads

Sex	Frequency	Percent
Female	25	9.3
Male	245	90.7
Total	**270**	**100.0**

Majority of the household heads were male (90.7%) and only a small proportion being female (9.3%). Male dominance among the irrigating households may be explained by cultural factors that exclude women in land-owning. In addition, the household head was not always the farmer but the person bearing legal responsibility for the land farmed. This means that majority of the farming decisions such as use of irrigation systems are dominated by the male gender. This implies that any measures put to ensure gender balance in economic activities often place more emphasis to supporting men than women (World Bank, 2009). Involvement of both men and women in economic activities is the key to successful gender mainstreaming (Guslits & Phartiyal, 2010). Women are increasingly being seen as active agents of change and the dynamic promoters of social transformations that can alter the life of all members in the society. According to Nyanjom (2011) the exclusion of women in decision making not only delays delivery of benefits but also affects equity and institutional efficiency. Gender sensitivity is therefore important when investigating decision making at household level.

Randela (2005) confirms that in several studies, women participate in farming mainly with an aim of ensuring family food security rather than being driven by profit motives. The dominance of males is therefore a matter that needs immediate redress. Patriarchal societies tend to favor males in most benefit. This could be achieved by changing mind sets that regard women as inferior to men, particularly through education and women empowerment, including focusing financial assistance towards women led farming ventures.

Gender is an important determinant in irrigation technology adoption. Empirical evidence suggests that male household heads are more likely to adopt manual irrigation systems than women due to their labour requirements. The dominance of male farmers in irrigation farming is consistent with a study by Adetola (2009) on the impact of irrigation technology on poverty in Ghana and Owusu *et al*. (2011) on the livelihood impact of improved onfarm water control in sub Saharan Africa. The results were however inconsistent with DiGennaro (2010) who found out that the female farmers were more likely to adopt micro irrigation technologies.

4.1.2 Age of the Head of Household

The mean age of the household heads was 38.49 years with a standard deviation of 11.37 years. A cumulative 64.4% of the household heads were aged between 25 – 50 years (Table 6).

Table 6: Age of the Head of Household (Years)

Age bracket	Frequency	Percent	Cumm. Percent
25-30	7	2.6	2.6
31-35	23	8.5	11.1
36-40	49	18.1	29.2
41-45	43	15.9	45.1
46-50	52	19.3	64.4
51-55	25	9.3	73.7
56-60	61	22.6	96.3
Above 60	10	3.7	100
Total	270	100.0	

Note. Range = 25 – 65 years, Mean Age = 38.49, Std. Deviation = 11.37, n = 270

Different from other developing countries where farming is reserved for middle aged and older generation, farming is popular among young persons in Mali. Age has an influence on crop farming productivity and production due to the effect of technology adoption. According to Khandker, *et al*., (2014) and Mosca and Pastore (2008) young and middle aged farmers are generally receptive to new technology in farming. Furthermore, age has an influence on experience in crop farming (Alonso and Lewis 2001).

Age of the household head has an implication on the choice of farming strategies and consequently, the type of crops grown. This may be attributed to the preference of the older farmers for less labour intensive crops such as most staple crops (potatoes) while young farmers may comfortably grow crops that require more labour inputs such as tomatoes and shallots (Wamuyu *et al*., 2016).

According to Nkambule and Dlamini (2013), young farmers are the more economically active. Elderly farmers have experience, but old age is a factor that has a negative effect on access to new information and promotion of active economic resilience in farming. Furthermore, farmer's individual job performance tends to decrease with age, particularly for tasks that require problem solving, learning and speed. However, elderly farmers are however able in jobs requiring experience and verbal abilities, particularly in maintaining a high level of productivity.

Bashir, Schilizzi and Pandit (2012) noted that the age of the household head is inversely related with farming efficiency and therefore food security where an increase of age year in the age of household head decreases the chances food security by 4.5%. The younger people are stronger than the elders and can perform better in agriculture.

4.1.3 Household Heads' Level of Education

Level of formal education plays a major influence in farming. Majority (47.6%) of the farmers were illiterate with no formal education (Figure 8). About 21.1% had primary, 17.5% had secondary while 9.7% had local language proficiency level of education (alphabetization).

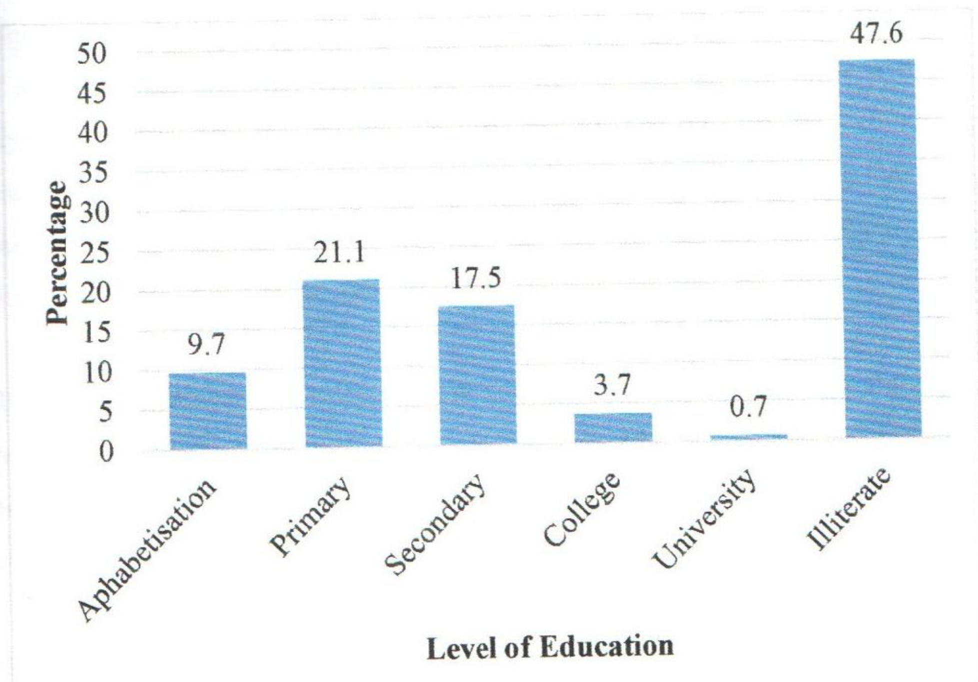


Figure 8: Level of education of the head of the household

Adequate formal education is necessary for better modern farming. In addition to this, the level of education of the household head can influence the kind of decision that may be made on behalf of the entire household with regard to use of technology like irrigation on crop farming. More educated farmers are likely to make better decisions as well as quickly adopt new technologies in farming as compared to their less educated counterparts. Education is of key importance as a means of empowering farmers with the necessary skills and knowledge to perform in their respective farming activities. As a result higher level of education is likely to increase farming success. High literacy levels also reduce gender parity in economic activities such as farming. In addition to this, education of a farmer is also correlated to their agricultural skills such as production and marketing (Perry & Johnson, 1999).

Education level is important in adoption of new technologies and quality of decision-making by smallholder farmers. Literate farmers are likely to be more receptive to new ideas. Skills and knowledge are closely linked with education, which can be obtained formally or informally (Winters, 2011). Access to formal education enables people to gain skills and knowledge in ways that provide official recognition for their educational achievements in the form of qualifications, which typically improve their opportunity to make a living (Ellis, 2000; Kyei & Gyekye, 2011). Literature has indicated the role of informal education in the transfer of traditional knowledge, which may include knowledge of farming (Mango, 2002). Mohamed (2006) reported that smallholder irrigators at Dzindi learnt to farm in informal ways, from their parents and from one another.

World Bank (2017), revealed that illiteracy is a major constraint magnifying the state of poor performance in agricultural activities. Uneducated persons are unable to understand and utilize technical information and therefore unable to make informed decisions in the light of increasing research findings in agriculture.

Education and experience play an important role in the level of efficiency. The effect of schooling on farming is normally positive as better educated farmers are expected to have more skills to run their farm more efficiently (Steven, Ludwig & Guido, 2008). Furthermore, investment in education can be seen as a strategy to improve agricultural productivity, principally through its complementarity with inputs as fertilizers, pesticides, irrigation, high-yielding varieties, and effective research. Steven *et al.* (2008) further argued that farmers with more years of schooling tend to be less inefficient.

Education enhances a farmer's ability to seek and make good use of information about production inputs. Therefore, expected to influence efficiency positively. Education plays a great role in adoption of most new technologies that normally calls for better management including consistent record keeping and proper use of the various inputs in farming (Cheryl *et al.*, 2003).

Some empirical studies such as Owour and Shem (2009) have shown a negative relationship between education and technical efficiency of farmers. One possible explanation is that technical skills in agricultural activities, especially in developing countries are more influenced by 'hands on' training in modern agricultural methods than just formal schooling. Another school of thought has it that technical inefficiency tends to increase after 5 years of schooling. This could probably be explained by the fact that high education attenuates the desire for farming. Therefore, the farmer probably concentrates on salaried employment instead (Kibaara, 2005).

Other studies show that education enhances the managerial and technical skills of farmers. According to Battese and Coelli (1995) education is hypothesized to increase the farmers' ability to utilize existing technologies and attain higher efficiency levels. Accesses to better education enable farmers to manage resources in order to sustain the environment and produce at optimum levels. Educated farmers easily adopt improved farming technology and therefore should have higher efficiency scores than farmers with low level of education (Seyoum *et al.*, 1998).

Although majority of the literature postulates a positive relationship between educational attainment of farm heads and technical efficiency, some few studies reveal otherwise (Fleming & Lummani, 2001; Hasnah & Coelli., 2004; Giang, 2013). Farms headed by household heads who have higher education are sometimes less technically efficient than those headed by heads who have lower education. Farmers' schooling and their productive capacity need not be significantly related under all circumstances. For example, in a technologically advanced area, where there are no serious production constraints, such as input availability, the schooling of farmers is not necessarily an important factor for efficiency. Informal education is sometimes more significant for the productive efficiency of smallholders than formal education at levels beyond primary education. Sometimes a high level of education does not necessarily contribute to the ability of farmers to access useful information or knowledge for cropping. This implication is also in agreement with Huynh and Yabe (2011) who found higher returns to vocational training in terms of its impact on raising agricultural productivity as compared to primary and secondary education from rice production in Vietnam. Significant efficiency gains would therefore be achieved through the promotion of education schemes tailored to the specific technical needs of farmers. Sometimes where a labour surplus exists and higher education allows opportunity for the farm head to have other jobs outside agricultural sector and subsequently not pay as much attention to their crops relative to other farms. Vu (2008) found that the off-farm income ratio was positively associated with the household farm head's years of schooling, thus farmers with higher education who completed secondary and high level tend to shift to non-farm activities and therefore their education does not contribute to improving farm technical efficiency.

Education is globally considered a vital tool for combating poverty. The adoption of improved agricultural technologies and embracing of new development projects are significantly affected by educational attainment. The irrigation farmers' level of education is an important factor that determines their ability to understand policies or programmes that affect farming (Adesina & Kehinde, 2008). According to Umar (2012), literate farmers are more productive because their level of education will enable them to make inquiries as regards new innovations in farming. Due to their level of education and exposure, their farm produce could be much better compared to others with lower levels of education. Also, other colleagues could go to them for advice and information because they are among the early adopters of innovation since they are highly educated.

4.1.4 Main Occupation of the Farmers

The most popular occupation practiced was agriculture (crop and livestock farming) as depicted in Figure 9.

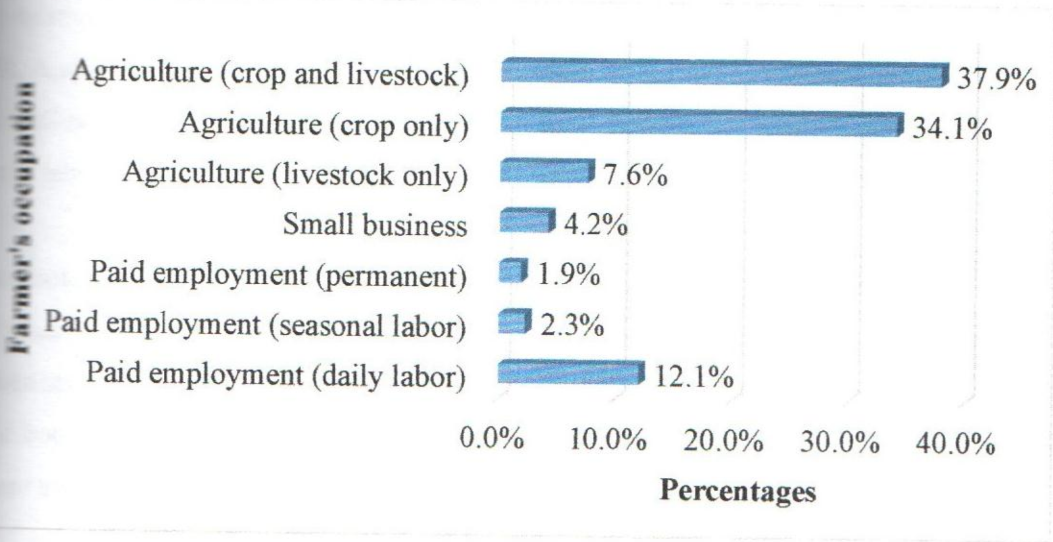


Figure 9: The main occupation of the farmers

Majority of the households were engaged in crop and livestock agriculture as their main occupation represented by 37.9%. About 34.1% were engaged in crop production while livestock was practiced by only 7.6%. About 12.1% of the households were engaged in paid employment as their major occupation (Figure 9).

4.1.5 Household Size

The size of households in adult equivalent varied as shown in Table 7.

Table 7: Household sizes in adult equivalent

Household sizes	Frequency	Percent
1 – 3	55	15.0
4 – 6	211	57.2
7 – 9	93	25.0
10	11	2.8
Total	**370**	**100.0**

Minimum = 1, Maximum = 13, Mean = 5.51, Standard Deviation = 2.184

Majority of the households (57.2%) had 4 - 6 adults. About 25.0% had 7 – 9 adult members while 15.0% had 1 – 3 adult members. It was a minority (2.8%) of the households who had 10 adult members or more. However, the mean household size (in adult equivalent) was 5.51 and relatively similar to the national average for agricultural household which is about 5.1 (IER, Annual Report, 2017). The size of the household influence the expenditure on food and availability of family labour. This implies that most households could benefit from adequate family labour in their farming activities.

Household size sometimes is known to be a source of farm and off-farm income generating activities (Sentumbwe, 2007). The size of farmers' household is another factor that influences the efficiency of farmers. Abdulai and Eberlin (2001) pointed out that although large household size puts extra pressure on farm income for food and clothing, they at times ensure availability of enough family labour for farming activities to be performed on time.

Amos (2007) revealed in his study that family size have a positive and significant effect on technical efficiency among cocoa producing households in Nigeria. A study carried out by Jema (2006) also indicated a positive and significant effect of family size among small-scale vegetable farming households in Ethiopia. Farmers with surplus labour force are likely to use the rest of the family labour. Hence operate inefficiently or farmers with bigger household size would have to allocate more financial resources to health, education and so on for members of the household and thus affect production (Nchare, 2007).

According to FAO (2013), household size can give an indication of the extent of pressure that could be exerted on the household resources as well as an indication of the available family labour. Crops that are grown under labour intensive activities may be better adopted by large household sizes as compared to their counterparts with few members.

Some studies in developing countries highlight the disadvantages of surplus labour on efficiency of farming economies (Coelli *et al*., 2002; Haji, 2006; Bozoglu and Ceyhan, 2006; Tran, 2007). This is largely attributed to overuse of inputs including family labor in production.

4.1.6 Income Earning from Non-Farming Activities

The distribution of household members who earned incomes from non-farming activities is as shown in Table 8.

Table 8: Number of household members who earn income from non-farming activities

Household members	Frequency	Percent	Cumm. Percent
None	67	24.8	24.8
1 - 2 members	143	53.0	77.8
3 – 4 members	39	14.4	92.2
5 – 6 members	10	3.7	95.9
7 members and more	11	4.1	100.0
Total	**270**	**100.0**	

Majority of the households (53%) had 1 – 2 members who were earning income from non-farming activities. About 24.8% had no member earning income from any non-farming activities. About 14.4% and 3.7% of the households had 3-4 and 5-6 members who earned incomes from non-farming activities respectively. It was only 4.1% of the households that had 7 members and more earning incomes from non-farming activities.

This confirms that the economy of the study area is dependent mainly on agriculture, with the sector contributing the highest portion of income. This agrees with USAID (2018) and Ministère de l'Agriculture (2018) which observed that agricultural activities are engaged by 80 percent of Mali's population and that majority of the population derives their incomes from agriculture. It is the backbone of the country's economy holding great potential for steering sustainable economic growth.

4.1.7 Size of Land

Households land size is taken to mean the size of land owned by the household plus that which is rented. Table 9 shows the amount of land that was available to households.

Table 9: Land size

Land size (ha)	Frequency	Percent
‹ 5	183	67.8%
5 - 10	68	25.2%
›10	19	7.0%
Total	**270**	**100.0%**

The results in Table 9 show that majority (67.8%) of the households had access to land that was less than 5 hectares. About 25.2% accessed land 5 - 10 hectares while only 7.0% accessed more than 10 hectares of land. These results suggest farmers are basically smallholders. This may be the major reason for choice of irrigation agriculture. Kay (2001) asserts that irrigation is not only an important tool in helping farmers insure against droughts and playing an integral role in transitions from subsistence to commercial farming but can substantially boost the production of staple foods and high-value crops, amidst low land holding.

Jin and Jayne (2013) argued that one of the main characteristics of production systems of smallholder farmers is gross inefficiencies. Smallholder farmers differ in individual characteristics, farm size, resource distribution between food and cash crops, their use of external inputs and hired labour and the proportion of food crops sold. Even though smallholder production is important for household food security, the efficiency of this sub-sector is quite low. This may be the reasons why most households fail to benefit from farming and either abandon or are uninterested in agricultural production. There is therefore a need to significantly increase the efficiency of smallholder farmers to ensure long term success in farming. This can be achieved by among others encouraging smallholder farmers to pursue well organized irrigation farming. Smallholder farmers can play an important role in livelihoods creation amongst the rural poor.

Giang (2013) found that there was a significantly positive relationship between farm size and technical efficiency. The larger the farm size the greater technical efficiency scores farms have. Javed *et al.* (2010) however, noted that the relationship between land area and technical efficiency of farms could be negative due to small variation in farm size as characterized among most small holder farmers. However, Lund and Price (1998) argued that land area would be a poor economic measure of farm size since land would be so variable in its agricultural attributes and farms of different types could require vastly different areas of land for the same value of output. In the context of diversified crops the output values among crops are variable in a given land area, thereby land area may not be a good measure of farm size.

4.3.8 Crop Irrigation by Households

All (100.0%) of the households practiced irrigation farming. Majority of the households chose to irrigate their farms in order to maximize their productivity. Farmers under irrigation farming are able to grow their crops more frequently and compensate for low land holding. The popularity of irrigation is also associated with climate change that has severely threatened the livelihoods of farmer's dependence on rain-fed agriculture.

The main water sources to the households irrigating their crops include dams/water ponds, boreholes/shallow well, water pumps, dams, rivers and tanks for water harvesting. The time for irrigation varied across the seasons as depicted in Figure 10. Majority of the households (48.8%) irrigated crops in the months of November to January. About 33.5% irrigated between August and October. A few (14%) irrigated between February and April while in the month of May and July, 3.7% practiced irrigated farming. The higher intensity of irrigation in the period between August and January is mainly associated with the dry season while the period between February and July is mainly a wet season.

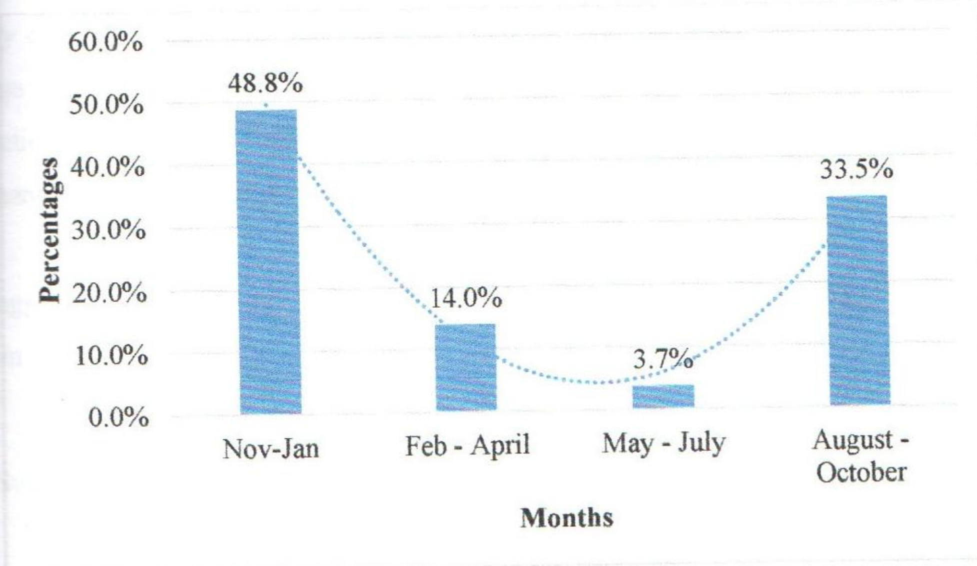


Figure 10: Period that respondents used irrigation on their farms

4.1.9 Challenges and Suggested Solutions of Irrigation

The main challenges faced by farmers in the practice of irrigation are summarized in Figure 11.

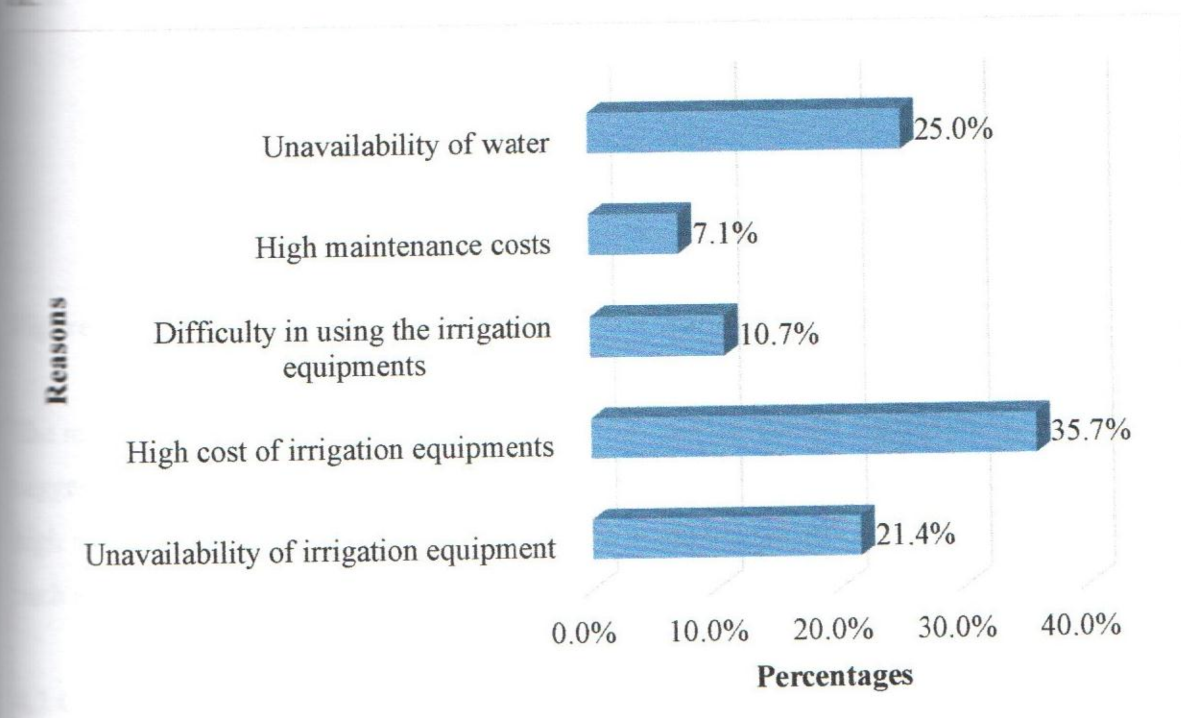


Figure 11: Challenges encountered in the practice of Irrigation

Majority of the farmers (35.7%) cited the high cost of irrigation equipment as the main challenge in irrigation. Other challenges were unavailability of water (25.0%), unavailability of irrigation equipment (21.4%), difficulty in using irrigation equipment (10.7%) and high maintenance cost in their implementation of irrigation farming (7.1%).

The suggested solutions for the challenges facing the adoption of irrigation farming are shown in Figure 12.

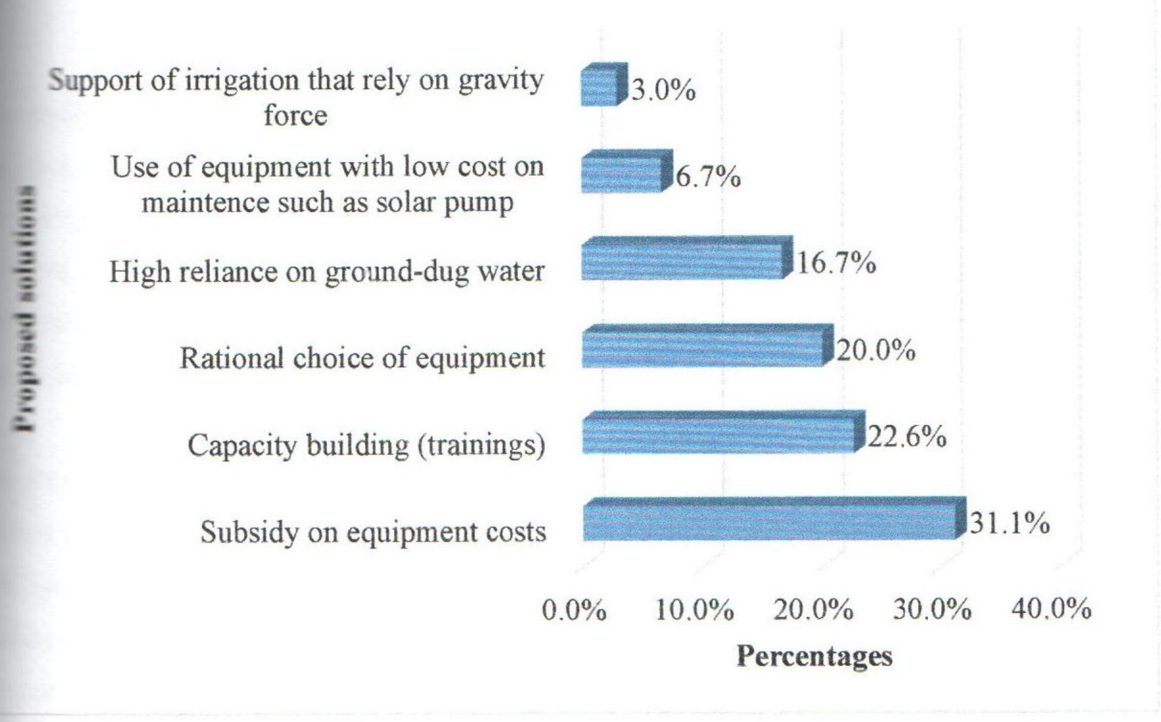


Figure 12: Proposed solutions for challenges in irrigation farming

The most prevalent solution suggested is subsidization of irrigation equipment (31.1%). Other suggestions were capacity building/trainings (22.6%), rational choice of equipment (20.0%), high reliance on ground-dug water (16.7%), use of equipment with low cost on maintenance such as solar pump (6.7%) and support of irrigation system that rely on gravity force (3.0%).

4.2 Characteristics of the Production Systems and Small Scale Irrigation Technologies

The major type of irrigation systems practiced are shown in Table 10.

Table 10: Major type of irrigation systems used for crop production

Irrigation system	Frequency	Percent
Drip	46	17.0
Sprinkling	55	20.4
Californian	87	32.2
Canal-Gravity/IP	11	4.1
Manual	71	26.3
Total	**270**	**100.0**

The practiced irrigation system in order of preference was Californian (32.2%), manual irrigation (26.3%), sprinkling irrigation (20.4%), drip irrigation (17.0%) and IP and Gravity canal irrigation (4.1%). Karlinsky (2005) explained that Californian irrigation system is preferred because of its nature of economy in using water where the underground installed water tubes direct water much nearer to the crops. Due to financial limitations of most smallholder farmers, manual irrigation is also popular.

The area of land under various irrigation systems dedicated for potatoes, tomatoes and shallots production are indicated in Table 11. Drip irrigation was practiced on an average of 1.49 Hectares (with a standard deviation of 0.70 Hectares). However, more land was used for shallots (0.68 ha) and tomatoes (0.52 ha) than potatoes (0.27 ha). The reason for this pattern is that due to the economy of the drip irrigation on its utilization of water, those who used the irrigation system often applied the technology on a vast area

In sprinkling irrigation, the main crops planted were tomatoes (1.88 ha) potatoes (0.80ha) while shallots covered the smallest area (0.54 ha). Sprinkling irrigation technology was relatively affordable to most farmers and was well suitable for majority of the crops grown in the study area, especially tomatoes and potatoes.

The area planted to the three crops using canal IP was (0.29 ha, 0.39 ha, and 0.34 ha) for potatoes, shallots and tomatoes respectively. Compared to drip and Californian systems, the area planted is smaller mainly because the technology consumes a lot of water that is not well supported by the prevailing climatic situation which is characterized by inadequate precipitation in some areas.

Table 11: Area of crops under different irrigation systems

		Irrigated Area (Ha)			
Irrigation system	**Crop**	**Min**	**Max**	**Mean**	**Std. Dev.**
Drip	Potatoes	0.02	1.00	0.27	0.34
	Shallots	0.10	7.00	0.68	0.92
	Tomatoes	0.10	7.00	0.52	0.83
	Aggregate	***0.02***	***7.00***	***0.49***	***0.70***
Sprinkling	Potatoes	0.10	8.00	0.80	1.31
	Shallots	0.10	3.00	0.54	0.74
	Tomatoes	0.20	7.00	1.88	0.04
	Aggregate	***0.10***	***8.00***	***0.41***	***0.69***
Californian	Potatoes	0.10	0.50	0.29	0.15
	Shallots	0.10	0.50	0.30	0.18
	Tomatoes	0.10	0.50	0.37	0.16
	Aggregate	***0.10***	***0.50***	***0.32***	***0.16***
Canal IP	Potatoes	0.10	1.00	0.29	0.20
	Shallots	0.10	0.50	0.39	0.17
	Tomatoes	0.10	0.50	0.34	0.19
	Aggregate	***0.10***	***1.00***	***0.34***	***0.19***
Manual	Potatoes	0.05	1.00	0.40	0.31
	Shallots	0.05	3.00	0.51	0.69
	Tomatoes	0.05	1.00	0.35	0.34
	Aggregate	***0.05***	***3.00***	***0.42***	***0.45***

Comparable with canal IP, the area planted with the three crops using manual systems was low. Shallots covered more area (0.51 ha) compared with potatoes (0.40 ha) and tomatoes (0.35 ha). Due to the extent of labour intensity, manual irrigation could only be practiced on a small piece of land

A comparison of the area planted under different irrigation systems was done using F-test and the results are presented in Table 12.

Table 12: Comparison of area under irrigation systems for the selected crops

Crops	Irrigation systems	Mean	Std. Dev.	F-Ratio	P-value
Potatoes	Drip	0.27	0.34	58.34	0.000**
	Sprinkling	0.80	1.31		
	Californian	0.52	0.83		
	Aggregate	***0.53***	***0.83***		
Shallots	Drip	0.68	0.92	25.61	0.000**
	Sprinkling	0.54	0.74		
	Californian	0.30	0.18		
	Aggregate	***0.51***	***0.61***		
Tomatoes	Drip	0.29	0.15	67.96	0.000**
	Sprinkling	1.88	0.04		
	Californian	0.37	0.16		
	Aggregate	***0.85***	***0.12***		

The results in Table 12 shows that most farmers prefer to irrigate their potatoes crops using sprinkling irrigation technology. Use of Californian and drip irrigation technologies is not preferred in the production of potatoes. An average of 0.80 Ha per household was irrigated using sprinkling technology as compared to 0.52 Ha and 0.27 Ha that is irrigated using Californian and drip technologies, respectively. The calculated F-Ratio of 58.34 is significant at 5% level implying that sprinkling is actually more popular in potatoes production as compared to other irrigation technologies.

Shallots are mainly irrigated using drip and sprinkling technologies. Californian irrigation technology is rarely used in shallot farming. An average household irrigated about 0.68 Ha and 0.54 Ha of land under shallots using drip and sprinkling technologies, respectively as compared to 0.30 Ha of land that was irrigated using Californian technology. The calculated F-Ratio of 25.61 is significant at 5% level implying that farmers prefer to use drip and sprinkling irrigation technologies in shallot farming with least preference on Californian irrigation technology.

Majority of the tomatoes farmers use sprinkling irrigation system. Use of other technologies is not popular in tomatoes farming. An average of 1.88 Ha of land under tomatoes was irrigated using sprinkling technology as compared to only 0.37 Ha and 0.29 Ha that is irrigated using Californian and drip technologies, respectively. The calculated F-Ratio of 67.96 is significant at 5% level implying that sprinkling is the most preferred technology in tomatoes farming while Californian and drip technologies are not popular in tomatoes farming.

There is scope to increase the area under irrigation in many countries through expansion or rehabilitation of irrigation structures. This is especially important in countries like Mali where farm size per household in irrigated system has been declining because of population growth and lack of new land developed for irrigation (SWAC/OECD, 2011). With irrigation, farmers can reduce production risks and be able to lift their crop enterprises to a higher production efficiency level through intensification. It can also open up possibilities of achieving more cropping seasons per year even against the prevailing climatic conditions (Woperies *et al*, 2013).

4.3 Economic Efficiency of Water Use in the Small Scale Irrigation Systems

The second objective sought to evaluate the economic efficiency of water use in the small scale irrigation systems. The use of Data Envelopment Analysis (DEA) was employed. Following Coelli *et al*. (2005), analysis was done in two stages. The first stage analysis shows the total value of output of the three crops and the costs of inputs used but with impact on the efficiency of irrigation farming. The second stage is split into exogenous/environmental variables. The results of first-stage DEA are presented in Table 13 and the second stage in Table 14.

There was a significant difference in the value of output from the three irrigation technologies ($F=12.54$; $p<0.05$). An average farmer produced vegetables with a value of FcFa.

184,021,232.00 (327,556.48 USD) distributed as drip (74,024,751.90, i.e. 133,243.49 USD), sprinkling (69,456,321.60, i.e. 125,020.38 USD) and Californian (40,540,158.50, i.e. 72,971.70 USD) as shown in Table 13.

There was a significant difference in total cost from the three irrigation technologies (F=6.73; p<0.05). On average households incurred a cost of FcFa. 1,312,041.67 (2,361.66 USD) on the total costs distributed as 340,993.33, i.e. 613.78 USD (drip), 523,431.58, i.e. 942.17 USD (sprinkling) and 447,616.76, i.e. 805.70 USD (Californian).

Table 13: Values of output and input costs in first stage of DEA

	Items	Drip	Sprinkling	Californian	Total	F-ratio	P-value
Value of output (FcFa)	Potatoes, tomatoes, shallots	74,024,751.9	69,456,321.6	40,540,158.5	184,021,232.0	12.54	0.000
Inputs costs (FcFa)	Seeds	137,892.60	142,964.80	152,564.47	433,421.87	1.67	0.190
	Manure	15,864.83	86,436.40	21,165.44	123,466.67	15.37	0.000
	Fertilizers	47,580.30	75,924.68	66,165.02	189,670.00	6.42	0.000
	Pesticides	18,620.20	44,913.56	50,029.91	113,563.67	5.38	0.000
	Labor	76,964.70	118,356.78	143,240.52	338,562.00	17.30	0.000
	Transport	43,085.40	42,689.52	36,015.75	121,790.67	1.94	0.146
	Other costs	985.30	2,145.84	408.86	3,540.00	2.09	0.126
	Total	340,993.33	523,431.58	447,616.76	1,312,041.67	6.73	0.000

F-critical = 3.03; degrees of freedom = 2 (numerator) and 267 (denominator)

There was no significant difference in seed cost from the three irrigation technologies (F=1.67; p=0.190). The average seed cost in the production of potatoes, tomatoes and shallots was FcFa. 433,421.87 (771.49 USD), distributed as drip (FcFa. 137,892.60), sprinkling (FcFa.

42,964.80) and Californian (FcFa. 152,564.47). There was a significant difference in manure cost from the three irrigation technologies (F=15.37; p<0.05). An average household was spending about FcFa. 123,466.67 (219.77 USD) on manure, distributed as drip (FcFa. 15,864.83), sprinkling (FcFa. 86,436.40) and Californian (FcFa. 21,165.44). There was a significant difference in fertilizer cost from the three irrigation technologies (F=6.42; p<0.05). An average household was spending about FcFa. 189,670.00 (337.61 USDA) on fertilizer, distributed as drip (FcFa. 47,580.30), sprinkling (FcFa. 75,924.68) and Californian (FcFa. 66,165.02). There was a significant difference in pesticide cost from the three irrigation technologies (F=5.38; p<0.05). Pesticides were costing farmers an average of FcFa. 113,563.67 (202.14 USD) distributed as drip (FcFa. 18,620.20), sprinkling (FcFa. 44,913.56) and Californian (FcFa. 50,029.91). There was a significant difference in labour cost from the three irrigation technologies (F=17.30; p<0.05). On average households incurred a cost of FcFa. 338,562.00 (602.64 USD) on labour, distributed as 76,964.70 (drip), 118,356.78 (sprinkling) and 143,240.52 (Californian). There was no significant difference in transport cost from the three irrigation technologies (F=1.94; p<0.146). On average households incurred a cost of FcFa. 121,790.67 (216.79 USD) on transportation, distributed as 43,085.40 (drip), 42,689.52 (sprinkling) and 36,015.75 (Californian). There was no significant difference in other cost from the three irrigation technologies (F=2.09; p<0.126). On average households incurred a cost of FcFa. 3,540.00 (6.30 USD) on other costs distributed as 985.30 (drip), 2,145.84 (sprinkling) and 408.86 (Californian).

Unlike first stage analysis that results in efficiency scores for all the selected irrigation systems, the second stage is used to distinguish traditional inputs from other relevant variables that impact on the efficiency of the crop production systems. Such variables are referred to as 'exogenous' factors that influence the efficiency and are out of the farmers' control. The second stage variables are measured by making a regression of coefficients that are adjusted to the efficiency scores that tally with the analyzed factors (Coelli *et al.*, 2005) with the cost of water and energy being the variables considered.

The mean variable costs on exogenous variables in the production of tomatoes, potatoes and shallots using varied irrigation methods are shown in Table 14.

Sprinkling consumed the highest energy cost with a mean of FcFa. 195,946.85 (352.70 USD) while drip and Californian irrigation systems reported an a mean energy cost of about FcFa. 121,654.90 (218.98 USD) and FcFa. 128,328.60 (218.98 USD), respectively. Sprinkler irrigation has the highest energy cost, because when sprinkler irrigation is used, there may be additional energy needs to meet water pressure requirements.

Table 14: Values of exogenous variables used in second stage analysis

Exogenous/ environmental variables	Irrigation system	Mean	Standard Deviation
Energy cost	Drip	121,654.90	8,473.67
	Sprinkling	195,946.85	17,429.50
	Californian	128,328.60	7,241.55
Water cost	Drip	24,862.90	1,675.44
	Sprinkling	60,898.79	5,217.95
	Californian	18,542.40	1,320.76

Likewise, the mean expenditure on water costs shows that sprinkling comprised the highest cost with a mean of FcFa. 60,898.79 (108.40 USD) while drip and Californian irrigation systems reported a lower mean water cost of FcFa. 24,862.90 (44.26 USD) and FcFa. 18,542.40 (33.01 USD), respectively. While drip and Californian irrigation systems are known to consume less water due to their ability to direct water much nearer to the plant, sprinkling irrigation system does not. Sprinkling irrigation system involves wetting the whole area where the crops are planted, thereby increasing the cost of water.

In order to estimate the relationships between crop yields per hectare and the cost of inputs, correlation analysis was performed and the results presented in Table 15.

Table 15: Correlation coefficient analysis between value of crop yield and cost of inputs

	Tomatoes		Potatoes		Shallots	
Cost item	r	P-value	R	P-value	r	P-value
Seed	0.380**	0.022	0.259**	0.018	0.117	0.282
Manure	0.189	0.582	0.218**	0.024	0.148	0.185
Fertilizers	0.341**	0.000	0.203**	0.022	0.366**	0.014
Pesticides	0.242**	0.038	0.189**	0.048	0.251**	0.032
Labour	0.427**	0.008	0.374**	0.001	0.330**	0.025
Transportation	0.216**	0.031	0.072	0.528	0.057	0.344
Other costs	0.112	0.420	0.063	0.558	0.156	0.213

** means significant at 5% percent level

In tomato production, the results show that seed (r=0.380**), fertilizer (r = 0.341**), pesticides (r=0.242**), labour (r=0.427**) and transportation (r=0.216**) costs are significantly correlated with tomatoes yields at the 0.05 level of significance. In contrast, manure (r=0.189) and other (r=112) costs were insignificant

Quality of seeds is an important factor in tomato production. The cost of seeds has a direct relationship with seed quality which is a crucial determining factor of yield and quality of crop production (Basra, 1995). Good quality seed with genetic and physiological purity and by extension, higher spending on seed results in better production as compared to other seed (Bradford & Bewley, 2002).

According to Yara (2018), tomato grows from a tiny seed into a mature plant putting out dozens of fruit. To achieve this development, tomatoes are heavy feeders. Use of fertilizer in tomato farming is credited with significant increase in yield. Most fertilizers add nitrogen into the soil. Nitrogen is a key component of enzymes, vitamins, chlorophyll and other cell constituents, all of which are essential for crop growth and development. It is thus one of the most important nutrients required for high tomato crop yields.

Pesticides cost is a key factor in production of tomatoes. Tomatoes farmers use many types of pesticides to control pests and diseases that attack these crops. When used responsibly, pesticides can boost tomatoes production (Ngowi, *et al*., 2007).

Sanchez, Orzolek, Harper and Kime (2003) confirms that majority of the activities in tomatoes production (transplanting, weeding, spraying, harvesting, marketing) are labour intensive. For instance, harvesting of fresh-market tomatoes is labor intensive and requires multiple pickings. Tomatoes generally are harvested four to six times during the growing season, depending on plant type, maturity and market value.

Due to multiple pickings (harvesting) associated with potato production, transportation cost is key (Sanchez *et al*., 2003). Unlike, vegetables such as potatoes and shallots which are harvested once, tomatoes which are harvested four to six times during the growing season, consumes more transportation costs. Transportation cost of tomatoes is further exacerbated by the fact that the commodity is perishable and must be sold immediately when harvested. This implies that improving infrastructure by providing better and affordable transportation is deemed necessary for enhancing commercialization in developing (Shilpi & Umali-Deininger, 2008).

For potatoes, t seed (r=0.259**), manure (r=0.218**), fertilizers (r=0.203**), pesticides (r=0.189**) and labour (r=0.374**) were significantly correlated with potatoes yields at the 5 percent level of significance. In contrast, the cost of transportation (r=0.072) and other (r=0.063) costs were not significant

Potato yields are affected by among other factors, the quality seed. The average yield increase from the use of good quality seed is 30 to 50 percent compared to farmers' seeds (FAO, 2018). Morris, Tripp and Dankyi (1999) applied qualitative approach to evaluate the performance of seed quality in Ghana, under the grains development project. They found that improved seed varieties significantly increased yields for farmers switching from local varieties. The yield increase would even be much higher if the farmers applied fertilizer on the improved varieties. This showed that the improved varieties performed better under an improved management system. Even with less improved management approaches, the improved varieties still performed better than the local varieties.

Good returns from potato production are the driving force for using fertilizers and manure. As long as potato growers can achieve higher profits, they are willing to incur costs on fertilizers and manure. Poor farmers prefer to use manure owing to its lower costs. Since, potato crop management practices are related to local conditions, production purposes and utilization and growers' experience, both manure and fertilizer are perceived as important factors of production. The yield-enhancing effects of fertilizer in Kenya have also been observed by Owino (2010) who used experimental data in Trans Nzoia District. Owino further noted that the yields vary with different improved varieties, fertilizer types and intensity and with management practices.

Most farmers use a combination of insecticides and fungicides on potato due to prevalence of fungal diseases (potato blight) and insect pests which are perceived to be equally important (Ntow et al., 2006). Use of pesticides enables farmers to safeguard their potatoes against pest attacks and thereby adverse effects on yields.

Just like most vegetable crops, production of potatoes is labour intensive. Major potato production activities such as planting, weeding, spraying, harvesting and transportation are normally executed manually. Farmers who are well endowed with adequate labour (family or hired) are well able to grow potatoes and achieve high yields.

The Pearson's coefficient for shallots shows that fertilizers (r=0.366**), pesticides (r=0.251**) and labour (r=0.330**) were significant at 5% level. The cost of seeds (r=0.117), manure (r=0.148), transportation (r=0.057) and other costs (r=0.156) were not significant.

Application of fertilizer in shallot production is a key factor for good returns. Since, shallots take a shorter time to mature, nutrient requirement as supplemented by fertilizer application is useful. Unlike manure, the formulation of most inorganic fertilizer is such that it is able to release the required nutrients to a plant in the required time without unnecessary delays.

Application of pesticides is also an important factor in the production of shallots. They protect plants from pests such as insects. Extremely low yield may be realized without enough mechanisms of controlling pests in shallot production.

Shallot production is labour intensive. A shallot farmer is expected to dedicate a huge extent of labour for better yield. Consequently, most farmers opt to grow shallots in smaller parcels of land due to labour constraints.

4.2.3 Comparison of DEA average scores across the irrigation systems

DEA was used to measure the relative efficiency scores. Efficiency scores across the irrigation systems and farming enterprises; under the assumption of both variable return to scale (VRS) and constant return to scale (CRS) are presented in Tables 16 and 17.

One way ANOVA was used in making comparison of DEA average scores across the three irrigation systems. The results are summarized in Table 16. A closer look at the individual irrigation systems, revealed significant fluctuations in average scores. Under the VRS and CRS assumptions, there existed a significant mean difference in DEA scores across the three irrigation systems (Calculated F-Ratio of 532.35(VRS) and 4.89(CRS) are greater than critical F-Ratio of 3.03).

Table 16: Average DEA efficiency scores across the irrigation systems

	Output-oriented VRS		Output-oriented CRS	
Irrigation system	Mean	Std. Deviation	Mean	Std. Deviation
Drip	0.90	0.019	0.20	0.029
Sprinkling	0.75	0.015	0.17	0.026
Californian	0.64	0.011	0.14	0.026
Total	0.76	0.105	0.17	0.027

F-Ratio (VRS) = 532.35, F-Ratio (CRS) = 4.89, Critical F-Ratio (2,267) = 3.03

The average DEA efficiency scores were highest under VRS in drip (0.90), sprinkling (0.75) and lowest in Californian (0.64) irrigation systems as compared with 0.20 , 0.17 and 0.14 respectively under CRS . This implies that the technical efficiencies for the three irrigation systems were low under CRS. However, under VRS, households would have to increase their inputs used in drip, sprinkling and Californian irrigation by 10%, 25% and 36%, respectively in order to become efficient.

There are two types of scales; Constant Return to Scale (CRS) and Variable Return to Scale (VRS). In these results, CRS assumption that an increment in inputs results in proportion increment in outputs cannot be used. For instance, Charnes et al. (1978) did not recommend Constant Returns to Scale (CRS) in calculating resulting technical efficiency indices due to a rigid assumption that all DMUs must be functioning at an optimal scale. External factors such as government control, imperfect competition, financial limitation, among others, may explain why a DMU may not actually perform at its optimal scale. Hence, distorted technical efficiency scores will be yielded if production is not at its optimal level under CRS assumption.

However, since there exists a significant relationship between the size of DMU and efficiency, VRS assumption that an increment in inputs results in a disproportionate increment in outputs is adopted (Cooper & Seiford, 2001). Majority of the efficiency tests are based on VRS frontier (Coelli, 2008). Variable Returns to Scale (VRS) assumption helps in detecting scale effects, which is not the case with CRS (Coelli, 2008).

The results in Table 16 shows that the values of VRS and CRS differ significantly. The values found in variable returns to scale are better than those for constant returns to scale. This is attributed to the law of variable proportions or diminishing returns.

These results agree with Pair *et al.* (1975) who revealed that drip irrigation is water use efficient and that it makes use of little water available and good moisture control enhancing high and quality crop yield. This study agrees with FAO (2002) which stated that sub-surface

Drip irrigation improves water use efficiency (WUE) significantly when used with various crops and vegetables.

Drip irrigation technologies may be adapted for more-effective and rational uses of limited supplies of water and are preferable to less efficient traditional surface methods. The evaluation of drip irrigation system proved its importance in water use efficiency improvements in crops such as cotton, sunflower, sugar beet and potato with reduced evapotranspiration imposed throughout the growing season. Relative to sprinkler; drip cover less surface water application area, maintain moisture and water is directed to crops, simultaneously reducing farming cost (Pair *et al*, 1975).

FAO (2002) confirmed through the irrigation system used by small-scale farmers in north-central Namibia that both drip and sprinkler irrigations, when used on vegetable crops, were efficient. With respect to farmers' perception, majority indicated drip irrigation as not only suitable but also more efficient than sprinkler irrigation. They based their opinions on the perception that comparable to sprinkler irrigation, drip uses less water (less production cost, conserve water), associated with few pests (weeds, insects and diseases such as; fungal diseases and cracking in tomato production). Based on their past and present experience they highlighted a huge difference in harvest or crop yield between the two irrigation systems. Sprinkler harvest was less relative to other farmers using drip.

Dasberg and Or (2013), revealed that field application efficiency of drip irrigation can be higher as 90% relative to 60-80% of the sprinkler. This is associated with the ability to maintain an optimal balance between soil water and aeration, reduction in evapotranspiration, runoff and nutrients leaching (Caswell & Zilberman, 1986; Dasberg & Or, 2013; Postel, 1998). Further, they revealed that drip requires less energy and is adaptable to soil pathogens and plant pathogen incubation. Caswell and Zilberman (1986) stated that drip conserves water and increase yield as growers become more experienced with the technology. In contrast, sprinkler lower air temperature around growing plants, reduce water stress and transpiration. Despite, both drip and sprinkler are adaptable to area with relative land quality and water scarcity.

Hegney and Hoffman (1997) indicated that sprinkler irrigation is more favorable than drip (due to perceptions that drip does not suit poor soil quality. The irrigation technology is also suitable to majority of the crops. Therefore it is preferable to farmers with cropping diversification system (, field crops and vegetables). Sprinkler is more favorable with crops that require more water such as; cabbage and maize relative to drip which is suitable for crops like tomatoes.

4.2.4 Comparison of DEA average scores across the crop enterprises

The results for average efficiency scores across crop enterprises are summarized in Table 17.

Table 17: Mean DEA efficiency scores across the crop enterprises

	Output-oriented VRS		Output-oriented CRS	
Crop enterprises	Mean	Std. Deviation	Mean	Std. Deviation
Tomatoes	0.78	0.14	0.19	0.04
Potatoes	0.75	0.13	0.13	0.03
Shallots	0.76	0.13	0.18	0.03
Total	0.76	0.13	0.17	0.03

F-Ratio (VRS) = 0.04, F-Ratio (CRS) = 3.51, Critical F-Ratio (2,267) = 3.03, P-value = 0.96 (VRS) and 0.09 (CRS)

Under the assumption of VRS and CRS, there is no significant mean difference in DEA scores across the three enterprises [P-value (VRS) = 0.96 and P-value (CRS) = 0.09].

The mean DEA scores under the VRS assumption in the production of tomatoes (0.78), potatoes (0.75) and shallots (0.76) did not differ significantly. Likewise, the mean DEA scores under the CRS assumption in the production of tomatoes (0.19), potatoes (0.13) and shallots (0.18) did not differ significantly. Significant levels of inefficiencies ranging between 22% - 25% and 81% - 87% was observed in the three major enterprises under the VRS and CRS, respectively.

The mean efficiency score across the three crops reveal that there is indeed a presence of inefficiency in the irrigation systems as used in production of the three main crops. This implies that on average farmers can improve their efficiency or reduce their inefficiencies proportionately, by augmenting their outputs by approximately 24% and 83% without altering the inputs levels, under the assumptions of VRS and CRS, respectively. Not only do the results tell us about the level of efficiency, but they also give a strong indication of room for efficiency improvement in the selected irrigation systems.

4.4 Economic Viability of the Alternative Small Scale Irrigation Systems

The third objective sought to determine the economic viability of the alternative small scale irrigation systems. The Benefit-Cost Ratio (BCR) analysis was used also for judging the economic soundness of irrigation projects.

Summarized results on running cost, duration to maturity, yield and market information in the production of potatoes, tomatoes and shallots in the various irrigation systems are presented in Table 18. To verify the feasibility of alternative small scale irrigation systems the benefit cost ratio was calculated. The cost of capital (interest) on the irrigation systems was calculated at the prevailing market rate.

The main reason for discounting is to account for the time value of money. This is because a dollar available now can be invested and earn interest and would be worth more than a dollar in future. With an interest rate of r, a dollar invested for t years will increase to $(1+r)^t$. Therefore, the amount of money that would have to be deposited now so that it would grow to be one dollar t years in the future is $(1+r)^{-t}$. This called the discounted value or present value of a dollar available t years in the future.

Table 18: Running cost (Fcfa), duration to maturity, yield and market information in the production of tomatoes, potatoes and shallots per Ha.

Parameters	Crops	Tomato	Potato	Shallot
Running costs	Seeds	399,916	750,200	150,150
	Manure	125,400	125,000	120,000
	Fertilizers	150,050	212,540	206,420
	Pesticides	95,000	175,127	70,564
	Labor	250,000	415,625	350,061
	Transportation	125,000	125,000	115,372
	Other costs	2,530	5,050	3,040
Duration to maturity and yield	Vegetative cycle (month)	2 to 3	3 to 4	3 to 4
	Yield (t/ha)	10 to 40	25	70
Marketing/Commercialization:	Producers (Fcfa/kg)	150	125 to 275	100
	Market (Fcfa/kg)	500	156 to 533	400
Return	Gross (Fcfa/ha)	37,500,000.00	34,450,000.00	112,000,000.00
	Net	36,377,500	32,644,375	110,992,000

The benefits and costs are in constant value dollars and therefore the discount rate used must be the real interest rate. In this study, the present value of the streams of benefits and costs are discounted at a 13 percent back to time zero since the interest rate on long term bonds is 18 percent and the rate of inflation is 5 percent.

The results of benefits-costs ratio of the three irrigation systems in the production of potatoes, shallots and tomatoes are presented in Table 19.

Table 19: A comparison of BCR of the selected irrigation systems in producing potatoes, shallots and tomatoes in the year 2017

	Benefit Cost Ratio (BCR)			
Irrigation systems	Potatoes	Shallots	Tomatoes	Mean
California	1.499	2.024	2.147	1.890
Drip	1.964	2.825	2.948	2.579
Sprinkler	1.727	2.252	2.375	2.118

Calculated F-Value (4,269) = 11.15, P-value = 0.001, Critical F-Ratio (2,267) = 3.03

NB: Discount rate = 18%, Inflation Rate = 5%

The BCR of all irrigation systems (California, Drip and Sprinkler) were all greater than unity (1) implying that they lead to greater benefits as compared to costs. The excess benefits (compared to costs) is realized more with drip irrigation system (BCR = 2.579) with the second best being sprinkler (BCR = 2.118) and the third being California (1.890).

The test of differences in average BCR of the various irrigation systems was performed using one-way ANOVA. The calculated F-value of 11.15 was greater than the Critical F-ratio of 3.03 and thus significant. This implies that the average BCR for the selected irrigation systems were significantly different with the Drip (2.579) yielding the highest BCR scores. This was followed by Sprinkler (2.118) and Californian (1.890), respectively.

Dahigaonkar (2008), Asawa (1999) and Rao (2008) concur that there are many essential irrigation benefits in agriculture associated with drip, sprinkling and Californian technologies. These technologies do not only ensure that crops do not depend on the rain only but also allows the introduction of high yielding crops. Because irrigation is a supplementation of precipitation by storage and transportation of water to the fields for the proper growth of agricultural crops, the implementation cost is often lesser than the benefits.

When irrigation farming is practiced, the outcome is not only credited with increased production but also timely yields that can fetch better prices. A farmer is also able to benefit more cropping seasons per year when practicing irrigated agriculture as compared to rain fed agriculture (BADC, 2012).

This study agrees with Bright Hub (2018) which noted that the BCR of drip irrigation is higher than most of the other irrigation technologies because less resources are used as water is spread drop by drop onto the root of the plants. Losses due to runoff and evaporation are reduced to a considerable extent.

Practice of drip, sprinkling and Californian irrigation technologies is more likely to lead to greater benefits than cost. This study concurs with Rao (2008) who noted that augmentation of irrigation and the concomitant expansion of an irrigated area result to numerous direct and indirect benefits. Irrigation helps to increase agricultural production with the yield for irrigated crops being two to three times higher. It helps to better utilize land for agriculture. Farmers can also benefit from high valued cash crops whose supply is normally not uniform throughout the year. From the irrigated fields, the yields are stable and reliable. Assured production targets can be met. There is reduced fluctuations in the year-to-year yields and the risk of crop failure due to drought. Irrigation allows for continuous cultivation.

This study is consistent with Kang'au (2011) who found that the BCR of various irrigation technologies in smallholder pumped irrigation systems in Kenya to be greater than unity (1) implying their ability to lead to greater benefits as compared to costs. The economic analysis of smallholder pumped irrigated agriculture under horticultural crop production was observed to be a highly profitable and beneficial investment with tomatoes leading to highest net returns per hectare (as compared to French beans and water melon).

4.5 Technical Efficiency of Small Scale Vegetables Production under Different Irrigation Systems

The fourth objective sought to determine the technical efficiency of small scale vegetables production under different irrigation systems. This objective was analyzed using Cobb-Douglas stochastic frontier production regression model (Battese, 1993; Coeli, 1995; Mbaga *et al.*, 2009).

4.5.1 Ordinary Least Square Estimates of Cobb Douglas Production Function

The efficiency estimates of the irrigation systems were measured using a Cobb- Douglas stochastic frontier production model (Battese & Coelli, 1992). A two-step process was employed to find the technical efficiency using maximum-likelihood method. In the first step, the ordinary least square (OLS) estimates of the parameters were obtained. The obtained estimates were used to estimate the maximum-likelihood estimates of the parameters treated as the frontier estimates of Cobb- Douglas stochastic frontier production model during the second stage. Table 20 shows the OLS estimates of the parameters in the model.

Table 20: OLS estimates of Cobb Douglas production function

Variables	Coefficients	Std. Error	t-value
Constant	0.786**	0.116	6.776
Seeds	0.146**	0.034	4.294
Manure	0.143	0.109	1.312
Fertilizers	0.246**	0.083	2.964
Pesticides	0.123	0.157	0.783
Labor	0.265**	0.131	2.023
Transportation	0.041	0.074	0.554
Sigma-squared	0.538		

** means significant at 5% percent level

From the results in Table 20, the coefficient of seed cost was significant at 5% level with a value of 0.146. The coefficients for costs of fertilizers (0.246) and labour (0.265) were significant at 5% level. However, the coefficients for cost of manure (0.143), pesticides (0.123) and transportation (0.041) were insignificant at 5% level. The parameter sigma-squared was positive, which indicates that the observed output differed from frontier output.

These results imply that the cost of seeds, fertilizers and labor are important factors of production in vegetable production. More investment in good quality seeds, inorganic fertilizers and farming labour has a positive influence of vegetable production. According to Sudha, Gajanana and Murthy (2006), seed quality significantly impact the levels of output in vegetable production since quality seed should have high genetic purity, longevity / shelf life, market value, pure seed percentage (physical purity), germinability, vigour and field establishment. In addition, quality seeds are free from pest and disease.

This study agrees with Olowoake (2014) who noted that fertilizer is very important in growing of vegetable crops. Nitrogen which is provided by most inorganic fertilizer is necessary to know the effect of sources of nitrogen is a major component of chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide (i.e., photosynthesis). It is also a major component of amino acids, the building blocks of proteins. Without proteins, plants wither and die.

According to Everaarts and de Putter (2009), vegetable crops require a comparatively high number of hours of labour per hectare per growing day. Labour requirement on a vegetable farm, however, usually is characterised by peak demands (soil preparation, sowing/planting, irrigation, harvesting) and needs to fit in with other labour requiring household economic activities. Labour is the highest single cost in crop production with majority of it being hired. Without substituting hired labour for own labour, the introduction of drip irrigation would save most on labour for watering the crops and thereby increase profits. In most places, traditional practices, necessities or other income earning opportunities dictate own labour, or time, for a large part to be spend outside vegetable production. Households with large family sizes may cultivate more land, mainly because of the use of family members, who provide cheap labour force.

4.5.2 Maximum-likelihood estimates of Cobb Douglas production function

Table 21 presents the maximum-likelihood estimates of the parameters of Cobb- Douglas stochastic frontier production model. The coefficients of costs of seeds, fertilizers and labour were significant at 5% level, with values of 0.549, 0.067 and 0.056, respectively; indicating that the crop yield (output) was explained by 54.9% of seed costs, 6.7% of fertilizer costs and 5.6% of labour costs (Table 21). On the other hand, the coefficient of cost of manure, pesticides and transportation were insignificant with values of 0.166, 0.031 and 0.075.

Table 21: Maximum-likelihood estimates of Cobb Douglas production function

Variables	Coefficients	Std. Error	t-value
Constant	0.995**	0.196	5.071
Seeds	0.549**	0.144	3.807
Manure	0.166	0.118	1.401
Fertilizers	0.067**	0.008	8.519
Pesticides	0.031	0.292	0.107
Labor	0.056**	0.011	5.333
Transportation	0.0785	0.371	0.203
Sigma-squared	0.042*	0.005	8.061
Gamma	0.014	0.010	1.412
Eta	0.956**	0.291	3.289

** means significant at 5% percent level

The coefficient of seed costs showed a positive sign, indicating that farmers who spent more on quality seeds realized more yields. In the same way, the coefficients for fertilizer and labour costs were also positive, indicating that greater use of these inputs significantly resulted to higher production.

The value of γ (Gamma) was estimated to be 0.014, which demonstrates that 1.4 percent variations in output among the irrigation systems were due to the differences in technical efficiency. It is also evident from the results that the estimate of gamma (0.014), which is significantly different from zero, indicates a good fit of the model used. As the estimates for the η (eta) parameter were observed to be positive, it can be concluded that the technical inefficiency effects tend to decrease.

4.5.3 Comparison of Technical Efficiency under Different Irrigation Systems

This section attempts to ascertain the existence of difference (or otherwise) in technical efficiencies scores of the three major types of irrigation technologies practiced. Knowledge about the relative efficiencies of vegetable production with varied types of irrigation technologies is of importance and worth investigation. The performance of drip, sprinkling and Californian irrigation systems in terms of technical efficiency is presented in Table 22.

Table 22: Average technical efficiency scores of vegetable production under different irrigation systems

Crop	Drip	Sprinkling	Californian
Potatoes	89.14	90.88	76.35
Shallots	92.67	90.53	78.79
Tomatoes	93.22	90.26	75.46
mean	***91.68***	***90.56***	***76.87***

Calculated F-Ratio $_{(2, 267)}$ = 76.78, Critical F-Ratio $_{(2, 267)}$ = 3.03

The results demonstrate an overall variation in pure technical efficiency scores under different irrigation systems (the mean pure efficiency scores differs across the irrigation systems). With respect to the vegetable production of potatoes, shallots and tomatoes, the technical efficiency scores are highest in drip irrigation (91.68 percent) and followed by sprinkling irrigation (90.56 percent). The technical efficiency scores are lowest in Californian irrigation system (76.87 percent).

According to Shock (2013), drip irrigation has many advantages over sprinkling and Californian system that are responsible for its high technical efficiency in vegetable production. One most important advantage for growers with limited or expensive water is the water savings that a well-designed and managed drip system provides. Drip irrigation can minimize runoff, deep-percolation and evaporation. Irrigation application uniformity is improved and application occurs directly to the plant's roots. Drip irrigation allows for frequent, efficient irrigation that works well for establishing crops and for shallow rooted crops. Other advantages include decreased weed and disease pressure, lower pumping needs, uninterrupted field operations, precision in fertilizer application and adaptability for uneven topography and oddly shaped fields. However, further analysis using Bonferroni multiple comparison test reveals a non-existence of difference between drip and sprinkling irrigation technologies (Table 22).

The mean difference in efficiency scores of drip and sprinkling irrigation systems (1.12) is not significant at 5% level. The mean difference in efficiency scores existing between drip and Californian irrigation system (14.81) as well as between sprinkling and Californian irrigation systems (13.69) is significant at 5% level as can be observed from P-values of <0.001 and <0.001, respectively. This implies that both drip and sprinkling irrigation technologies make better (economical) use of inputs in their production as compared to Californian. They utilize less input costs (than the Californian system) for same level of output.

Table 23: Comparison of technical efficiencies of irrigation systems using Bonferroni multiple comparison test

	Drip	Sprinkling
Irrigation technologies	Mean diff (P-value)	Mean diff (P-value)
Sprinkling	-1.12 (0.561)	-
Californian	-14.81 (0.000)	-13.69 (0.000)

Table 23 shows that with respect to technical efficiency of use of drip irrigation technology on vegetable production, the system is most efficient in production of tomatoes (93.22) with shallots (92.67) being the second best. Drip irrigation is least efficient in production of potatoes (89.14). The difference in efficiency scores of drip irrigation on production of selected horticultural crops was significant at 5% level (p-value <0.05).

Because tomatoes and shallots are prone to pests and diseases, their farming is popular with drip irrigation that permits proper irrigation scheduling which influence pest management strategies (Burt & Styles, 2011). According to Shock (2013), soil water decreases the mobility of cutworms and potato tuber moth, protecting the tubers from attack. Systemic insecticides sometimes are used in drip systems for enhanced insect and nematode control.

Table 24: Technical efficiency scores of different irrigation technologies on vegetable production

Irrigation technology	Potatoes	Shallots	Tomatoes	F-Ratio	P-value
Drip	89.14	92.67	93.22	6.43*	0.001
Sprinkling	90.88	90.53	90.26	2.94	0.121
Californian	76.35	78.79	75.46	4.27*	0.001
Average	85.46	87.33	86.31		

Critical F-Ratio $_{(2, 269)}$ = 3.03

As far as sprinkling irrigation was concerned, the technology was most efficient on production of potatoes (90.88), followed by shallots (90.53) and then tomatoes (90.26). The difference in efficiency scores of sprinkling irrigation was however not significant at 5% level (p-value = 0.121).

Geerts and Raes (2009) asserts that potato growing requires a continuous yet appropriate quantity of supplemental watering which is well provided by sprinkling irrigation system. Reduction of soil moisture can have significant consequences on tuber yield and quality. Water stress can significantly affect the health of a potato crop. Too little moisture and soil moisture fluctuations can affect tuber quality. According to Rowe (1993), water is a major constituent of potato plants, comprising 75.85% of tubers. Under optimal conditions, well-watered potato plants transpiring at an average rate will replace their entire water content about four times a day (Rowe, 1993). Potatoes are sensitive to water deficiency and have a shallow root zone (40 cm). Potato plants are relatively poor conductors of water, possibly a result of having a relatively small root length per unit land area compared to more drought-resistant plant species (Gregory and Simmonds, 1992).

Table 24 shows that the difference in efficiency scores of Californian irrigation technology on production of selected horticultural crops was significant at 5% level (p-value <0.05). Californian irrigation technology was most efficient on production of shallots (78.79), followed by potatoes (76.35) and then tomatoes (75.46).

These results agree with Bailey (1990) who found that Californian irrigation system is the best for shallots since the crop need lots of sun and good drainage. The bulb plants also are heavy feeders and require a reliable supply of nitrogen and phosphorous nutrients. Californian irrigation allow regulation of moisture, thus avoiding rotting of the crop. Californian irrigation system is also suitable for potatoes and tomatoes (though at varying degrees) due to its flexibility of water regulation.

The results arising from this study are similar to Makombe *et al.* (2017) who calculated average technical efficiency for modern irrigation systems (drip, sprinkling and Californian) in production of potatoes as 71%. This is also similar to that of 77% found by Bogale and Bogale (2005) for modern smallholder irrigating potato farmers in the Awi zone of Ethiopia.

The results are also similar to Giang (2013) whom in an analysis of technical efficiency of crop farms in the northern region of Vietnam, found the efficiency of the sample to be 0.83. The estimated mean level of technical efficiency. Vu (2008) and Huynh and Yabe (2011) explains that higher estimates on technical efficiency is possible where farmers are not highly diversified.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The study investigated the economic evaluation of alternative small scale irrigation systems used in vegetables production in Koulikoro and Mopti Regions in Mali. This section presents summary of key study findings as well as conclusions and recommendations which are logically arranged in line with the objectives of the study. Some areas of further research have also been suggested.

5.1 Summary of Findings

The following were the key findings of this study:

i) A smallholder production system was characterized by more male involvement in decision making and more female engagement in provision of labour. Most of the smallholder farmers are middle aged and illiterate with no formal education. With agriculture being the most popular occupation practiced in the study area, most households have only a few members engaged in farming activities for income generation. High cost of irrigation equipment, unavailability of water, difficulty in using irrigation equipment and high maintenance cost are the major challenges of irrigation, forcing most households to irrigate their fields only in dry months such as November to January.

ii) On average farmers could improve their efficiency or reduce their inefficiencies proportionately, by augmenting their outputs by approximately 24% without altering the inputs levels. For individual irrigation systems, there exist fluctuations in average scores. The average scores in drip and sprinkling irrigation systems were relatively higher than those of Californian system. There was a great variation in the performance of different crops in the study area.

iii) It was economic undesirable to produce potatoes, shallots and tomatoes using manual irrigation system. The BCR of other irrigation systems (California, Drip, Sprinkler and Canal IP) were all greater than unity (1) implying that they led to greater benefits as compared to costs. The excess benefits (compared to costs) was realized more with drip irrigation system with the second being sprinkler and the third being Californian and the fourth being canal IP irrigation system.

iv) There was a significant variation in technical efficiency scores under different irrigation systems. With respect to the vegetable production of potatoes, shallots and tomatoes, the technical efficiency scores were highest in drip followed by sprinkling and lowest in Californian irrigation system. Both drip and sprinkling irrigation technologies make better use (economical) of inputs in their production as compared to Californian. They utilize less input costs (than the Californian system) for same level of output. Drip irrigation was more efficient in production of tomatoes and shallots when compared to the production of potatoes. Sprinkling irrigation was equally efficient on the production of potatoes shallots and tomatoes. Californian irrigation technology was most efficient on production of shallots followed by potatoes and least on tomatoes.

5.2 Conclusions

From the findings, the study concludes the following:

i) Majority of the farming decisions such as use of irrigation systems are dominated by male gender. Farming is popular among the young and middle aged persons. Most farmers lack adequate formal education which is necessary for better modern farming. The most popular occupation practiced agriculture (crop and livestock). The main sources of irrigation water includes dams/water ponds, boreholes/shallow well, water pumps, dams, rivers and tanks for water harvesting. The major type of irrigation systems practiced in the study area include drip, sprinkling, Californian, canal-Gravity/IP and manual irrigation systems.

ii) The irrigation systems as used in production of the three main crops present a level of inefficiency. An average farmer in the study area can improve their efficiency or reduce their inefficiencies proportionately, by augmenting their outputs by approximately 24% without altering the inputs levels. This means that there is room for efficiency improvement in the selected irrigation systems. Drip and sprinkling irrigation systems is relatively more economically efficient as compared with Californian system.

iii) The use of drip, sprinkling and Californian irrigation systems lead to greater benefits as compared to costs. The excess benefit (compared to costs) is realized more with drip followed by sprinkling and the third being California irrigation system.

iv) The cost of seeds, fertilizers and labour were significant at 5% level indicating that greater use of these inputs significantly results to higher production. About 1.4 percent variations in output among the irrigation systems was due to the differences in technical efficiency. With respect to the vegetable production of potatoes, shallots and tomatoes, this study noted that the pure technical efficiency scores are highest in drip irrigation, followed by sprinkling irrigation and lowest in Californian irrigation system. Drip irrigation was most efficient in production of tomatoes, followed by shallots and least efficient in production of potatoes. Sprinkling irrigation technology was most efficient on production of potatoes, followed by shallots and least efficient in tomatoes. Californian irrigation technology was most efficient on production of shallots, followed by potatoes and then tomatoes.

5.3 Recommendations

In view of the findings and the conclusion drawn above, this study makes the following recommendations:

i) The government should implement measures to ensure gender balance in economic activities. Involvement of both men and women in economic activities is the key to successful agriculture. The exclusion of women in decision making often delays delivery of benefits from agriculture. Since farming is popular among the young and middle aged persons, use of ICT in delivery of extension services is important. The lack of adequate formal education necessary for better modern farming should be compensated by increased trainings and extension service provision. Owing to limited land holdings, the government and development agencies should strive to strengthen irrigation farming (through subsidies, tax holidays and grants) in the study area. These benefits can be easily harnessed through farmers' membership to water management associations. For greater adoption of irrigation farming in the study area, government subsidy on equipment costs, capacity building/trainings, rational choice of equipment, high reliance on ground-dug water, use of equipment with low cost on maintenance and support of irrigation that rely on gravity force is key.

ii) More training and capacity building should be channeled to the farmers in the study area with an aim of reducing their levels of inefficiencies in horticultural crop production. There exists greater room for efficiency improvement in drip, sprinkling and Californian irrigation systems.

iii) Farmers should be supported to adopt the use of drip, sprinkling and Californian irrigation systems which lead to greater benefits as compared to costs. The use of drip, sprinkling and California irrigation systems can turn around the profitability status of most farmers in their vegetable production.

iv) Drip, sprinkling Californian irrigation systems presents a good opportunity for superior technical efficiency in vegetable production. These irrigation technologies should be promoted. Drip irrigation should be promoted more in production of tomatoes and shallots as compared to potatoes while sprinkling irrigation technology should be promoted more on production of potatoes and shallots as compared to tomatoes. Californian irrigation technology should be promoted more on production of shallots and potatoes as compared to tomatoes.

5.4 Policy Implication

The above results have important policy implications. Based on the findings of this study the following policy implications were drawn:

i) Policies meant in ensuring gender inclusiveness in agricultural economic activities are the key to successful agriculture. Young and middle aged persons who wish to embrace irrigation farming should be supported with business ideas as well as tax incentives. Persons who chose to undertake technical and academic agricultural courses in tertiary institutions should further be encouraged through a suitable government support. Owing to limited land holdings, the government and development agencies should strive to strengthen irrigation farming (through subsidies, tax holidays and grants). These benefits can be easily harnessed through farmers' membership to water management associations.

ii) Investing in trainings and capacity building was found as reasonable policy instrument in improving reducing their levels of efficiencies in horticultural crop production. Although complementary measures such as extension services, access to credit must also be present. Farmers should be trained regularly on good farming practices in addition to irrigation systems so that they can see its benefit and even practice the technology more efficiently. Farmers should be trained on best irrigation practices to ensure that they make informed decision on their horticultural crops farming. The government should ensure that farmers access extension services regularly. More extension officers need to be employed to reach more farmers and to do more follow-ups on farmers.

iii) In order to encourage the use of drip, sprinkling and Californian irrigation technologies in horticultural farming government can make use tax holidays and subsidies. Subsidies can be a good mechanism to ensure the country achieves increased use of irrigation technologies that lead to greater benefits than costs. Smallholder farmers may be supplied with subsidized irrigation materials. The government should facilitate the development of market systems that improve linkages between smallholder farmers (producers) and irrigation input sellers as well as finance, insurance, and technology providers in high the study area. There is need for support of expansion of small scale irrigation input systems to ensure uninterrupted supply of improved inputs for use in drip, sprinkling and Californian irrigation technologies.

iv) Drip, sprinkling Californian irrigation systems presents a good opportunity for superior technical efficiency in particular vegetable crops. Subsidized irrigation materials as well as grants could be channeled towards stable and registered horticultural farmers groups with an intention of supporting drip irrigation on tomatoes and shallots production groups. Sprinkling irrigation technology could best be promoted among potatoes and shallots production groups. Californian irrigation technology should be promoted more on shallots and potatoes production groups.

5.5 Suggestions for Further Research

The findings of this study would act as a base for more research on economic evaluation of irrigation systems used in vegetable production in Koulikoro and Mopti Regions of Mali. This study was not exhaustive and suggests further research as follows:

i) A similar study involving a larger sample size.

ii) Economic evaluation of irrigation systems use in crops other than tomatoes, potatoes and shallots vegetables in Koulikoro and Mopti Regions of Mali

iii) To determine the economic viability of the alternative small scale irrigation systems using pay-back-period.

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APPENDICES

APPENDIX 1: HOUSEHOLD QUESTIONNAIRE

Introduction

HALLO, my name is ______________________________ and I am part of a research team from Egerton University and other institutions (IER, BHEARD) conducting a survey on assessing the economic efficiency of IRRIGATION SYSTEMS on smallholder farm households. You have been randomly chosen to participate in this study. You are therefore requested to provide the researcher with accurate information being sought in this questionnaire. Your participation is VOLUNTARY and you are also assured that the information you provide will be treated with CONFIDENTIALITY and used for the sole purpose of research. Your support to the researcher by participating in this interview is highly appreciated. For more information or clarification you can contact the scientific coordinator of IER through the following address: ______________, Irrigation/SPGRN Project Coordinator, Rural Economic Institute, PO Box 236, Bamako. Cell phone: +223____.

Section A: General Information

1. Date of interview [______________________________]
2. Name of enumerator [______________________________]
3. Name of Respondent (optional [______________________________]
4. District/Region [______________________________]
5. Division [______________________________]
6. Location [______________________________]
7. Village [______________________________]
8. Household location (GPS Readings) Northings____________Eastings___________

Section B: Household Characteristics

9. Full Name of the Head of Household: ____________________________________

10. Sex of the Head of the household: 1. Male [ ] 2. Female [ ]

11. Age of the Head of Household (Years) ____________

12. Level of education of the head of the household

   a. **Schooling years** **[ ]**

   b. **Highest level of education** **[……………………..]**

13. The main occupation of the household:

   a. Agriculture (crop and livestock) [ ]
   b. Agriculture (crop only) [ ]
   c. Agriculture (livestock only) [ ]
   d. Petty trading [ ]
   e. Paid employment (permanent) [ ]
   f. Paid employment (seasonal, daily labor) [ ]

14. The secondary occupation of the household

   a. Agriculture (crop and livestock) [ ]
   b. Agriculture (crop only) [ ]
   c. Agriculture (livestock only) [ ]
   d. Petty trading [ ]
   e. Paid employment (permanent) [ ]
   f. Paid employment (seasonal, daily labor) [ ]

15. Household Size (number of members residing in the farm): ……………

	Female (Numbers)	Male (Numbers)
Adults		
Children:		
✓ Age below 5 years	_________	_________
✓ Age 5 - 10 years	_________	_________

16. Number of household members who earn income from non-farming activities? [ ]

17. What type of residential house does the household own?

a. Iron-roofed and mud floor [ ]

b. Iron-roofed and cemented floor [ ]

c. Roof made of grass/other materials and cemented floor [ ]

d. Roof made of grass/other materials and cemented floor [ ]

e. Roof made of grass/other materials and mud floor [ ]

18. a. How much land does your household have access (in hectare)? ______________

NB: Indicate the following details on Household members (including HH head) who were home for at least one month within the last one year (Jan - Dec 2015)

House hold memb numb HMN	First Nam	Sex 1=Ma 0=Fen	Year of birth	Relationship to head 1=head 2=spouse 3=Child 4= Parent 5= Niece 6= Nephew 7= Worker 8= Grand child 9=Brother/sis.in 10=Bro./sis 11=Other	Num of mon livin at hom the 12 mon	Marital statu 1=Single 2=Monogam 3=Polygamo 4=Divorced 5=Windowe 6=Separated 7=Other	Educatior level Level of education 0= none 1= Prima 2=Second 3= Tertia college 4= Universit	Was tl person involv in any Incom earnin activit in the past 1 month 1 = Y 2 = N (got to next memb	If yes, Which Incom earnin activit (See Activi Code below)		Month involv in the activit in the 12 month		Monthly income from activity (Ksh)	
									IG	IG	IG	IGA	IGA	IG
1														
2														
3														
4														
5														
6														

Income generating activities : 1=Formal employment 2= Informal employment (farm) 3=

18. b. Type of wall for the house 1 = Mud, 2 = Wooden 3= Bricks 4 = Stone, wall________

18. c. Type of roof for the house 1 = Grass, 2 = iron-sheet, 3 = Tiles roof_______

18. d. Type of floor 1 = Earth 2 =Cemented 3 = Tiled? floor______

18.e. What is the Household Production System Characteristic?

e_1. Small scale [ ]

e_2. Land scale system [ ]

e_3. Intercropping [ ]

e_4. Integrated system (Crops production and Livestock) [ ]

Section C: Irrigation Systems / Access and Property right of Irrigation Water (PRIW)

19. Do you use irrigation for crop production? 1. Yes 2. No.

20. What source (s) of water do you use for irrigation?

    a. River (diversion)

    b. Dug well

    c. Dam

21. Which type of irrigation systems do you use and on which crops?

Types /Irrigation Systems	**Crops and Irrigate Area (ha)**									
	Potato		Shallot/Onion		Tomato		Others		Others	
	P	R	P	R	P	R	P	R	P	R
a. Drip										
b. Sprinkling										
c. Californian										
Others:										
d. Canal										
e. Manual										
f.										

Types/Irrigation Systems (IS)	J	F	M	A	M	J	J	A	S	O	N	D	Rank
a. Drip													
b. Sprinkling													
c. Californian													
Others:													
d. Canal													
e. Manual													
f.													
Rank IS (by order): 1, 2, 3,………………, 6													

23. How do you access irrigation water (Cross X on the blank space)

a. My own private

b. Membership in a group

c. Free /communal access

d. Through payment of money to others

e. Other means (specify): ………………………………………

24. Are you a member of Water Users Association (WUA)?

a) 1=Yes [ ]

b) 2=No [ ]

c) There is no WUA [ ]

25 Cost of Water and Irrigation Systems

25.1. Drip Irrigation System on Tomato Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.2. **Drip** Irrigation System in **Potato** Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.3. **Drip** Irrigation System in **Shallot** Production

Designation	**Quantity**	**Cost Unit**	**Total Cost (f. CFA)**
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.4. **Sprinkling System on Tomato** Production

Designation	**Quantity**	**Cost Unit**	**Total Cost (f. CFA)**
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.5. Sprinkling System in Potato Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.6. Sprinkling System in Shallot Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.7. Californian System on Tomato Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.8. Californian System in Potato Production

Designation	Quantity	Cost Unit	Total Cost (f. CFA)
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

25.9. **Californian** System in **Shallot** Production

Designation	**Quantity**	**Cost Unit**	**Total Cost (f. CFA)**
Land preparation			
Materials/Equipment			
Installation			
Maintenance			
Energy:			
Gasoline powered pumps			
Kerosene powered pumps			
Lubricating Oil			
Depreciation (Duration)			
Water pumped (m^3/ha)			

Section D: Farm Labour

26. Please tell us about the labour allocated farming activities in your farm for the past 1 year (Jan – Dec 2015). Include enterprises, livestock as well as farming

a) Labour allocated to the field in the past season

Activity (use codes below)	Type of labour 1=Family 2=Casual 3=Permanent worker 4=Gang labour	Men involved			Women involved				Children involved	
		No. of men	No. of days	Hours pday	No. of women	No of days	Hours pday	No. of children	No of days	Hours pday
Activity	ltype		daymn	Hpday		Daywm	hpday		daych	hpdayc

Activity type: 1=land preparation 2=Weeding 3=planting 4= spraying 5=mulching 6= compost preparation 7=manure application 8=collection of farm yard manure 9= harvesting 10 = shelling 11=threshing 12= packaging 13=Grading 14=processing 15=Other (specify) ________________

a. What is the average daily wage for casual farm work in the area? (F. CFA) wage____________________

b. In case you have a salaried farm worker, how much do you pay per month (F. CFA) salary____________________

Section E: Access to Institutional Support, Information, Education and Training

27. During the last cropping year, what was your experience with agricultural extension service providers?

a) No contact with extension people at all [ ]
b) Visited by extension workers [ ]
c) I visited the extension workers office [ ]

28. During the last cropping year did you participate in any farmers training program?

a. 1=Yes [ ]
b. 2=No [ ]
c. 3=There was no training program in our area [ ]
d. If YES, what was/were the topic (s) of the farmers training you participate in
e. About crop production [ ]
f. About livestock production [ ]
g. About irrigation management [ ]
h. About soil and water conservation [ ]
i. About agricultural marketing [ ]
j. About crop protection [ ]
k. About post-harvest and storage [ ]
l. Other (specify): ....

30How much is the usefulness of the training (s) for your farming activities?

a. Very useful [ ]
b. Somehow useful [ ]
c. Low use [ ]
d. Not useful [ ]
e. I have not evaluated it yet [ ]

31During the last cropping year did you visit any extension demonstration site?

f. 1=Yes [ ]
g. 2=No [ ]
h. There is no extension demonstration site in our area [ ]

32Do you get useful information related to agricultural production and marketing from the following sources?

	Yes	No	No such information
Radio			
Television			
Newspapers			
Market places			
Others farmers			

33Please indicate the following details on road conditions in the region

	Distance for all weather portion (Kms)	Distance for tamarked portion (Kms)	Fare (Kshs)
Nearest shopping centre			
Nearest urban Centre			

34Frequency of extension provider per month in the last year (fill in the details in the table below):

Extension services offered (see codes below)	Extension Provider (see codes below)	Number of times (past 1 year)	Did you pay? 1=yes 2=no	Cost per each time

Extension Services codes: 1=crop production 2=livestock

Extension service provider: 1=Government extension workers 2=private extension providers 3= NGOs/development agencies 4=Other farmers 5=University 6 = Private Company 7= Other (specify)_______________

35.1. Has anyone in the household attended a farmer training last year?

1= yes 2= no train_____

35.2. If yes, how many times

train number____

35.3. What was the training about?

train 1_____ train 2_______ train 3______

1=soil erosion 2=fertilizer use 3=tree planting 4=irrigation systems 5=water management 6=other (specify)____________________

Section G: Credit Access and Group Membership

36. Did the household try to access credit last year 1=yes 2=no

37.1. If yes, fill in the table below:

Credit source	Granted? 1=yes 2=no	Credit type 1=Money 2=In kind	Amount of credit requested	What was purpose of credit?	Repayment period	Interest rate	If not granted, give reasons

Source codes: 1= Commercial bank 2= AFC 3=Cooperative 4= MFI 5=Input store 6=Local money lender 7=Other (specify)________

Purpose codes: 1=school fees 2= business capital 3= household consumption 4=farm inputs (crops) 5 hospital 6= medication 7=biogas plant 8=livestock 9=other (specify)_______________

Not granted reasons codes: 1= lack of security 2= had outstanding loan 3=lack of enough savings 4=defaulted previously 5= other (specify)

Repayment period codes: 1=weekly 2=monthly 3=fortnightly 4=quarterly 5=annually 6=semiannually 7=other (specify)_____________

37.2. Is anybody in the household a member of a group? 1=yes 2=no

Groupment_________

37.3. If yes, fill the details in the table

Group type	No. of female members	No. of male members	Year started	Group activities	Meetings per month	Savings per month	Required Collateral for loans

Group types: 1=Self Help group 2= Welfare group 3=Cooperative Society 4= Other (Specify) __

Group activities: 1=Farming 2=Business 3=HIV/AIDS 4=Advocacy 5= Other (specify)______

38. Please indicate details on **other sources of income** for the household

Type of earning	No. of months earned income	Av. monthly income
Transfer earnings from relatives		
Value of gifts received		
Income from Land rented out		
Income from buildings rented out		
Income from other structures rented out		
Motor vehicle rented out income		
Other income		

APPENDIX II: METHODOLOGY FOR COMPUTING B.C. RATIO

		B.C.Ratio			(fCFA. In Mali)		
					Pre project		Post-project
A		Gross receipts					
	1	Gross value of farm produce					
	2	Dung receipt(30% of B6)					
	3	Total (A) gross receipts					
B		Expenses					
	1	Expenditure on seeds					
	2	Expenditure on manure					
	3	Expenditure on fertilizers					
	4	Expenditure on pesticides					
	5	Expenditure on hired labour					
	6	Fodder expenses (15% for pre and 10% for post project of A1)					
	7	Depreciation (2.7% of A1)					
	8	Share and cash rent(5% for pre and 3% for post project of A1)					
	9	Land revenue (2% of A1)					
		Total (B) expenses					
C		Net value of farm produce					
	1	Total gross receipts					
	2	Total expenses					
		Net value (1-2)					
D		Annual benefits					
	1	Net value of produce after project					

	2	Net value of produce before project					
	3	Annual benefits (1-2)					
		Cost of the project					
	(a)	Capital cost (After apportionment)					
	(b)	Cost of land development @ 150000 f. CFA per ha of CCA -		ha			
		Total					
E		Annual cost					
	1	Interest on total cost					
	2	Depreciation of the project @ 1 % of the capital cost					
	3	O & M charges @ 50000 f. CFA per Ha on		ha			
	4	Maintenance of head works @ 1% of the cost of head works of lac f. CFA.					
	5	Total annual cost					
		B. C. ratio (D3/E5)					

Estimated value of Produce and cost of inputs before Irrigation

Cost of inputs

S. No.	Crops	Area (ha)	Cost of inputs per hectare						Total cost in fCFA.
			Seed	Manure	Fertilizers	Pesticides	Labour	Total	
	Tomato								
1									
2									
3									
	Potato								
1									
2									
3									
	Shallot								
1									
2									
3									
	Total								

Estimated value of Produce (Output) before Irrigation

S.No.	Crops	Area (ha)	Yield (Qtls./ha)	Rate Rs./Qtl.		Receipt (fCFA.)		Total Value of Produce (fCFA.)
				Levy	Market	Levy	Market	
	Tomato							
1								
2								
3								
	Potato							
1								
2								
3								
	Shallot							
1								
2								
3								

Total

Estimated value of Produce and cost of inputs after Irrigation

Cost of inputs

S. No.	Crops	Area (ha)	Cost of inputs per hectare						Total cost in fCFA.
			Seed	Manure	Fertilizers	Pesticides	Labour	Total	
	Tomato								
1									
2									
3									
	Potato								
1									
2									
3									
	Shallot								
1									
2									
3									
	Total								

Estimated value of Produce (Output) after Irrigation

S.No.	Crops	Area (ha)	Yield (Qtls./ha)	Rate Rs./Qtl.		Receipt (fCFA.)		Total Value of Produce (fCFA.)
				Levy	Market	Levy	Market	
	Tomato							
1								
2								
3								
	Potato							
1								
2								
3								
	Shallot							
1								
2								
3								
	Total							

APPENDIX III: LIST OF INTERNATIONAL CONFERENCES PRESENTATIONS

Kane, A.M., Lagat, J.K., Langat, J.K., Teme, B. and Quresh, A.S. (2018). Economic efficiency of water use in the small scale irrigation systems used in vegetables Enterprise production in Koulikoro and Mopti regions, Mali. *Eldoret National Polytechnic 8th CIRIS International Conference, 27th – 29th March 2018. Main Campus, Eldoret, Kenya. pp 60*

Kane, A. M., Lagat, J. K., Langat, J. K. and Teme, B. (2018). Economic Evaluation of Alternative Small-Scale Irrigation Systems used in Vegetables Production in Koulikoro and Mopti regions, Mali. *Egerton University 12th International Conference, 27th – 29th March 2018. FEDCOS Complex, Njoro Campus, Kenya. pp 97*

Kane, A. M., Lagat, J. K., Langat, J. K. and Teme, B. (2018). Economic Viability of Alternative Small Scale Irrigation Systems used in Vegetables Production in Koulikoro and Mopti Regions, Mali. *Strathmore Business School 12th International "Symposium on Climate Change and Droughts Resilience in Africa", 27th – 29th March 2018. FEDCOS Complex, Njoro Campus. Kenya.*

Kane, A. M. (2017). Enhancing Vegetables Nutrition, Soil and Water Management and Economics use in Drip Irrigation System in Koulikoro and Mopti regions, Mali. *BHEARD 2nd Regional Conference, 2nd – 8th July 2017. Elementaita, Kenya.*

Kane, A. M. (2017). Scaling up Small scale irrigation technologies for improving Food Security in Sub-Saharan Africa: case in Mali. *International Center of Agricultural Biosaline (ICBA)/ISRA, Annual International Conference, Small scale irrigation technologies – challenges and prospects 27th – 29th March 2018. Fleur de Lyle, Dakar. Senegal.*

Kane, A. M., Lagat, J. K., Langat, J. K., Sijali, V.I. and Teme, B. (2017). Characterization of Small-Scale Irrigation's Technologies: Case of Californian System used in Vegetables Production in Koulikoro and Mopti Regions, Mali. *Egerton University 11th International Conference and Innovation Week, on Knowledge and Innovation for Social and Economic Development 29th – 31st March 2017. FEDCOS Complex, Njoro Campus. Kenya. pp 05*

Kane, A. M., Lagat, J. K., Langat, J. K., Dembélé, D., Teme, B.and Sijali, V.I. (2015). Integrated Crop and Seed Production Systems under Water/Irrigation Management In Sub-Saharan Africa: Case Study in Mali. *Manchester Metropolitan University, Climate Service and ICCIP World Symposium on Climate Change Adaptation Manchester, UK, 02nd -04th September 2015 United Kingdome UK. pp*

Kane, A. M., Lagat, J. K., Langat, J. K. and Teme, B. (2015). Technical Efficiency and Its Determinants II in Sub-Saharan Africa's Rice Production: Mali Case Study. *Egerton University 10th International Conference Research and Innovation for the Advancement of Humanity 30th March – 1st April 2015. FEDCOS Complex, Njoro Campus. Kenya. pp*

APPENDIX IV: LIST OF RELEVANT PUBLICATIONS

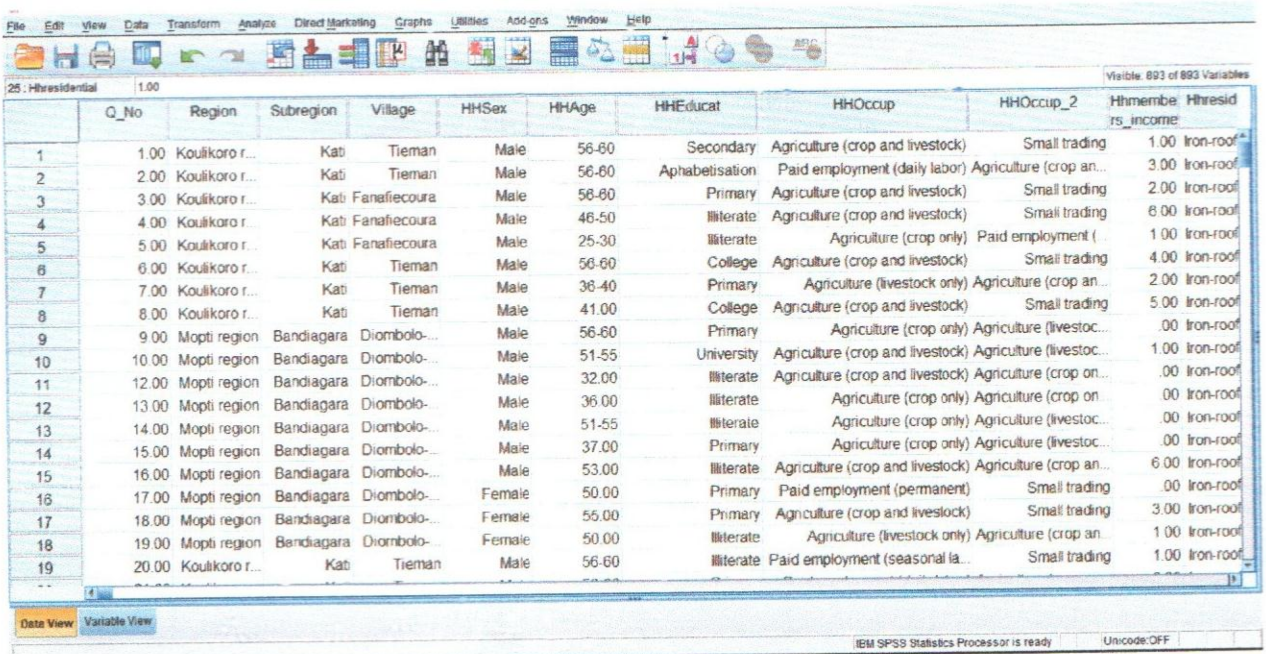
Kane, A.M., Lagat, J. K., Langat, J. K. and Teme, B. (2017). Economic Viability of Alternative Small Scale Irrigation Systems used in Vegetables Production in Koulikoro and Mopti Regions, Mali. *Springer journals*. Available online at https://meteor.springer.com (Accepted on 07th January, 2018; under publication).

Kane, A. M., Lagat, J. K., Langat, J. K. and Teme, B. (2018). Economic efficiency of water use in the small scale irrigation systems used in vegetables production in Koulikoro and Mopti regions, Mali. *Advances in Agricultural Science journal (AAS)* (Accepted on 30th May, 2018; under review).

Paschal A. M., Fiona M., **Kane, A. M.**, Ngibuini, H. M. (2017). An Assessment of Early Warning Systems to Drought Resilience among Agricultural Communities in Tanzania, Kenya and Mali. *Elsevier journals*, (Contribution to a Book chapter: Handbook of Climate Change Resilience) (Accepted on 30th April, 2018; under review).

Kane, A. M., Lagat, J. K., Langat, J. K. and Teme, B. (2018). Technical efficiency of small scale vegetables production under different irrigation systems in Koulikoro and Mopti regions, Mali. *American Journal of Agricultural and Forestry* (Paper Number: 2321083, Accepted on 03th June, 2018; under publication)

APPENDIX V: ADDITIONAL ANALYSIS RESULTS



	Q_No	Region	Subregion	Village	HHSex	HHAge	HHEducat	HHOccup	HHOccup_2	Hhmembers_income	Hhresid
1	1.00	Koulikoro r...	Kati	Tieman	Male	56-60	Secondary	Agriculture (crop and livestock)	Small trading	1.00	Iron-roof
2	2.00	Koulikoro r...	Kati	Tieman	Male	56-60	Aphabetisation	Paid employment (daily labor)	Agriculture (crop an...	3.00	Iron-roof
3	3.00	Koulikoro r...	Kati	Fanafiecoura	Male	56-60	Primary	Agriculture (crop and livestock)	Small trading	2.00	Iron-roof
4	4.00	Koulikoro r...	Kati	Fanafiecoura	Male	46-50	Illiterate	Agriculture (crop and livestock)	Small trading	6.00	Iron-roof
5	5.00	Koulikoro r...	Kati	Fanafiecoura	Male	25-30	Illiterate	Agriculture (crop only)	Paid employment (...	1.00	Iron-roof
6	6.00	Koulikoro r...	Kati	Tieman	Male	56-60	College	Agriculture (crop and livestock)	Small trading	4.00	Iron-roof
7	7.00	Koulikoro r...	Kati	Tieman	Male	36-40	Primary	Agriculture (livestock only)	Agriculture (crop an...	2.00	Iron-roof
8	8.00	Koulikoro r...	Kati	Tieman	Male	41.00	College	Agriculture (crop and livestock)	Small trading	5.00	Iron-roof
9	9.00	Mopti region	Bandiagara	Diombolo-...	Male	56-60	Primary	Agriculture (crop only)	Agriculture (livestoc...	.00	Iron-roof
10	10.00	Mopti region	Bandiagara	Diombolo-...	Male	51-55	University	Agriculture (crop and livestock)	Agriculture (livestoc...	1.00	Iron-roof
11	12.00	Mopti region	Bandiagara	Diombolo-...	Male	32.00	Illiterate	Agriculture (crop and livestock)	Agriculture (crop on...	.00	Iron-roof
12	13.00	Mopti region	Bandiagara	Diombolo-...	Male	36.00	Illiterate	Agriculture (crop only)	Agriculture (crop on...	.00	Iron-roof
13	14.00	Mopti region	Bandiagara	Diombolo-...	Male	51-55	Illiterate	Agriculture (crop only)	Agriculture (livestoc...	.00	Iron-roof
14	15.00	Mopti region	Bandiagara	Diombolo-...	Male	37.00	Primary	Agriculture (crop only)	Agriculture (livestoc...	.00	Iron-roof
15	16.00	Mopti region	Bandiagara	Diombolo-...	Male	53.00	Illiterate	Agriculture (crop and livestock)	Agriculture (crop an...	6.00	Iron-roof
16	17.00	Mopti region	Bandiagara	Diombolo-...	Female	50.00	Primary	Paid employment (permanent)	Small trading	.00	Iron-roof
17	18.00	Mopti region	Bandiagara	Diombolo-...	Female	55.00	Primary	Agriculture (crop and livestock)	Small trading	3.00	Iron-roof
18	19.00	Mopti region	Bandiagara	Diombolo-...	Female	50.00	Illiterate	Agriculture (livestock only)	Agriculture (crop an...	1.00	Iron-roof
19	20.00	Koulikoro r...	Kati	Tieman	Male	56-60	Illiterate	Paid employment (seasonal la...	Small trading	1.00	Iron-roof

Figure A: A screenshot of the analysis data

Table A: Mode of access of irrigation water

Mode of access of irrigation water	Frequency	Percent
Private means (own water sources)	169	62.6
Free (communal access)	83	30.7
Purchasing from water vendors	13	4.8
Membership in a group	5	1.9
Total	**270**	**100.0**

Table B: Membership to water management association

Membership status	Frequency	Percent
Yes	108	40.0
No	162	60.0
Total	**270**	**100.0**

Table C: Functionality of the Water Management Association (CGB)

Response	Frequency	Percent
Yes	45	16.7
No	13	4.8
Don't know	212	78.5
Total	**270**	**100.0**

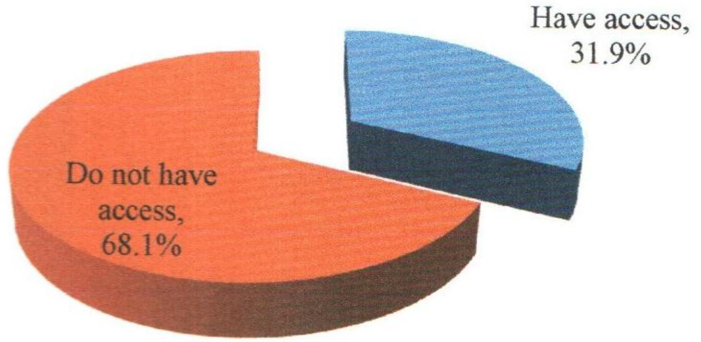


Figure B: Respondent's access to extension services

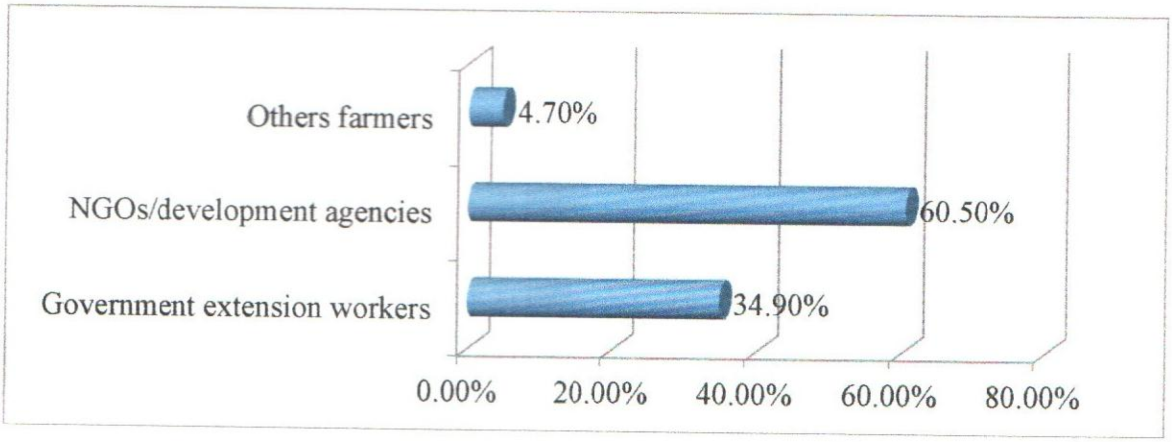
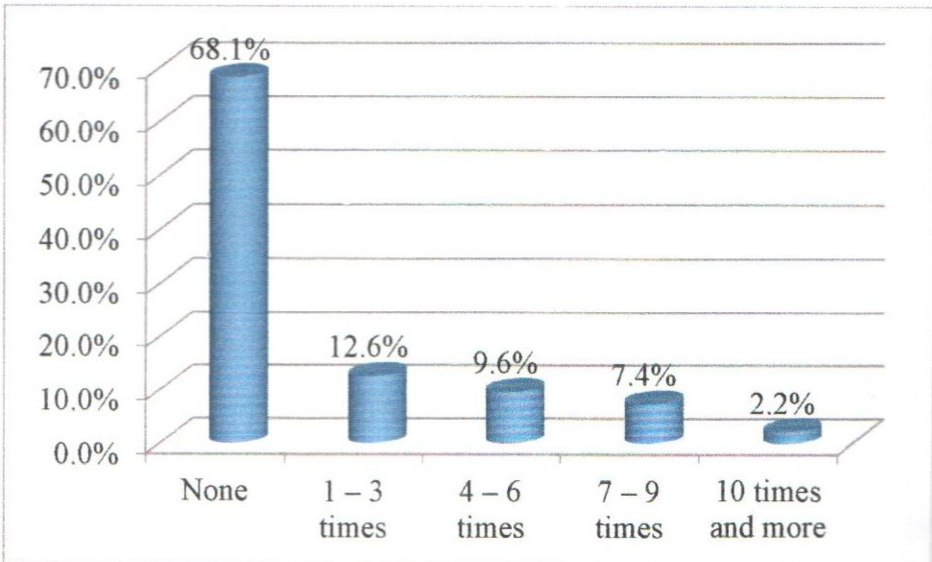


Figure C: Farmers' extension providers in vegetable production



Minimum = 0, Maximum = 13, Mean = 2.423, Standard Deviation = 1.18

Figure D: Frequency of extension providers visits to the respondents

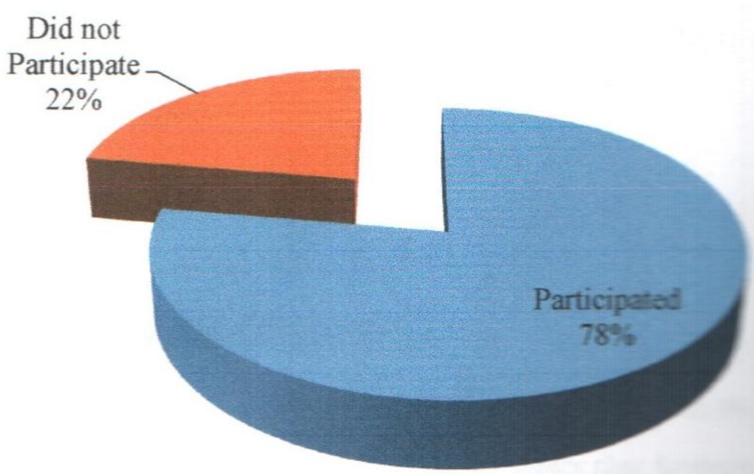


Figure E: Farmers participation in irrigation training programmes (last cropping year)

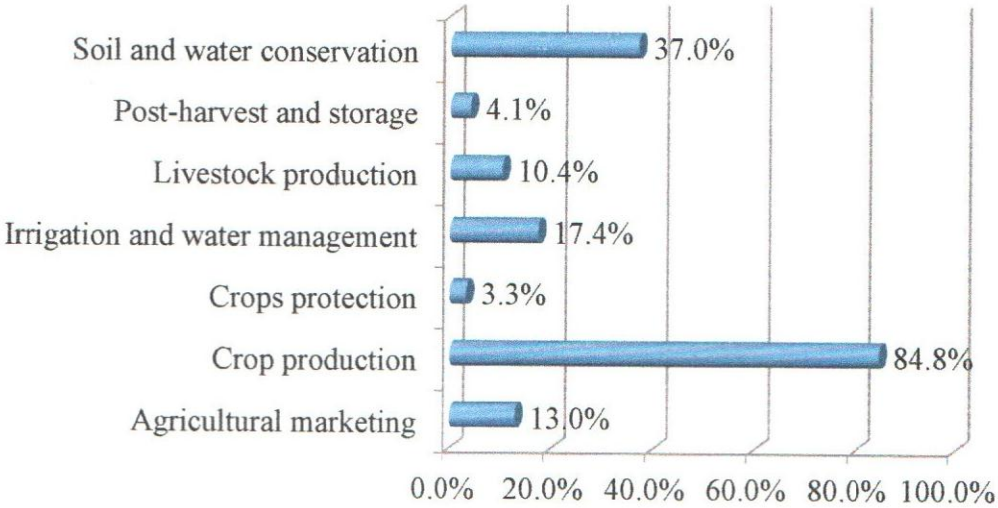


Figure F: Topics accessed during farmers training

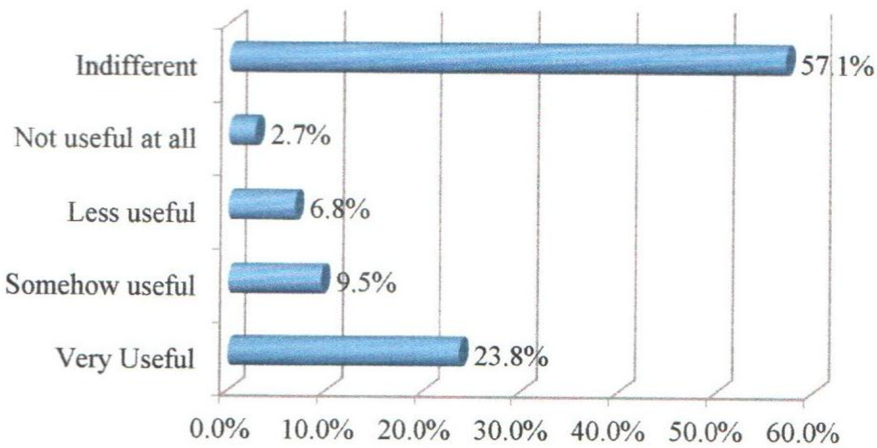


Figure G: Usefulness of the training topics that farmers received

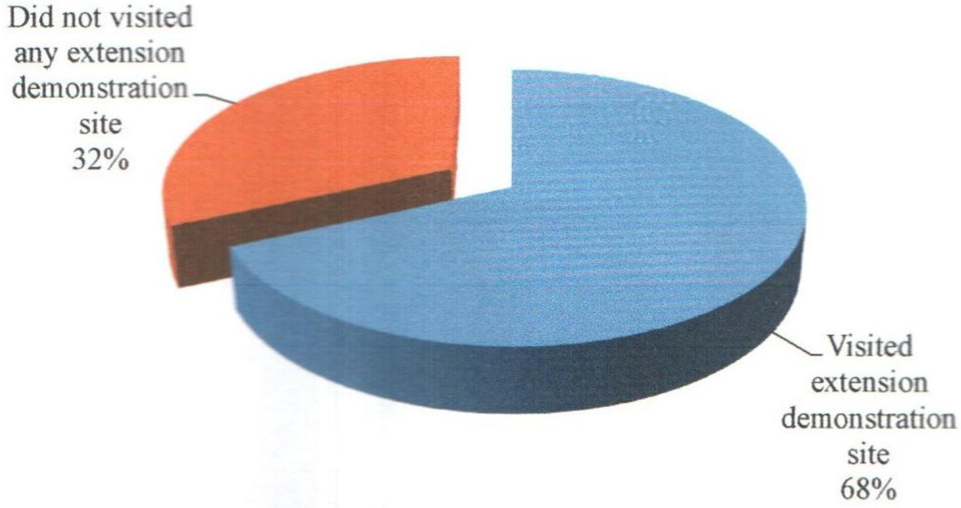


Figure H: Farmers' visit of extension demonstration site

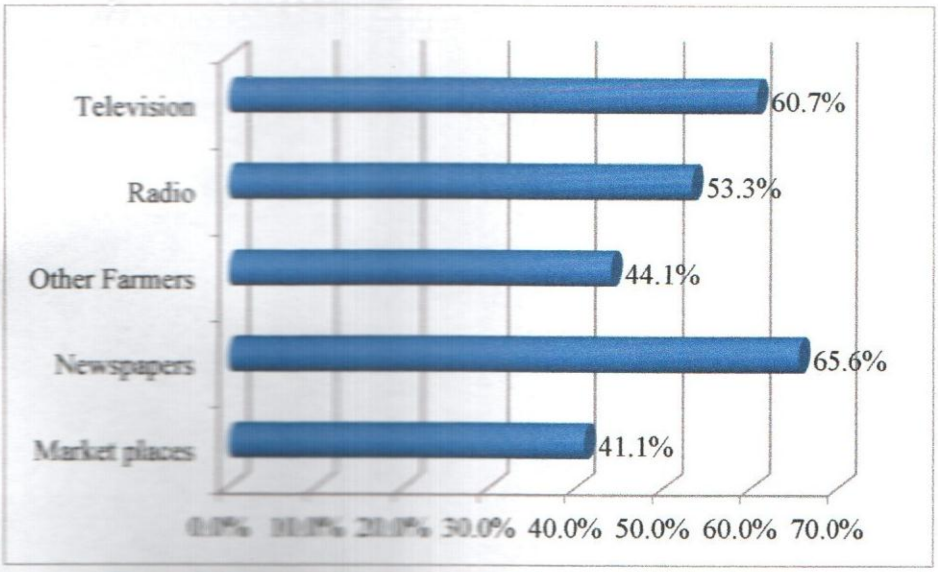


Figure I: Farmers' sources of agricultural information

Table D: Farmers' perception on road conditions in the region

Centre	All weather portion	Tarmacked portion	Fare (Kshs)
Nearest shopping centre	6.23 (6.56)	15.47 (16.10)	800.57 (93.35)
Nearest urban Centre	8.06 (10.32)	19.97 (9.98)	505.56 (47.88)