School of Management
Curtin Business School

Effect of Type of Irrigation System on Productivity and Income of Date Palm Growers in Sebha, Libya

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This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

February 2016

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number HR 76/2013

Signature:

Date: 29/02/2016

List of Publication from the Thesis

- Aridah, A., Rola-Rubzen, M.F. and Singh, Z. 2015, ***Effects of Irrigation Systems on Productivity of Date Palm in Sebha Region, Libya***, Presented at the Curtin Business School Doctoral Colloquium, 31 August - 1 September, Perth, Australia.

- Aridah, A., Rola-Rubzen, M.F. and Singh, Z. 2015, ***Characteristics of Date Palm Farming Systems under Different Types of Irrigation Systems in Sebha Region, Libya*** Presented at the Curtin Business School Doctoral Colloquium, 31 August - 1 September, Perth, Australia.

- Aridah, A., Singh, Z. and Rola-Rubzen, M.F. 2015, ***Effects of Irrigation Systems on Physical Characteristics of 'Talees' Dates in Different Locations in Sebha, Libya***. Presented at the International Conference on Sustainable Water Management, 29 November – 3 December, Perth, Australia.

- Aridah, A., Singh, Z. and Rola-Rubzen, M.F. 2015, ***Irrigation Systems and Growing Locations in Sebha Region, Libya Do Not Affect Chemical Characteristics of 'Talees' Dates***. Presented at the Inaugural CUPSA Conference. 2 – 3 September, Perth, Australia.

Abstract

Worldwide, there is an increasing urgency to achieve more efficient use of water resources and improving crop productivity. Libyan agriculture and food production is putting increased pressure on the country's limited water resources. The need for efficient irrigation systems and techniques has assumed greater importance for incremental increases in crop production in Libya. Date palms represent an important economic crop in Libya since they contribute to the agriculture industry, foreign exchange earnings, farmers' income and employment. However, the date palm industry relies on large amounts of water for growing the crop. Farmers use a variety of irrigation systems, and water of differing quality and quantity, which affects productivity, and the physical and chemical characteristics of the dates cultivated and, therefore, the income generated by farmers.

This study examined three irrigation systems used by date palm producers in South Libya using data from a sample of 210 farmers from four major areas in Sebha, South Libya - Tamanhant, Samnu, Al-zighan and Ghodduwa. Effects of different types of irrigation systems on fruit quality of common cultivar 'Talees' date were investigated. The study also analysed the economics of date palm production under different types of irrigation systems, assessing the pros and cons of different types of irrigation systems for date palm production. Finally, the study examined the determinants of date production, particularly, looking at whether the type of irrigation system influences productivity and hence, income, of farmers.

Two methods were used to collect the data. Firstly, a survey of 210 farms was conducted using a structured questionnaire. The study employed different models to evaluate the relationship between irrigation systems and other determinant factors affecting productivity and efficiency. Stochastic frontier production analysis and OLS multiple regressions were run using Frontier 4.1, SPSS and STATA. The second method involved experiments using a set of date fruit samples from Sebha region. The experimental data were analysed using two-way analysis of variance (ANOVA) using GenStat14.

The findings revealed that various variables have substantial impacts on date palm production under three different irrigation systems. The results showed that number of trees, amount of water, sprinkler irrigation and human labour are significantly and positively related to palm productivity. On the other hand, type of soil, drip irrigation, manure and family member square are negatively related to productivity. The analysis showed that the type of irrigation system has a significant effect on productivity, with the sprinkler irrigation system having a higher effect on palm production compared to surface irrigation; however surface irrigation system has a higher effect on the palm production compared to drip irrigation. In addition, the type of soil has a significant effect on productivity under, and productivity of farms under clay soil is higher compared to those under fine, medium and silt soils.

The date palm farm productivity analysis found significant variations in the technical efficiency under irrigation methods in study area. There are still significant numbers of inefficient date palm farmers; this means there is still some scope for improvement. The level of education, coarse soil and distance between trees were found to significantly affect farm-specific technical efficiency suggesting that increasing the level of education for young farmers by formal or informal training generally, and in date palm farming, new technology and irrigation practices, more specifically, would improve the productivity of farms in the area.

Findings also showed that the irrigation method significantly affected only fruit weight whilst fruit breadth and length, pulp thickness, stone weight, stone width and stone length, individual sugars and organic acids were not significantly affected by irrigation methods. When the average of different irrigation methods were taken, the mean fruit weight, breadth and length, pulp thickness, stone breadth and length were found to be significantly different by location. Moreover, the interactions between different irrigation methods and locations were found to be significant ($p \leq 0.05$) for fruit weight, breadth and length, pulp thickness, stone breadth and length.

The study provided valuable information on the factors influencing the production of date palms, which will be beneficial in improving the agricultural sector in Libya. The findings also brought to light new information on the efficiency of key irrigation systems used by farmers in South Libya and provided information on the type of irrigation system that is most effective in improving productivity. These information can help local farmers in investing in the right type of irrigation system and on improving their productivity and income.

Acknowledgment

I am thankful to Allah Almighty, without his support it was impossible to complete my PhD thesis.

I am very grateful to my supervisor, Associate Professor Fay Rola-Rubzen whose continued support and academic genius made it possible for me to learn and accomplish this thesis. My deepest appreciation to Professor Zora Singh, my co-supervisor, for his support and advice during my academic journey from beginning to the end of my research work. In addition, my special thanks goes to Professor Brian Hardaker (University of New England), Dr. Yuki Miyomoto, for their academic assistance and help; any research-related query or request, their responses were always immediate and overwhelming. Special thanks to Jenny, Dean, Desmond, Hafez, Jon Marx, and Abdallah for their wonderful assistance. I am also thankful to Ms. Susan Petersen, Mubarak Alrashedi (Department of Environment and Agriculture, Curtin University) and Dr Beng Chua (Manager, Life Sciences Research Facility) for the technical support and assistance during my laboratory work.

I am grateful to the Ministry of Higher Education of Libya and Libyan Cultural Affairs in Australia for providing me with the financial support during my studies.

My special thanks also goes to my wife for her support, cooperation and patience, in difficult times during my PhD studies. My special thanks to my sons (Abdularhman and Sanad) as well as my daughter (Raneem) for their love and interesting times.

I would like to thank my parents to whom I owe a great deal, Salaha Mohammed (May Allah have Marcy on her) and Mohammed Aridah. I thank them for showing me that the key to life is enjoyment, I am so happy their sacrifices did not get wasted. To my brothers and sister, their efforts were matchless and their sincerity, beyond a shadow of doubt. I am also thankful to all my relatives and friends for their good wishes.

Finally, I would like to thank all my colleagues and friends in Australia and Libya, with whom I shared study experiences. Many thanks to all date palm farmers in Al-zighan, Ghodduwa, Samnu and Tamanhant for providing experimental fruit for physical and chemical analysis and participated in the field surveys during my PhD studies in Libya.

Lastly, I would like to offer my regards and blessing to all of those who supported me in any respect during the completion of this work as well as expressing my apologies that I could not mention them personally one by one.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

°C= degree celcius

ANOVA= Analysis of variance

ARC= Agricultural Research Centre

BC= before Christ

C= ascorbic acid

CBL= Central Bank of Libya

CD= Cobb-Douglas

DAFF= Department of Agriculture, Fisheries and Forestry

DEA= Data Envelopment Analysis

DFAT= Department of Foreign Affairs and Trade

E=East

EU= European Union

FAO = United Nations Food and Agriculture Organization

FAOSTAT = the Statistics Division of FAO

FW= Fresh weight

GDP= Gross Domestic product

HPLC= High performance liquid chromatography

LD= Libyan Dinar

LEPC= Libyan Export Promotion Centre

LSD= Least significant different

mb/d = million barrels oil per day

MENA= Middle East and North Africa

Mg= magnesium

mgL-1 =milligrams per Litre

MRP= Made River Project

N= North / Nitrogen

n= Number of replication

NPV= net present value

NS= Not significant

OLS = Ordinary least squares

OPEC= Organization of the Petroleum Exporting Countries

P= Probability

PC= Pre-climacteric

pH = negative logarithm (base 10) of the activity of hydronium ions

Rmp= Rounds per minute

SD= Standard Deviation

SF= Stochastic Frontier

SP-36 = Superphosphate

SPSS= Statistical Package for the Social Science

TK= Bangladeshi Taka

TL= Transcendental logarithm

UAE = United Arab Emirates

UK = United Kingdom

UN= United Nations

USA = United States of America

μM= Micromolar (s)

Chapter 1
Introduction

1.1. Background

Dates (*Phoenix dactylifera L.*) are a fruit of considerable economic significance that grow in difficult environments around the world (Agoudjil et al., 2011). They belong to the Arecaceae family and are acknowledged as an important and economic resource of the family (Yang, Zhang, & Le, 2010). Dates are very high in nutritional value. They contain minerals, protein, fats, carbohydrates, vitamins and dietary fibers (Agoudjil et al., 2011). Date plants bear fruit usually three to four years after planting (Ali, 2010). The growth of date palms and their fruit may be divided into four stages. The first stage is the Altalaa' stage, which lasts three to five weeks. In this stage the dates are covered with glue and look very small. Primarily, the Kimri' stage is where the date is mostly characterized by green, hard and immature dates which are likely to ripen quickly (Al-Shahib & Marshall, 2003; Besri, 2010). The Khalal' stage is where the date colour changes first from green to yellow and then later changes to red which depends largely on the cultivar. Some consumers prefer to eat dates at this stage, especially in coastal areas in Libya (Al-Shahib & Marshall, 2003; Ashraf & Hamidi-Esfahani, 2011). The Rutab' stage is when the date begins to ripen and where the fruit changes to a dark colour or to black after two to four weeks. A 'Tamr' stage is where the dates are dried for market, but some varieties may not reach tamr stage (Al-Shahib & Marshall, 2003; Ashraf & Hamidi-Esfahani, 2011).

Dates are grown in more than 50 countries around the world especially, the Middle East and North Africa (Arab countries) which account for approximately 75 per cent of world production (El-Juhany, 2010). Dates are grown over an area of 1 059 608 m ha globally, with an annual production of 7 713 496 mt in the world (FAOSTAT, 2011). Presently, among different date producing countries, Egypt dominates date production with 18 per cent of the total production in the world, followed by Saudi Arabia, Iran, United Arab Emirates, Pakistan, Algeria and Iraq, which contribute about 14 per cent, 13 per cent, 10 per cent, 10 per cent, 9 per cent and 7 per cent, respectively (FAOSTAT, 2011).

In terms of exports and imports, the United Arab Emirates ranks first in the world in exporting dates (164 119.3 mt) worth US$ 41 855 m (FAOSTAT, 2011). Pakistan is the second major exporting country with an average value of about 89 956.17 US$ m followed by Tunisia, Algeria and France with date export values of US$ 121 million; US$ 17 372.8 and US$ 24 288.8 m, respectively. India, United Arab Emirates and the European Union together accounted for approximately 76.96 per cent of the major world date importing countries, with the total quantity of 234 108.9 mt (US$ 68 463.33 m), 76 888.33 mt (US$ 248 222 m) and 65 512.5 mt (US$ 145 468.3 m).

Edongali and Aboqilh (2005) noted that in Libya, palm trees can be found in the coastal areas and scattered oases providing an indication of the existence of groundwater in that region as farmers mainly depend on groundwater supply. The cultivation of date palm in a number of locations across the country is made possible because such crops can withstand difficult environmental conditions. According to the Food and Agriculture Organization (2010), the total production of dates in Libya between 2000 to 2010 was approximately 465 173 tonnes. The production of dates increased from 120 thousand tonnes in 2000 to 200 thousand tonnes in 2001, 2002 and 2003, respectively. In 2004, there was a decrease in date palm production and between 2004 and 2010, the numbers fluctuated between 150 thousand tonnes and 161 thousand tonnes (FAOSTAT, 2011).

It can be observed that the interior oases of Libya are where date palm trees are mostly planted as they are mostly tolerant of the harsh weather and environmental conditions. Date palm trees have the strength to withstand drought, salinity and high temperatures (Ali, 2010). However, water availability is critical to the date palm industry in Libya. As can be seen worldwide, a decrease in water availability has become a global challenge for both advanced and less developed economies. Domestic and agricultural activities rely on groundwater and surface water as the two sources constitute the major source of water supply (Calzadilla, Rehdanz, & Tol, 2010). Even though there are a number of countries experiencing dry summer periods due to serious drought, they do not have adequate strategies in place for management and maintenance of water sources; an example of this is Libya (Windust, 2003). The lack of rain and the lack of promising renewable water sources are likely to continue into the future. The consequences to the agricultural sector are imminent, thus, there is a need for alternative strategies to address these future challenges.

The agriculture sector worldwide is one of the largest water consumers. For instance, studies conducted by the Food and Agriculture Organization (Gruber, Kloos, & Schopp, 2009) show that agricultural activities use 70 per cent of the world's water resources compared to industrial and other economic activities. However, the Libyan agricultural sector contributes only 2.8 per cent of GDP though the various irrigation systems in the country but use about 80 per cent of the total water supply (FAO, 2011; Shaieb & Elzen, 2008). According to Diamond and White (2007), the agricultural sector contributes to the food security of most countries, but this comes at considerable environmental cost.

1.2. Research problem

The date palm production in Libya is a critical industry because it provides nutrition, income and links to traditional and historical values. Therefore, finding ways to increase date palm production through irrigation systems is of great importance. In South Libya (Sebha), surface irrigation systems have helped sustain production of date palms and other crops over the last century (Shaki & Adeloye, 2007). This traditional irrigation system has various problems, such as cracks in the channels leading to water leaks and the spread of weeds around date palms. This has resulted in poor water and nutrient uptake and reduced fruit yield (Sinai & Jain, 2005). To overcome these issues, private farms and government projects have introduced other irrigation systems such as sprinkler and drip irrigation in the Sebha region (Alghariani, 1994). Despite employing different systems of irrigation, date palm production and productivity has remained low (El-Juhany, 2010). There is also considerable depletion of groundwater in Sebha when compared to other provinces. This research will focus on analysing the effects of types of irrigation system on the production of date palms and a comparative economic analysis of different irrigation systems used in South Libya (Sebha). Given the issue of water scarcity, it is important to examine the comparative performance of various irrigation systems because water is a valuable commodity in Libya, a predominantly desert region.

1.3. Comparison of irrigation systems

There are different ways to irrigate mature date palms. These include flood, drip and sprinkler irrigation (Mumtaz & Prathapar, 2012). Previous studies have shown that the average water requirement for date palm is between 115 and 306 m^3 (Mumtaz & Prathapar, 2012). Saudi Arabia has the highest water usage for irrigation of date palm ranging from 150-350 m^3, followed by Libya and Oman (183-240 m^3), Morocco (105-200 m^3) , United Arab Emirates and Yemen (130-73 m^3). Egypt, Iran and Tunisia have a water usage for irrigation of date palm of about 86-124 m^3, 102-164 m^3 and 100 m^3 respectively.

According to FAO (2007), the productivity of date palm trees differs from one region to another. Productivity is widely calculated using yield average, which is measured in tonnes/ha and is then divided by the annual gross water use in m^3/ per annum; this produces the water value in kg/m^3 (FAO, 2007; Ludong, 2008). Egypt has the highest productivity in date palms (ranging from 2.28-3.31 kg/m^3 of water). This is much greater compared to Middle East countries and is followed by Tunisia (0.28 kg/m^3), Morocco (0.21-0.4 kg/m^3), Iran (0.21-0.34 kg/m^3), Saudi Arabia (0.15-0.37 kg/m^3), United Arab Emirates and Algeria (0.20-0.26 kg/m^3 and 0.14-0.67 kg/m^3 respectively). Libya, Oman and Yemen follow (about 0.15-0.21Kg/m^3 and 0.13-0.16 kg/m^3 respectively).

1.3.1. Approaches to irrigation technology in Libya

Irrigation is a basic requirement for successful cultivation of crops. The Libyan Government has invested a large amount of its budget to develop and improve irrigation systems and improve production of dates (Abdudayem & Scott, 2014; FAO, 2006). In Libya, 610 000 ha are irrigated by flooding (basin) and 199 200 ha rely on rainfall (FAO, 2007). There are several factors that affect the yield of date palms, including irrigation systems used, amount of pesticide, amount of fertilizer, number of employees and farmer experience (AbdulRazak, 2010; Benu, 2003; Shaloof & Areada, 2010). At the same time, irrigation systems are also affected by different factors, including the irrigation period, soil type, soil texture, plant type, evapo-transpiration rate, air temperature, relative humidity, cost and salinity (Cetin, Yazgan, & Tipi, 2004). The main types of irrigation systems employed in Libya are as follows.

1.3.1.1. Surface irrigation

Surface irrigation is the oldest and most commonly used system of irrigation for date palms (Larry & James, 1993). At least 40 centuries ago, farmers in Africa, Arabic countries, India and China used surface irrigation. In the United States, about two thirds of the 25 million ha of land is irrigated by surface irrigation (Larry & James, 1993). Globally, this is considered very high compared to other agricultural countries (Larry & James, 1993). Surface water sources available to farms in Libya include streams and basins. This has the advantage of low cost and is easy to use for farmers (Booher, 1974; Brouwer, 1988; Liebenberg & Zaid, 2002). There are three types of surface irrigation: Basin, Border or flood and Furrow irrigation.

Surface irrigation systems have almost similar advantages and disadvantages. They are used on many date palm farms, because of many benefits such as their suitability for dry climates. For example, in Libya, high water efficiency, uniform irrigation and a less expensive initial cost is typical especially in fairly flat areas (Al-Subaiee et al., 2013; Bekheet & El-Sharabasy, 2015; Mumtaz & Prathapar, 2012). Surface irrigation is controlled by farmers and does not need maintenance (Liebenberg & Zaid, 2002). Previous studies have shown that the production costs and operating costs are very low (Gillies, Smith, & Raine, 2008; Liebenberg & Zaid, 2002). It also is suitable for irrigating farms specializing in the cultivation of palms together with other crops, and also for all types of soil (Brouwer, 1988; Larry & James, 1993). There are some limitations to surface irrigation; for example, water in surface irrigation can evaporate quickly in hot areas, such as in South Libya (Gillies et al., 2008; Liebenberg & Zaid, 2002). Poor uniform distribution is another limitation (Gillies et al., 2008; Liebenberg & Zaid, 2002). Surface irrigation can also lead to erosion, but farmers can deal with this issue by using basins or border irrigation (Fahong, Xuqing, & Sayre, 2004). In addition, greater depths are needed to avoid water leakage and to drive the water around the date palm trees (Gillies et al., 2008; Liebenberg & Zaid, 2002). Furthermore, irrigating clay soils using surface irrigation requires long periods of time to infiltrate into the soil, and results in higher soil salinity and crust formation on the soil surface. As a result, a large volume of water may be lost and cannot be used by the date palms because of evaporation and transpiration (Brouwer, 1988; Larry & James, 1993).

1.3.1.2. Sprinkler or bubbler irrigation

According to James (1988), in a sprinkler irrigation system the distribution of water on the plants and crops is in the form of raindrops or natural rainfall by a pressure method (Brouwer, 1988; James, 1988). With the sprinkler irrigation system, the water is mostly distributed with the use of pipes through pumping. The water is then sprayed with the use of sprinklers which is then broken into drops. The sprinklers and the pump supply system needs to be designed properly to ensure a uniform supply of the water into the ground (Brouwer, 1988). This is one of the most efficient forms of mechanical irrigation according to Kahlown et al. (2007); and ur Rahman, Zahura, and Rezwan (2014).

According to FAO (2007), sprinkler irrigation systems are one of the most widely used irrigation systems for date palm production over the last 50 years in most regions in Libya because they have many advantages. Firstly, it is easy to control the amount of water used and is more efficient and less labour intensive (FAO, 2007). Secondly, sprinkler irrigation is suitable for different topographic conditions, types of soils and different kinds of crops. Brouwer (1988) suggests that sprinkler irrigation is suitable for row and tree crops as the water can be sprayed on both sides either under or over the canopy of the crop. By controlling the amount of water and time of irrigation, equal amounts of water are distributed on the date palm trees (Liebenberg & Zaid, 2002). Furthermore, sprinkler irrigation protects the agricultural environment by reducing erosion and runoff and can be operated by unskilled farmers using simple equipment (Mumtaz & Prathapar, 2012).

However, clean water with no suspended sediments is required to prevent sprinkler nozzle blockage. Furthermore, water with sediments can spoil the crops as they are coated with sediments (Brouwer, 1988). According to Liebenberg and Zaid (2002), sprinkler irrigation is not an appropriate system for date palm seedlings, because water can enter into the overhead growth point of the plant. Small water flows cannot be used as in other micro-irrigation systems. There are also disadvantages associated with environmental factors such as wind. Firstly, 25 per cent of water is lost by evaporation to changes in the direction of irrigation by high speed winds. This leads to low production due to non-uniform water distribution (Ludong, 2008). Water cannot be applied in the micro-irrigation system by spray, if the amount of water is emitted by very small emitters (Mumtaz & Prathapar, 2012). Secondly, sprinkler irrigation used on sandy soil, in South Libya (Sebha) showed that non-uniform wetting and excess water flow through the root-zone causes leaching of nitrates and other soluble nutrients (Ludong, 2008; Mumtaz & Prathapar, 2012). However, it is interesting to note that a sprinkler irrigation system is more flexible as it can adapt to either undulating or uniform farmable slopes. In order to minimize changes in the pressure at the sprinklers as well as provide uniform irrigation, it is required that the lateral pipes which supply water to the sprinklers are laid out along the land contour (Brouwer, 1988). On the other hand, Brouwer (1988) further suggests that large sprinklers should not be used for the irrigation of crops considered delicate (lettuce) as the large water drops may damage such delicate crops.

1.3.1.3. Drip irrigation

Drip irrigation is one of the more modern systems used to irrigate date palms in Libya. It supplies the plant with small amounts of water around the root zone, but at rates specified by the drip style (Brinegar & Ward, 2009). "Drip irrigation, refers to a trickle or low irrigation flow to provide near optimal soil moisture on a continuous basis while conserving water" (Elmakki, 2006, p. 4). There are two types of drip irrigation, surface and subsurface irrigation (Ahmed et al., 2012). Subsurface drip irrigation differs from surface drip irrigation; the latter requires that the water should be applied below the soil surface with the use of emitters which must be discharged at a rate within a similar range just like drip irrigation systems (Camp et al., 2000). The subsurface system supplies water and fertilizers through a network of pipes around the root zone underground (Elmakki, 2006).

Drip irrigation is the most effective system for reducing water waste. This is very important for the environment (Capra & Scicolone, 2007). According to Liebenberg and Zaid (2002), drip irrigation is the most appropriate way to irrigate date palms because it is easy to control the amount of water used. Drip irrigation also limits water loss by reducing evaporation from soil because of deep percolation (Rajput & Patel, 2006; Skaggs, 2001). Furthermore, drip irrigation has different devices to make adjustments (Skaggs, 2001). Drip irrigation can distribute nutrients, fertilizers and other chemicals (Cetin et al., 2004; Skaggs, 2001). This process can be labour saving, with a reduction in fertilizer use and can create a balance between climatic conditions and growing plants (Dasberg & Bresler, 1985).

In spite of the listed advantages of drip irrigation, it also has some disadvantages. Drip irrigation necessitates clean water, damage of pipe network by exposure to the sun can occur; as can the accumulation of salts (Al-Amoud, 2010). Drip irrigation does not cover the water needs of the date palm trees (FAO, 2007). This is due to poor distribution of the amount of water around the roots; so many farmers believe the quantity of water provided by drip irrigation is insufficient (FAO, 2007). Moreover, in developing countries, there are also many challenges in this system, because of the high cost of equipment and installation. The major challenge in the use of drip irrigation is the inability of farmers to secure the required financial resources to apply such irrigation techniques (Barth, 1999; Sharif, Sanduk, & Taleb, 2010; Skaggs, 2001).This has produced some negative results, especially in old date palm farms (FAO, 2007; Liebenberg & Zaid, 2002) due to misunderstandings involving the systems and how they are operated (FAO, 2007; Liebenberg & Zaid, 2002). The operation of drip irrigation requires clean water (Capra & Scicolone, 2007; Liebenberg & Zaid, 2002) and high technical skills for maintenance and preparation for irrigation (Skaggs, 2001). Drip irrigation cannot reduce the temperature around the root zone of the date palm, and consequently increases water consumption. In contrast, surface irrigation can reduce the temperature around date palm trees in desert areas (Skaggs, 2001). Elmakki (2006) observed that drip irrigation can also increase salinity and can pose a problem. An accumulation in the pipes of salt is an issue that must be resolved.

1.4. Research questions

Libya is an African country that has been suffering from drought; desertification and climate change over the last three decades. Moreover, most parts of the country are either dry or unsuitable for cultivation (Shaki & Adeloye, 2006). Diamond and White (2007) identified water shortages, poor conservation measures and poor agricultural practices as contributing factors causing damage to the environment. The depletion of the water resources stems from poor water utilization or the lack of efficient water utilization which is impacting negatively on the environment; this creates a need to ensure sustainable water management (Abdudayem & Scott, 2014; Diamond & White, 2007).

Agriculture in Libya consists of the cultivation of crops, vegetables and fruits. Date palm cultivation has received much attention from the government compared to other agricultural crops (Edongali & Aboqilh, 2005; Wani & El-Ammari, 2001). This is because date palm plays a role in sand storms and pollutants especially carbon dioxide (CO_2) and assures the protection for the growth and productivity of other fruit trees and associated crops. In addition, dates are a whole food source and many industries depend on their by-products. Palm trees assure the equilibrium and stability of ecosystems in the dry and desert regions (Awad & Al-Qurashi, 2012b; Mohamed et al., 2011). The Libyan Government is making efforts to increase date palm production to ensure sustainable livelihood among farmers and also maintain food security in the country (Agoudjil et al., 2011; Wani & El-Ammari, 2001).

Irrigation is a critical factor in date production, particularly in Libya, a dry desert region. However to date, there is no definitive study on the impact of the type of irrigation system on production and productivity of date palms in Libya. This study therefore looks into this issue.

The research questions this study aims to investigate are:

1. Does type of irrigation system have an effect on date palm production and income in the Sebha region, Libya?
2. What is the most economically efficient irrigation system for date palm production in the Sebha region, Libya?
3. Does irrigation system have an effect on water use efficiency and fruit quality in dates?
4. What other factors influence production, productivity and income of date palm farmers in the Sebha region?

1.5. Research objectives

The main objectives of this research are to examine the impact of the main irrigation systems in South Libya on the production and productivity of date palm in the region. The specific aims of this study are:

1. To determine the variables affecting the productivity of date palm and income of date palm farmers in the Sebha region.
2. To assess the effects of different types of irrigation system on fruit quality of an economically important cultivar of dates (Talees dates) in South Libya.
3. To assess the economics of date palm production under different types of irrigation system.
4. To assess the pros and cons of different types of irrigation system for date palm production.

1.6. Research approach

Date palm production is one of the few crops that are cultivated by the people of Sebha located in South Libya. Sebha was selected as the study site owing to the fact that the region constitutes a major player in date palm production. State projects can also be found in the region. A quantitative study approach was used to meet the objectives of the study. Bazeley (2002) and Brannen (2005) argue that a quantitative study provides a more objective and formal approach; and provides systematic steps with the help of numerical data to understand a research phenomenon.

A survey was initially conducted to illustrate and compare the amount of water consumed under various irrigation systems used for palm cultivation such as surface, sprinkler and drip irrigation. A comparison between the amounts of water consumed for some main varieties of high quality dates in the study area was done. Data on inputs and outputs for date palm production was gathered from date palm farmers in the Sebha district in Libya and data were statistically analyzed.

This study mainly used primary data from surveys, due to the lack of information about the amount of water consumed and economics of water use. However, it also used secondary data from official sources, for example, books, journal articles, research reports, online articles, theses and reports issued by international organizations.

The effects of different irrigation systems on water use efficiency, yield, quality and profits from 'Talees' dates in the Sebha region were also investigated. 'Talees' is one of the most economically important date palm cultivars grown in the Sebha region.

An experiment was conducted to analyse and assess fruit quality attributes including fruit weight, stone weight, pulp stone ration, fruit length, breadth, individual and total sugars, as well as organic acids. Water use efficiency was also calculated. Finally, an economic analysis was conducted to compare the profitability of each irrigation system.

1.7. Significance of the study

This study will be useful in developing policies and guidelines that can help in improving the agricultural sector in Libya. Although the contribution of the agriculture sector is small relative to the oil sector, investments in irrigation infrastructure can play an important role in improving rural incomes and reducing poverty level by boosting agricultural production.

This thesis provides new insights into factors that affect date palm production in the study area. It contributes to existing knowledge through the development of a unique data set on date palm production in Sebha, Libya. By utilising this thesis's data, the effects on different types of irrigation can be determined.

The current findings determined production functions relating to water use in date production in Sebha, Libya, as well as factors determining heterogeneity in production. The latter was estimated by inefficiency models that considered individual characteristics to estimate productivity. These findings had not been founded previously for date production in Libya. Moreover, the estimation of the effect of irrigation system on fruit quality and the efficiency of water use of commercial dates (Talees) in this study is the first of its kind. The methodology applied will help researchers make more accurate estimates of production frontiers in South Libya where surface, sprinkler and drip irrigation is widely distributed.

This study will provide valuable information on the factors influencing production of date palms, information on the efficiency of key irrigation systems used by farmers in South Libya, and the type of irrigation system that is most effective. These information can help local farmers to invest in the right type of irrigation system which will be beneficial in improving the agricultural sector in Libya.

1.8. Thesis outline

The thesis consists of ten (10) chapters. The structure of the thesis is illustrated in Figure 1.1 below.

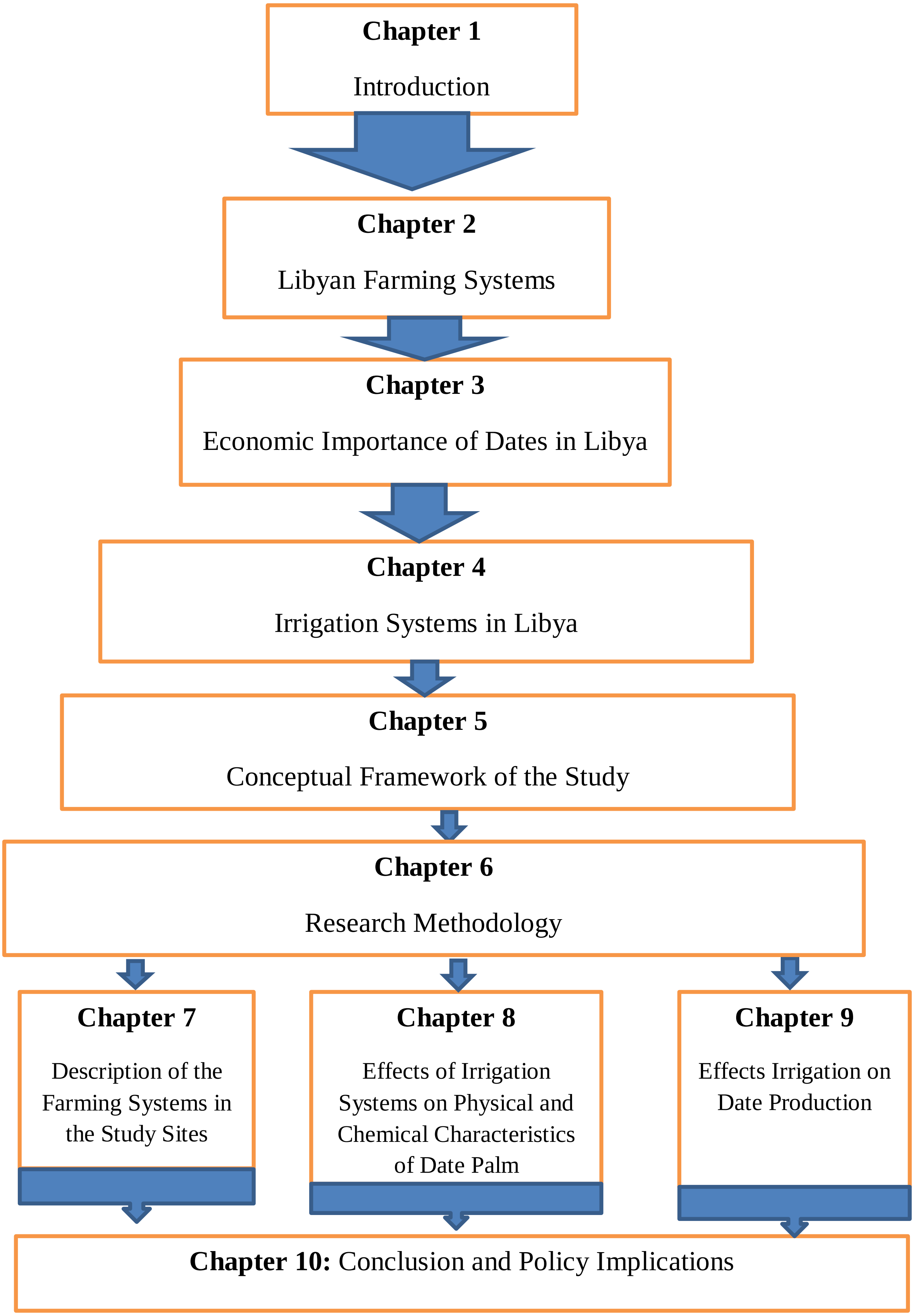

Figure 1-1 Structure of the study

Chapter 1 is the introduction to the thesis and covers the background of the study to provide general information on the problem specification including the research objectives and significance of the study. Chapter 2 describes Libyan farming systems, in general and more specifically, the importance of agricultural development in Libya. Chapter 3 presents a literature review on the economics of date production. In particular, the chapter includes a description of date palm, some examples of origin and botanical description of date palm; and the economics of importing dates including date production in the world and in Libya.

Chapter 4 contains detailed information regarding irrigation systems in Libya, Chapter 5 deals with the development of the conceptual framework, while Chapter 6 will provide a detailed methodology of the approach taken and the various analytical tools employed to analyse the results. Chapter 7 provides an overview of the research site and is devoted to four sections including characteristics of farmers and description of date palm production and farming practices under surface, sprinkler and drip irrigation. Chapter 8 is concerned with the analysis of the effects of different irrigation systems on physical and chemical (individual sugars and organic acids) analysis of 'Talees' dates. Chapter 9 focuses on the analysis of the effects of type of irrigation in date production. Chapter 10 presents the summary and main conclusion and recommendations drawn from the analysis.

Chapter 2
Libyan Farming Systems

2.1. Introduction

This section is designed to provide detailed information regarding farming systems in Libya. It also describes the historically significant role of oil revenues in the economic development of the Libyan economy. The rest of the chapter is divided into six sections. Section 2.2 describes the general background of Libya. Section 2.3 discusses the Libyan economy by highlighting the economic outlook with emphasis on the contribution of the oil discovery, and the importance of agriculture to the Libyan economy. Section 2.4 describes major agricultural crops while Section 2.5 discusses the farming system in Libya. Section 2.6 deals with agricultural societies in Libya, while section 2.7 is devoted to the conclusion of the chapter.

2.2. Background of Libya

2.2.1. Location

Libya is located in the North of Africa sharing borders with Egypt from the East, Tunisia and Algeria from the West while the north is occupied by the Mediterranean Sea, with latitudes 10° to 25° E and 20° to 34° N. Libya has a coastline of nearly 1800 km, and in the South by Sudan, Chad and Niger (1 055 km, 354 km, and 383 km, respectively) (Figure 2.1) (Shareia & Irvine, 2014). Libya has a significant physical asset because the country is strategically located. Libya occupies about 1.76 million km^2 of total land area and ranks the 15^{th} largest by area size in Africa. The country is well-known for its desert nature and about 95% of the country is considered desert and semi desert and forms part of the Sahara desert in Africa. It is important to note that only 5% of the total land area can be put to economic use as the land is characterised by severe aridity. A significant part of the eastern and central parts of the country are engulfed by tropical air where, due to latitude, anticyclone conditions are permanent causing severe aridity (Abdullah, 2014; El-Tantawi, 2005). The national language in Libya is Arabic, with English and Italian as the second languages.

Figure 2-1 Location of Libya

Source of basic data: Werner (2004)

2.2.2. Population of Libya

Libya has the lowest population in North Africa. It has a population of 5 323 991 million which is mostly concentrated in the major coastal cities such as Tripoli with an estimated population of 1 004 406. Other cities include Benghazi (622 847), Misratah (517 478), Al Jafara (425 858), Al Margheb (415 304) and Al Jabal Al Akhdar (290 335). On the other hand, the population distribution is low in Libya's southern cities such as Sebha (125 886), Wadi al-Ajal (72 382), Wadi al-Shati (68 023), Al Kufrah (42 888) and Ghat (21 399) (Libyan Statistics, 2008). Due to development imbalances as a result of poor economic planning and a volatile political system, there is a high rate of rural-urban migration. The effect of the rural-urban migration is the high population density in Benghazi and Tripoli. It is expected that increasing the rate of urbanisation in Libya will create better living and employment opportunities (Elbendak, 2008). According to the Islamic Development Bank (2014), the Libyan population has slightly increased with males (50.4%) and females (49.6%). Most Libyan people are in the age categories of 16-64 years representing 65.8% of the population; while 29.5 % are in the 0-15 years group, and 4.7% are 65 years and over. However, the Libyan population has increased from 6.4 million in 2014 to 6.5 million in 2015 (Country Meters, 2015). Figure 2.2 shows the human population of Libya in different cities.

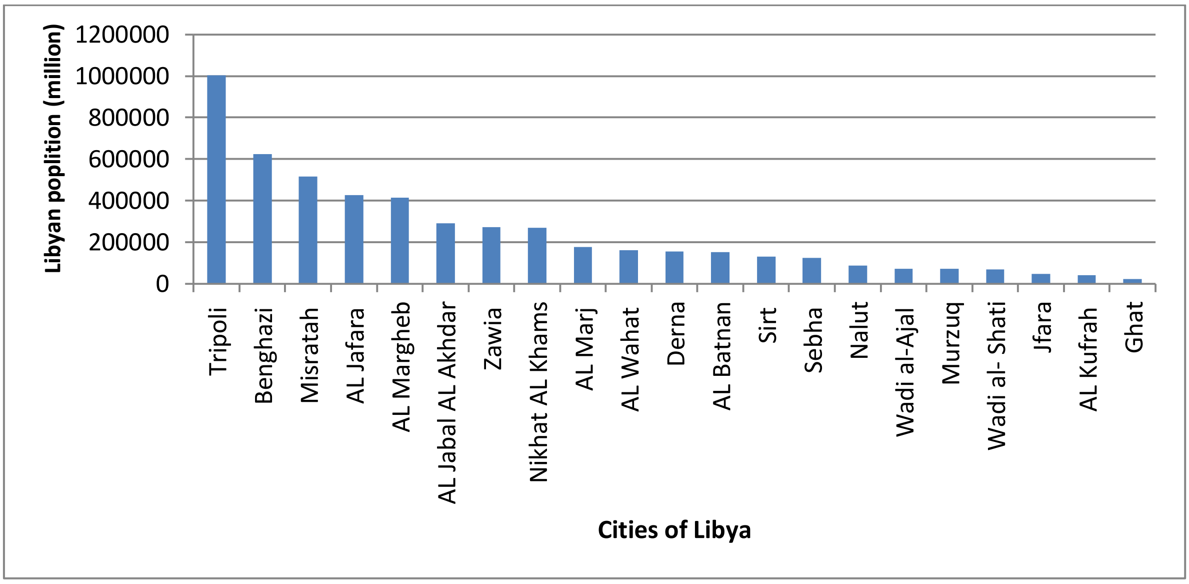

Figure 2-2 Human population in different cities of Libya

Source of basic data: Libya Statistics (2008)

2.2.3. Climate of Libya

The climatic conditions vary between the Mediterranean coast from the North compared to what is experienced in the south which is largely a desert (Hamad, 2012a). North Libya is influenced by Mediterranean depressions during the winter season (December-February) as a result of its geographical location. Thunderstorms and rain storms are observed in various places including hail, especially on the mountainous areas in the west and east of Libya. Sometimes snow falls when the country is affected by the Atlas Mountains and Siberian depressions, e.g., the Nafusah Mountain and Al Akhdar Mountain highlands have higher rainfall, humidity, low temperatures, and snow on the hills in the winter season.

Precipitation is low, and the vast majority of the country is desert, as only a few areas in Libya have sufficient precipitation to allow agricultural use. Rainfall averages from about 200 to 500 mm in north Libya, with maximum recordings in the regions of Akhdar Mountain areas in Eastern Libya of 850 mm. Meanwhile, the Nafusah Mountain areas in Western Libya are 750 mm. Rainy days range between one month and three months, with the maximum rainfall in a day reaching about 150 mm, especially in the closest regions of west and east of Tripoli (Elfadli, 2009). The level of precipitation is similar in many locations, but fast declines from north to south (Hamad, 2012a). In the South Libyan areas including Sebha, there are desert climatic conditions, with variations in temperatures. Rain is very low and mostly irregular and southern parts of the country sometimes record no rain at all. However, most of the precipitation falls in late autumn, winter and early spring and shows high variability from year to year.

2.2.4. Terrains of South Libya

The southern region of Libya is a part of the African Sahara. It has a desert climate that is very harsh and dry. There are important Oases in South Libya, amongst these are Ghat and Murzuq. The source of irrigation is underground water-bearing aquifers in the Murzuq basin (Shaki & Adeloye, 2006). The Murzuq basin provides complete self-sufficiency for some vegetables and fruits including date palm farms (Lawgali & Meharg, 2011). There are also two insulated mountain areas in southern Libya including Tibesti and Acacus Mountains. A large part of these mountain areas is found in the northern part of Chad, which extends into southern Libya. In fact, the Tibesti and Acacus Mountains consist of several inactive volcanoes with the highest peak reaching 3415 m (Adkins, Demenocal, & Eshel, 2006; Biagetti, 2015). Tibesti Mountains are prominent and have very rugged slopes, however, these mountains become less sloping when heading to Ghat Oases and Shahra of Murzuq and Ubari (El-Tantawi, 2005). In the south eastern region of Libya, there are small Oases called Al Kufrah Oases. Al Kufrah Oases are located at low hills with a height of about 700 m. There is also Uwainat Mountain, which is located near the south-west borders of Egypt and north-west borders of Sudan. Finally, Uwainat Mountain comprises sub-mountains reaching an elevation of 1 934 m (Brophy, 2013).

2.3. Economy of Libya

According to Vandewalle (1996), Libya was characterised by poverty and categorised as one of the World’s poorest countries after independence in 1951. The economy was mainly based on agriculture and foreign aid from the United Nations, which contributed about 26% of gross domestic product (Alfitouri, 2004; El-Azzabi, 1974), in addition to rents from military bases used by some western countries

(Vandewalle, 1996). After the discovery of oil in the 1950s and the export of oil to many countries around the world, the Libyan economy improved significantly (El-Azzabi, 1974). In 1955, the exploration of oil in Libya began, and by early 1960, international companies were engaged in oil exploration and production. The economy started recording a balance of payments surplus (35 million Libyan dinars) owing to the revenues from the oil production boom (Alfitouri, 2004). The national income increased by 344% from 131 million Libyan dinars in 1962 to 789 million Libyan dinars in 1968. Figure (2.4) shows the production of crude oil during the period 1961 to 2012. As shown in the figure, Libya produced only 0.018 million barrels per day in 1961, but this figure increased gradually to more than 1.2 million barrels per day by 1965. By 1970, Libyan oil production reached 3.3 million barrels per day. This trend of increasing production in the 1960s can be mainly attributed to the production policies that were formulated by international oil companies and several concessionary agreements that were applied in the country during 1955-1970.

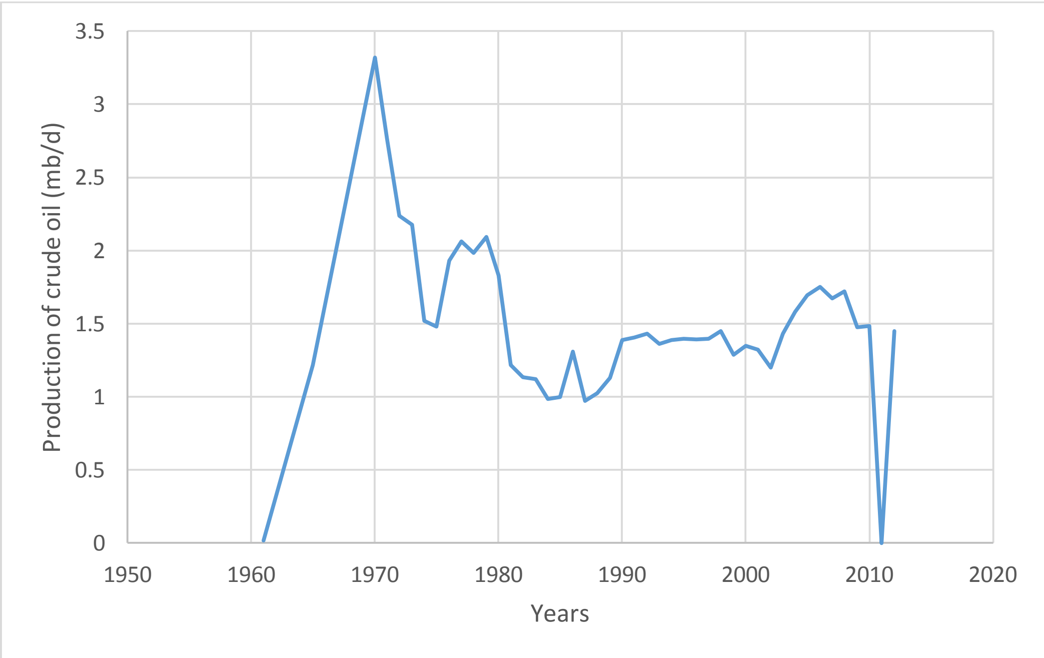

Figure 2-3: The production of crude oil during the period (1961 -2012)

Source of basic data: OPEC (2013).

During the period 1980-2002, with the exception of the years 1980 and 1991, the production of oil ranged between 0.972 to 1.4 million barrels per day. It is likely that the reduction of production capacity of oil resulted from the embargoes imposed by the United States, one of the World's largest consumers of oil. Following the embargo, sanctions were also imposed by the United Nations in the 1990s and this further affected the country's oil production. In addition, because Libya has been a member of the Organization of the Petroleum Exporting Countries since 1962, OPEC imposed a limited quota during the 1980s. Since most spare parts are made in the USA and other western countries, the oil sector in Libya, during the period of sanctions and the trade embargo, suffered seriously from a lack of appropriate and emergency maintenance. Therefore, the oil sector's production capacity was significantly reduced by the lack of foreign investment and modern technology, as well as due to the effects of economic sanctions. However, oil production started increasing steadily from 2003 reaching a record of l.7mb/d in 2006. The production increase is attributed to the lifting of the embargo and UN sanctions between 2003 and 2004. Furthermore, the nominal oil price experienced a sharp increase since 2000. These increases also provided an opportunity for the country to attract major multinational enterprises (MNEs) into the oil and gas industry to boost oil production.

Despite the Libyan oil and gas sector accounting for more than 60 % of GDP, in nominal terms, in 2003 it employed only 3 % of the formal workforce. However, the employment in the oil sector grew at an annual average estimate of 10 % between 1999 and 2003. The data in Table 2.1 indicate that Libya contributed about 4-14% of total oil production from 1961 to 2012 as a member of OPEC. Libya has the potential to increase oil production given its proven oil reserves of 43.67 billion barrels as at 2007 (OPEC, 2013).

Table 2-1: Average Libyan oil production (1961-2012) and share of daily oil production (%)

Years	Libya (1)	OPEC (2)	Share of daily oil% (1/2)
1961	0.0182	8.6826	0.21
1965	1.2188	14.3254	8.51
1970	3.3180	23.3881	14.19
1971	2.7608	25.3213	10.90
1972	2.2394	27.1082	8.26
1973	2.1749	30.9905	7.02
1974	1.5213	30.6960	4.96
1975	1.4798	27.0946	5.46
1976	1.9326	30.6502	6.31
1977	2.0634	31.2091	6.61
1978	1.9825	29.7627	6.66
1979	2.0917	30.8622	6.78
1980	1.8316	26.8556	6.82
1981	1.2178	22.5317	5.40
1982	1.1360	19.5317	5.82
1983	1.1211	17.0306	6.58
1984	0.9846	16.3958	6.01
1985	0.9977	15.4332	6.46
1986	1.3080	18.1990	7.19
1987	0.9725	17.2801	5.63
1988	1.0227	19.5943	5.22
1989	1.1292	21.1379	5.34
1990	1.3891	22.7809	6.10
1991	1.4059	23.0555	6.10
1992	1.4327	24.7147	5.80
1993	1.3610	25.0755	5.43
1994	1.3898	25.5324	5.44
1995	1.3990	25.5884	5.47
1996	1.3940	25.8263	5.40
1997	1.3958	26.5271	5.26
1998	1.4490	28.8196	5.03
1999	1.2872	27.3112	4.71
2000	1.3472	28.8733	4.67
2001	1.3235	28.0083	4.73
2002	1.2009	25.5953	4.69
2003	1.4319	28.1879	5.08
2004	1.5807	31.0768	5.09
2005	1.6932	32.3057	5.24
2006	1.7512	32.4486	5.40
2007	1.6739	32.0771	5.22
2008	1.7215	32.0754	5.37
2009	1.4739	28.9271	5.10
2010	1.4866	29.2494	5.08
2011	489.5000	30.1212	1.63
2012	1.4500	32.4242	4.47
Total	67.0501	1150.6800	262.85
Average	1.4900	25.5707	5.84

Source: (OPEC, 2013).

2.3.1. Agricultural sector and the Libyan economy

The concept of the word agriculture varies significantly in meaning, from ploughing or planting to other processes of agricultural productivity. One definition of agriculture is production of crops or plants and different animals by following different agricultural techniques (Tnobi, 1996). These include knowledge of physical, chemical, engineering and other methods such as conversion of agricultural resources, human and non-human, to agricultural goods and services. This means that agriculture is an industry and involves the production of crops and animals (Tnobi, 1996).

2.3.2. Importance of agriculture in Libya

The vital role of agricultural development in the overall economic development of a country can be judged by the role of agriculture as a vital production sector in the national economy. Therefore, it is necessary to consider the importance of agriculture, in general, to the socio-economy of a country (Allan, McLachlan, & Penrose, 2015). From a historical point of view, it is evident that economic growth in any country cannot be achieved without achieving a considerable degree of efficiency in the agricultural sector. Therefore, agriculture as a production sector should integrate with other economic activities, as these activities are more or less interrelated, whether directly or indirectly. However, agriculture is indispensable for the continuity of life, as it is the source of human food. This explains why boosting agricultural production in rural areas is the core of economic policies in many countries in the world. Furthermore, agriculture is counted as an important earner of foreign exchange. In the event of the failure of the agricultural sector to meet the needs of the society for food materials, the state resorts to importing these materials. This will be at the expense of other vital imports, which will burden the national budget, especially in underdeveloped countries. Also, the huge tax revenues generated by agriculture are an important source of funding for other economic activities. In most of the third world countries, agriculture is the main tax generator, where the tax revenues are used for funding social projects, the military and many other projects. Moreover, agricultural reserves are also a second source for funding other economic activities, although these reserves are affected by a number of economic factors, such as the prevailing production relationships, the procurement system, income and production, agricultural technology in use, savings of farmers and the distribution of wealth. Therefore, agriculture as a production activity is paramount in the national economies of different countries. Hence, boosting the efficiency of the agricultural sector, especially in developing countries, is an urgent issue. This urgency stems from the fact that the development of the agricultural sector is an objective prerequisite for industrialization in particular and economic development in general, for the following reasons:

Firstly, developed countries could fund the industrial sector through agricultural development, at the expense of the rural population. Economic reserves are also used for funding the inefficient industrial sector. The current state of the developing countries, in particular Libya, implies that these countries should pay attention to boosting their agricultural production, so that part of the economic surplus could be used to improve the economic conditions of farmers, and the rest of this surplus, for funding the ever-demanding industrial sector (Amara, 2004). According to Shareia and Irvine (2014), in the Libyan case, the oil revenue is the main source of funding agricultural and industrial sectors in Libya.

Secondly, changes in consumption patterns are very slow in highly developed countries compared to the dramatic increases in consumption that characterize developing countries, such as Libya, due to the adoption of Western lifestyles. This necessitates the adoption of certain policies in Libya aimed at the development, diversification and the restructuring of agricultural production (Amara, 2004). Musaiger (2011) and Miladi and Musaiger (1998) reported that the change in consumption pattern was very high in Libya compared to the Middle East and North African countries.

Thirdly, developed countries can easily find suitable markets for their products. The vast markets in their previous colonies have become a substitute for weak local markets. However, in the case of developing countries such as Libya, the chances of finding suitable markets are quite slim. Often, the only option is to rely on local markets and to try to expand these markets. In this respect, the agricultural development sector has a crucial role to play in creating the required markets for its products (Amara, 2004). This is because of poor management, government intervention in the marketing sector by subsidies or support, and changes in laws and directives ever year, due to the low quantity of Libyan products in local markets (FAO, 2006; Shareia & Irvine, 2014).

Finally, industry in highly developed countries has succeeded in accommodating surpluses in the workforce, whose growth is very slow given the slow population growth in these countries. In contrast, in Libya, the industrial sector cannot cope with the fast growing population (Abdudayem & Scott, 2014; Mabro, 1970), due to low investment programs in human development in Libyan communities (El Kailani, 2012), and therefore, unemployment is always liable to rise. Therefore, the only alternative for this country is to create jobs by developing the agricultural sector (Abdudayem & Scott, 2014; Amara, 2004).

2.3.3. Major issues faced by Libyan agriculture

Libya, one of the third world countries, has suffered from various problems. One of the reasons this country lags behind in the field of agricultural development is that it failed to use the available resources in a way that helps the agricultural sector to contribute effectively to the national economy and to boost economic development (Allan & McLachlan, 1976). The following points highlight some of the major issues faced by agriculture in Libya (Allan & McLachlan, 1976; Azzabi, 1993).

1. Prevailing tribal relationships, the distribution of land and the breadth of land are unfit for agriculture in this country.
2. Low productivity per unit area due to many factors such as lack of irrigation, fertilizers and pesticides and the low capital investment in the agricultural sector.
3. Prevailing government policies aimed at production for local consumption rather than for export.
4. High unemployment and low income of the workforce in rural Libya, especially after the exploration of oil.
5. The weak contribution of the agricultural sector to the national income as compared to other economics sectors.
6. Illiteracy among farmers whose contribution to anticipated agricultural development plan is vital; otherwise the whole plan will collapse.

Furthermore, as Omar et al. (2012) pointed out, modern technology, training and development of human resources and other resources are vital for the achievement of agricultural development in the rural area. Therefore, the above problems cannot be overcome in Libya by chance, but rather by the implementation of certain policies and measures that could lead to overcoming these problems. Thus, development of the production power in rural areas should be improved. This will make the agricultural sector move forward and will actively play a role in the economic development as a whole (Minten & Barrett, 2008). It can be said that the agricultural development plan must consider all aspects of development relevant to the agricultural sector. Agricultural development is a process that should be consistent in increasing the income of the rural population, for fairness in the distribution of wealth, and for adopting the right policies that allow the agricultural sector to assume its vital role in the overall economic development plan. This process will ultimately boost the productivity of the agricultural sector (Abro, Alemu, & Hanjra, 2014).

2.3.4. Agricultural sector in the Libyan economy

The overall strategy for economic and social development in Libya during the period 1971 - 2007 was to find alternative sources of income to reduce the economy's dependence on the oil sector. This strategy targeted the agriculture and industry sectors to play a major role in the growth process and to provide an alternative source of income. It has also considered the agriculture sector and agricultural activities as an essential base for economic construction while at the same time considering industrial activity essential for achieving sustained growth for the economy. In addition, the Libyan economy also remained greatly dependent on the oil industry, which is the main source of funding investments in all other economic sectors in the country, particularly the agriculture sector (Ben-Hamed, 2014). As a result, money has been invested in the agricultural sector to achieve the desired objectives in achieving economic development in this sector and increase the contribution of the agricultural sector to GDP.

Investments in the agriculture sector grew during the period 1970 - 2007. As shown in Figure 2.5, actual investment during the period 1970 - 1972 was about 135 million dinars compared to the period 1976 - 1980 which was higher, because of the recovery of the economy and massive flow of financial resources in the 70s to achieve a number of economic gains. A decline in the value of investments occurred from 1986 to 1990 of about 1494.10 million dinars. This decline was due to a decrease in investments in the agriculture sector. This decline coincided with the oil crisis in the early 80s, as there was a decline in oil revenues, which constituted the main source of finance. Therefore, agricultural investments were in their lowest value from the period 1991 - 1999. The value of investments recovered in the period 2000 - 2005, which amounted to about 1226.40 million dinars. From the period 2006 - 2007 investments declined to about 505.44 million dinars, however, these investments increased to about 1455.91 million dinars from 2008 - 2013.

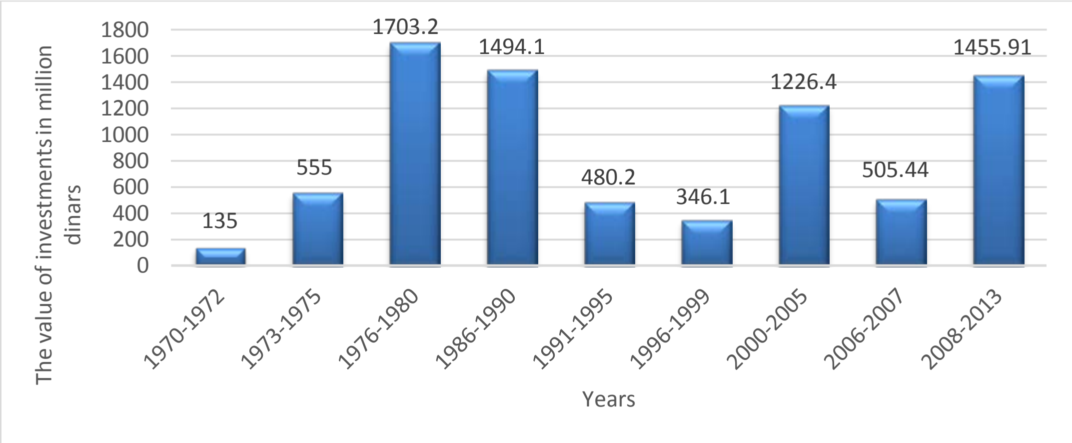

Figure 2-4 : Actual investment in the agricultural sector at current prices (1970-2013)

Source of basic data: AOADSTAT (2014) and Central Bank of Libya (2013)

2.3.5. Libyan gross domestic product and the agricultural sector

The Libyan government has implemented several development plans since the early 1970s, which stressed the goal of building a viable economy by diversifying and by increasing the share of the other sectors, particularly the manufacturing and agriculture sectors, to the Libyan gross domestic product. However, the contribution of oil production to real gross domestic product has been considerable during both the oil boom from the late 1970s, 1980s and 2000s, and non-oil boom periods. Moreover, the contribution of the non-tradable sector, such as that of services and construction, in the real gross domestic product has experienced a considerable increase, meaning that the oil boom was followed by an expansion in the other sectors (Elmessallati, 2007). As can be seen from Table 2.2, the total Libyan gross domestic product amounted to 881,108.4 dinars at current prices during the period 1970 - 2012. The average for this period amounted to 2 049.03 billion dinars at current prices. The GDP increased from 1289.30 billion dinars in 1970 to about 81

915 billion dinars in 2012. In the same way, the total agricultural GDP during the period from 1970 to 2005 amounted to 31 732.23 billion dinars at current prices, while the average of that period amounted to 737.96 million dinars at current prices. Although the agricultural sector contributed to the Libyan gross domestic product, it did not achieve the development objectives desired, such as a high proportion of self-sufficiency and efficient use of economic resources. Table 2.2 provides the statistics of agricultural sector contribution to GDP in Libya.

Table 2-2: Contribution of the agriculture sector as % of total GDP from (1970-2012)

Years	Total GDP (1)	Agriculture (2)	% (2/1)
1970	1289.3	33.1	2.6
1971	1586.5	33.0	2.1
1972	1748.0	43.6	2.5
1973	2182.7	60.0	2.7
1974	3795.7	64.7	1.7
1975	3674.3	82.9	2.3
1976	4768.1	99.7	2.1
1977	5612.7	90.0	1.6
1978	5496.1	122.1	2.2
1979	7603.0	140.4	1.8
1980	10553.8	236.4	2.2
1981	8798.8	273.6	3.1
1982	8932.4	285.7	3.2
1983	8511.3	303.0	3.6
1984	7804.7	323.0	4.1
1985	7854.1	342.2	4.4
1986	6960.7	384.7	5.5
1987	6011.6	411.2	6.8
1988	6186.0	423.3	6.8
1989	7191.0	439.8	6.1
1990	8246.4	482.9	5.9
1991	8757.3	542.4	6.2
1992	9231.9	630.2	6.8
1993	9137.7	708.8	7.8
1994	9670.8	827.9	8.6
1995	10672.2	933.4	8.7
1996	12327.3	1074.5	8.7
1997	13800.5	1267.0	9.2
1998	12610.6	1394.3	11.1
1999	14720.2	1449.9	9.8
2000	18456.9	1439.7	7.8
2001	18720.2	1392.0	7.4
2002	25914.1	1348.8	5.2
2003	31731.8	1375.0	4.3
2004	41577.0	1439.3	3.5
2005	54537.0	1554.0	2.8
2006	54976.0	1643.1	3
2007	67690.0	1905.3	2.8
2008	87236.0	2247.9	2.6
2009	62106.6	1906.2	3.1
2010	73823.7	2004.1	2.7
2011	36688.4	685.1	1.9
2012	81915.0	928.7	1.1
Total	**881108.4**	**31732.2**	**3.8**
Average	**2049.0**	**737.1**	

Source: Central Bank of Libya (2013)

2.4. Major agricultural crops in Libya

Agriculture is the main sector satisfying the food requirements of a growing population. It is also responsible for the main sources of sustenance for people residing in the rural areas of Libya. Crops are selected whether in small farms or in large farms, to meet a cropping pattern that will achieve a good economic outcome from using groundwater. This will meet the general food strategy of Libya in terms of achieving a high rate of self-sufficiency in agricultural production, particularly in grains and fodder. Furthermore, the government has considered the matter of simplifying the necessary agricultural activity, particularly in small farms. There is a governmental focus in proposing a specific crop pattern to produce fodders/grains that are used as food for sheep. After allocating a portion of fodders to sheep, the government markets the remaining fodder surplus to the local market. A limited area inside every small farm was allocated to the production of certain fruit and vegetables to cover home consumption and the rest geared towards the local market (MRP, 1990). Some crops have been selected by the government for investment projects in regions in Libya for the following reasons: first, barley is an essential crop in small farms because it is the traditional winter grain for all farmers, and it is the most easily acclimatized of all crops. Second, wheat is a strategic crop targeted in the general plan of the Libyan government to achieve food security through achieving self-sufficiency. Therefore, wheat is the principal grain among these crops. Third, alfalfa is a highly productive fodder crop, and it reliably gives a high quantity of protein and energy to livestock throughout the whole year. In addition to this, alfalfa has good economic value in local markets and makes a good source of income for farmers when they sell the surplus. Next, maize is considered as a seasonal fodder when the growth of alfalfa is slow in winter, while sorghum and maize play that role in summer. Finally, fruit trees, vegetables, such as tomatoes, zucchini, beans, okra, grapes, figs, pomegranates, dates and olives are most suitable to irrigated agriculture under local environmental conditions. The usual market for most of these products is the local market, where these products are transferred from the farmers to the consumers (Libyan Statistics, 2008). Table 2.3 lists the production and areas for the major crops in Libya.

Table 2-3: Area and production of crops in Libya by (tonnes/ha)

Crops	2010		2011		2012		2013	
	area	production	area	production	area	production	area	production
Wheat	135000	106000	150000	166000	165000	200000	160000	200000
Barley	186500	102000	207000	98130	210000	98000	200000	97000
Maize	1500	2900	1463	2860	1450	2900	1450	2900
Olives	205000	180000	216013	139091	205000	135000	210000	138000
Vegetables	5600	61000	5728	81571	5800	82500	-	-
Fruit	64878	386050	64879	402548	67585	411900	-	-
Dates	30000	161000	30056	165948	32000	170000	-	-

Source of basic data: FAOSTAT (2014) and AOADSTAT (2014).

Fruit, wheat, dates and olives are the major crops grown. Fruits are the number one crop during 2010 - 2013, taking up the highest production. Fruits are mainly produced for domestic consumption.

Due to sufficient rainfall patterns and other good environmental conditions such as land fertility; about 1 536 thousand hectares of the rainfed land is utilized for the cultivation of food crops such as barley, wheat, olive trees and vegetable crops (AOADSTAT, 2014). About 850 thousand hectares of total land is uncultivated. This land is used mainly as pasture. The total area of forests is 600 thousand hectares, Al-Idrissi et al. (1996) reported that 35 per cent of forests have been converted to cropping areas, especially in East Libya. The irrigated area represents 258 thousand hectares, as the date palm trees are cultivated in the irrigated area. However, there has been an issue related to the irrigated area, which is fragmentation of irrigated land.

The fragmentation of irrigated land is due to several factors. For example, Islamic inheritance laws require that property is divided equally among all heirs leading to fragmentation of holdings. Subdivision may also occur if a farmer rents his land for business proposals. In addition, government land distribution policies allow small farms such as in the South Libya projects area. This can be shown through the distribution of cultivated land in Libya as shown in Figure 2.6.

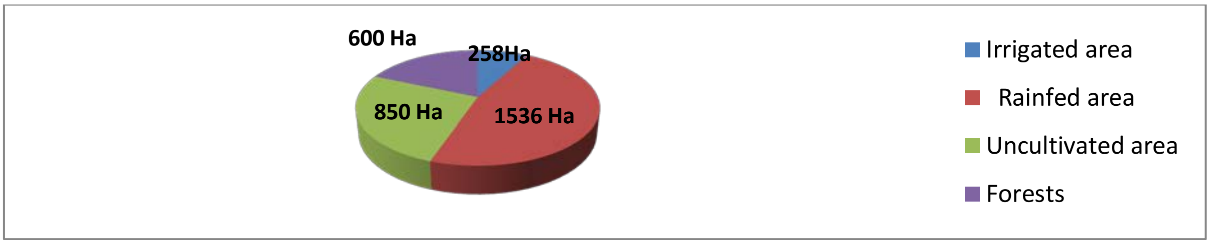

Figure 2-5: Distribution of cultivated land per hectare in Libya (2011-2012)

Source of basic data: FAOSTAT (2011).

Despite a structural shift towards oil, agriculture still constitutes a major sector of the Libyan economy. According to statistics provided by the Central Bank of Libya, the highest contribution by agriculture was 11.1% of the GDP in 1998. Among countries located closer to the Mediterranean sea and commonly known as Mediterranean developing countries, Libya is among the most highly urbanized of all but agriculture still employed 3.47% of the labour from 2010 - 2012 (AOADSTAT, 2014). Agriculture contributes about $US 352.19 million (405.01 million Libyan dinars) to foreign exchange from the total agricultural export earnings during 2005 - 2012. According to Elbeydi (2013), agriculture in Libya is expected to boost economic growth and satisfy the food requirements of a growing population. Saloum (2013) suggested that any development expenditure will help agriculture reach higher productivity rates. Currently, Libya exports potatoes, onions, vegetables and tomatoes at a rate of 320, 243, 79, 49 and 32 thousand tonnes per hectare, respectively (FAOSTAT, 2011) as shown Figure 2.7.

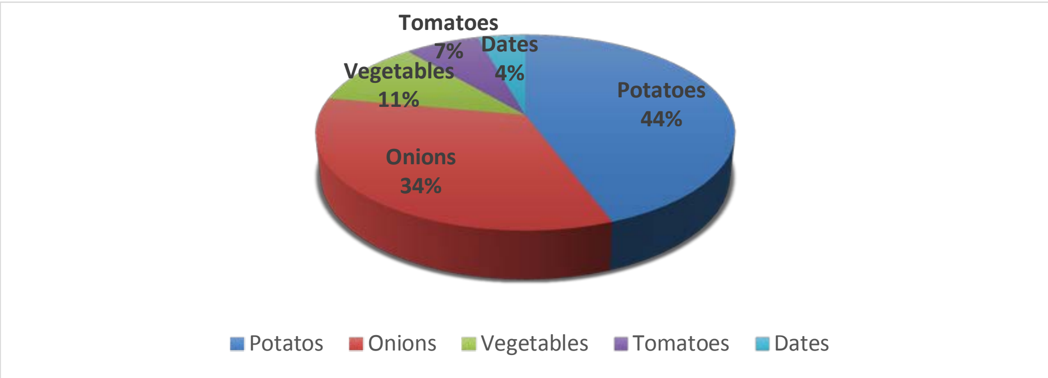

Figure 2-6: Libyan agricultural exports (2011-2012*)*

Source of basic data: FAOSTAT (2011).

Overall, agricultural exports are still low, because of inadequate processing, grading, packaging and marketing services, poor quality of the produce and severe water shortage together with a low level of food self-sufficiency. The fossil water that is pumped through the Nubian aquifer scheme is the main source of water for irrigation. However, it has become uneconomic because of the high cost of pumping the water.

2.5. Farming systems in Libya

In Libya, most arable land is owned by the farmers, while the remaining arable land is owned by the management of the Made River Project (MRP) and the Agricultural Research Centre (ARC). In the arable land owned by the government[1],three irrigation systems, surface, sprinkler and drip irrigation systems are utilised, and fertilizers and pesticides are used (Abdudayem & Scott, 2014). The private farming sector (i.e., in particular, individual farmers) heavily utilise and depend on manual labour; however, Government Farming Corporations greatly depend on machines and equipment (Abdudayem & Scott, 2014). The main types of farms based on water irrigation are irrigated farms, partially irrigated farms, and rainfed farms. Each are described below:

2.5.1. Irrigated farms

2.5.1.1. Traditional irrigated farms

Traditional farms are known as *Swina* in Libyan. They are one of the main small holdings (less than one hectare) and are managed by farmers who have good agricultural expertise in the field of irrigated agriculture. Farmers are however elderly, illiterate and prefer to use traditional farming methods (Allan et al., 2015).

2.5.1.2. Modern irrigated farms

The farms are dependent on high growth and new lands, such as different crops cultivated in large farms, and are characterised by efficient use of groundwater and the development of irrigation systems, use of foreign labour and optimum efficiency of fertilizers, chemicals, and pesticides. They are managed by new farmers with limited experience in irrigated cultivation (Bukechiem, 1987; FAO, 2009).

2.5.2. Partially irrigated

Partially irrigated farms are dependent on rainwater and groundwater techniques for their water source (Razzagh, 2011). Ahmadi et al. (2010, p. 13)

[1] State lands are usually allocated to private individuals to cultivate date palm or other crops which differ in terms of size, length of time as well as amount of water irrigation required.

defined "partial irrigation as a water-saving irrigation method that cuts down irrigation amounts of full irrigation to crops. The amounts of irrigation reduction is crop-dependent and generally accompanied by no or minor yield loss that increases the water productivity". Winter crops such as wheat, barley and fruit trees are cultivated in partially irrigated farms; irrigation by underground water often offsets the deficit in the amount of rainwater for irrigation, which raises the production in rainfed crops.

2.5.3. Dry (rainfed) farms

Entirely dependent on rainfall during the growing season, rainfed agriculture includes two types:

2.5.3.1. Traditional rainfed farms

Traditional rainfed farms are managed by simple methods, such as the use of ploughing animals, manual harvesting, and inputs usage (fertilizer and pesticides) remains low as a result of inadequate financial resources, low fertilizer use and inadequate knowledge in modern farming practices and high risk of production. Farmers or farm households are responsible for crops cultivated, and breeding animals (Hordofa et al., 2008).

2.5.3.2. Modern rainfed farms

This type of farm is one of the largest specialized farms for the production of crops. They use fertilizers, machines and skilled labour. Specialized commercial agriculture farms have areas exceeding 20-50 hectares to meet local and international market requirements (Karwat-Woźniak & Sikorska, 2008).

2.5.4. Mixed rainfed farms (Mixed farming systems)

Mixed rainfed farms have the same characteristics as modern rainfed agriculture farms, but mixed rainfed farms invest in animal production by providing crop residues for the animal feeds and investment in the other agricultural sectors (Alemayehu et al., 2012).

2.6. Patterns of agricultural societies in Libya

There is no doubt that economic, natural and geographical circumstances control agricultural societies in addition to the type of agriculture (irrigated and not irrigated) and the size of population and area of the farm. The previously mentioned elements directly affect the forms of settlement in rural societies which are usually in the form of a separated farm, a village on the main road, linear village or gathered village. Hence, the people in Libyan villages are divided into many groups distributed over different areas in Libya in the form of:

2.6.1. Village society

This group represents about 20% of the population (Elbendak, 2008).Village society is a small village in which people work in official business in addition to some other economic activities in relation to agriculture and animal breeding.

2.6.2. Agricultural society

People in agricultural societies live on farms in modern houses built outside cities in the form of a long road village or linear agricultural village. This form of village in Libya usually starts with the gathering of some groups around service centre tents; later Government built free modern houses as part of the government-sponsored agriculture programs. Therefore, such programs have led to establishment of non-irrigated and irrigated farms. These villages are usually comprised of 100-150 farms attached with a house; the houses are built in groups of four houses, every two adjacent houses face another two adjacent houses on the opposite side of the road. In general, the population of agricultural societies forms 5% of the total population (Elbendak, 2008).

2.6.3. Pastoral society

This type of society includes nomadic Bedouins forming either villages or semi-villages (Elbendak, 2008). These are one of the newest settlement forms in the Libyan countryside after the construction of agricultural projects. Usually, a pastoral society is near minor roads and may include about 40 houses (Elbendak, 2008). Indeed, the Libyan pastoral society forms an origin of villages. In other words, the majority of the Libyan society is a rural society, as most of the Libyan people live in harsh environments, for example, 90% of the Libyan land is the Sahara Desert. Thus, the people, who live in Sahara settings, have strong social relationships; however, they usually avoid interacting with urban people who live in big cities in Libya such as Tripoli. The pastoral society constitutes about 3% of the Libyan population.

2.6.4. Oasis societies

People in Oasis societies usually live in sprinkled and isolated oases in the south, in stable but badly built houses made of bricks or palm leaves, working in primitive agriculture and animal breeding. Their life has changed for the better through the construction of modern houses and the provision of many services (Elbendak, 2008). The Oases population forms 4% of the total Libyan population.

2.7. Conclusion

In this chapter, a detail description of farming systems in Libya is provided. The chapter started with an overview of the general background of Libya, such as a growing population and its dominant arid geography and desert climate. The Libyan economy and the importance of agriculture to the Libyan economy were discussed. The impacts of reliance on oil revenues on the agriculture sector have been discussed, as well as the significant challenges faced by the agricultural sector. Generally, it has been demonstrated that the domestic food production does not meet demand, since the cultivation is limited by a lack of arable land and water. In addition, despite institutional support, the Libyan water department has not been effective and did not play a role in funding water development projects to cover Libya's water deficiency. Finally, major agricultural crops, farm systems and societies in Libya were presented and discussed.

Chapter 3
Economic Importance of Dates in Libya

3.1. Introduction

This chapter is designed to provide a detailed account of the economic importance and production of date palm in Libya. The chapter is divided into six sections. After this brief introduction, Section 3.2 describes date palms. This is followed by Section 3.3 in which the importance of dates as food is discussed. Section 3.4 focuses on the economics of dates in Libya while Section 3.5 outlines the constraints of date palm tree production. Finally, Section 3.6 presents a summary of the chapter.

3.2. Description of date palms

3.2.1. Origin of date palms

One of the oldest plants on the earth, which is cultivated by humans, is the date palm. The origins of the date palm are still unknown and controversial (Riad, 1996). Many researchers agree that date palm originated in the Arabian Gulf region (Al-Abdoulhadi et al., 2012). Date palm trees have been cultivated by man since ancient times. In Babylon times, for example, evidence was found of date palm use, which dates back to four thousand years BC. The ancient people used tree trunks and fronds for roofing their houses. The medicinal purposes and food value of the date were documented in several studies (Al-Shoaibi et al., 2012; Hoseinifar et al., 2015; Tang, Shi, & Aleid, 2013). In the Nile valley civilization, small seedlings were found around Sagar graves about 3200 years BC. In Egypt's Nile Valley, the date palm leaf was used in Egyptian hieroglyphics as a kind of symbol for a year, as well as a kind of symbol for a month (Dowson, 1982). Many ancient texts in religious books agree that palm tree dates were a fount of goodness and blessing and called “Blessed Tree”. In the Bible, supporters of Christ waved palm branches along the way when he entered Jerusalem. There are also several examples of evidence in the Islamic religion, which have indicated the importance of date and date palms.

For example, in the Holy Quran, dates and date palm have been mentioned in 17 chapters. In addition, the record of the teachings of Prophet Muhammad (peace be upon him) has shown that he encouraged the Muslim community to cultivate date trees and possess date palms. He also mentions that dates can cure many diseases and ensure food security to the Muslim nation (Abusta, Almthnani, & Al Mubarak, 2012). Very high consumption of dates occurs during the holy month of Ramadan; dates consumption increases as Muslims use date to break the daily fasting in Ramadan month. It is one of the annual events celebrated by Islamic communities which lead to high date sales in Islamic countries (Reilly, Reilly, & Lewis, 2010). Although date palm is broadly cultivated, no one has found wild plant. Progenitors believe that the origin place of date palm is in *Phoenix reclinata Jacq*, which is from tropical Africa or *Phoenix sylvestris (L). Roxb*, which is from India. Both *Phoenix reclinata Jacq* and *Phoenix sylvestris* have palatable fruits with inferior quality.

In past centuries, the cultivation of date palms spread into two distinct directions: from southwestern Asia and North Africa, through Arabic northern countries, such as Libya, Tunisia and Algeria, to the south countries, such as Sudan, Chad, Niger and Mali. The date spread can be noted from North Syria to South Yemen until the Indo-Iranian borderlands (Tengberg, 2012).

3.2.2. Botanical description of date palm

Dates *(Phoenix dactyliferal* L.*)* are a fruit of considerable economic significance that grow in different environments around the world (Agoudjil et al., 2011). Date Palm belongs to the *Arecaceae* family, which is one of the economically important date families (Yang et al., 2010). Dates are very high in nutritional value and contain minerals, protein, fats, carbohydrates, vitamins and dietary fibers (Agoudjil et al., 2011). Date palm tree consists of three parts, the root, vegetative and reproductive organs.

3.2.2.1. Roots

Palm is a monocot plant. The root system is fibrous, for example, a maize plant. Secondary roots can be seen on the primary roots, which grow from the seed. It should be noted that the secondary roots generate other roots of the same type; these roots have the same diameter in terms of their length (Zaid, 2002). In fact, the pneumatics, which are the respiratory organs, are shaped by date palm roots. The length of date palm roots are six metres in the vertical direction, however 85 per cent of the roots are horizontally distributed in the zone between 2 metres in different soils (Zaid, 2002). Hodel, Downer, and Pittenger (2009) reported that planting date palm trees too deep or too high may decrease root growth and harmfully affect the establishment of transplanted palms. It should be noted that date roots have an ability to withstand wet soil for a month, however if wet soil conditions spread for several months, conditions can become damaging to the health of the roots of date palms, as well as the fruit production. Hodel, Downer, and Pittenger (2005) reported that roots of date palms tend to be long during spring, summer and fall, while in the winter they become shorter.

3.2.2.2. Vegetative organs

3.2.2.2.1. Trunk

The trunk of date palms grows cylindrically and vertically and as it grows upwards. The height of the trunk varies from 10 to 30 meters depending on climate conditions, location, variety and soil; and particularly irrigation and farming practices, (Zaid & De Wet, 1999). Al-Suhaibani et al. (1988) reported tree height ranging from 4.38 m to 9.82 m with maximum and minimum values of 17.43 m and 1.00 m in different farms. Jahromi et al. (2007) reported height of trunk palms ranging from 1.44 to 10.32 m in different age categories of palms. The average annual growth of the trunk rate was 30-90 cm. The trunk consists of tough and fibrous vascular bundles that are consolidated together in a matrix of cellular tissues, as these tissues surround the date palm trunk (see Figure 3.1). The fibrous vascular bundles cover the trunk and bases until the top of the date palm, making it rough; however, these date palm trunks and bases become smoother when the palm becomes older. The date palm’s growth is correlated with its terminal bud (i.e., phyllopod) that has an average height of 20 metres. In the summer period, the trunk contains a suitable amount of carbohydrates and starch for the growth of fruits. Figure 3.1 shows a date palm tree.

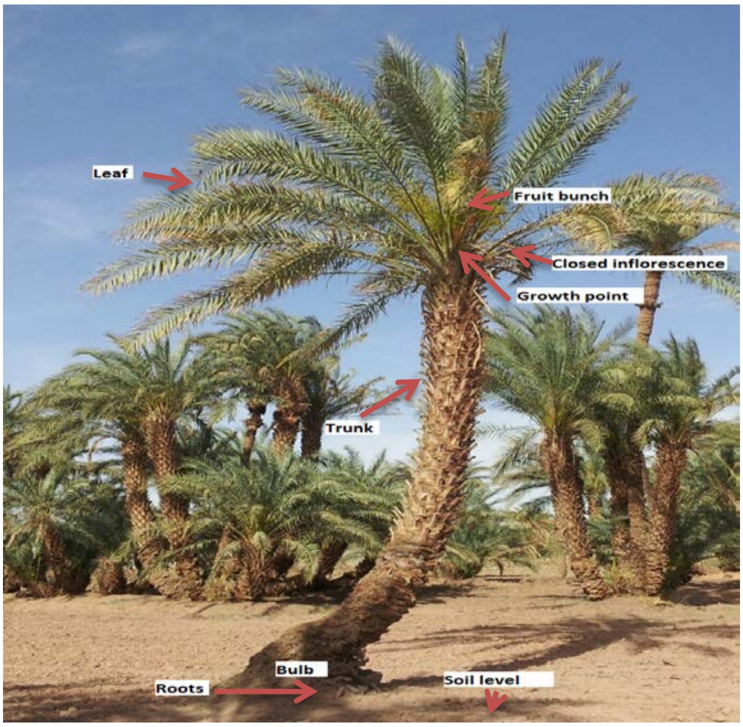

Figure 3-1: Different parts of a date palm tree.

3.2.2.2.2. Leaves

A date palm has feathery leaves ranging in length from 3 to 6 meters, and has a regular life of 3 to 7 years (Mashhadani, 2014; Shamsi & Mazloumzadeh, 2009). One palm tree can ideally carry about 30-150 leaves depending on environmental conditions (Ibrahim & Sinbel, 1989). The average annual production of palm leaves is from 10-20 leaves. In contrast to other fruit trees, old leaves of date palm are not shed and do not drop on their own; however they need to be removed by the farmers. One date palm typically has just about 100 to 125 leaves with a yearly rate from 10 to 26 new leaves (Zaid, 2002). In Saudi Arabia, Hussein, Moustafa, and Kahtany (1977) studied the impact of leaf ratio on fruit quality and yield of Barhee date palm and found that size, fresh weight, pulp weight and moisture content of fruit tended to increase with the number of leaves. Furthermore, old leaves are less active than the young ones but removing the old leaves has no harmful effect on date palm tree productivity (Nixon & Wedding, 1956). However, green leaves of palm assist the photosynthetic process (Al-Sekhan, 2009). The date palm's leaves remain attached to the date tree until the leaves become senescent and die. The farmer then has to manually prune these leaves. Figure 3.1 shows different parts of a date palm tree.

3.2.2.3. Reproductive organs

3.2.2.3.1. Flowering inflorescences

Date palm consists of male and female flowers, that is, it is a dioecious and separate plant (Al-Muhtaseb & Ghnaim, 2006). The male and female flowers are arranged as clusters and are grown between axes of the previous year leaves (spadix). Spadix involves an essential stem, which is named as rachis or spikelets that are ranging from 50 to 150 lateral branches; they differ with growth and age of trees. The length of spadix also varies among varieties and average between 25 to 10 cm. The annual number of spathes of date palm is from 9 to 25 in females, with the number of spathes in males greater. Branches of the inflorescence of the female palm are less densely crowded at the end of the rachis; however, the inflorescence of a male palm is more densely crowded at the end of the rachis. The inflorescence of a male palm is wider and shorter than the inflorescence of the female palm (Zaid & De Wet, 1999).

3.2.2.3.2. Spathe

The early stages of growth of the inflorescence of date palm trees are covered by a hard coverage (spathe). The spathe splits and opens the flowers. The spathe then exposes the entire inflorescence for the pollination season (Farboodniay et al., 2014; Masmoudi-Allouche et al., 2009). The delicate flowers of the date palm are protected by the spathe, as the intense heat leads to shrivelling up of these flowers until they have become mature and ready to execute their functions (Farboodniay et al., 2014; Masmoudi-Allouche et al., 2009) Figure 3.2 shows a hard covering on a date palm tree.

3.2.2.3.3. Spikelet

A huge number of tiny flowers are carried by the spikelet, as these tiny flowers account for about 8,000 to 10,000 in female palms and more in male palms (Zaid & De Wet, 1999). Figure 3.2 shows the spikelet on a date palm tree.

Figure 3-2: A hard covering and spikelet on date palm tree

Source: Tazbeet (2015)

3.2.2.3.4. Flowers

The male flower usually possesses six stamens, and their waxy scale-like petals and sepals surround the flower (Zaid & De Wet, 1999). Each stamen consists of two small yellowish pollen sacs. On the other hand, the female flower possesses a diameter of approximately 3 to 4 mm and possesses three carpels and rudimentary stamens firmly pressed together and the ovary. The three petals and three sepals are combined in order to diverge only at the tip. When the female flowers are opening, there will be a yellow colour that becomes clearer and more intense, while in the male ones, the white colour becomes more obvious, like white dust. After the bursting of the spathe, the pollen sacs normally open within an hour or two hours. Only one ovule per flower can be fertilised; this can bring about the development of one carpel that sequentially gives a fruit, which is known as a date (Zaid & De Wet, 1999).

3.2.2.4. Dates

Date plants bear fruit usually 3 to 4 years after planting (Ali, 2010). The growth of date fruit may be divided into four stages with Arabic names; these names have been used internationally by several authors including (Ali, 2010; Shabana & Al Sunbol, 2006). The first stage is called *Altalaa'* stage that lasts for 3 to 5 weeks. The date in *Altalaa'* stage is small and covered with glue. The *Kimri*' stage can be described by hard, green and immature dates that ripen rapidly (Al-Shahib & Marshall, 2003; Besri, 2010). *Khalal'* stage or fresh date is where the colour of the palm dates transforms from green colour to yellow colour and finally to red colour; however the transforming process relies on the cultivar. Some consumers prefer to eat date at this stage, especially in coastal areas in Libya (Al-Shahib & Marshall, 2003; Ashraf & Hamidi-Esfahani, 2011). *Rutab'* stage or ripe dates is when the date begins to ripen, where it changes to the dark color or black after 2 to 4 weeks. *Tamr'* stage is fully mature and ready to be harvested. The skin of the fruit is soft and semi-dry or dry. At this stage, the date contains more sugar and has lost moisture. However, most date varieties, if not pollinated, may not reach *Tamr'* stage (Al-Shahib & Marshall, 2003; Ashraf & Hamidi-Esfahani, 2011). Figure 3.3 shows different stages of the growth of dates.

Figure 3-3: Stages of the growth, development and ripening of dates

3.3. Importance of dates

3.3.1. Nutritional value

Dates are considered as a worthy source of human food because of their high nutritional value. In actual fact, the date palm fruit is rich in nutrients because of its dietetic values that have been held in high regard by consumers compared to other kinds of fruits. Dates provide more than 3,000 calories per kilogram. In addition, date fruit consists of 70 per cent carbohydrates (mainly sugars including glucose and fructose), this making the date one of the most nourishing natural foods to people. The date sugars are easily digested and can be moved to the blood. They can be metabolized to release energy for various cell activities (Mohamed Al-Farsi et al., 2005; Al-Shahib & Marshall, 2003; Khan et al., 2008). The water content of the date is between 15 to 30 per cent depending on the variety and the maturity stage of the date fruit. The main flesh of dates contains between 60 to 65 per cent sugars, approximately 2.5 per cent fiber, 2 per cent protein and less than 2 per cent each of minerals, pectin substances and fat. Date fruits can be also considered as an excellent source of minerals, for example, iron, calcium, potassium and sodium; coupled with low fat content. Furthermore, there are moderate quantities of chlorine, copper, silicon, phosphorous, magnesium, selenium and boron (Mohamed Al-Farsi & Lee, 2008; Ali-Mohamed & Khamis, 2004) in dates. Date fruits are very rich in phosphorous content similar to that found in apricots, pears and grapes together. A date is considered as useful food in the treatment of brain cancer; for the reason that the date has a high content of magnesium, which contains ±600 mg per 1kg of dates. Date consumers in desert regions are identified to possess the lowest percentage of cancer diseases; this is due to the large quantity of magnesium that is found in dates. In addition, dates are considered as good food, because the dates have a low sodium content, which is only 1 mg of sodium per 100 g. Dates also contain about 3 mg per 100 g of iron; this quantity is just about a third of the Recommended Dietary Allowance for an adult male. It is high in fiber which is of good high value because it can play a role in keeping the digestive system healthy. There is evidence that shows most dates are very good for people and a diet fairly high in fiber is better than one low in fiber. Additionally, fresh dates have a higher source of vitamins compared to dry dates. Dried dates can be regarded as moderate sources of the vitamins riboflavins pyridoxine, nicotinic and folic acid, following by thiamin, vitamin A and C (ascorbic acid). The level of protein in date fruit is about 2.37g. On average, the flesh of date fruit contains 1.7 per cent protein on fresh weight basis and varies among cultivars and harvest maturity. Table 3.1 shows the average nutritional value of dates.

Table 3-1: Nutritional value of dates

Average Nutrition Value*	Per 100g
Energy Calories	349
Vitamins	A, B and C
Sodium	12 mg
Protein	2.37g
Potassium	667 mg
Phosphorus	60 mg
Magnesium	50 mg
Iron	1.2 mg
Glucose	48.5g
Fructose	35.5g
Fat	0.43g
Carbohydrates	87.4g
Calcium	52 mg

Source: Reilly et al. (2010).

* Average of nutritional values depend on the date varieties.

3.3.2. Food and other industries

Dates are an important element in food preparation in Libyan communities, and are used in snacks, confectionery, baking products and delicatessen e.g., pastry, beverages, salads. Dates are also used in canned products, for example, chocolate-coated, macerated chips, fully pitted dates, extruded date pieces, date paste, diced dates, date paste mixtures, dehydrated dates, date flour, stuffed dates, date jams, condiments, date preserves, caramel, date butter and date desserts. Moreover, there are some derivatives from date fruit products such as liquid sugar and date juice for soft drinks, fermented products such as vinegar, wine, alcohol and organic acids (Anjum et al., 2012).

Parts of palm trees are used as a source of local industries in Libya. For example, palm trunks are used in staircases for houses and huts. The stem is utilised for enveloping the roof of rural houses and producing boats, as well as paper and wood industries. Date palm trunk fiber is used in the production of starch and sugar, ropes, stuffing in seats, mattresses, filters and pot scourers. Palm leaves are also used to produce huts, furniture, cages, shading and packaging, insulation and cladding floors (Anwar, 2006). Leaflets are mainly used to make bags, hats and hand fans (Figure 3.4). According to Ashraf and Hamidi-Esfahani (2011, p. 101), the foliage of date palms is used in making handicrafts such as fans and straw hats. They are also used for wax production for cars and furniture polishing. In addition to the production of vinegar, ground seeds provide animal feed. Palm tree material is also used in the manufacturing of vegetable oils, dyes and fertilizers (Anwar, 2006).

Figure 3-4: Leaves are used in industry for manufacturing bags, hats and hand fans

3.3.3. Environmental benefits

There are many environmental advantages of planting palm trees in most countries. According to previous studies, date palms have the ability to maintain an environmental balance in some Arab countries, for example, Libya. The first advantage of date palm in the environment is that the date palms play a significant role in fighting desertification and contributing to the appearance of rural or desert communities (Sharif et al., 2010). Additionally, date palm trees, which are established as forests and oases in desert regions can lead to reducing temperature and preventing movement of sand dunes to the coastal cities. As a result, this can play a role in combating climate change (Khairi, Elhassan, & Bashab, 2010; Sharif et al., 2010).

Palm trees have an ability to grow in areas that utilise less water mainly in the areas that are desert and semi-desert. Palm trees need little amounts of water for irrigation compared to other plants (Sharif et al., 2010). Palm fibers are also used as an alternative to plastic materials, because the palm fibers have a rapid decomposition, thus preserving the environment (Stark & Rowlands, 2003).

Palm trees provide equilibrium and stability of ecosystems in dry and desert regions. Also, favorable environmental conditions help in the success and expansion of cultivation of palm trees, especially in the central and southern regions and the oases (Aoda, 2011; Awad & Al-Qurashi, 2012a).

Finally, date palm can grow in different types of soils. Thus, it can give aesthetic and tourism value to coastal cities, because, they bear the salt concentration in soil and irrigation water to reduce air pollution. For instance, in Jordan, the problem of heavy metal pollution in an urban area has been addressed by cultivating palm trees on road shoulders, as well as in residential and industrial areas (Al-Khlaifat & Al-Khashman, 2007).

As has been demonstrated above, date palm does not only provide fruit that has nourishing food, but the date can be preserved and carried over long distances, particularly in dry periods or climates. Palm can also provide an appropriate site for the settling of nomadic individuals by generating shade and protecting people against strong desert winds. Palm trees are also used for landscaping and beautification of the Libyan cities, for example, streets, plazas and parks (Al-Mana & Ahmad, 2010).

Figure 3-5: Pictures from South Libya showing efforts to control desertification through the use of date palms

3.4. Economics of date production in Libya

3.4.1. Production of Libyan dates in the world

Dates are grown in more than 50 countries in the world particularly in the Middle East and North Africa region, which accounts for approximately more than 75 per cent of world production (El-Juhany, 2010). Dates are grown over an area of 1 104 596 million ha in the world, with an annual production of 7 548 918 million tons (FAOSTAT, 2014). Presently, among the different date-producing countries, Egypt dominates date production with 21.8 per cent of the total production in the world, followed by Iran, Saudi Arabia, Algeria and Iraq which contribute about 15.8 per cent, 15.6 per cent, 11.7 per cent and 9.6 per cent respectively (see Figure 3.6).

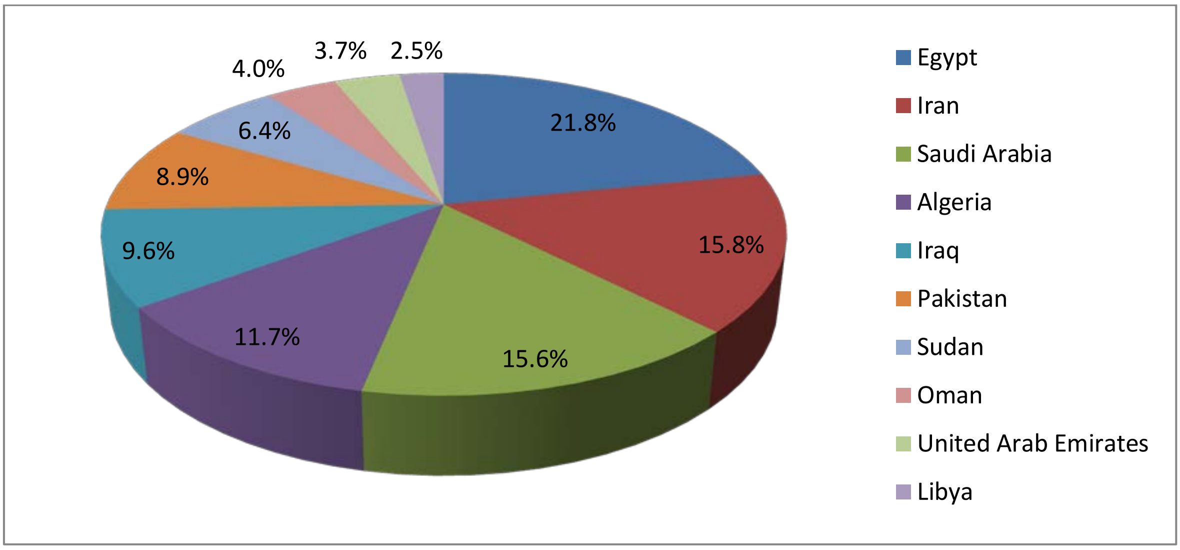

Figure 3-6: Position of the production of Libyan dates in the world (2012)

Source of basic data: FAOSTAT (2014)

The next five most important countries include Pakistan, Sudan, Algeria, Oman, United Arab Emirates and Libya, which contribute about 8.9 per cent, 6.4 per cent, 4 per cent, 3.7 per cent and 2.5 per cent, respectively. Libya is the tenth date producing country in the world for 2012 as shown in Figure 3.6. Kader and Hussein (2009) stated that in 2006, the world production of dates was approximately 7 million tonnes. The top three date producing countries were Egypt, Saudi Arabia, and Iran, followed by UAE, Pakistan, Algeria, Sudan, Oman, Libya and Tunisia. The total world date production has risen by 2.9 per cent in the last decade; however export of dates has only increased by 1.7 per cent in the same period. This indicates that there is an increase in the demand for palm dates (Al-Shahib & Marshall, 2003).

3.4.2. Average Libyan dates exports and imports in the world (2000-2011)

The United Arab Emirates ranks first in the world in quantity in date exports (164 119.3 thousand tonnes) worth US$ 41 855 million (FAOSTAT, 2014) (Figure 3.7). Pakistan and Tunisia are the second and third major exporting countries (89 956.17, 55 714.08 thousand tonnes) with average value of about US$ 34 771.75, US$ 121 185.8 million followed by Algeria, France, Egypt, United States of America, EU countries, The Netherlands and Libya, with average date exports (12 093.67, 9 366.67, 7 831.83, 3 900.75 1 997.75, 1 671.67 and 135.3 thousand tonnes, respectively and values of 17 372.8, 24 288.8, 7 224.3, 17 771.7, 6 042.3, 6 316.2

and 76.83 US$ million, respectively. These countries export their surplus and re-export imported dates.

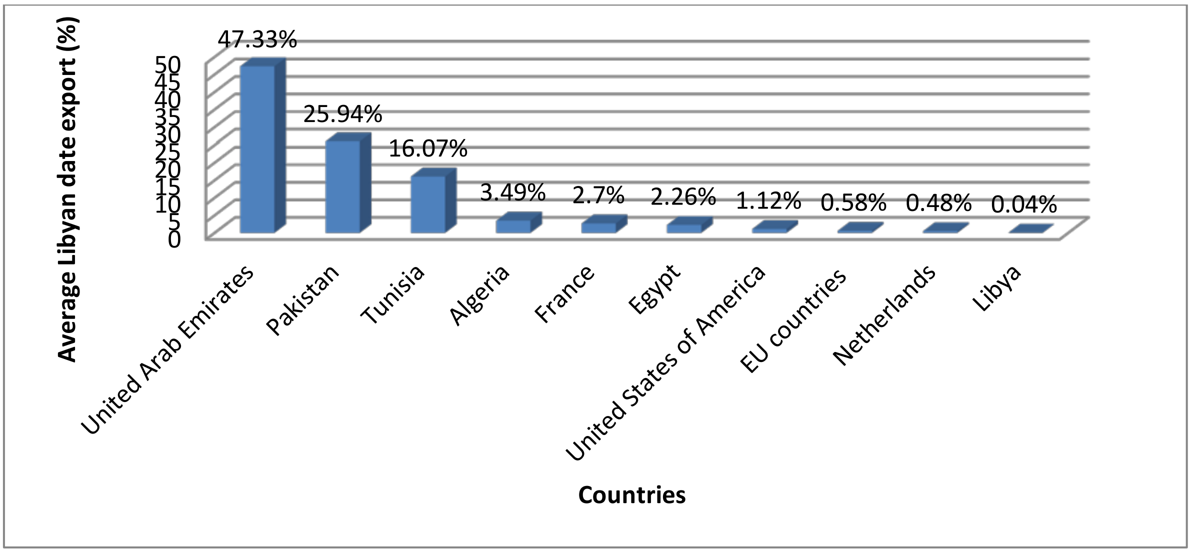

Figure 3-7: Average Libyan date export in the world 2000-2011

Source of basic data: FAOSTAT (2014)

Mbaga et al. (2011) found Tunisia accounts for only 1 per cent of world date production; however, it is ranked as the first country in terms of the value of date export and the fourth country in terms of the quantity of date export. This is primarily because of the high value of the Deglet-Nour variety in the market, which is well appreciated in foreign markets and is a good quality product, leading to higher market share. Elsabea (2010) claimed that the United Arab Emirates plays an important role in exporting and re-exporting dates especially to American countries, Asian countries and Europe by activating a complementary strategy with Saudi Arabia and concentrating on consumer's needs for fresh, dried and semi dried dates; as well as manufactured dates.

India and the United Arab Emirates are the first and second major date importing countries (234 108.9 and 6 888.33 thousand tonnes, respectively) with average value of about US$ 68 463.33 and US$ 248 222 millions , respectively. The EU countries accounted for approximately 13.4 per cent of the major world date importing countries as shown in Figure 3.8, with total quantity of 65 512.5 thousand tonnes equivalent to US$ 145 468.3 million. This is because EU countries (except Spain which has very small quantity) do not produce dates. They also re-export imported dates to countries including China and Singapore (Dada et al., 2012), whilst, France, the United Kingdom and Italy accounted for 9.21 per cent of total EU imports of dates in volume.

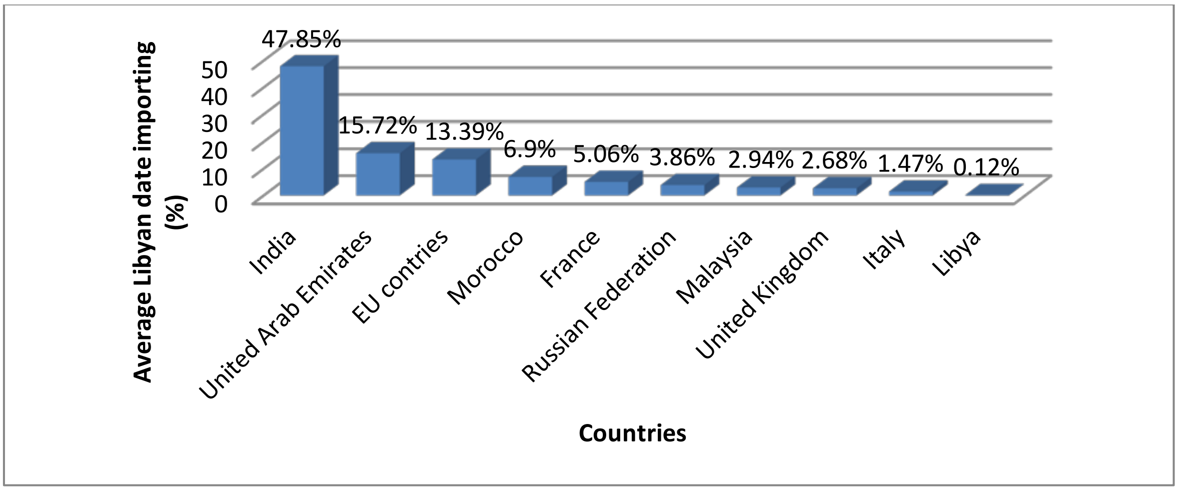

Figure 3-8: Average Libyan date importing in the world 2000-2011

Source of basic data: FAOSTAT, (2014).

Morocco, one of the date producing countries in the world, has not achieved self-sufficiency in dates. Non-producing countries, especially the emerging markets in East Europe, Australia and Canada are promising as potential markets for date palm producing countries. Markets for date producers can increase the present demand, supported by the awareness of the nutritional value of dates (Salem, 1998). However, the figures on the average annual imports of Libya showed that imports accounted for 0.12 per cent. This decline corresponds with an increase in their average production in the same period (2000 - 2011).

3.4.3. Libyan exports and imports of dates (2000-2012)

Libyan date exports were the highest in 2000, which was 352 thousand tonnes (US$ 230 thousand). This happened due to the high date supply in local markets which caused increased export of date palm products such as concentrated energy food in international markets especially Turkey, Italy, Germany and Spain. After 2004, date palm production in Libya decreased. As a result, date palm exports from Libya to the world market decreased about 32 thousand tonnes (US$ 56 thousand) in 2012. Figure 3.9 shows the date palm exports in Libya from 2000 - 2012.

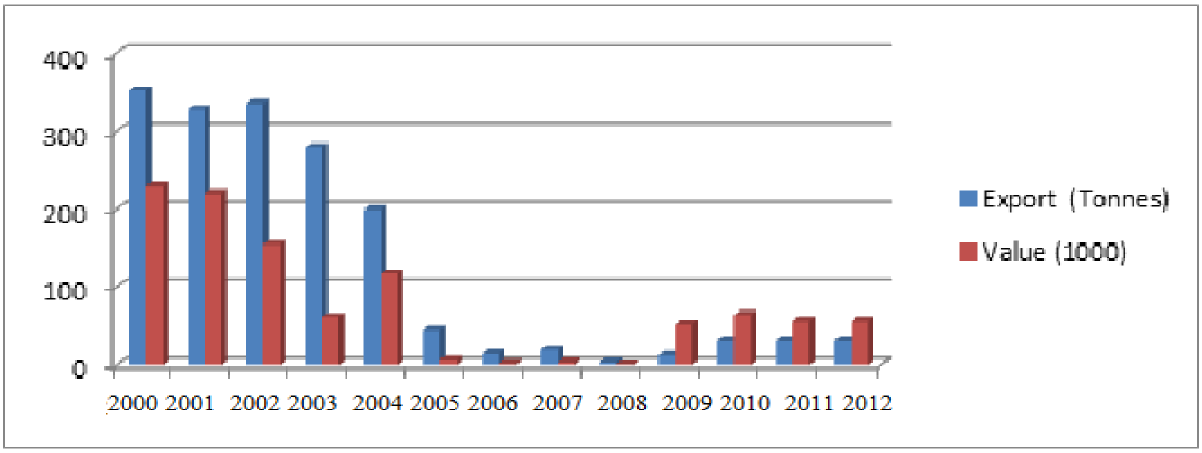

Figure 3-9: Date exports in Libya during 2000-2012

Source of basic data: FAOSTAT (2014).

Libyan date imports varied greatly over the period 2000 to 2012. In 2000, date imports were 54 thousand tonnes (US$ 166 thousand) and reached a high of about 2 228 thousand tonnes (US$ 2 392 thousand) during 2010. In 2003 to 2006, date imports decreased gradually and 8 thousand tonnes (US$ 13 thousand) were imported in 2005, due to lower date production and short supply of dates in Libyan markets. Date imports increased gradually to about 599 thousand tonnes (US$ 685 thousand) in 2007 while imports during 2012 were recorded as 1014 thousand tonnes (US$ 1 581 thousand).

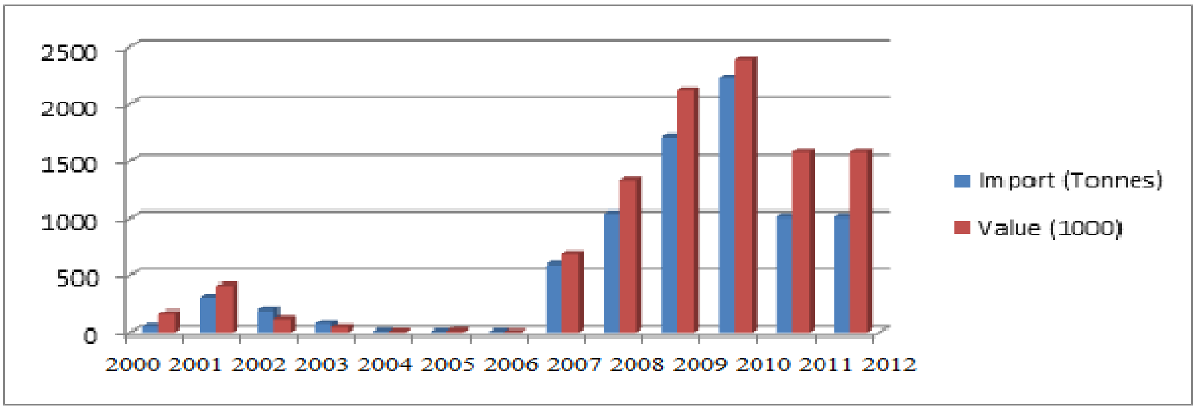

Figure 3-10: Date importing in Libya during 2000-2012

Source of basic data: FAOSTAT (2014).

3.4.4. Distribution of palm trees in Libya

Libya is strategically located in Africa's North Gate. The Mediterranean climate decreases as one moves further from the coast, closer to the desert. Libya is a suitable area for palm production. In Libya, date production starts from mid-summer (June) and extends for the period of maturation of dates until the end of February. The average production age of palm tree (fertility and production-wise) is about 6-20 years. Moreover, date palm trees are perennial and can live to about 150 years (El-Lakwah et al., 2011). Hence, Libya is one of the optimum regions of the world for the production of the high quality dates throughout the year. A palm tree census in Libya estimated about 8.3 million palm trees with more than 400 different date varieties. According to Racchi et al. (2014), Libyan dates are an important genetic resource material for hybridization and the development of better varieties and varieties resistant to diseases. The number of date palms is increasing at a rate of 500 thousand seedlings per year. Unsurprisingly, Libya is second ranked in terms of number of varieties.

Dates can be classified according to the morphological and fruit characteristics at harvest by area of production: Coastal region: stretching from east to west Libya. Most varieties in this region are fleshy-fruited varieties. The total number of palm trees is around 1.8 million. Oases in the Central region which are best for date production include Al-Jaghboub Oasis east then Jfara (Waddan, Hun and Sukna) and Gadames in the west. Semi-soft varieties are famous in the Central regions. The total number of palm trees at these oases is about 3.5 million trees. The South region is located on a large geographical area in Libya including Wadi al-Shati, Murzuq, Wadi al-Ajal, Sebha and Ghat. The less succulent varieties are in the southern regions. Palm tree census of these areas is about 3 million palm trees. Figure 3.11 shows date growing regions in Libya.

Figure 3-11: Major date growing regions in Libya

3.4.5. Total date production in Libyan municipalities

Most areas of date palm production in Libya are located in the Central and Southern regions. In 2007, Al Wahat was the highest date producing area, accounting for 41.5 per cent by volume of domestic production (421.097 thousand tonnes), followed by Wadi al-Shati (144.603 thousand tonnes), Murzuq (101.311 thousand tonnes) and Al Kufrah (85.729 thousand tonnes) which were also significant date producers accounting for 14.2, 9.97 and 8.4 per cent of total production, respectively. Sabah is the fifth largest date producing area contributing 8.1 per cent of total date production in the country with 82.041 thousand tonnes. Jfara (79.462 thousand tonnes), Misratah (51.999 thousand tonnes) and Wadi al-Ajal (49.532 thousand tonnes) were 7.8, 5.1 and 4.9 per cent respectively. The total production was 1, 015, 774 thousand tonnes during 2007-2008 (Table 3. 2).

Table 2-3 : Total date production in Libyan municipalities (2007-2008) [2]

Municipalities	Production (thousand tonnes)	Share (%)
Al Wahat	421 097	41.5
Wadi al- Shati	144 603	14.2
Murzuq	101 311	10.0
Al Kufrah	85 729	8.4
Sebha	82 041	8.1
Jfara	79 462	7.8
Misratah	51 999	5.1
Wadi al- Ajal	49 532	4.9
Total (Libya)	**1 015 774**	**100**

Source: Libya Statistic (2007)

Libya has a comparative advantage in terms of labour and low salary, and land availability, compared to other countries that produce dates. Based on data of the Libyan Date Centre (2007), the largest share of date palm numbers is found in South Libya, which represents 43.8 per cent of the total date palm trees in Libya. The Libyan government has announced the existing date palm expansion by 86 350 palm trees under 16 date palm projects at different Sebha areas in South Libya (Sager, 2013). There are more than 50 date palm cultivars that include soft, semi-dry and dry fruits grown in Sebha areas (Ahmodi, 2013).

3.4.6. Date production and area harvested in Libya 2000-2012

According to the Food and Agriculture Organization (2014), the total production of dates in Libya during 2000 to 2012 was approximately 2 064 469 thousand tons. In 2000, the production of dates had increased from 120 thousand tons to 140 and 200 thousand tons in 2001, 2002 and 2003, respectively (FAOSTAT, 2014). However, there was a decrease in date production from 200 to 150 thousand tons between 2004 and 2008 (FAOSTAT 2014). Rajab (1982) explained that variation in the average productivity of date palm in Yemen, Saudi Arabia, Tunisia, Algeria, Oman, Iraq, Libya and Morocco was due to the use of allocated resources for the production of dates. However, Libya is ranked tenth in date production in the world with 2.5 per cent of the total production in the world (FAOSTAT, 2014). The date fruit that is produced mainly in the hot, arid parts of Libya is marketed all over

[2] Due to Libyan civil war (2011), the Libyan Statistic Office has not been updated data about total date production in Libya municipalities until now.

Libyan cities as a fruit crop and high-value confectionery. Date crop remains particularly important in most of the desert areas in Libya. Estimated date production in Libya during 2000-2012 is given in Figure 3.12

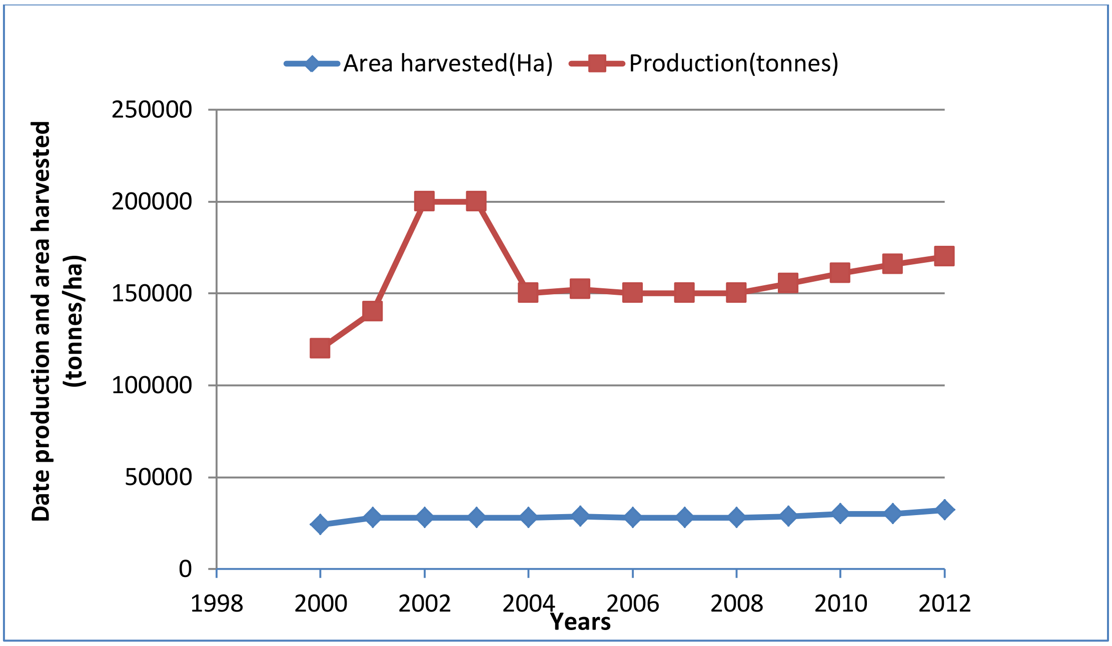

Figure 3-12: Date production and area harvested in Libya 2000-2012 (tonnes/ha).

Source of basic data: FAOSTAT (2014).

Shown in Figure 3.12 is the area of dates harvested in Libya during 2000-2012. The area harvested was 24 000 thousand per hectare in 2000, which increased gradually to 28 000 thousand per hectare during 2003, 2004, 2006, 2007 and 2008, respectively (FAOSTAT, 2014). The highest area harvested was 32 000 thousand per hectare in 2012. The average for the period 2000-2012 was 28 422 thousand per hectare annually. The increasing area of date palm production was due to expansion in the cultivation of seedlings in many projects by the Libyan Development Date Palm Centre (Libyan Date Centre, 2007). Libya is currently considering planting one million trees of high quality varieties annually for the next five years in order to boost the production of date palms. The country will be able to increase export dates in the world market and thus generate foreign currency earnings. It is expected that farmers and the economy as a whole will benefit from this expansion in the cultivation of date palm trees (Libyan Date Centre, 2007).

3.4.7. Date productivity in Libya 2000-2012

The productivity of date palm in Libya during 2000-2012 is shown in Figure 3.13. As shown in the figure, date productivity has been increasing annually but there was no significant increase during 2000 - 2012 as shown in Figure 3.13. It rose substantially in 2002 to 2004 with an average of 6.53 tons per hectare. All this increase has been due to expansion in area planted, rather than increase in yields. This implies that the growth in date productivity in Libya is caused by the expansion of the area under date palm cultivation (Libyan Date Centre, 2007). However, productivity declined from 7.1 tonnes per hectare in 2003 to 5.4 tonnes per hectare in 2012. The reason for the declining trend of productivity is mainly the change of cropping pattern and low number of date farms in Libya during the last few years (Madhusudhana, 2013). Due to the increase in the Libyan population, there is currently little scope for expanding date production through expansion in cultivated land (Libyan Date Centre, 2007). The government has to establish a date palm settlement scheme and develop a specific policy to increase the productivity of the private sector, as an increase in food production is needed to keep pace with the population growth rate (Dada et al., 2012).

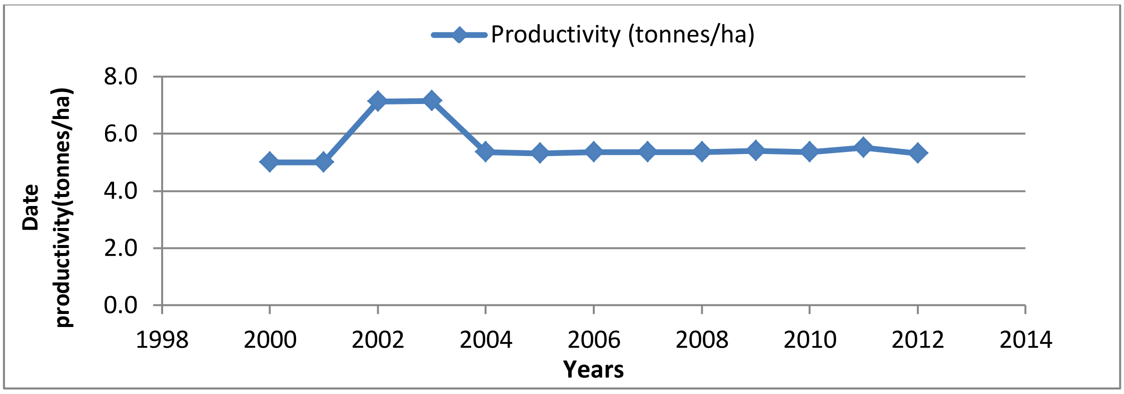

Figure 3-13: Date productivity in Libya 2000-2012

Source of basic data: FAOSTAT (2014).

3.4.8. Average per capita consumption of Libyan dates

A large number of Libyan people consume dates as the main component of their meal at least once or three times a week (Ishrud et al., 2001). Ezat, Mohamed, and Eldoklal (2007) found that consumption of date in three Islamic countries; Saudi Arabia, Emirates and Libya were the highest at 33.5, 17.5 and 14.5 kg per year, respectively. Recently, a study on per capita consumption of dates found that Emirates, Libya, Algeria and Egypt had per capita consumption of 17, 15, 14 and 13 kg per year, respectively (Siddiq & Greiby, 2013). The average date per capita consumption in Libya from 2000-2012 is shown in Figure 3.14. Date consumption in Libya averaged 27.99 kg per person annually from 2000-2012. Date consumption rapidly increased by 37.45 and 36.88 kg per person in 2002 and 2003 respectively. In 2008, the consumption of dates decreased by 25.52 kg per person. This is due to the reduced domestic production and higher prices. However, date consumption increased by 27.62 kg per person in 2012 (Figure 3.14).

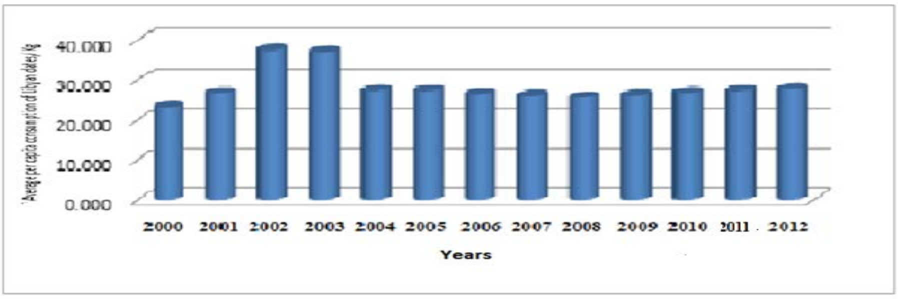

Figure 3-14: Average date per capita consumption in 2000-2012

Source of basic data: FAOSTAT (2014).

3.4.9. Contribution of date palm to the Libyan agricultural economy

Dates are one of the international agricultural commodities for Libya. According to FAO (2014), date palm was the most significant agricultural export of Libya (FAOSTAT, 2014). Libya has expanded date palm plantation since 2005, through labour-saving methods, modern irrigation systems and industrialization of dates (Al-Marshudi, 2002). For instance, South Libya is the largest producer of date palms and contributes about 65 per cent to date palm production in Libya (Ahmodi, 2013). Currently, locations of date palm expansion are in South Libya, for environmental reasons and the availability of land (Wani & El-Ammari, 2001).

Date palm industry contributes to the Libyan agriculture sector particularly through significant contributions of agricultural smallholders and rural communities. In terms of the economic contribution of date palm to the Libyan agricultural economy, Table 3.3 shows that between 2000 to 2012, date palm significantly increased in terms of its share in the agricultural sector. Date palm has a higher share of the agricultural sectors in 2000, 2001, 2002 and 2011 at 12.78, 12.64, 9.19 and 6.53 per cent, respectively.

Table 3-3: Contribution of date palm as percentage of total agricultural economy (2000-2012)

Years	Agriculture $US million(1)	Date palm income $US thousand (2)	% (2/1)
2000	1799.63	230	12.78
2001	1740.00	220	12.64
2002	1686.00	155	9.19
2003	1718.75	62.0	3.61
2004	1799.13	117	6.50
2005	1942.50	7.00	0.36
2006	2053.88	2.00	0.10
2007	2381.63	4.00	0.17
2008	2809.88	1.00	0.04
2009	2382.70	52.0	2.18
2010	2505.01	65.0	2.59
2011	857.48	56.0	6.53
2012	1160.86	56.0	4.82
Total	**24837.49**	**1027.0**	**4.13**
Average	**1910.58**	**13.4**	**-**

Sources: Economic Bulletin of the Central Bank of Libya (2013). FAOSTAT (2014)

Date palms also contribute to rural development in Libya. Date palm expansion in Libya creates job opportunities for rural societies. In some areas, date palm is considered as the dominant sector that contributes mainly to the GDP of the local economies, such as in South Libyan regions. Moreover, the date palm industry is considered as a labour intensive sector; thus, it significantly contributes to employment in rural societies or areas. The middle and south of Libya represent the most important date palm cultivation regions in the country, where extensive date palm cultivation in the last two decades represents the main income of date farmers (Wani & El-Ammari, 2001). Aayd (2001) stated that the date palm industry in Libya can generate employment and increase income for people in rural areas. Aayd (2001) mentioned that the date palm industry in South Libya can also provide a secure income for farmers.

Another key contribution of the date palm sector is on smallholders. In 2002, date palm industries contributed to an increase of date manufacturing from 108.48 to 221 tons (Aayd, 2001). The Libyan government implemented several supporting programs for rural persons who engage in date palm plantation. These programs established networks and cooperation between smallholders and private estate firms of date palm plantation. The programs are established by the Libyan Export Promotion Centre (LEPC) that gives tractors to farmers who are working in date palm plantation as an incentive (Libyan Export Promotion Centre, 2013). These programs were successful, since in 2013 the number of farmers who work in date palm plantations increased significantly.

3.4.10. Contribution of date palm to the income of agricultural labour

Date palm is one of the most important means of livelihoods of Libyan farmers. It plays an active role in the agricultural economy and cultural heritage of local populations (Al-Khayri, Jain, & Johnson, 2011). There were different economic returns from the cultivation of date palms in Libya. The highest average annual income was US$ 2.13 and US$ 2.12 per man-labour in 2000 and 2001, respectively; while the lowest income was about US$ 0.01 per man-labour in 2008. The total average palm tree annual contribution to agricultural labour income was US$ 0.87 per man-labour during 2000-2012 (Table 3.4). In addition, the farmers can improve their revenue by selling other palm products such as leaves and small seedlings.

Date palm has become an economic crop that can contribute to GDP and help reduce poverty in Libya. It was observed that Libya is listed among the date palm producing nations in the world. However, reports from FAO (2014) provide evidence to suggest that there is a stagnation or continuous decline in the level of date palm production over the last few years which have resulted in a decline in export and income. For Libya to reach its full potential, the commercial development of date palm products is imperative. Therefore the government should establish a date palm settlement scheme and develop policies in partnership with the private sector to increase productivity in date palm chains of date palm production.

Table 3-4: Contribution of date palm on income of agricultural labour (2000-2012)

Years	Total agricultural *labour/thousand(1)	Date palm income US$ thousand (2)	Average income (2/1)
2000	108.0	230	2.13
2001	104.0	220	2.12
2002	101.0	155	1.53
2003	97.00	62.0	0.64
2004	93.16	117	1.26
2005	91.00	7.00	0.08
2006	88.89	2.00	0.02
2007	86.83	4.00	0.05
2008	86.83	1.00	0.01
2009	84.82	52.0	0.61
2010	82.85	65.0	0.78
2011	80.93	56.0	0.69
2012	80.93	56.0	0.69
Total	**1186.24**	**1027.0**	**0.87**
Average	**91.23**	**13.4**	**0.15**

Source: Economic Bulletin of the Central Bank of Libya (2013)
*This is including date palm farmers and other farmer's.

3.5. Constraints of date palm trees production in Libya

In Libya, underground water is the main water resource, however; it can be noted that over-extraction is consuming most of the water resources. In North Libya, for instance, there is an increase in the seawater intrusion along the coast, and many wells are drying up. Salinity in the fresh water aquifers is significantly growing year after year as reported by Bindra (2013). The high salinity in the fresh water has devastated all pomes trees, the citrus orchards and other types of fruits. One main reason that is responsible for these problems was the transformation of areas of land and rainfed agriculture into irrigated farms to grow different crops that require large quantities of water e.g., watermelons, peanuts, citrus and tomatoes. There are huge underground water resources in South Libya, however, the key problem is that these resources are situated in the middle of the desert. Furthermore, the soils that are pure sand do not have organic matter and have extremely poor water and nutrient holding capacity (FAO, 2009). The Sebha region suffers more dry months within a year and unpredictable weather patterns. Abusta et al. (2012) reported that the poor irrigation infrastructure for sustainable development in Sebha during the past 25 years led to a decline in underground water at the rate of more than one meter per year due to excessive increase in the use of water. Financial institutions like rural banking and rural cooperatives provide affordable funds for farmers to improve irrigation systems and other agricultural outputs.

The major constraints of date palm tree production and cultivation are:

3.5.1. Water demand

Countries in the North African region including Libya suffer from severe water shortages (Wheida & Verhoeven, 2007). According to Bhat, Bhat, and Lekha (2012) water use by date palms under arid and semi-arid areas in North African countries record different averages. In Morocco, the irrigated water average is 16 500 m^3 per ha, followed by Algeria and Tunisia at 15 300 m^3per ha and 23 600 m^3 per ha, respectively. However, Libya utilizes a higher volume of irrigated water at 18 750 m^3 per ha for irrigated date palm trees (FAO, 2007). The huge increase in the area of agricultural land and the limited precipitation has put a significant pressure on groundwater usage. Abusta et al. (2012) pointed out that groundwater levels in Southern Libya, such as Sebha, Wadi al-Shati and Ghat have been decreasing sharply at about 0.97, 1.7, 2.3 metres per year, respectively. In north Libya, especially in the Tripoli area, farmers caused overexploitation of the aquifers by proliferation of illegal well drilling. Poor and inefficient irrigation management has made this situation worse (FAO, 2009). Water tables have continued to fall and they consequently result in seawater intrusion in coastal aquifers, resulting in increased salinity, which poses a serious threat to the productivity of farms that rely on irrigated farming (FAO, 2009). As a consequence, Libya's land has been affected by salinity. The salinity of groundwater in most farm wells ranges between 11 000-13 000 mgL^{-1}, in some cases; but it has reached 17 000 mgL^{-1} (Dakheel, 2005). Irrigating saline water causes salts to be deposited on the soil surface following water evaporation. This is causing a serious problem for agriculture in Libya. If appropriate action is not taken to solve the present water issues, the groundwater shortage and further degradation of its quality, will aggravate problems further for the agricultural sector.

Current water consumption and the shortage of groundwater have increased the dependence on the expensive process of desalination of seawater. Libya is one of the few countries that have taken steps to increase the use of desalinated seawater. Wheida and Verhoeven (2007) reported that groundwater contributes about 88 per cent of the available Libyan water supplies; recycled water provides 6 per cent; other water sources (i.e., desalinated water and surface water) contribute 3 per cent of total available water. In addition, the government has built over 16 dams to enhance groundwater recharge, thus improving groundwater quality and reducing seawater intrusion (FAO, 2009).

The Made River Project (MRP) is in place in Libya to help solve the water shortage. The government is distributing groundwater around the country for agricultural uses. This project will provide water to the northern, central and eastern regions. Optimistically, this expensive project will end Libya's difficulties with fresh water resources.

3.5.2. Salinity of water

The date palm is a halophytic plant that can tolerate high levels of salinity. In actual fact, the date palm is more salt tolerant than any other fruit crop (Al-Mulla, Bhat, & Khalil, 2013). Furr (1975) reported that it is obvious that the date palm has a greater ability to resist salt soil than barley, and that date palm is considered as one of the plants that has the ability to grow in salty soil. Barley is the most salt-tolerant crop, and it can grow in the cool season. However, date palms could grow in the hot weather when salinity has an adverse influence on other plants. Furthermore, some varieties can tolerate salinity levels up to 22 000 mgL^{-1}; however, date palm growth and yield productivity are affected (Erskine et al., 2004), where the yield decreased 50 per cent at 11 500 mgL^{-1} and 100 per cent at 20 500 mgL^{-1} (Zaid & Klein, 2002).

Libya has been struggling with another crisis: the growing soil salinity of many agricultural areas caused by increased groundwater salinity. In arid regions, salinity is very common because of the lack of fresh water resources and high evaporation rates. Tripoli, Benghazi and Sebha areas have been seriously affected by salinity. Furthermore, many farmers have abandoned their farms and soon the soil in other areas will not be able to support crops unless a solution is found.

3.5.3. The slow economic returns from date palm

Date palm requires between five to ten years to start full production (Chao & Krueger, 2007). Therefore, the investment in date palm is not an easy decision that can be taken by Libyan farmers, because growing dates involves two years of spending without revenues (Alshuaibi, 2011). In addition, date palm intercropping is not possible in mechanized plantations, due to the mobile equipment having a negative effect on yield and fruit quality of fruits, as reported by Morton (1987).

The traditional practice in Libya especially in the northern region is to grow crops among date palm trees (FAO, 2007). Date palm trees can provide sufficient space for intercropping other crops (Akyurt et al., 2002). For instance, vegetables and fodders might be grown together with date palms during winter and summer seasons (Shirazi, Izadi, & Khademi, 2008). In the oases in south Libya, it is highly recommended that date palms are intercropped with citrus, to grow a mixed fruit orchard (FAO, 2007; Morton, 1987). Date palm intercropping with suitable crops brings high income; improves soil fertility and saves irrigation water (Nagwa, Faissal, & Al-Hussein, 2014). Intercropping of some vegetables in date palm plantations located near the cities can be practiced if sufficient irrigation and management facilities are available. Ali, Karibl, and Aoof (1998) reported that intercropping can lead to improving the quality and yield of legumes by more than 50 per cent. Moreover, the intercropping of legumes such as cowpea and pigeon pea has a positive effect on the soil, and consequently this leads to an increase in the quality of date by 35 per cent. They also indicated that date palm farmers can cultivate several crops, e.g., alfalfa; okra and tomato by utilizing both intercropped and surface irrigation, which also leads to increased income of date palm farmers compared to drip irrigation (Ali et al., 1998). Likewise, in Libya, date palm is intercropped with other crops like wheat, barley, alfalfa and different vegetables (Bashir et al. 2010).

In the Northern State, (Sudan), Reyad, Dawood, and Ibrahim (1997) reported that farmers intercrop alfalfa with date palm. Seventy per cent of total farms have used intercropping of alfalfa with date palm. Elmakki (2006) found firstly that intercropping alfalfa with date palm leads to increasing the income per hectare up to US$ 3 085 per year. He also found that tomato and okra increase the date palm yield per hectare by US$ 2 740 and US$ 1 621 per year, respectively. Similarly, the study of Abouziena et al. (2010) studied intercropping mango, mandarin and clover with date palm in the same area. They found mango gave the highest return of US$ 8 213 followed by mandarin and clover US$ 3 992 and US$ 3 132 per ha per year, respectively. However, farmers must pay more attention in providing the water requirements for both date palm trees and other crops.

3.5.4. Fertilizers

Fertilizers have important macro-nutrients such as nitrogen, potassium and magnesium (Al-Rawi & Al-Mohemdy, 2001). They are necessary to economically improve date palm production. In South Libya for example, fertilizers are one important practice for many date palm farmers (Al-Rawi & Al-Mohemdy, 2001). The amount of fertilizer depends on the soil, fertilizer type and age of the tree. In the last decade, Libyan farmers have applied manure into the soil to keep it moist until planting time (Zaid, 2002). At that time the mixture is dug out and then distributed around the date palm roots. However, most date farmers have modified their practice of producing date without applying fertilizer or only applying limited amounts of fertilizers.

There are some factors that contribute to low fertilizer usage by farmers. For one, the extension service system can play an important role in driving demand for fertilizer by its transmission of information about new fertilizer technology to date palm farmers. Limited access to credit (price subsidies) and high price of fertilizers compared to other input also contribute to the low fertilizer usage (Akpan, Patrick, & Udoka, 2012; Zhou et al., 2010). There is evidence to suggest that fertilizer can improve greatly date production and quality of fruit (Elmakki, 2006; Khayyat et al., 2007). For instance, Ibrahim et al. (2013) examined the effects of applying chemical fertilizers on date yield and the fruit quality of date palm in Egypt. The results showed that the use of more quantities of nitrogen (N), phosphorus (P) and potassium (K) led to increasing the fruit quality and economic revenues for farmers. In addition, researchers found that minerals and organic fertilizers proved to be extremely effective in improving fruit quality and fruiting of many fruit trees, e.g., date palm (Abdel-Migeed, El-Ashry, & Gomaa, 2006; Hegazi et al., 2007).

Application of potassium is important during March, June and September, as this increases the fruit quality and date palm yield (Osman, 2010a).

Khayyat et al. (2007) reported that the yield and the fruit quality of Shahany date palm can be increased by mineral nutrients especially boron as compared to boric acid, urea, zinc sulphate and potassium sulphate. Abou- Sayed et al. (2005) studied the effect of fertilizer application of N, P and K on date palm production in sandy soils. They found that the best application to raise the date palm yield was 0.40 kg N per date palm tree.

3.5.5. Need for skilled labour for farming date palm

Date palm trees require a higher skilled labour for date palm operations. According to Browen (1983), the following farming operations, i.e., labour, pollination, harvesting, and pruning, contribute 80 per cent of the total production costs. One of the toughest components of date palm farming operations is the ability of the worker to reach the crown of the tree. There is a high risk of workers falling from date palm trees due to the height of the plants. In Libya, a traditional way of farming is for farmers to use the tree trunk leaf as a way to climb the date palm tree (Nixon & Carpenter, 1966).

There are two important farming operations for date palm. Firstly, pollination which involves placing male pollen in the region available to the female tree. This manual pollination of palm trees is undertaken several times per week by farm workers. This is because female palms do not bloom all at one time. In Libya, one male palm tree is sufficient to pollinate 50-100 female date trees, therefore it is common practice to plant 2 to 4 male palm trees per hectare. Extensive research by AI-Obeed and Abdul-Rahman (2002) and Monselise (1986) demonstrates conclusively the effect of pollination on fruit set, ripening and quality of date palm.

Other studies found the impact of pollination on chemical and physical characteristics of dates, for example the period of fruit ripening, fruit colour, fruit size and weight of fruit and fruit stone (Al-Delamiy & Ali, 1970; El-Ghayaty, 1983). According to Gasim (1993) the male parent, which is used in female pollination, had an important effect on the fruit quality of date palm. However, the effect is dependent on the type of male parent. Shafique et al. (2011) suggested that the best male trees must be selected manually for their respective female trees to obtain the most desired characteristics. Secondly, pruning of date palms involving the removal of entire bunches is needed when the number per palm is very high. In fact, if the number of fruit bunches per palm is not decreased by date farmers to an appropriate level; the date palm production the following year will be very low. In addition, keeping a proper balance between the number of fruit bunches and leaves is very important. The number of fruit bunches for each palm to carry safely relies on its size, vigour, variety, age and the number of good green leaves it carries (Harhash, 2000; Moustafa, 1998). Bunch thinning leads to a substantial increase in fruit volume and weight; fruit diameter and length; along with seed and flesh weight in Succary cultivar (Al-Obeed, Harhash, & Fayez, 2005). A study in Egypt by Abdulla, Meligi, and Rysk (1982) reported that leaving three active leaves for each bunch in Hayany date palms can improve fruit quality and yield. According to Bacha and Shaheen (1986) and Hussein and Abdallah (1973), workers should be informed that the appropriate leaf per bunch ratio differs according to the cultivar.

Harhash, Hussein, and El-Kassas (1998) investigated the Zaghlool date palm grown in Egypt and found that pruning to a 1:9 bunch per leaf ratio gave the best yield per bunch weight. Meanwhile, Osman and Soliman (2001) found that the pruning for 12 leaves per bunch was the best option for yield and fruit quality in Egypt. Samany cultivars were subjected to four prunings concerning the leaf per bunch ratio: control, slight, moderate, and heavy pruning. They found that the moderate pruning resulted in the greatest yield and total production. On the other hand, leaf per bunch ratio had no effect on the Khlass fruit yield, and no significant differences were found between treatments, under Saudi Arabian conditions (Al-Wusaibai et al., 2012).

3.5.6. Access to credit (financial resources)

There are several barriers to the effectiveness of sustainable date palm cultivation. Economic factors, such as the inability of date farmers to access financial resources and the high cost of consultancy services (Rasouliazar et al., 2011) are some of the barriers. Financial resources are considered to be one of the main factors that play a significant role in improving date production by allowing purchase of farming inputs and the necessary work to be undertaken to enhance the competitiveness of farms (Ganpat et al., 2000). Farming decisions are largely influenced by the degree of access to financial resources. Capital is not easily available to farmers (Ganpat et al., 2000). Some farmers use credit to obtain farm inputs.

Generally, there are two kinds of credit - first, credit from commercial banks which is available at high interest rates; second, credit from individual's sources which can be in the form of farm inputs from relatives, rich farmers and friends. With small date palm farmers, who cannot provide the credit guarantees required by creditors, the situation is worse (Betru & Long, 1996). Also, banking procedures for payment of agricultural loans are not available and still involves very complicated procedures (FAO, 2002). In addition, farmer losses in agricultural markets also lead to reducing or limiting the capacity of farmers to pay for services and outputs, inputs and credit markets. As pointed by Rivera and Alex (2004), market limitations have an adverse effect on the ability of farmers to use new technologies and inputs.

3.5.7. Agricultural Extension service

One of the contributing factors in ensuring sustainable agricultural development is agricultural extension services as they provide training on modern farming practices and how to improve crop yield. Allahyari (2009) argues that traditional extension models have been ineffective in supporting farmers to adopt contemporary farming practices to enhance agricultural sustainability. For example, the Libyan extension organizations have identified a number of factors facing farmers.

Libyan farmers are characterized by their inadequate skills and practical knowledge to adopt advanced farming practices. They also have inadequate financial resources to adopt new technologies in farming (FAO, 2002). In addition, poor agricultural infrastructure and local organizations play any role in sustainable agricultural development planning and implementation (Kalantari et al., 2008). In Libya, agricultural extension has been negatively associated with poorly motivated staff, insufficient finances, heavy duties in their job and poor policy regulation to coordinate the work and tasks by the agricultural extension office (Kizilaslan & Kizilaslan, 2007). However, the limitations or weaknesses in the present agricultural extension system is mainly caused by weak linkages and coordination between extension wings and scientific research (Nisar et al., 2004). Azizah (2011) suggests that the lack of qualified and talented staff from the agricultural extension office is hampering the advancement of sustainable agricultural development as the officers lack the knowledge to train farmers on sustainable agricultural practices. In addition, the lack of adequate personnel at the agricultural extension office in Libya is also a major challenge. This is due to the lack of incentives and low salary for the field staff (Cho & Boland, 2004). This has led to deficiencies among date palm farmers and as such farmers are unable to access production information (Owona Ndongo et al., 2010). Thus, farmers need to train to adapt to sustainable agricultural practices.

3.6. Summary and conclusion

This chapter provided detailed information about the economic importance and production of date palm in Libya. The chapter described the botanical structure of date palm and the importance of dates for food and nutrition, as raw materials for food and beverage as well as for the protection of the environment. Clearly, palm dates have contributed to the Libyan economy. Moreover, date palms have made a significant contribution to the agriculture sector and the improvement of labour income. Date palm has contributed significant benefits socially and economically to households and the government in relation to revenue generation and foreign exchange. Date palm supports the protection of the environment by reducing sand and wind erosion. In a nutshell, date palm has become an important crop owing to its numerous benefits to farmers, the government and the protection of the environment. However, important constraints also face date palm tree production. Moreover, different areas of Libya, under government projects, have produced varied results in the area, productivity, production, exports and incomes of expanded date palm cultivation. Thus, more scientific attention is needed regarding the current condition of the date palm trees grown under dry environments, and the constraints in date palm production.

The next chapter focuses on the different irrigation systems for growing date palm trees.

Chapter 4
Irrigation Systems in Libya

4.1. Introduction

This chapter is devoted to an extensive overview of irrigation systems currently used in Libya and is divided into seven sections in order to explore irrigation and relevant concepts. Section 4.1 is the introductory portion. Section 4.2 outlines the importance of managing water in Libyan farms while Section 4.3 focuses on water resources in Libya. Section 4.4 discusses the water balance in Libya, which explores the water requirements of date palm trees in Libya, followed by Section 4.5 which contains an overview of date palm irrigation technologies used in Libya. Finally, Section 4.6 presents the conclusion.

4.2. Importance of managing water in Libyan farms

Libya has long suffered from water insecurity and increasing water demand. The agricultural sector is a major consumer of water. Growing the food needed to feed the population requires a large water supply, which will need to be sourced from groundwater systems and managed efficiently by farms. In view of water-use trends in Libya, it will be very difficult to supply this additional water in an ecologically sustainable manner in the future (Postel, 2000; Wheide, 2012). According to FAO (2009), poor water management and low irrigation efficiency has led to expansion of demand for water for agricultural crops. For example, water use for barley, wheat and date palm projects in Libya is more than in other countries with similar arid conditions. The Libyan agricultural sector aims to achieve nutritional and food security and has a policy of self-sufficiency. As such, the Libyan agricultural sector has contributed to the expansion of irrigation but has done nothing to minimise food waste (Wheide, 2012).

Water use efficiency can be achieved in two ways. First, technical efficiency can be reached by using more efficient technologies. Lawgalia (2008), Alghariani

(2006) and Shaki and Adeloye (2006) studied the determinants of the demand for water in the agricultural sector in Libya. They reported that an increased quantity of water consumed was related to excess irrigation and irrigation systems. The second way by which efficiency for water can be achieved is by improving the scheduling of water applications in water distribution systems and by using crop and soil moisture sensing systems that are associated with computer-controlled water distribution. Finally, domestic water can also be used more efficiently by installing more water efficient equipment to reduce the quantity of water used per capita (Wheide, 2012).

4.3. Water resources in Libya

Libya is mostly dry and semi-dry land and has limited water resources and poor distribution systems or mechanisms in place (Wheida & Verhoeven, 2005, 2007). Libyan water resources could be divided into three groups: groundwater, surface water and non-conventional water (desalination and wastewater recycling) resources. Groundwater is the main source of water supply in Libya, representing about 88 per cent of the total water used by different sectors. The agriculture sector accounts for the largest part of water consumption, about 85 per cent, particularly in irrigated agriculture, followed by urban or commercial users and industries which consume approximately between 11.5 per cent and 3.5 per cent respectively. Surface water is supplied by rainfall; however, there is a shortage in the rainfall levels because of the absence of permanent streams. The surface water supplies only about 3 per cent of the total water consumption (Wheida & Verhoeven, 2007). Non-conventional water resources include desalination and treated sewage. Desalination water covers only 3 per cent of the domestic and industrial water demand. Wastewater recycling contributes about 6 per cent of total water used mainly in irrigation purposes. Non-conventional water resource is still very limited in use for agricultural irrigation in Libya (Salam, 2007). The water sources used in Libya are shown in Figure 4.1.

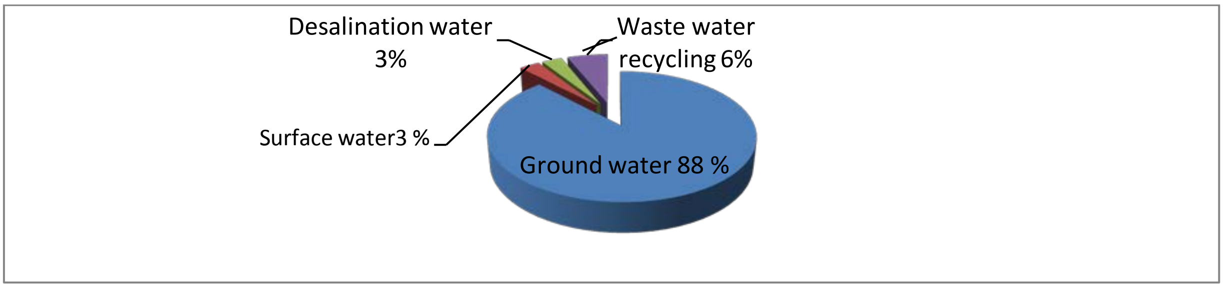

Figure 4-1: Water sources use in Libya

Source of basic data: Wheida and Verhoeven (2007)

4.3.1. Groundwater

In Libya, groundwater is the major source for freshwater. It supplies about 88 per cent of the total water consumption by domestic, industry and agriculture activities. The groundwater in the country has been divided into five water zones representing the major groundwater basins; three of them in Northern Libya, which are Jeffara Plain, Jabal Akhdar and Hamada Hamra; and the other two zones in Southern Libya, which are Murzuq and Kufrah-Serir as shown in Figure 4.2. In the northern region, the aquifers could be recharged if sufficient rainfall is available while those belonging to the great sedimentary basins in the central and southern parts are considered not renewable. However, the major part of the groundwater is located in Murzuq, Tazirbu and Kufrah-Serir basins, as all these three basins are located in southern Libya (Pallas, 1978; Shaki, 2002).

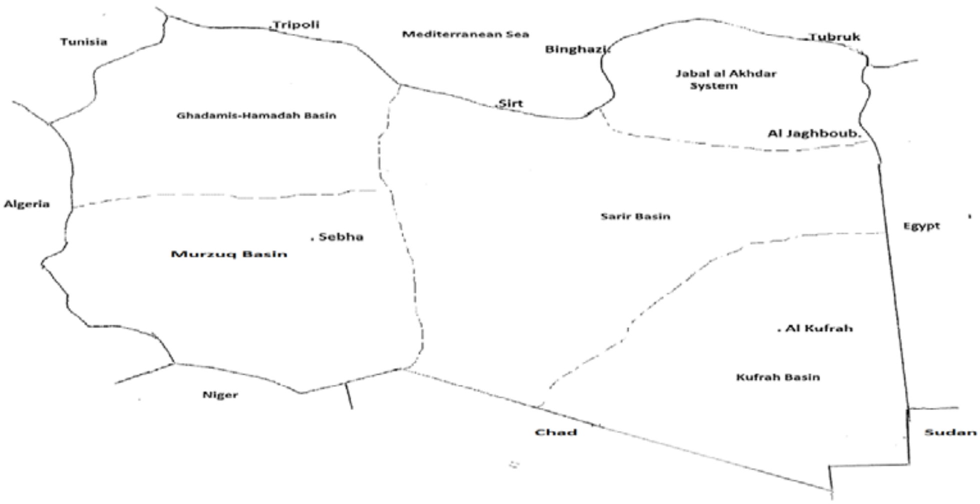

Figure 4-2: Main groundwater basins in Libya

There is variation in the balance of water basins in Libya. For example, Jeffara Plain and Jabal Akhdar have a huge deficit in water supply, due to the high density of population in these regions. Meanwhile, there is a shortage in the water supply in the southern basins because water resources are not renewable. It is clear that the gap between supply and demand is extremely high in the northern basins (Jeffara plain and Jabal Akhdar) which are about 77 per cent and 52 per cent, respectively (Ben-Mahmoud, Mansur, & Al-Gomati, 2003).

4.3.2. Water transfers

The Manmade River Project (MRP) is one of the world's largest and most expensive groundwater pumping projects. To solve the water deficit in the northern areas of Libya, this project started in 1984, and the last stage is still under construction. In the last century, the operations of governmental oil companies in south Libya have led to the discovery of huge oil reserves along with aquifers containing large quantities of fresh groundwater. The project aimed to use four meter diameter pipes over a length of about 4000 km to transfer 5.68 million m^3 per day from the southern basins to north Libya: 3.68 million m^3 per day to the eastern conveyance system and two million m^3 per day to the western system, with 80 per cent of its water currently used for irrigation (MRP, 1990).

The project consists of five stages. The major part of the project has already been constructed. It aims to transfer two million m³ per day of water to the east coastal regions in Libya. The water is transferred through two pipelines discharging a combined constant flow of 700 million m³ yearly in a large balancing circular reservoir that has a four million m³ capacity. The water is carried to Sirt and Benghazi from wellfields at Sarir and Tazirbu. The reservoir is located near the city of Ajdabiy which is in the eastern part of the country and the reservoir is divided into two other branches. The first branch transfers the groundwater to Benghazi city and its surrounding plains. The second branch transfers water to the city of Sirt and surrounding plains. The water flows, by gravity, from the two wellfields toward the end of the routes. In addition, the project is designed to be expanded to carry 3.68 million m³ per day of water from wellfields in Kufrah (Gijsbers & Loucks, 1999; MRP, 1990).

The first phase of the project was formally inaugurated in 1991. The second phase aims to transfer one million m³ of water daily from wellfields in Murzuq Basin to the western coastal regions and in particular to Jeffara Plain. It is designed to accommodate a further one million m³ a day in the future (MRP, 1990). This phase was completed in 1996 and started supplying water to Libya's capital, Tripoli. The third phase is an expansion of the first phase. It is designed to increase water flow by 1.68 million m³ daily. The additional water will be obtained from Al Kufrah Basin, as there are new pumping stations and 700 km of new pipelines to transfer a total capacity of 3.68 million m³ per day. The project is also designed to connect the first phase with the second phase to overcome the need for water in the western side of Libya (Jeffara plain) (MRP, 1990). The fourth phase aims to provide fresh groundwater to the north-western cities (Zawara and Zawia) through pipelines from the Gadammes region. In the fifth phase, there is a proposal to supply fresh groundwater by developing pipelines from the Jaghboub oasis to the eastern side of Libya, for example, Tubruk city. All phases will be completed in 2015 (El-Tantawi, 2005). However, the 2011 events underestimated these projects and plans. According to MRP (1990), water transfer was the cheapest option during the 1990s to meet the water needs of the country as compared to water desalinisation. El Asswad (1995) stated that the estimated cost per m³ is about US $ 0.20 and this cost is very small compared to other sources such as coastal desalinisation, where the cost is approximately US $ 3.75 per m^3. However, Alghariani (2003) argued the cost of extracted groundwater from MRP was comparable with desalination, but over time the cost benefit factor has moved in favour of desalination. The desalinated seawater's average price has fallen from US $ 5.5 per m^3 in 1979 to less than US$ 0.55 in 1999 (Owens & Brunsdal, 2000). Based on the above values, it seems that the MRP water transfer projects have lost their economic benefits over the rapid development and expansion of the desalination technology. Although the main efforts of the Libyan authority concentrated on the MRP, wastewater treatment and desalination plants are seen as the non-conventional sources of water. Nevertheless, desalination plants have low operating capacities of supplying water due to factors such as poor management, lack of spare parts and maintenance. Due to these factors, desalination plants have not been successful in Libya especially during the 1970s period. In addition, wastewater has an important role particularly in the agricultural and industrial sectors, since it can be used to meet water demand in the country for these sectors (Abdulla & Ouki, 2015).

4.3.3. Surface water

The surface water resources in Libya contribute a small quantity to the total water supply in the country. The total average annual runoff of surface water in the northeast and northwest of the country is roughly estimated at 200 million m^3 per year (Aqeil, Tindall, & Moran, 2012; Gintzburger, 1986). However, about 50 per cent of the runoff water is either evaporated or infiltrated for recharging the aquifers. Currently, in the North of Libya, there are several reservoirs and 16 dams that are built to collect 60 million m^3 every year, as the average rainfall is above 200 mm (FAO, 2009; Gintzburger, 1986). The total annual storage capacity of these dams is about 385 million m^3 and contains about 61 million m^3. Furthermore, these dams serve as water reservoirs and protect cities from flooding and erosion control (Aqeil et al., 2012).

4.3.4. Non-conventional water resources

In addition to the above, there are two non-conventional water resources in Libya – desalination and wastewater recycling.

4.3.4.1. *Desalination*

Desalination technology is growing rapidly to cater for water supply in many countries. The majority of the Middle East and North Africa (MENA) countries depend on desalination plants, followed by the Americas and Asian countries (Zotalis et al., 2014). Libya overlooks the Mediterranean Sea; it has also invested in desalination projects as a supplementary water resource since 1964. Thus, both thermal and membrane desalination technologies have been used in Libya to supply water for both household consumption and sectoral consumption (Wheida & Verhoeven, 2007; Zotalis et al., 2014). Desalination technology mainly focuses on seawater desalination with a total cumulative installed capacity exceeding 60 million m^3 per year. The cost of desalinated seawater has dropped significantly during the last two decades because of a significant revolution in desalination technology. The average price of desalinated seawater has dropped from US$ 5.5 per m^3 in 1979 to less than US$ 0.55 per m^3 in 1999 including capital recovery, interest, management, operation and cost. As a result, desalination has become a rival source of water (Owens & Brunsdal, 2000). Overall, the global capacity of desalination plants is expected to grow more than 9 per cent per year from 2010 to 2016 (Zotalis et al., 2014). However, in Libya, the overall water produced is still low per year because of poor operating desalination plants conditions caused by lack of spare parts for repairs, poor management and shortage in local skills (Aboabboud & Elmasallati, 2007).

4.3.4.2. *Wastewater recycling*

Wastewater recycling has been used in Libya since the early 1960s (Hamad, 2012b). Over the past four decades, Libya has shown an increase in its population along with dense urbanization in the coastal cities (Abughlelesha & Lateh, 2013; Wheide, 2012). This development has led to the establishment of wastewater treatment plants by the Libyan government to achieve two main objectives. Firstly, the environment will be protected by reducing polluted water and its negative influence on public health. Secondly, to develop extra water resources from non-conventional sources (Wheide, 2012).

Two kinds of wastewater treatment techniques are used in Libya; trickling filters and activated sludge. The first generation of treatment plants in Libya in the 1960s used the trickling filters technique. However, most of these types of treatment plants are currently out of date. The activated sludge technique has been used in Libya for treating wastewater since 1972 and became the most common technique used in the country. For instance, during the time-period of 1963–1995, 25 such treatment plants were built. However, three out of the 25 plants worked with good efficiency; two with medium efficiency and the rest were either out of operation or worked inefficiently (Wheida & Verhoeven, 2007). The design capacities vary from 150 m^3 per day to larger ones of 110 000 m^3 per day. Most of these treatment plants were built to produce treated water suitable for agricultural purposes. The present production of wastewater treatment is projected at roughly 40 million m^3 per year. However, this amount is much smaller than the designed capacity (Wheida & Verhoeven, 2007). The treated wastewater is used for agriculture utilization only in the major Libyan cities (Abdulla & Ouki, 2015; Hamad, 2012b). According to Kellis and Gikas (2013), Libya is still struggling to achieve a minimal level of wastewater recycling. This is because of some problems related to operations and maintenance of wastewater recycling plants (Wheida & Verhoeven, 2005).

4.4. Water balance in Libya

There is a large surplus of underground fresh water in South Libya, which still awaits utilization. This surplus amounts to about 90 per cent of the underground storage of Al Kufrah reservoir, and 84 per cent of the surplus of Sarir reservoir and can be used to compensate for the severe shortage of water in the coastal cities (Elaalem, 2010). Figure 4.3 shows that water used for agricultural irrigation will be expected to increase further from 2000 to 2025. This includes surface water, desalinated water and treated water for rural and industrial purposes. Overall, in 2000, total water use was 5 579 m^3 per year. In 2015, it increased to 7 180 m^3 per year. The Libyan government seeks to implement alternative methods to exploit the underground water in South Libya. However, large water consumption for agricultural production has led to water shortage and low productivity of crops and soil, which resulted in economic losses and loss of environmental resources. Figure 4.3 exhibits the expected water balance in Libya; based on present growth rates.

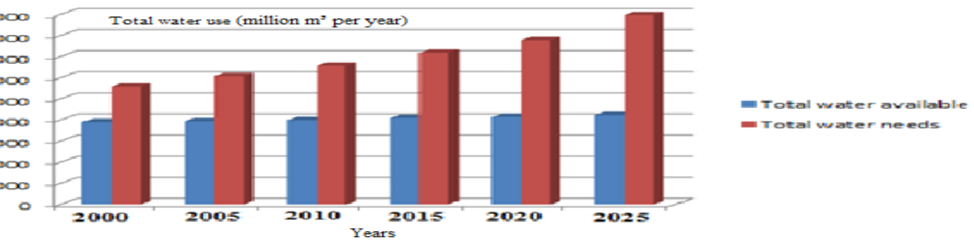

Figure 4-3: The expected water balance in Libya (million m³ per year)

*2000- 2025 are preliminary estimates.

Source of basic data: Elaalem (2010).

4.4.1. Water requirement for agriculture

Population increase is usually the major determinant for increased demand for water in all economic sectors such as agricultural, industry and domestic uses. As shown in Figure 4.4, agriculture shaped the great majority of water demand in Libya from 2000 and is expected to increase in 2025. The amount of land under irrigation is expected to be doubled. This is because of the increase in Libyan population growth and consequently increased demand for food. However, poor soils, difficulty of transferring agricultural products to market centres, especially poor storage facilities for fresh horticultural produce (vegetables and fruit) and lack of sufficient manpower to cultivate in the southern desert areas are also contributing to the challenges hindering agricultural advancement in Libya. Industry requires water for cooling and manufacturing processes, and to remove waste generated by these processes. Domestic consumption, which mainly consists of washing and cleaning, watering gardens, drinking and food preparation, represents a small portion of total water usage in Libya.

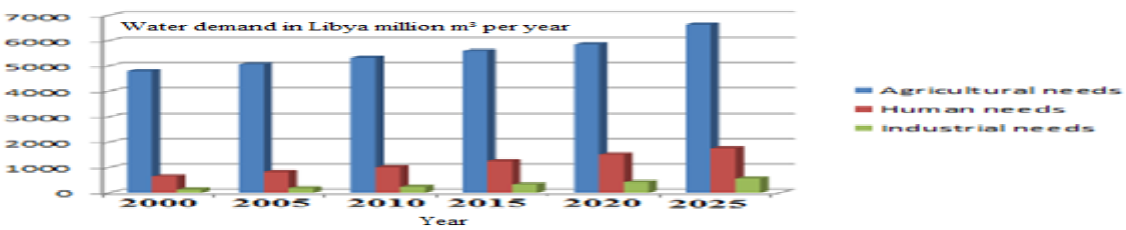

Figure 4-4: Water needs for different applications in Libya (million m^3 per year)

*2000- 2025 are preliminary estimates.

Source of basic data: Elaalem (2010).

4.4.2. Water requirements of date palm trees in Libya

Many previous studies showed that the average water requirement for date palm is between 115 to 306 m^3 per year[3] (Mumtaz & Prathapar, 2012). Saudi Arabia has the highest water usage for irrigation of date palm trees ranking 250 m^3, followed by Libya and Oman 212 m^3, Morocco 153 m^3, United Arab Emirates and Yemen 152 m^3, and Iran, Algeria, Egypt and Tunisia at 133, 122, 105, 100 m^3 respectively. Average water consumption of water for date palm trees per year in the world is shown in Figure 4.5

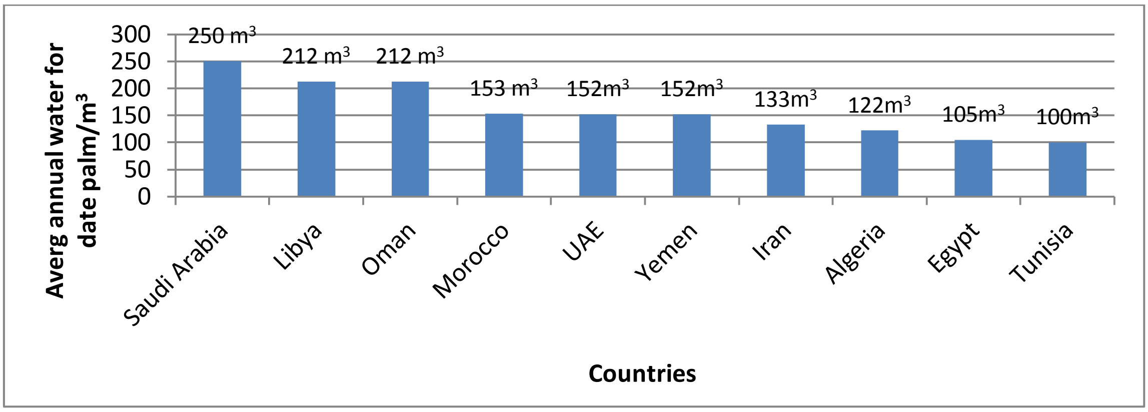

Figure 4-5: Average annual water consumption for palm trees in the world

Source of basic data: FAO (2007)

Date palm tree is usually irrigated by surface method, such as basin. As this method delivers a large volume of water, the cost of water is minimal; however, the efficiency of this method is greatly dependent on farmer's experience (Alamoud et al., 2012). According to FAO (2007), there are differences in monthly water requirements in Libya (see Figure 4.6). They range between 8800 m^3 per ha to 20900 m^3 per ha in North Libya to South Libya. The consumption varies with in Libya, due to many factors, mainly climatic factors, such as temperature, humidity and wind; and age of trees. However, the annual water requirements for immature date palm may range between 7 800 and 29 700 m^3 per ha depending on the cultivar,

[3] m^3 = 1000 Litres of water

climatic conditions, soil types and irrigation system used (AL-Baker 1972).

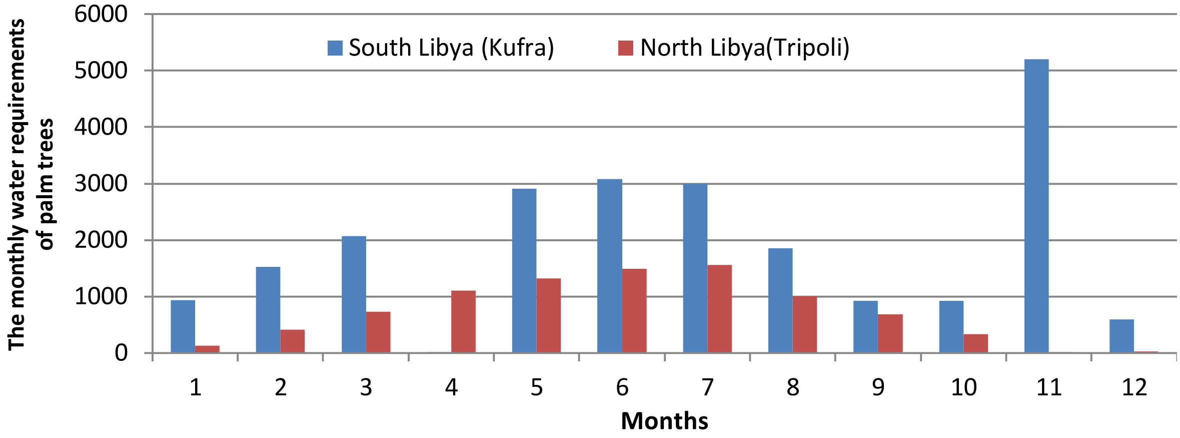

Figure 4-6: Water requirement of palm trees in North and South Libya

Source of basic data: FAO (2007)

4.5. Date palm irrigation technologies in Libya

Irrigation is a basic requirement for successful cultivation of crops. The Libyan government has invested a large amount of resources annually to develop and improve the irrigation systems to increase production of dates (Libyan Statistics, 2008). In Libya, 610 000 ha are irrigated by flooding (basin) and 199 200 ha under rain-fed (FAO, 2007). There are several factors that affect the yield of date palm, including irrigation systems used, cultivars, the amount of pesticide and fertilizer, number of employees and experience in growing (AbdulRazak, 2010; Benu, 2003; Shaloof & Areada, 2010). Similarly, the irrigation systems are also affected by different factors, including irrigation period, soil type, soil structure and texture, plant type, evapo-transpiration rate, air temperature, relative humidity, cost and water salinity .(Cetin et al., 2004). In Libya, several types of irrigation systems are employed:

4.5.1. Surface irrigation

Surface irrigation is used in Libya because of its advantages such as low cost and easy use for farmers (Brouwer, 1988; FAO, 2007; Zaid, 2002). There are three main types of surface irrigation - basin irrigation, border irrigation and furrow irrigation.

4.5.1.1. Basin irrigation

Basins irrigate flat areas of land that is surrounded by an artificial low border called a bund. In the basin irrigation, the water can be prevented from flowing to the adjacent fields by the bunds. Trees can be grown in basins, as one tree is frequently located in the middle of a small basin. Generally, the basin method is an effective way for crops that are not impacted by standing in water for long time periods (Brouwer, 1988, p. 65). Basin irrigation has been used on many date palm farms, because it is suitable for dry and semi-arid regions like Libya. It is controlled by farmers and does not need maintenance (Zaid, 2002). Previous studies have shown that the availability of capital for production cost and operating costs are very low using basin irrigation systems (Zaid, 2002).

There are, however, some limitations to basin irrigation; for example, water in basin irrigation can lead to excessive evaporation in hot areas, such as in South Libya (Zaid, 2002). Poor distribution uniformity due to soil variability means large flows are needed to achieve distribution uniformity (Zaid, 2002). Basin irrigation can lead to soil erosion. It needs greater depths to avoid water leakage and drive water around date palm trees (Zaid, 2002). Figure 4.7 shows the irrigation of date palm by basin irrigation.

Figure 4-7: Irrigation of date palm by basin irrigation

4.5.1.2. Border (flood) irrigation

Border irrigation is an area of land surrounded by a border strip or earthen barrier. These strips may differ in width and length; they are about 3 to 30 meters wide and about 100 to 800 meters long in Oases and large farms (Brouwer, 1988; Larry & James, 1993). This method is widely used especially in villages and oases in Libya where large quantities of water for irrigation are available (Larry & James, 1993). Figure 4.8 shows the irrigation of date palm by flood irrigation.

Figure 4-8: Irrigation of date palm by flood irrigation

There are some advantages when applying water to date palms using border (flood) irrigation system. Border irrigation helps to limit soil erosion especially in agricultural land (Larry & James, 1993). Border irrigation is suitable for irrigating farms specializing in the cultivation of palms together with other crops (Larry & James, 1993).

According to some researchers, the disadvantage of using border irrigation is that this system uses large quantities of water. Libyan farmers are still using this irrigation system for date palm and other crops (FAO, 2007; Larry & James, 1993). Moreover, it is not convenient to irrigate in clay soils compared to other surface irrigation systems, because water requires a long time to infiltrate the soil of this type (Larry & James, 1993). As a result, a large volume of water may be lost and cannot be useful for date palm because of evaporation and transpiration (Larry & James, 1993). Therefore, border irrigation may lead to higher soil salinity and crust formation on the soil surface (Larry & James, 1993).

4.5.1.3. Furrow irrigation

Furrow irrigation is a modified form of surface irrigation combined with basin irrigation (Mumtaz & Prathapar, 2012). The flow of water is through narrow channels. These channels are separated into equal lines (Brouwer, 1988). Crops grow along the furrows and in the beds between the furrows (Brouwer, 1988). Figure 4.9 shows furrow irrigation.

Figure 4-9: Furrow irrigation for crops and date palm in Libya

Furrow irrigation has some advantages, compared to basin and border methods. For one, its primary cost is small when the land or farm is uniform. Most farmers use furrow irrigation because it is easy and does not need complex technology (Brouwer, 1988). Furrow irrigation is one of the more successful ways to irrigate line crops like maize and soybean (Brouwer, 1988). This method is also suitable to irrigate citrus trees (Brouwer, 1988). It is suitable for all types of soil, especially soil that is easily broken into small pieces. If the level of water is lower than the level of the growing crop, the soil crumbles (Brouwer, 1988).

Some vegetables such as potatoes, tomatoes and beans may be exposed to loss if water covers the stems of the plant (Larry & James, 1993). Furrow irrigation system requires more farmers to control irrigation water (Larry & James, 1993; Zaid, 2002). In addition, skillful farmers are needed to divide water from the supply channel into a number of long narrow open canals, so the process of division controls rates of flow during the process of irrigation (Larry & James, 1993; Zaid, 2002). In farms that are sloped, levelling of land is usually required to avoid erosion and poor uniformity (Larry & James, 1993; Zaid, 2002). Overall, these methods basically redesign surface irrigation.

4.5.2. Sprinkler irrigation

Sprinkler irrigation has been gaining impetus in Libya in recent times (FAO, 2007). Sprinkler irrigation is one of the most efficient ways in terms of mechanical irrigation (Al-Kayssi & Mustafa, 2016; Zaid, 2002). It is a method that applies irrigation water that is similar to natural rainfall (Brouwer, 1988). Alvarez et al. (2004) studied sprinkler irrigation systems in semi-arid region. The authors reported that economic benefit for irrigating date palm, barley, maize, garlic and onion crops was attained with high uniformity coefficient at 90 per cent. Figure 4.10 shows the irrigation of date palm by sprinkler irrigation.

Figure 4-10: Irrigation of date palm by sprinkler irrigation

Sprinkler irrigation is a very adaptive method as it can be used for any farmable slope, whether undulating or uniform. With sprinkler irrigation, there should be a layout of lateral pipes to supply water out along the land contour whenever possible. Therefore, this can lead to minimising the pressure changes at the sprinklers and providing a uniform irrigation (Brouwer, 1988).

Similar to all other techniques of irrigation, sprinkler irrigation has its own advantages. It is easy to control the amount of water used and is more efficient and less labour intensive (FAO, 2007). Sprinkler irrigation is suitable for different topographic conditions, types of soils and different kinds of plants, such as vegetables and fruit. Sprinkler irrigation can be used for different crops, as the water can be sprayed in different directions for crops (Brouwer, 1988). By controlling the amount of water and time of irrigation, sprinkler irrigation leads to equal amounts of water distribution on date palm trees (Zaid, 2002). It may also protect the agricultural environment by reducing erosion and runoff. Sprinkler irrigation can be operated by unskilled farmers, and it uses simple equipment (Mumtaz & Prathapar, 2012).

However, sprinkler irrigation has some disadvantages. It is not appropriate for seedling (small palms), because water can enter from above into the growth point of the plant (Zaid, 2002). The relatively small water flows could not be used for other micro-irrigation systems. In addition, large sprinklers are not strongly recommended for the irrigation of delicate crops in particular, lettuce, because the large water drops supplied by the sprinklers can damage the crop (Brouwer, 1988). Further, there are other disadvantages associated with environmental factors such as wind, which has two negative results. Firstly, 25 per cent of water is lost by evaporation through the change of direction to other areas by high speed winds. Azevedo et al. (2000) reported that speed and wind direction is a dominant factor in their uniformity of application, followed by the pressure and speed of rotation of the sprinkler. This leads to low production of date palm trees from non-uniform water distribution (Ludong, 2008). Non-uniform wetting of the field and excess water flow through the root zone causes leaching of nitrates and other water soluble nutrients (Ludong, 2008; Mumtaz & Prathapar, 2012). The blockages in sprinkler nozzles and spoiling of the crop are major problems; however, they can be avoided by removing sediments (Brouwer, 1988). Ahaneku (2010) found that the main factors, which affect performance of sprinkler irrigation, are spout size and pressure; spacing; climate change; type of soil and volume of water used. These factors lead to negative results such as large water consumption, higher use of energy and poor outcomes.

4.5.3. Drip irrigation

Drip irrigation is a pressurized system of water to irrigate many crops in the farm. This system uses a wide network of pipes of small diameters that deliver water straight to the zone or tree root (Elmakki, 2006). The system usually possesses a fertilizer injection system, supplying plants with needed nutrients. This type of irrigation is also called "trickle or low irrigation flow to provide near optimal soil moisture on a continuous basis while conserving water" (Elmakki, 2006, p. 4). In drip irrigation, the main objective is to provide each plant with a continuous supply of soil moisture that is sufficient to meet transpiration demands (Keller & Karmeli, 1974). A filter is used to reduce blockage of the emitters by removing clay and organic matter. In addition, a pumping station includes control valves, as such valves are installed to provide suitable pressure heads to the irrigation system (Bralts & Wu, 1980; Brinegar & Ward, 2009; Hansen, Orson, et al., 1980).

There are two types of drip irrigation, surface and subsurface irrigation (Alamoud et al., 2012). Figure 4.11 shows the irrigation of date palm by drip irrigation.

Figure 4-11: Irrigation of date palm by drip irrigation

According to Capra and Scicolone (2007), drip irrigation offers unique agronomic and economic advantages for the efficient use of water. It is considered as the most water saving method of irrigation, thus ideal for use to irrigate date palms in limited water resource areas. It is also beneficial in hot areas, reducing evaporation from soil and deep percolation compared to surface and sprinkler irrigations which are subject to big water losses due to high evaporation (Rajput & Patel, 2006; Skaggs, 2001). Drip irrigation is the most appropriate way to irrigate date palm because it can control water usage through time management or by using different types of emitters (Alamoud et al., 2012; Liebenberg & Zaid, 2002). Drip irrigation reduces the problem of deep percolation and loss in the soil and saves water in the root zone (Liebenberg & Zaid, 2002). This system can be applied very efficiently to small trees and widely spaced crops such as tomatoes, citrus and grapes

(Wu & Gitlin, 1977). In arid regions with good management, the ratio of transpired to applied water is at least 0.9 (Hansen, Orson, et al., 1980). Water application efficiencies approach 100 per cent and water savings of 30 to 50 per cent over other irrigation systems are obtained for crops and conditions favouring drip irrigation (Hansen, Orson, et al., 1980). Drip irrigation can create a balance between climatic conditions and growing trees by distributing nutrients and fertilizers (Cetin et al., 2004; Skaggs, 2001). This process can be labour saving, with reduction in the waste of fertilizers (Dasberg & Bresler, 1985). Minimizing the wetting of the soil surface leads to reduced insect, disease, fungus, weeds, and soil crusting; thus, less soil compaction interference with harvesting problems (Hansen, Orson, et al., 1980).

Drip irrigation also has some disadvantages. Clogging of the small conduits in the emitters of drip irrigation is one of the most serious problems. Sand and clay particles, accumulation of salts and damage of pipe network by exposure to the sun can block flows through emitters. Clogging occurs gradually and leads to poor distribution of water around tree roots; so many farmers believe the quantity of water provided by drip irrigation is insufficient (Al-Amoud, 2010; FAO, 2007). Drip irrigation also cannot reduce temperature around date palm trees in desert areas compared to surface irrigation (Skaggs, 2001). Consequently, it increases the water consumption and the productivity of palm trees is variable, because some palm trees do not obtain the required quantity of water due to evaporation. The operation of drip irrigation requires clean water to avoid emitter and filter clogging by suspended solids (Capra & Scicolone, 2007; Zaid, 2002). Clogging occurs mainly due to the passage of water containing suspended particles, salts and dissolved fertilizers through the very fine pores of the emitters. Thus, emitters with smaller passages are more susceptible to blockage (Skaggs, 2001). However, drip irrigation requires high labour skills for maintenance by using acid injection or replacing new emitters. Both solutions for the clogging problem require more time and huge running costs to maintain the system (Gilbert et al., 1981). Moreover, uneven flow rate due to pressure head loss is another major problem of this system. Drip irrigation systems do not apply water with perfect uniformity along the crop rows. Some of the variability is caused by manufacturing imperfection in the emitters, but the major problem crops up from the stance of the system design, in terms of the frictional loss in the direction of flow through the lateral pipe or tubing where emitters are attached (Myers & Bucks, 1972).

Drip irrigation usually operates under low pressure. Pressure distribution inside a lateral or manifold is greatly affected by the friction and slope of the pipe laying. This variation of pressure changes the discharge of emitters along the line. However, the ideal drip irrigation is that which can irrigate uniformly such that each emitter delivers equal discharge as required by the plant per irrigation (Wu & Gitlin, 1973).

In terms of economic consideration, drip irrigation requires high capital costs and spare parts are also costly. Due to the large initial and running costs, the system has limited application in irrigation farming in developing countries because often, farmers do not have sufficient financial resources for the application of agricultural techniques in irrigation and water resources management using drip irrigation systems (Barth, 1995; Singh et al., 2009; Skaggs, 2001).

4.6. Conclusion

Water usage for agriculture is expected to increase in Libya in the future because the Libyan population is expected increase. The main sources of irrigation in Libya are groundwater, surface water and non-conventional water resources. Most irrigation systems in Libya are dependent on groundwater. The main irrigation systems are surface, sprinkler and drip irrigation; each has its own advantages and disadvantages and has an effect on production and efficiency. Given the importance of water and the looming water scarcity issue, determining the type of irrigation system that has the best impact on production and productivity is important.

In the next chapter, the conceptual framework of the study will be presented.

Chapter 5
Conceptual Framework of the Study

5.1. Introduction

This chapter deals with the development of the conceptual framework for this study. The chapter commences with a review of the literature on the variables that influence crop production. From this review, the conceptual framework for the study is then developed.

This chapter is divided into three sections. Section 5.2 covers existing literature on the factors influencing crop productivity of date palm. It outlines and discusses the farmer characteristics, agronomic characteristics, irrigation characteristics and other input characteristics. Next, Section 5.3, presents the discussion of the conceptual framework. Finally, the conclusion section (Section 5.4) summarises the current chapter.

5.2. Factors influencing crop productivity and productivity

Studies have reported many factors that influence production and productivity (Al-Shahib & Marshall, 2003; Chao & Krueger, 2007; Shabani, Kumar, & Taylor, 2012). These are broadly categorised into the following key areas, namely: farmer characteristics, agronomic characteristics, irrigation characteristics, and other input characteristics.

5.2.1. Farmer characteristics

Farmer characteristics play an important role in crop production. Farmer characteristics include age, education, training, number of family members, experience and incomes of farmers (Bhende & Kalirajan, 2007; Bravo-Ureta & Evenson, 1994; Kalirajan, 1990; Parikh & Shah, 1994). Several studies have shown a positive relationship between technical efficiency, productivity and farmer characteristics (Bhende & Kalirajan, 2007; Bravo-Ureta & Evenson, 1994; Kalirajan, 1990; Parikh & Shah, 1994). These studies are outlined below.

5.2.1.1. Age

Adesina and Baidu-Forson (1995), for example, examined the influence of farmers age on date palm farms, and reported a positive relationship between farmer's age and adoption of date palm varieties in Burkina Faso and Guinea. Shaloof and Areada (2010) revealed that older farmers are more efficient than younger farmers. However, farmers who have more experience of date production also have higher technical efficiency. However, Das et al. (2010) and Al-Subaiee et al. (2013) found farmer's age on farms under irrigation technologies and farming experience to have a negative relationship on date palm production in Nigeria and Saudi Arabia. There are other studies (Lawal & Oluyole, 2008; Tabi, Vabi, & Malaa, 2010) that provided results about intercropping with date palm, these results are in agreement with Al-Subaiee et al. (2013) which demonstrated that there is a negative correlation between age and date production and improved inputs use for date palm. Langyintuo and Mekuria (2005) explained the reason behind the negative correlation, as they explained that the findings about age of farmers and other inputs use are controversial findings. However, Langyintuo and Mekuria (2005) admitted that young farmers may have lower income, limited contacts to agricultural extension services, and low skilled for management of farms, thus, such young farmers are not able to adopt and use improved agricultural technologies compared to older farmers. Hence, Langyintuo and Mekuria (2005) found that the farmer's age has a positive correlation with improvement in the production of crops, as the crop improvement is caused by adopting technology (Langyintuo & Mekuria, 2005). On the other hand, young farmers are sometimes thought to be more open to change and hence eager to try out new ways of doing things, thus a negative relationship between age and improved inputs use and productivity (Langyintuo & Mekuria, 2005).

5.2.1.2. Education

Another factor that influences production is education. Educated farmers are supposed to have good abilities to understand and respond to improved technologies and productivity of crops than their rivals with low levels of education (Tabi et al., 2010). Some studies found the effect of education level of farmers on date production was positive and significant, which is different compared to other empirical findings. Perz (2003), Tabi et al. (2010) and Sherif and Dar (1996) reported a positive relationship between efficiency and education. Wang, Cramer, and Wailes (1996) suggested that farmers who have higher education are more efficient than those with lower education for improved agricultural practice and outputs. Khan et al. (2009) demonstrated a significant role of both formal and agricultural education in raising efficiency and date palm cultivation in Pakistan. Farmers, who are more educated, are more likely to access and obtain information from the office of agricultural extension, which encourages them to adopt and use improved inputs (Ezebilo, Elsafi, & Garkava-Gustavsson, 2013; Khan et al., 2009). Moreover, in the Middle East and North Africa (MENA) region, education and incomes have been found to be positively correlated with improved production, because they affect farmers' ability to buy farming inputs (Yasmeen, Abbasian, & Hussain, 2011).

However there are also studies that find otherwise. For example, Battese and Coelli (1995) and Llewelyn and Williams (1996) reported that factors like farmers' education does not have a significant impact on farming efficiency in India and Indonesia. Similarly, the findings of both Wadud and White (2000) and Coelli, Rahman, and Thirtle (2002) did not show any substantial effect of education level on production efficiency. On the other hand, Khan et al. (2009) and Adesiji et al. (2013) found a negative relationship between farmers who have less education and date production in Pakistani and Nigerian farms, respectively.

5.2.1.3. Household size

Number of family members is also critical in date production development. Das et al. (2010) found the effect of family size on date cultivation and production is positive and significant in Bangladesh. Adesiji et al. (2013) reported that increased family members on average 6-15 persons can improve output of dates. Ezebilo et al. (2013) found that family size has a significant positive effect, because more family members provide more chance to plant small seedlings, which leads to growing quality of date palm cultivar from different locations in Sudan. On the other hand, Al-Yahyai (2006) reported that there is a negative relationship between the number of family members who work in their farms and date production. This is because of low skills and training. The reason behind the negative relationship between farmers with large families and date palm production in rural areas is because most farmers spend large financial resources on basic needs such as food, compared to agricultural inputs used in farms. However, a large family encourages the adoption of improved pesticides and fertiliser inputs that require more labour (Asfaw & Admassie, 2004; Perz, 2003; Weir & Knight, 2004). However, Adesiji et al. (2013) reported that demographic characteristics such as family size and marital status were not significantly correlated with date palm technology utilization.

5.2.1.4. Farming experience

Previous studies conducted showed that farming experience is an important factor for date palm production. Shaloof and Areada (2010) found significant yield variation among date palm farms due to years' experience of farmers in Libya. Later, two studies (Adesiji et al., 2013; Ezebilo et al., 2013) confirmed the findings of Shaloof and Areada (2010). However, Adesiji et al. (2013) reported that farming experience had no significant effect on date palm production in Nigeria. This is due to obtaining adequate training and recommendation on date palm technologies through relatives and friends. According to Adesiji et al. (2013) and Altarawneh and Ebraheem (2013), to develop date palm production, focus is needed on the use of information and adoption of agricultural methods recommended by extension services.

5.2.2. Farm and agronomic characteristics

Agronomic characteristics also have an effect on crop farming. (Kassem & Lairje, 2012) estimated the annual growth rate of dates in the Arab world. The cultivated area, the productive palm trees and production of dates were at 2.42%, 1.54%, and 2.5%, respectively. It has been observed that Arab countries, such as UAE, Saudi Arabia, Iraq and Libya have the potential to increase date palm production due to the availability of land suitable for cultivation of palm trees.

5.2.2.1. Farm size

Abadi, Zadeh, and Zadeh (2013) evaluated the effect of some agronomic variables on date palm production in Iran and found date palm farm size to be significantly correlated with date palm production. Altarawneh and Ebraheem (2013) reported that number of date palm trees and size of farm has a significant effect on production, cost and return of date palm in Jordan. Meanwhile, Kotb and Amin (2008) reported that farm size positively affects wheat, cotton and date palm crops production at two locations in Egypt. On the other hand, there was a negative relationship between farm size, number of trees, intercropping (e.g., with date palm) and output of wheat in the study of Croppenstedt (2005). Meeanwhile, Alshuaibi (2011) reported that increased numbers of date (new date tree planting) and size of farm may lead to significantly low revenue and investment of farmers in Saudi Arabia. Due to slow growth rate of date palm, at least 5 years are needed to start production and obtain revenue.

5.2.2.2. Distance between trees

Distance between trees can also improve crop productivity including for date palm. For example, Puri and Bangarwa (1992) reported that production of fruit, e.g., date palm, increased with distance between trees from 5 to 7 meters at four locations in Northern India. Puri, Singh, and Kumar (1994) suggested other areas cultivated with date palm trees under suitable distances between trees led to increase in productivity.

Latifian, Rahnama, and Sharifnezhad (2012) evaluated the effect of distance between trees of less than 5 meters and more than 5 meters on date production by Kolmogorv-Smince normality test. They found that the distance of more than 5 metres led to an increase in date production. This production increase could be attributed to the decrease in pests and weeds. Other crops, e.g., cocoa and wheat have different results compared to date palm crops as reported by Onumah, Al-Hassan, and Onumah (2013) and Younis and Ahmad (2012).

5.2.2.3. Soil type

Bäckman and Lansink (2004) analysed the effect of soil type on barley, wheat and oats production. They indicated that clay soil was the most efficient and productive compared to organic and silt soils. Binam et al. (2004) and Wollni (2007) and Wollni and Brümmer (2012) reported that technical efficiency and productivity of farms are positively influenced by the quality of soil, chemical applications on soil and other environmental factors. Ogundari and Ojo (2007) used a multi-stage sampling technique using stochastic frontier production function technique and reported that the number of trees, farm size and cost of operating are significantly related to changes in cassava crops in Nigeria. The variations in output from the frontier are attributed to differences in the farmer's technical efficiency which was 75 per cent, while the relative contribution of inefficiency to total variance equalled 64 per cent. The technical efficiency of farmers varied between 0.168 and 0.974 with a mean technical efficiency of 0.81. Onumah et al. (2013) analysed the productivity related to technical efficiency of cocoa in Ghana. Using a multi-stage random sampling technique with cross sectional data they found that farm size, pesticides, fertilizers and labour were positively related to productivity of cocoa, while productivity responded negatively to increased age and number of trees. El-Juhany (2010) reported saline soil type had a negative impact on the date palm production in arid regions, especially in Libya. Some authors such as Belloumi and Matoussi (2006) and Shaloof and Areada (2010) confirmed that farm size, soil type and number of trees and distance between trees negatively affects date palm production.

Jaradat and Zaid (2004) and Chao and Krueger (2007) considered distance between each tree, age and number of trees, type of soils, e.g., saline water and soil; and intercropping with other crops as the key constraints in the future for date palm production worldwide.

5.2.3. Irrigation characteristics

Many studies considered irrigation characteristics as important for crop production. Irrigation characteristics do not only influence date palm farming in Libya; generally, the amount of water and length of irrigation time improves productivity.

According to Dilip et al. (2014), the production of onion was significantly influenced by different irrigation systems under different stages. The highest yield was 1110.89 kg per ha while the lowest yield was 897.70 kg per ha. Gudugi et al. (2012) conducted a study on the effect of irrigation interval on tomato crops. The results show that irrigation interval had a significant effect on growth and productivity of crops during different seasons in Nigeria. Al-Ghamdi, Hussain, and AL-Noaim (1991) found intervals of irrigation and water use efficiency had an effect on sunflower yield in Saudi Arabia and suggested that an irrigation interval of ten days, equal to 60 per cent depletion of available water is optimal for sunflower production.

Seed and El-Nadi (1997) investigated the effects of frequency of irrigation on the growth and yield of alfalfa in northern Sudan. They concluded that alfalfa crops in dry conditions must be watered regularly and lightly to reach high yields. In the same country, Croppenstedt (2005) estimated a Cobb-Douglas frontier production function for wheat production. Results showed that quantity of water and frequency of irrigation were found to raise wheat production from 7 to 14 per cent. In Nepal, Singh, Sharma, and Prasad (2001) found that increasing number of irrigation times by 10 per cent increased rice production by 1.2 per cent. Meanwhile, Belloumi and Matoussi (2006) found that increasing irrigation water by 10 per cent may lead to increase in date production by 2.23 per cent in Tunisia. However, in a study by Younis and Ahmad (2012) it was revealed that increasing quantity of irrigation water by one per cent dropped wheat production in Iraq by 0.81 per cent. This led to a waste of water resources and a decrease in technical efficiency.

Several studies also demonstrated the effect of sprinkler irrigation on crop productivity. Bogale and Bogale (2005) studied technical efficiency of surface and modern irrigation for potato farms in Ethiopia using Translog production function and Likelihood ratio test. They found that even in large irrigation systems, the technical efficiency of surface irrigation was higher at 97 per cent than drip and sprinkler irrigation, which were at 77 per cent. However, Pelusey (2006) reported that sprinkler irrigation is the best method for saving large amounts of water in Australia compared to other techniques. Al-Jamal, Ball, and Sammis (2001) also indicated that irrigation water use efficiency was higher for sprinkler irrigation compared to drip and surface irrigation, so many farmers can conserve water and increase yield by employing sprinkler irrigation.

Albaji et al. (2010) analyzed two types of irrigation systems (sprinkler and surface) by focusing on various soil characteristics. These researchers concluded that sprinkler irrigation improved soil and crop productivity. Luhach et al. (2004)

examined the economical use of surface, drip and sprinkler irrigation by using primary data. The authors reported that sprinkler irrigation system was more economical, because it reduced labour and operation costs so there should be an increase in investment in sprinkler and drip irrigation usage. Contrarily, Bond (1998) noted that sprinkler irrigation systems are unsuitable for fruit trees like date palm, because it may lead to wetness around tree trunks, which results in increased spread of weevil and low production of date palm. In addition, large water loss by evaporation was found when sprinkler irrigation systems were used in a study conducted by Hillel (1983) and Uddin (2012). Meanwhile, FAO (2007) conducted an experiment to compare drip irrigation with sprinkler irrigation in terms of reducing water consumption and date palm productivity. The result showed that for drip irrigation, the yield was approximately 145 kg per tree while for sprinkler irrigation; yield was 109 kg per tree.

Other studies have also demonstrated that drip irrigation increased date palm tree productivity. For instance, FAO (2007) and Liebenberg and Zaid (2002) asserted that drip irrigation system will become more common with increased fruit size, higher date palm production, better water availability and its ease of use. According to Al-Amoud (2010); Hakimian and Nugent (2005); Calzadilla et al. (2010); Rijsberman (2003); Karlberg and Penning de Vries (2004); and Shaki and Adeloye (2006), there are increases in yield e.g., for date palm, and considerable savings in water when drip irrigation systems are used. They argued that the field application efficiency of drip irrigation can be as high as 90 per cent compared to 60-80 per cent for sprinkler and 50-60 per cent for surface irrigation. They also found that there are some examples of successful drip irrigation systems, as the drip systems can lead to reduced water use and increased yields. One example is in the USA were drip irrigation was found to be an effective method in terms of reducing the water usage of irrigation and cost of irrigation by 50 per cent. Thus, the USA Government has increased investment in drip irrigation systems, whereby farmers have achieved high annual incomes.

In Nepal, the government attempted to double irrigate areas by using drip irrigation systems as a way of reducing water usage and cost. Hansona et al. (1997) and Soussa (2010) reported that drip irrigation has saved about 40 per cent of consumed water when compared to surface irrigation. They deduced that drip irrigation might lead to solving the biggest issue in date palm farming by reducing soil moisture around the root zone area. Elmakki (2006) also compared two types of irrigation systems - canal irrigation and drip irrigation. He used both quantitative and qualitative methods to collect primary data on canal and drip irrigation. The results showed that the investment cost of date palm in canal irrigation was less than drip irrigation per ha at US$12 068 and US$ 2338, respectively. The net present value (NPV) per hectare was low (US$ 4168) in canal irrigation compared to drip irrigation (US$ 7140). The internal rate of return for canal and drip irrigation was 6 per cent and 16 per cent, respectively. However, the NPV was negative for drip irrigation, and increased productivity of date palm was about 42 kg per palm tree. A study in Ethiopia by Yohannes and Tadesse (1998) found water use efficiency increased by 50–100 per cent with usage of drip irrigation as compared to surface irrigation (furrow irrigation).

However, there are other studies that found drip irrigation systems have negative results. One example is the work of Cetin et al. (2004), who conducted a cost-benefit analysis between surface and drip irrigation using NPV analysis. The findings of their study suggested that olive farmers encounter challenges in measuring the costs and benefits of drip irrigation scheme, when compared to surface irrigations which is a common irrigation system found in Turkey. However, the results of Cetin, et al. (2004) indicated the NPV was negative for surface irrigation and positive for drip irrigation for olive production. Hanson and May (2004) found that the production of some vegetables decreased when drip irrigation was used, while it increased when surface irrigation (furrow) was used.

In many countries, plants using intercropping with date palms usually require the same water and there are no differences in the water for the palms and water for the other crops (FAO, 2007). As a result, many farmers prefer to use flood irrigation system because they can practice mixed cultivation with the same use of irrigation water. Mixed cultivation is a practice where farmers plant date palms with other crops within the same plot of land. The benefit of this practice is that irrigation can be done at the same time which may improve water use efficiency.

5.2.4. Other input characteristics

Agricultural machineries, labour, land, pesticide and herbicide inputs can have an effect on date palm farming. In Tunisia, Belloumi and Matoussi (2006) reported a positive relationship between water quantities, labour and pesticides and date palm productivity but not for farmyard manure. Similar results have been reported in Iran, where Mahdavi, Farjam, and Faraji (2014) found that agricultural machinery and pesticides led to increased date production. They further found chemical fertilizer and land size have a negative effect on date production.

Meanwhile, Rana and Islam (2010) found that adequate use of traditional mechanization and local labour had a positive effect on date palm farms in Bangladesh. The findings showed that date palm sap had higher income per tree by TK 2400 compared to coconut at TK 750 per tree. Dada et al. (2012) reported that mechanization had an effect on date palm productivity and a positive effect on income in Nigeria. They recommended farmer support to improve farmers' acceptance of the use of mechanization in their agricultural activities by providing loans, market facilities, information on price of dates and training for rural farmers on medium agriculture technology.

In another study, Altarawneh and Ebraheem (2013) reported a positive relationship with respect to farm size, number of trees and labour on Medjool date production in Jordan. Another researcher, Memon et al. (2015) compared the use of inputs such as fertilisers and labour in date palm farms in Pakistan. They found that average yield increased about 30-50 kg to above 100 kg per tree - this increase was caused by introducing high quality varieties of dates and adopting production technologies, e.g., weeding, chemical fertilizers and irrigation systems. Al Kahtani and Ghanem (2013) provided indication that an increase in one per cent in labour increase date production by 5, 4.8, and 4.5 per cent in Riyadh, Eastern, and Jwaf regions, Saudi Arabia, respectively, while an increase in one per cent in chemical fertilizer adoption of technology improves production by 0.2, 0.7 and 0.4 per cent, respectively in the same regions. Meanwhile, Umar et al. (2011) compared farmers' usage of farming inputs for gum arabic and date palm crops in Nigeria. The productivity and total revenue from gum arabic was found to be higher than date palm. Marzouk and Kassem (2011) suggested that higher organic manure led to an increase in date palm production compared to (inorganic) fertilization in Egypt.

Other studies (e.g., Wadud & White, 2000) confirmed that there are other inputs that not only affected date palm production, but other crops such as rice, corn and soybean. Wadud and White (2000) found that high levels of technical skills and productivity of rice farmers are influenced by labour, land, irrigation, pesticide and fertiliser variables. They used data envelopment analysis and stochastic frontier measures. Alm, Wax, and Stoller (2000) found using ultra-low rates of herbicide and fungicides for corn and soybean crops led to increased yield and consequently higher returns. Wagner et al. (2004) reported that herbicide application increased productivity of forest trees but was coupled with a negative effect on wildlife survival in USA and Canada. Amaza, Bila, and Iheanacho (2006) found that farm size, chemical fertilizer and hired labour had affected crops positively, and the coefficient was found to be statistically significant at one per cent level. Kotb and Amin (2008) studied economic efficiency for wheat and cotton crops using production function model. Seeds, labour, amount of phosphate fertilizer had a significant positive effect on the production of wheat outside the tilled drainage and exchange overlying areas. As for the cotton crop, the results of the logarithmic model explained that the amount of nitrogen fertilizer and cotton farm size positively affected cotton production within the outside and overlying drainage areas. Younis and Ahmad (2012) emphasised that mechanical technology, seeds and land had a positive relationship with wheat production. Narala and Zala (2010) investigated specific factors like labour, seed, machines used, irrigation, manure and fertilizers on farms in Gujarat. The technical efficiency of individual farms was estimated by a stochastic frontier. The results suggested that with a mean of 72.78 per cent of farm-specific technical efficiencies, the realized output could be raised by 27 per cent in the region by availability of technology and other resources.

Other studies such as by Kotagama et al. (2013) found that labour, fertiliser, capital and cost influenced production of different of ages of date palm. The results showed price and cost did not lead to renewed date palm trees. Al-Yahyai (2006) found that cost and higher number of labourers had a negative effect on date production in Oman. Meanwhile, Al-Hebshi (2010) found date palm farmers who used agricultural inputs have low net revenue. Chao and Krueger (2007) found that fertiliser used in some areas did not improve productivity and profitability for date palm crops compared to maize and potatoes.

Based on an extensive literature review, there seems to be no study that has investigated the effect of type of irrigation along with time of irrigation, distance between trees and types of soil. The time of irrigation is associated with the gross seasonal irrigation requirements. For example, Kassem (2007) found that each date palm requires 2191m^3/h every year, while the farmers consumed 19 960 m^3/h of water in the irrigation process. This means farmers consumption of irrigation water was at too great a rate compared to actual gross irrigation requirements. It is very important to examine this factor, because this plays a role in improving water management systems and date palm water requirements, as well as crop coefficient of trees, particularly in light of the water stress problem in desert areas such as Libya. Furthermore, the results of the existing studies are mixed and there seems to be no comprehensive study on date palms in Sebha Libya. Therefore, there is a need to investigate and understand the effects of various variables including farmer characteristics, and farm and agronomic factors. Quantities and prices of inputs such as pesticides, herbicides and manure, and the effect irrigation on date palm production in Sebha, Libya also needs to be examined.

The review above, albeit, ambivalent in terms of the impact of different variables on crop production and productivity, provides a starting point for the development of a conceptual framework for examining the effect of various factors on the production and productivity of date palm in Libya.

5.3. Conceptual framework of the study

The major source of economic livelihood in Libya is through date palm production and, as such, irrigation schemes contribute significantly to date palm production due to water scarcity. The challenges confronting water supply in Libya create a real need for efficient water management systems. Although over the years, farmers have employed different irrigation schemes to increase date palm production, production of date palms continue to remain low. The low production of date palm has affected the income of farmers in the Sebha region, in particular, where date palm production remains the major source of livelihood. To solve this issue, which is hindering date palm farmers in the Middle East and North Africa especially Libya, it is important to determine the specific factors that influence productivity and income. Some empirical studies have shown that integrating different characteristics (e.g., farmer characteristics or other output characteristics) and linking them with productivity and incomes, will support and increase agricultural production for different crops e.g., date palm (Alshuaibi, 2011; Altarawneh & Ebraheem, 2013; Elmakki, 2006; Evans & Ngau, 1991; Savadogo, Reardon, & Pietola, 1998; Shaloof & Areada, 2010). Such characteristics can lead to improved production, productivity, and fruit quality. Likewise, such characteristics can also improve irrigation systems in the agricultural sector.

As mentioned above, most researchers have so far focused on a limited number of variables such as gender, age, amount of water, fertilizer and pesticides, land, labour and costs of agricultural inputs when analysing production and productivity (Alamoud et al., 2012; Altarawneh & Ebraheem, 2013; Ezebilo et al., 2013; Otaibi, 2005; Shaloof & Areada, 2010). While studies on irrigation systems have been conducted, they are often not considered in conjunction with other variables. However, irrigation systems have contributed significantly to the increase in date palm productivity; hence, there is a need to explore the effect of this variable, together with other variables holistically, in agricultural systems. Moreover, studies on the effect of irrigation systems on the productivity of date palms in Libya are rare. Current studies have so far focussed on the efficiency of water use in this area in Libya. Although some studies addressed challenges and marketing costs of dates in Libya (Aayd, 2001; Al-Khayri et al., 2011; Aldawiny, 2004; Edongali & Aboqilh, 2005; Ezat et al., 2007), they have not yet addressed the three factors mentioned above together. Therefore, this area needs to be empirically investigated.

With regards to distance between trees, there are some studies that analysed the effect of ‘distance between trees on the genetics of date palms in different regions. However, no research has been conducted about the impact of distance between trees on productivity. According to El-Juhany (2010), distance between trees is related to production of dates. Finally, understanding the effects of type of soil helps in developing selection strategies for soil suitability for the production of date palm as soil type also influences date palm cultivation. Due to the ambiguity in those three factors, especially in terms economics of production, it is important to examine the effect of these factors when studying date production in the study area.

In the case of Sebha, Libya, to reduce loss of water irrigation and increase productivity and farmer income, there is a need to focus on different agricultural characteristics at the same time. Increase in date palm production and reduction in water irrigation are strongly associated with factors such as the characteristics of farmers, the use of irrigation, agronomic factors and the inputs used by farmers. Based on the literature reviewed in Section 5.2, a conceptual framework for analysing the effect of various factors on the production and productivity of date palm in Libya is thus, presented (Figure 5.1).

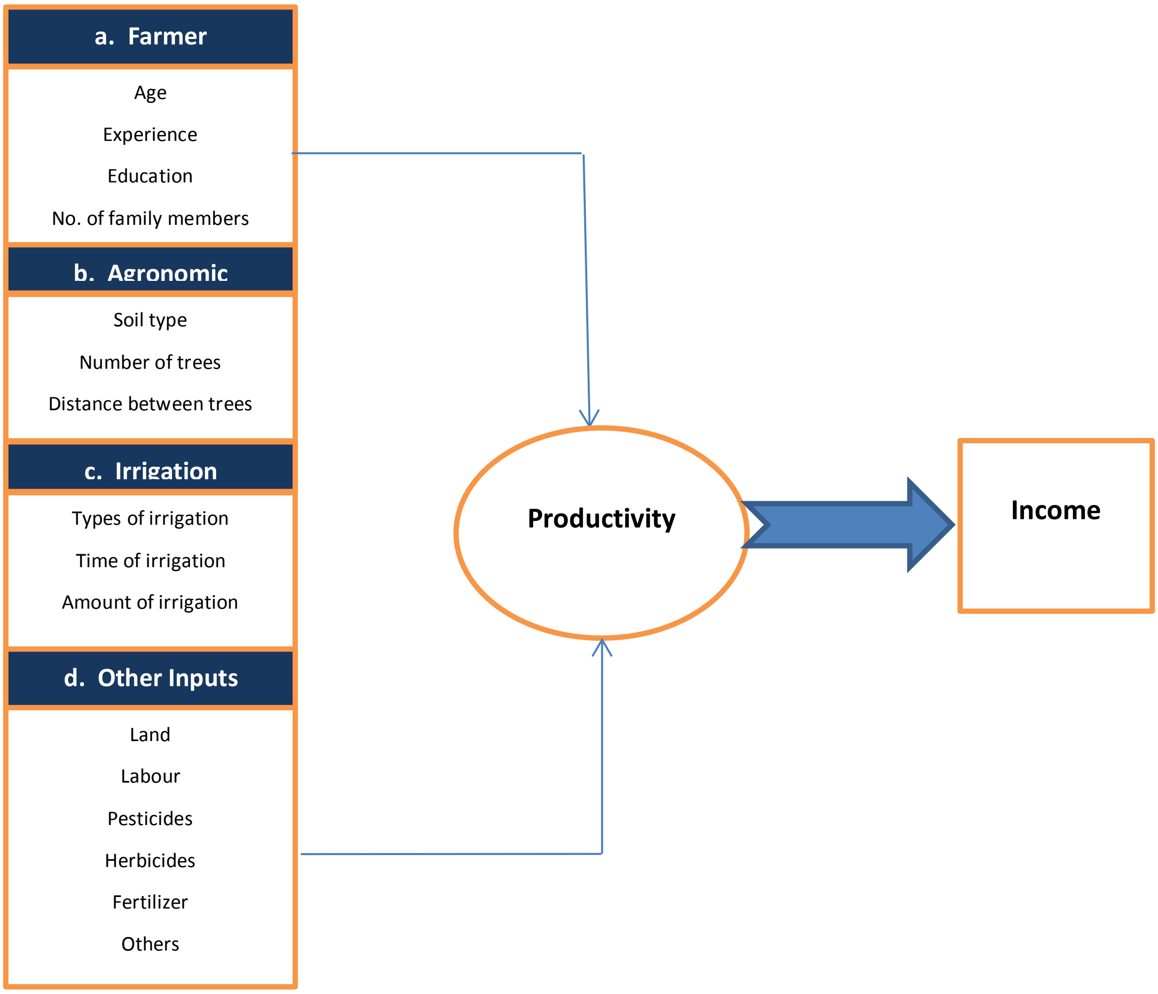

Figure 5-1: Conceptual framework of factors influencing crop productivity.

The conceptual framework above explains the effect of the variables under the four characteristics that are hypothesised to affect date palm production in the Sebha region: (a) farmer characteristics; (b) agronomic characteristics; (c) irrigation characteristics; and (d) other inputs.

Even though date palm is one of the oldest and most popular cultivated trees in Sebha, Libya (e.g Riahi, Mammou, & Thayer, 2009), there has been relatively few studies regarding the effect of type of soil, number of trees and size of farm; and distance between trees, together with other relevant variables. Thus, the current thesis attempts to overcome the gap in this area by developing an understanding of the effect of those factors on date production, under different systems of irrigation. In addition, other studies focus only on the physiological changes associated with date production and yield, however, this thesis provides a comprehensive review of how agronomic characteristics have an impact on date palms. The findings of this thesis, can also play a role in improving the agronomic characteristics, which, in turn, can improve date production.

In addition, this conceptual framework will be supplemented by an experiment which investigates how the types of irrigation systems impact on fruit quality of commercially grown cultivar of date (Talees) in Sebha. The literature review (see Chapter 4) also suggested that there is no known study that combined both statistical and experimental methods to examine the effects of these characteristics and test such conceptual framework. In this study, an attempt was made to combine both statistical and experimental methods in an attempt to holistically examine and understand how the types of irrigation systems impact on fruit quality and income levels of commercially grown cultivar of date.

5.4. Conclusion

Studies have highlighted various factors that could hinder or improve productivity including farmer characteristics such as farmer’s age, experience, education and family size. Agronomic characteristic factors also influence productivity directly or indirectly. Similarly, the type of irrigation and adoption of irrigation are important factors that could contribute towards explaining low efficiencies. Other variables such as agricultural machinery, labour, land, pesticide and herbicides all could influence date palm production. Thus, the hypothesized factors influencing date palm farming in Libya should be done with a proper investigation of all these variables.

As can be seen in the review above, several factors influence production and productivity of agricultural crops including date palms. Although inputs are directly related to date palm production, it can be noted that the majority of the literature has mainly focused on the impacts of these variables on one type of date palms in the Asian and Middle Eastern regions. Relatively, little is known about the impacts of certain characteristics on the date palm production in the North African region, in particular, Libya. As previously mentioned, the studies conducted in Libya focused on certain inputs but not holistically. For instance, some studies focussed mainly on farmer and agronomic characteristics, but not in conjunction with irrigation. Others looked at irrigation but did not include other variables that could potentially impact on production and productivity. Libya is an arid and semi-arid country and is negatively affected by global warming. Thus, it is important that research is undertaken into the most effective irrigation system that promotes efficient use of water irrigation to contribute solutions to the problems of depleted water resources and the increasing demand for water by the agriculture sector in Libya. As such looking at the impacts of irrigation is important, but at the same time considering also the other variables including farmer characteristics, agronomic characteristics, inputs and other relevant variables. This will allow us to have a complete understanding of the factors that influence productivity.

Irrigation characteristics are a key to obtaining profitable product with reduced wastage of water. The study of these characteristics for each irrigation system can lead to higher production of date palm crops as well as higher productivity of water use. It is now widely recognised that most countries will be suffering from the global water crisis in the future, thereby reducing water resources and according to FAO (2007), date palm crops consume the greatest quantity of water in Libya.

The following chapter will outline the research method used in this study, including how these variables will be gathered, what questions will be included in the questionnaire, and how they will be measured and analysed.

Chapter 6
Research Methodology

6.1. Introduction

This chapter provides an outline of the methodology employed in this study. Issues of research quality are considered and measures adopted to optimize the reliability, validity and generalizability of the findings are discussed. This chapter is divided into nine sections. After the introduction, Section 6.2 discusses the choice of research paradigm applied in the study. Section 6.3 provides the justification for the choice of the methodology used in the study by considering the epistemological and ontological context of the research problem. Sections 6.4 discusses the type of data used, the description of the questionnaire and data collection methods, while Section 6.5 discusses limitations of the data collection process. Section 6.6 discusses the economic analysis of date palm production under the different irrigation systems. Section 6.7, highlights the analytical procedure. Section 6.8 provided an overview of the model specification and included a discussion of the variables and data required according to the conceptual framework. Section 6.9 outlines the analysis of physical and chemical characteristics of 'Talees' dates. The ethical issues were elaborated in Section 6.10, followed by the conclusions in Section 6.11.

6.2. Selection of research paradigm

The philosophical foundation of a research directly influences the approach involved in conducting a study. Most researchers consider it important to begin based on a specific research paradigm to be applied in a study because it influences the researcher's reflections on the research problem, the design of research methodology and the interpretation of results.

The word paradigm comes from the Greek language *paradeiknyai* (Shtarkshall, 2004). In English it denotes a "cluster of beliefs and dictates in a particular discipline which influence what should be studied, how research should be done, and how the results should be interpreted" (Bryman, 1988, p. 4). A research paradigm is a set of fundamental beliefs and assumptions which provide a guide to the researcher (Jonker & Pennink, 2010). Ponterotto (2005, p. 127) defines a research paradigm as a:

> "*Set of interrelated assumptions that provides a philosophical and a conceptual framework for the organized study.*

Morgan (2007, p. 49) acknowledges a paradigm as "the set of beliefs and practices that guide a study, and it can be used to summarise the beliefs of researchers". The paradigm selected guides the researcher with an idea about the research and in the selection of tools, instruments, participants and methodological approach used in the study (Ponterotto, 2005, p. 127). According to Wahyuni (2012) and Collis and Hussey (2013), research paradigms comprise of positivism and interpretivism. However, the chosen paradigm illustrates the research problem which then determines the methodologies and produces results which can then be interpreted.

6.2.1. Positivism and Interpretivism

The positivism paradigm comes from the thoughts of French philosopher August Comte (1798–1857). The philosopher confirmed that the way to understand human behaviour is the reason and observation, while experiments serve as a method to develop knowledge (Crotty, 1998). Positivist thinkers accept and verify this approach of utilising scientific methods for knowledge generation; but this needs to be considered under a particular set of principles and assumptions, which Cohen et al. (2000) list as determinism, empiricism, parsimony and generality. Determinism implies that a particular event is caused by other circumstances, and both are essential to understanding the relationship between cause and effect. Empiricism refers to the collection of verifiable evidence which supports a theory or hypothesis. Parsimony describes the explanation of the event, while generality refers to a quality of observation or principle having general application.

The positivist paradigm is based on the principle of the systemisation of knowledge through quantification, which in turn improves the precision of descriptive parameters. Therefore, research depending on the positivist paradigm use quantitative and scientific approaches and involves the selection of a research method which clearly defines the research problem, a set of hypotheses, and use of a clear sampling technique such as survey, cross-sectional correctional, longitudinal, experimental and quasi experimental for scientific approach (Fontana et al., 1998). On the other hand, some critics of the positivist approach regarding human behaviour and its way of interpreting social reality have an emphasis on subjectivity in scientific enquiry as an alternative objective (Heltberg, 2001). Despite application of alternative paradigms by researchers in the world, the positivist approach has been popular among social scientists until now, compared to other approaches in the developed world such as the USA and Australia (Kaan, 1998; Orlikowski & Baroudi, 1991). Interpretivism is given as the alternative to the positivist paradigm. Interpretivism is defined as “a systematic analysis of socially meaningful action through the direct detailed observation of people in a natural setting in order to arrive at understanding and interpretation of how people create and maintain their social world” (Neuman, 2000, p. 71). Kroeze (2012, p. 2) defined interpretivism as ‘a philosophical system that focuses on reality as a human construction which can only be understood subjectively”. Some scholars suggest that an interpretivism paradigm has a close relationship with qualitative research (Brennen, 1992) and naturalistic enquiry (Patton, 1990). This paradigm is based on the assertion that reality is a complex phenomenon, it can have several explanations; therefore, when conducting a social survey, the paradigm recommended the application of the qualitative method. Klein and Myers (1999) stated that interpretive research tries to examine a phenomena by the meanings that people assign to them, without the need to predefine dependent and independent variables. This is possible because the research focuses more on the complexity of the human interaction that occurs as the situation emerges. The role of the researchers when using this paradigm is to orchestrate the dialogue and facilitate a dialectic communication between researchers and the researched. This interaction helps them develop viable meaning and understand the problem situation. In short, constructing the meaning of the phenomena is the major role of the researcher in this main research process and the outcomes of the research therefore do not usually generalise for different times and issues.

6.2.2. Selection of methodology

The selection of the paradigm to be employed in this study was based on consideration of the nature and kind of research questions, the need for quantification of research data, the need for generalizability, validity and reliability of the data derived from the research questions and pertaining to the objectives, and the need to ensure appropriate depth of analysis. After careful evaluation of the research questions and targeted objectives, the positivistic paradigm was deemed the most appropriate approach as its inherent advantages would ensure healthy and objective research findings. The selection of this paradigm ensured provision of data in numeric form which could be analysed using scientific tools and statistical procedures. Descriptive statistics such as mean, median, mode, frequency, standard deviation; and inferential statistics such as t-test, ANOVA, regression, correlation or more advanced multivariate analysis, gave a unique strength to the conclusions derived in the study. Results obtained from a quantitative research paradigm tend to be generalizable and robust; result verification and cross-verification increases its usefulness. This paradigm is also least affected by researcher bias and competency. Help from existing theories and literature on the subject under study, likewise, enhances the success of the research.

The selection of this research paradigm was consistent with the nature and scope of the research study and hypothesis under consideration. The nature of the study and its intended objectives clearly defined the need for a positivistic approach as the study is focused on measuring and analysing the effect of different types of irrigation on date palm production in Sebha, Libya.

6.3. Research design

The research design for the study, including the area of study and selection of samples is outlined below.

6.3.1. Area of study

This study was conducted in South Libya. South Libya is locally named Fezzan. The region occupies a large proportion of the desert in North Africa which is situated at 20° to 28° altitudes at 9.2° altitudes with a vast area of 550 000 km^2 occupying about 37 per cent of the total area of Libya (El-Hodairi, 1991). The Sebha region is located in South Libya and represents 0.87 per cent of the total area of Libya. Sebha city is the largest city in the Sebha region and is located in the middle of the Libyan desert; it is about 800 kilometres south of the Libyan capital (Tripoli) (Abdulsalam et al., 2013). The major settlements of Sebha city include Al-Mahdia, Sukrah, Alnssiria, Hagiara, Al Tanawia and AlJadeed. In addition, there are four major suburbs surrounding Sebha city: Tamanhant, Samnu, Al-zighan and Ghodduwa. Tamanhant, Samnu and Al-zighan are about 30, 60 and 70 kilometres, respectively, east of Sebha centre, but Ghodduwa is about 60 kilometres south of Sebha (Mbendi, 2014). Sebha region has a desert area with a series of east, west depressions, large hills of sand dunes and a few large oases along Wadi al- Shati and Wadi al-Ajal region (Karam & Tayeh, 1999). The area is influenced by a typical desert climate. It is very hot and the average temperatures daily can vary widely, especially during the winter season (December, January and February) when low nocturnal temperatures are fairly frequent. The temperature is high between June and August. The annual mean temperature ranges between 12 degrees at night and 30.5 degrees during the day. Sometimes the maximum temperature reaches as high as 45.7 degrees. The maximum relative humidity is 46 per cent in the winter season (January) whereas it decreases to 18 per cent in summer (June) (El-Hodairi, 1991). The level of rainfall is very low in the Sebha region, but groundwater is abundantly available from wells for each agricultural household (Karam & Tayeh, 1999). The population of the Sebha region is an estimated 133 056, but more citizens have come to this region from the different urban zones surrounding it and therefore, it has a heterogeneous society (Peeran et al., 2014).

Agricultural activities are the main occupation of the people in Sebha region and underground water is the major source for irrigation for many types of crops including date palm trees (Abdulsalam et al., 2013). Figure 6.1: below shows the geographic location of the research area.

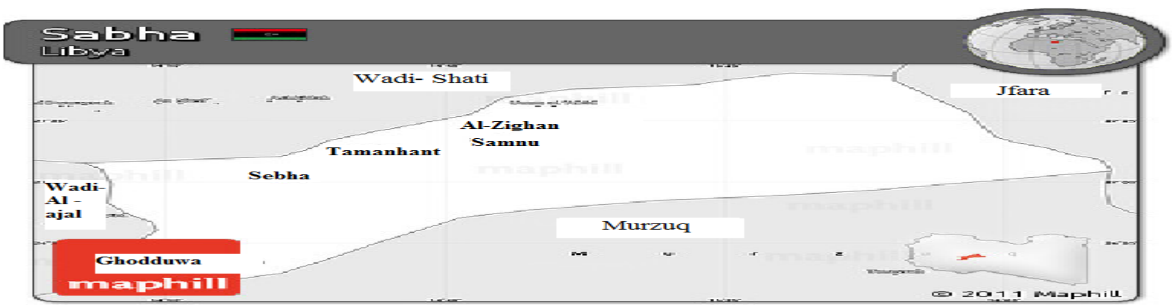

Figure 6-1: Geographic location of the research area.

Source: Maphill (2014)

6.3.2. Selection of samples

The region of Sebha is located in South Libya and is home to many date palm farmers owing to the suitability of the land for date palm production. The Sebha region contributes about 8.08 per cent of the total date palm production in Libya and is considered a significant region in relation to date palm production in Libya (Libyan Statistics, 2007). The choice of Sebha region for this study was occasioned by a number of factors. First, date palm has been considered a major source of food for the people of Sebha. Second, even though Sebha region has employed irrigation systems, date palm production in the region continue to remain low compared to other Libyan regions, thus this needs to be investigated. Finally, the low productivity of date palm in the region directly affects the income of date palm farmers, thus it is important to understand why this is so.

In order to allow all date palm farmers in the area to have equal probability of being selected for the study, the researcher employed simple random sampling technique (Dorofeev, 2006; Thompson, 2002). A large sample size (210 farmers) was used to reduce sampling error. Al-Faydi (1994) distinguished between large and small sample sizes by arguing that large sample size must have more than 100 cases or respondents whereas a small sample size could be limited to 30 cases or respondents. According to statistics from the Libyan Statistics (2007), it is estimated that there are 2096 farmers in the Sebha region. Of the 2096 farmers in the Sebha region, the study sampled 210 farmers which represent 10 per cent of the total farmer population of 2096. The study employed systematic random sampling technique; the researcher first picked his starting number, 1. Then the researcher picked his interval, 10. The members of his sample was therefore individuals 1, 10, 20, 30 until 210.

The farmer participants were selected from Ghodduwa, Tamanhant, Al-Zighan and Samnu. The main reasons for the selection of the four towns were because these areas are home to the majority of date palm farmers, and date palm farming is their main source of livelihood. Data was collected between August to November 2013 from farmers in the study area.

6.4. Data gathering method

6.4.1. Types of data

Two types of data were used in this thesis: qualitative and quantitative from both primary and secondary sources.

Primary data was collected directly from date palm farmers. Data about the farmers covered general characteristics such as age, education, marital status, farming experience, and the number of farmers' dependents, farmer training, and income of farmers. The data also included sources of income of the family from different economic activities, household expenses, farm management, number of date palm trees, age of trees and land utilization such as: farm size, other crops, in addition to date palm trees, cropping patterns, type of soil, irrigation water sources and types of irrigation used. Irrigation data consisted of data about production of date palm under surface, sprinkler and drip irrigation. Each of the three irrigation systems were examined under the three sections and included years' usage, experience in irrigation, land or farm size under irrigation system, types of irrigation, distance between date palm trees, inputs usage and costs (purchase, labour, pesticides, fertilizer and other inputs etc.), date marketing and prices, and advantages and disadvantages in the use of the irrigation systems etc.

Secondary data were collected from various sources, including agencies, the Ministry of Agriculture, Ministry of Water; and Centre of Agricultural Research in Southern Libya. Secondary data also included data on total farms, the number of farmers, farm input availability in the sub-district in Sebha, production and productivity, exports and imports of Libyan dates. Other data to support this study came from official sources for example, books, journal articles, research reports, online articles, theses and reports issued by international organizations.

6.4.2. Data collection

The survey was conducted using a structured questionnaire. The questionnaire was used: firstly, to collect data associated with the aims of the survey; and secondly, to collect valid, reliable and accurate data (Warwick & Lininger, 1975).

A total of 210 date palm farmers were interviewed using structured questionnaires, focusing on farmers who have used different types of irrigation, e.g., surface, sprinkler and drip irrigation. Two main reasons for employing this technique were firstly, structured questionnaires provide more accurate data than observations, especially quantitative data (Punch, 2013). Secondly, the use of a structured questionnaire assisted the researcher to avoid collecting unimportant data by pre-planned questions as well as to prevent the respondents from going off track. Some previous studies relating to agricultural productivity analyses used this type of questionnaire to collect final data. For example Battese, Malik, and Gill (1996) and Dhungana, Nuthall, and Nartea (2004) employed structured questionnaires to collect data related to inputs and outputs of rice and wheat farmers.

Pre-testing was carried out on some farmers to check whether the questionnaire would generate the required data, the respondent's grasp of the survey and the time taken to complete the questionnaire. The pre-test survey examined not only the questionnaire aspects, but also the effectiveness of the framework of fieldwork, the quality of the interviews, the justification and adequacy of the instruction, the frequency of different reasons for refusals and the overall correctness of the survey method (Oppenheim, 2000). The test led to an improvement in several areas such as the order of the questions, the unit measurement, improvements in scales and the general structure of the questionnaire. The questionnaire was translated into Arabic because most farmers in the research area only understand Arabic. The researcher engaged three final year students from the Faculty of Agriculture, University of Sebha (Libyan National University) as research assistants. This is because those students were familiar with various activities of date palm farmers in this area. The study area is large and the researcher alone would take a long time to collect the data. The students helped the researcher in accessing information and in interviewing respondents. The student assistants were familiar with the location of Sebha, and fully aware of cultural and religious customs, being Libyan nationals. Heltberg (2001) and Dundon and Ryan (2009) suggested that the building of a positive rapport between the researcher and participants could lead to the collection of superior, deeper and more meaningful data.

Each respondent was visited and interviewed face-to-face to gather reliable information because the respondents have a low-level of literacy and mail facilities were poor in the suburbs of Al-zighan, Samnu, Ghodduwa and Tamanhant in Sebha region. The interviews were conducted using the local dialect. An appointment for a convenient time was arranged and interviews were carried out on the farm. A field assistant was sometimes required to assist the researcher with transport from one farm to another. The researcher also utilized other strategies, for instance, visual representations, gestures and demonstrations to assist some illiterate farmers in providing relevant information. This included explaining questions in different ways and conducting on-site visits to date palm farms. Figure 6.2 shows researchers interviewing date palm farmers.

Figure 6-2: Researcher during an interview with date palm farmers

6.4.3. Questionnaire design

Questionnaire design is an important stage in generating data to meet the research aims (De Vaus, 2002; Oppenheim, 2000). There are general principles that play a role in designing a good questionnaire in terms of ensuring reliability, validity and participation of the respondents. The general principles are questionnaire wording, format and sequence, the inclusion of classification, knowledge and behavioral questions, awareness or perception and questionnaire length and output (Bird, 2009). The questionnaire in this thesis was designed with the intent of gathering maximum information needed for the research. The questionnaire was designed by considering the essential details required for data analysis (Figure 6.3). Questions regarding age, education, marital status, household size, experience, and land size; information regarding land fragmentation, crop rotation and cropping patterns were included.

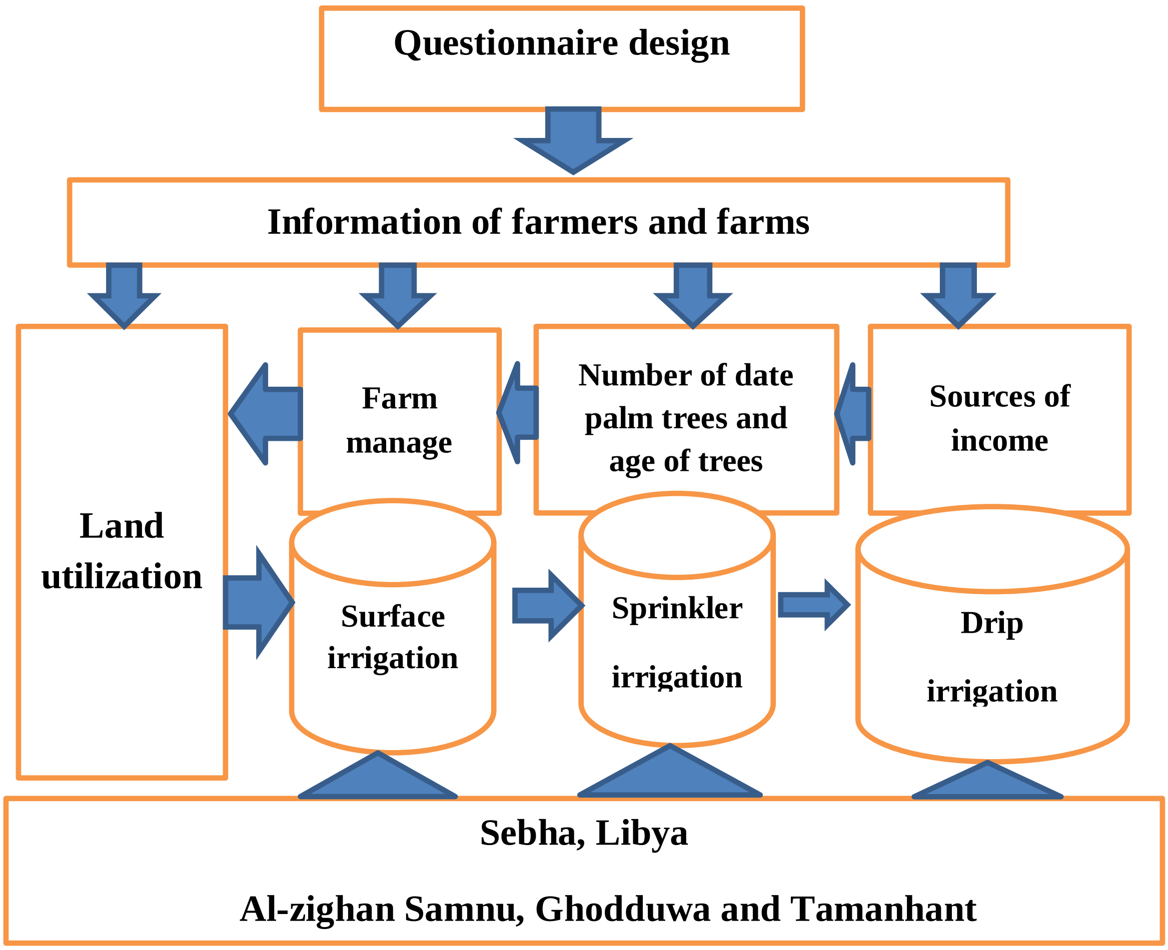

Figure 6-3: Questionnaire design

The questionnaire consisted of nine sections. Part 1 sought to gather general information about farmers. Questions in this section included issues such as: age of respondent, marital status, farmer's levels of education, training in farming, number of family members, farming experience, salary per month etc. Part 2 sought to describe other sources of income of the family from different activities including vegetable gardening, services, rentals, and subsidy from other family members, remittance from abroad, poultry, livestock rising, fruit trees and commission from sales. Part 3 included farm household expenses such as food, rental fee, tuition, allowances, books, and school supplies loans repayments etc. Part 4 sought to gather information on how farmers manage their farms during the irrigation operation. Part 5 also contained questions about the number of date palm trees and age of the trees that are over or under seven years. Part 6 collected data about land utilization which included farm size, crops in conjunction with date palm trees, cropping patterns, type of soil, etc. In this part, there were some additional questions on irrigation water sources of date palm and types of irrigation e.g., surface, sprinkler and drip irrigation. Parts 7, 8 and 9 were to provide detailed descriptions of surface, sprinkler and drip irrigation length of usage, experience in using irrigation, area of date palm under surface irrigation, timing of irrigation and distance between each date palm tree, input usage, purchase, labour, farm practices, fertilizer type, market and income from the date palm, advantages and disadvantages of irrigation systems, etc. Part 10 focused on the household goals, for example; meeting household food needs, savings, education, health, etc. Respondents were asked to answer the questions on a scale from 1 to 7 where one was not important at all, 7 extremely important. The questionnaire consisted of 83 questions in all (see Appendix A).

6.5. Limitations in data collection

Although, the survey was conducted during August, September, October and November when farmers were available and had free time, and all the agricultural operations of the season had been carried out, there have been some challenges and limitations in the data collection. For one, the recall process was used to obtain primary data during the survey because of the non-availability of written farm records. According to Norman (1973), the memory recall process was the most practicable and reasonable way to obtain primary data with less time and financial resources.

Time, budgetary constraints and illiteracy of farmers were the other problems which made it difficult to collect the data. The farmers were unable to grasp the idea of research and sometimes they refused to give any information due to illiteracy or fear that the interview may be related to paying taxes. However, methods were adopted to assist the farmers in thinking back to the agricultural operations; farmers were reminded about the cost items of farming activities and revenues from crops in previous answers to help in their memory recall process.

6.6. Economic analysis of date palm production under irrigation systems

This section is devoted to the method of analysis used in this thesis for the economic analysis of date palm production under different irrigation systems. The section is divided into three parts including the farm production function model, production function models and efficiency measurement.

6.6.1. Farm production function model

Production activity is a process of transformation of inputs into outputs. In agricultural economics, this activity is a key factor in the successful performance of a farm. The starting point of analysis for the neoclassical theory of the farm is the concept of a production function. Rushton (2009) defined a production function as a mathematical or quantitative description of various possibilities of production methods of a farm. A production function shows the current technology available to the farm involved, the maximum output that can be produced by a specified set of inputs, (Battese, 1992). Otherwise, a production function refers to an organisation of the minimum inputs required to produce designated quantities of output using a given available technology (Sinha, 2009). In other words, a production function is a physical relationship between (*Y*) which is a dependent variable and (*Xi*) which represents independent variables which take more than variables for the production process. Mathematically, this relationship can be expressed as follows.

$$Y= f\,(Xi) \qquad \textbf{(6.1)}$$

Production functions can have various forms, e.g., from the simplest linear relationship through to translog ones (Deorukhkar, 2007; Dillon & Hardaker, 1980).

According to Dillon and Hardaker (1980, p. 104), there are three important factors or reasons that must be considered in developing production functions:

1. The production function must be able to describe a real production process.
2. The algebraic form of the production function must be physically and economically logical.
3. The production function must be easy to measure and calculate.

Selecting the appropriate production function from various kinds of production function is subjective. However, there are some factors that should be considered to obtain a good production function as follows (Deorukhkar, 2007; Dillon & Hardaker, 1980; Nelson, 2005):

1. There is a logical relationship between the explained/dependent variable and independent/explanatory variables.
2. Statistical parameters estimated from the production function have to be highly significant level parameters. This can be seen from the coefficient of determination (R^2) and from the result of the t-test for each explanatory variable.
3. The production function can be logically and economically explained.
4. The production function is easy to analyse.
5. The production function has economic implications.

6.6.2. Types of production functions

Four types of mathematical production functions were used in this thesis. These are the linear production function, quadratic function, cobb-douglas and translog production function. Each of these production functions is presented below.

6.6.2.1. Linear production function

A linear production function is appropriate for describing the process where every addition of input will increase the quantity of output. This process is normally found in the manufacturing goods production process however the same process is used to describe the production model of an agricultural product.

The linear equation is written as follows:

$$Y= \sum_{i=1}^{n} \beta \ X \quad \textbf{(6.2)}$$

where Y is date palm production; β represents parameters to be estimated.

6.6.2.2. Quadratic production function

A quadratic production function is similar to a linear function however, it has an optimum point where the output will start going down. This model will not be practical if the numbers of independent variables are more than two (Ozsabuncuoglu, 1998). This model is more appropriate in an experiment that measures up to two independent variables, such as measuring the effect of nitrogen and phosphorous on the growth of certain variety of dates. The quadratic equation can be written as follows:

$$Ln\ Y= a+ ln\beta_1 x_1+ ln\beta_2 x_2+ ln\ \beta_3 x_1^2+ ln\beta_4 x_2^2 \quad \textbf{(6.3)}$$

where Y is date palm production; β represents independent parameters to be estimated.

Realising that the production process of agricultural commodity involves more than three farm inputs as independent variables, Byiringiro and Reardon (1996) and Ray (1999) suggested that the translog model is more appropriate to describe the process. Both of these types will be elaborated in more detail in Chapter 9.

6.6.2.3. Cobb-Douglass production function

The Cobb-Douglas production function is one of the most popular techniques of estimating production functions (Arsalanbod, 2005; Mythili & Shanmugam, 2000). The main reason researchers use this technique is because the logarithmic transformation of a Cobb-Douglas function (see Equation 6.1) is relatively easy to interpret compared to quadratic and square functions (Battese & Coelli, 1995;

Lindara, Johnsen, & Gunatilake, 2006). The main drawback is that they are vulnerable to multicollinearity and possible lack of sufficient degrees of freedom because of the presence of interaction terms (Coelli et al., 2005). The estimated parameters of a Cobb-Douglas function indicate the value of the elasticity for every input used. Each estimated parameter measures the responsiveness of output for a per cent change in the input (Nicholson, 2002). The sum of the parameters exhibits the production structure of technology. In addition, the returns to scale of the production process can also be calculated from the estimated parameters of a Cobb-Douglas function (Battese & Coelli, 1995; Coelli et al., 2005). The Cobb-Douglas function is also used both as a profit function (Cobb-Douglas profit function) and cost function (Cobb-Douglas cost function). This indicates the significance of the functional form in explaining crucial problems of economic phenomenon. The Cobb-Douglas production function is given below:

$$Ln\ Y = \sum_{i=1}^{n} \beta\ ln\ X \quad \text{.......................................} \quad \textbf{(6.4)}$$

where Ln represents natural logarithms, Y is date palm production, β represents parameters to be estimated.

6.6.2.4. Translog production function

The translog functional form is another type of production function commonly used in farm production analysis (Nicholson, 2002). This functional form is more flexible in nature (Bigsby, 1994; Parikh & Shah, 1994). Flexibility arises as both linear and quadratic terms are able to utilise more than two factor inputs (Christensen, Jorgenson, & Lau, 1973; Greene, 1997). Interaction and cross multiple terms provide an opportunity to explain the structure of a translog production function (Samoilenko & Osei-Bryson, 2008). However, the result of estimations using translog models with more than three independent variables is more complex and difficult to interpret. When data with many variables is fitted to a Cobb-Douglas model, the result of the estimation will be easier to interpret. The translog function has some disadvantages such as no prior restrictions being imposed such as for substitution elasticities, or the assumption of identical returns to scale (Battese & Coelli, 1995; Bigsby, 1994). Hence, this functional form is particularly more appropriate than Cobb-Douglas model with the structure of the production technology. Despite this model being more flexible, it needs prior testing for positivity and concavity. These tests are applied to identify conditions of non-negative marginal products and convex isoquants. However, Berndt and Christensen (1974) argued that these conditions are rarely fulfilled in global empirical studies. The general translog model can be written as follows (Chen, Huffman, & Rozelle, 2003; Naqvi & Ashfaq, 2013):

$$lnY_i = \beta_0 + \sum \beta_i \, Ln\, X_i + \sum\sum \beta_{ij} \, ln\, X_i \, ln\, X_j \quad \textbf{(6.5)}$$

where i and j = 1, 2,……., n; Ln represents natural logarithms, Y is date palm production, β_0 and $\beta_{1,}$ are same as that in the Cobb-Douglas model, and $\beta_{ij,}$ represents parameters to be estimated.

The functional form is selected largely on specific criteria consideration such as hypotheses, estimation, data, or application, and specific objectives of the research (Griffin, Montgomery, & Rister, 1987). Translog functional form is appropriate when determining the structure of a production technology along with efficiency estimation (Paul, Johnston, & Frengley, 2000). Similarly, the Cobb-Douglas functional form is also appropriate for analyzing the production structure and estimating efficiency (Ogundari, Amos, & Ojo, 2010; Siry & Newman, 2001). However, it is restrictive, because the Cobb-Douglas functional form imposes constant elasticity of substitution equal to one (Barrell & Te Velde, 2000). A study carried out by Coelli et al. (2005), suggested following the principle of parsimony and selecting the simplest functional form which accomplishes the objective of the study, and this favours the Cobb-Douglas form.

6.6.3. Efficiency measurement

Technical efficiency is defined as "the ability to minimize input use while maintaining a given output level, or the ability to maximize output production while fixing the amount of input use" (Chen et al., 2003, p. 6). There are three types of efficiency namely technical efficiency, allocative (price) efficiency and economic efficiency. Due to the limitation of data availability, this study focused on the analysis of technical efficiency which is important for this research.

There are two main approaches used to measure the production function: these are the parametric and the non-parametric methods (Coelli et al., 2005; Tozer, 2010). The parametric method uses the econometric estimation methods (Figure 6.4). On the other hand, the non-parametric method uses mathematical programming techniques, e.g., data envelopment analysis (DEA) (Kumbhakar & Lovell, 2003).

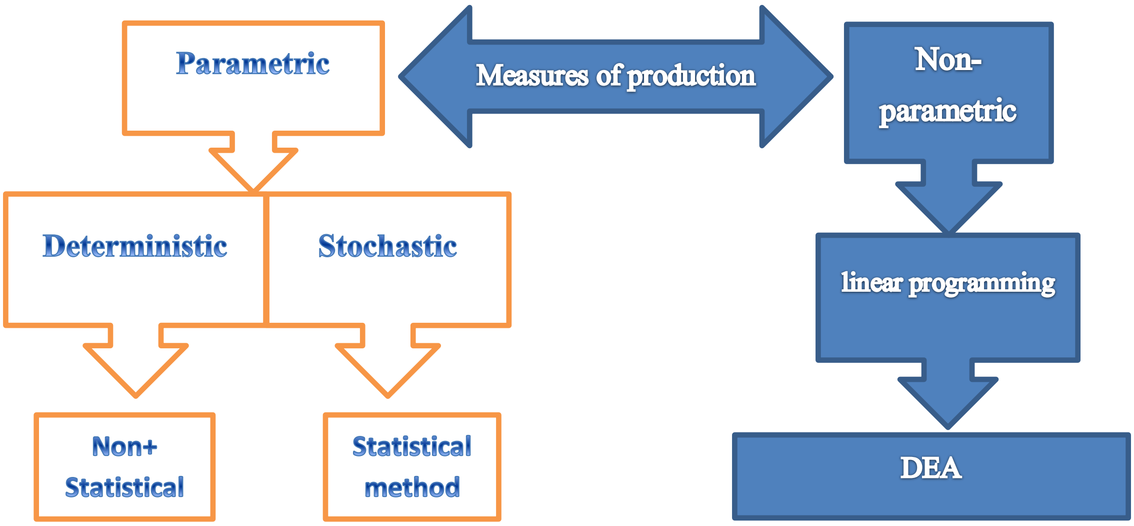

Figure 6-4: Estimation method for production frontier

The current thesis uses parametric analysis as DEA does not allow any statistical noise (error due to measurement or weather factor), this not acceptable for agricultural crops such as date palm, because it is affected by water factor, 2) DEA overstates a single farm inefficiency compared to a set of farms, 3) DEA is sensitive to outliers 4) the set of inputs and outputs in DEA is difficult to correctly identify, 5) DEA does not estimate parameters, whereas the parameter is very important in the economics interpretation (Battese & Coelli, 1995; Brown, 2006; Coelli et al., 2005; Harper, Hauck, & Street, 2001; Simar, 2007)

The parametric functional forms that have been used in productivity analysis, include Cobb-Douglas(CD), transcendental logarithm (TL), and the stochastic frontier (SF) (Coelli, 1996).

The current thesis used the stochastic frontier method of analysis because of two specific advantages, which are: (1) it is estimated by using maximum likelihood, which is similar to standard ordinary least squares (OLS) analysis. (2) It enables missing information or data and measurement errors to be captured in the error term (Coelli et al., 2005). Therefore, the stochastic frontier method is robust in measuring error and other disturbances (Chen et al., 2003).

6.6.3.1. Empirical stochastic frontier model (SFA)

The stochastic frontier production function was developed independently by Aigner, Lovell, and Schmidt (1977) and Meeusen and Van den Broeck (1977) as an alternative to productivity analysis and for addressing the weaknesses in the Cobb-Douglas and other models. Stochastic frontier was utilized in this study to evaluate the relationship between irrigation systems and other factors affecting productivity and efficiency. The stochastic frontier model is the maximum output a farm can produce from a given level of inputs (Singh 2007).

Many agricultural economics researchers (Kolawole, 2006; Oladeebo & Fajuyigbe, 2007; Rahman, 2003; Umar et al., 2011) have also used this approach. Gedara et al. (2012); Watto and Mugera (2014) and Chowdhury (2010) suggested the use of theoretical stochastic frontier function to investigate the effect of irrigation systems on wheat and rice crops productivity.

Under this model, all deviations from the frontier are assumed to be due to inefficiency. Furthermore, stochastic frontier analysis could decompose the deviations from the frontier into its stochastic noise and technical inefficiency components. It can be used to conduct conventional tests of hypotheses. Assumptions that apply to this study include: (1) non-negative input vector can produce at least zero output, (2) existence of technically efficient input and output vectors, (3) finite inputs cannot produce infinite output.

Wange and Schmidt (2002) and Kumbhakar and Lovell (2003) argued that since the inception of the stochastic frontier function in the late 1980s, the approach has dominated much of productivity studies. The model is segregated into an inefficiency component and the stochastic component and applies the one-step formula with the aid of the maximum likelihood procedure. Kumbhakar and Lovell

(2003) observed that the dominance of the model is attributed to how both the inefficiency and the stochastic components have been acknowledged with the one-step technique in the estimation process. This study employed the stochastic frontier and the maximum likely approaches for the different irrigation systems used in date palm production.

The strategy for identification of functional models in empirical research is essential because it will directly affect the result. Morgan (1990), in his work on identifying functional problems reported the challenge of estimating static models with data, and introducing stochastic elements into econometric models. There are several considerations such as biological, economic and environmental that should be taken into account for developing a model (Gujarati, 2003). The model adopted and developed should reflect the nature of the study.

Griffin et al. (1987) suggested four criteria in selecting a model: first, the model should be consistent with the theory or hypotheses and objectives whereby appropriateness can be assessed. In the absence of a theoretical base for adopting a given hypothesis, the functional form is unlimited or unrestricted with this hypothesis, second, data availability, data properties, data admissibility and the availability of computing resources can affect the ability of the model to produce a logical prediction; third, data specific - the comparisons among function forms require the use of a specific dataset and explain findings for specific studied phenomena; finally, parsimony which is related to model specification. Cody and Smith (1986) suggested emphasizing common sense and the principles of parsimony in deciding a model. A flexible model is usually preferred because it does not involve restrictions on both the parameters and technical relationships among inputs used.

The production function used for the stochastic frontier analysis in this study was a Cobb–Douglas function

The Cobb-Douglas production function was selected for this study because a Cobb-Douglas model is suitable for describing the production process (Murthy, 2002). Moreover, this model has been widely used to describe agricultural production activities (Theodoridis, Psychoudakis, & Christofi, 2006). They are specified for total irrigation, surface, sprinkler and drip irrigation. The Cobb-Douglas model is given below:

$Y = \beta_0 X_1^{b1} X_2^{b2} \ldots. \; X_i^{bi} \ldots X_n^{bn} e^u$ …………………………………………… **(6.6)**

This equation can also be re-written as follows:

$\ln Y_i = \beta_0 + \sum_{i=1}^{n} \beta \; ln \; Xij + \varepsilon$ ………………………………………….. **(6.7)**

where:

Y_i = date production of under irrigation system such as surface, sprinkler and drip in kg; Xi = independent variables representing some measure of the inputs, and j (j = 1, 2, 3) are unobserved population parameters; ε = error term; ln =natural logarithm.

The second step is constructing the stochastic frontier production function with the selected variables from step one. The formulation of the stochastic production frontier model is as follows:

$Ln \; Y + \sum_{i=1}^{n} \beta \; ln \; X + \varepsilon$ …...…………………………….……………. **(6.8)**

where: the variables X_y are the dependent variables as determined in step one and ε is the error term which is equal to (*vi – ui*). Therefore, the complete stochastic frontier model is given by:

$Ln \; Y = \sum_{i=1}^{n} \beta \; ln \; X + (v - u)$ ……………………………………………… **(6.9)**

The technical efficiency (TE) of the farmer in the year of observation can be calculated as:

$TE = exp(-u_i)$ ……………………………………………………………….. **(6.10)**

The technical efficiency of a farmer is between 0 and 1 and is inversely correlated with the level of the technical inefficiency. This value is estimated based on the stochastic frontier function analysis (Battese & Coelli, 1995; Seyoum, Battese, & Fleming, 1998). The parameters of the stochastic frontier function and technical inefficiency are estimated by the maximum likelihood method utilizing the computer package FRONTIER Version 4.1 (Coelli, 1996).

Applications of model specifications were tested by using R^2, F-test (see Chapter 9, Section 9.5.1) and the value of the Log-Likelihood Ratio test in the Maximum Likelihood estimation (see Section 9.5.2).

6.6.3.2. Production function and hypotheses testing

Frontier 4.1 was used to estimate Cobb-Douglas (6.4) and Translog function (6.5). Frontier was also used to conduct the likelihood-ratio test statistic (LR) for selecting suitable function forms, where the function of the likelihood-ratio test statistic (LR) is:

$$\lambda = -2 \{\log [L (H_0)] - \log [L (H_1)]\} \quad \textbf{(6.11)}$$

The researcher used three hypothesis tests as follows: (1) validation of the Cobb-Douglas function, (2) the absence of inefficiency effects, and (3) joint inefficiency variables. The researcher used the likelihood-ratio test statistic (LR) because Frontier 4.1 cannot provide a diagnostic test for the adequacy of the functional form. The likelihood-ratio test statistic (LR) was a popular statistical technique in agricultural studies and has been used by several researchers such as Coelli et al. (2005); Idiong (2007); Kamruzzaman and Islam (2008); Onumah et al. (2013); Shahid and Munir (2014).

In this study, the null *(H_0)* and alternate *(H_1)* hypothesis under the production frontier model is represented by *L (H_1)* and *L (H_0)* which are the log-likelihood values. According to Kodde and Palm (1986), the LR statistic test comprises asymptotic chi-square (χ^2) distribution which contains certain parameters equivalent to the number of controlled parameters usually imposed within the null hypothesis (H_0); rather it is only hypotheses (2) and (3) that encompasses a combination of chi-square (χ^2) distribution. Coelli (1996, p. 6) notes that hypotheses (2) and (3) involves the restriction that λ is equal to zero which defines a value on the boundary of the parameter space.

6.7. Analytical procedure

There are two stages in the production function analysis carried out in this thesis. In the first stage, the four models, linear, quadratic, Cobb-Douglas and translog production models, were estimated using Ordinary Least Squares (OLS) method. The analysis in this stage was applied four times according to the four models for each input to determine significant variables that affect production output for surface irrigation compared to sprinkler and drip irrigation systems and tested at 5% and 10% significance levels. In the four models, multicollinearity tests were carried out to assess the degree of correlation among the variables.

In the second stage, stochastic frontier production function analysis was then conducted. However in stage two, the researcher used only two models, Cobb-Douglas and translog production model. The Cobb-Douglas and translog production models were chosen based on the likelihood-ratio test statistic (LR) for selecting suitable function forms. The number of observations in this stage was 131 for surface irrigation, 119 for sprinkler irrigation and 137 for drip irrigation.

In terms of data analysis and processing, the survey data were first analysed using statistical techniques, conducted using SPSS. SPSS was used to compute simple averages; cross tabulations to examine associations among variables; compute correlations between variables; and conduct OLS regressions.

Stata was also used to run the linear, Cobb-Douglas, quadratic and translog models, respectively. The researchers chose this package because it is good for cross-sectional and panel data and for econometric modelling such as that required in this study (Baum, 2004). Stata uses higher estimation methods such as OLS and ML estimation (both analytical and numerical) (Baum, 2004).

Meanwhile, FRONTIER Version 4.1 was used to analyse cross section data to evaluate the efficiency and inefficiency of both Cobb-Douglas and translog models.

The experimental data were analysed by Excel and GenStat14. Excel was important to calculate the means of fruit quality including fruit weight, fruit length, breadth, pulp thickness, stone weight and stone length. GenStat was a flexible statistical system. It also has a powerful programming language, which can be used by non- statistical or non-technical researchers. The different techniques of GenStat used in this study included two-way analysis of variance (ANOVA) (Payne, 2009). Figure 6.5 below shows an overview of the research approach, data collection and data analysis of the thesis.

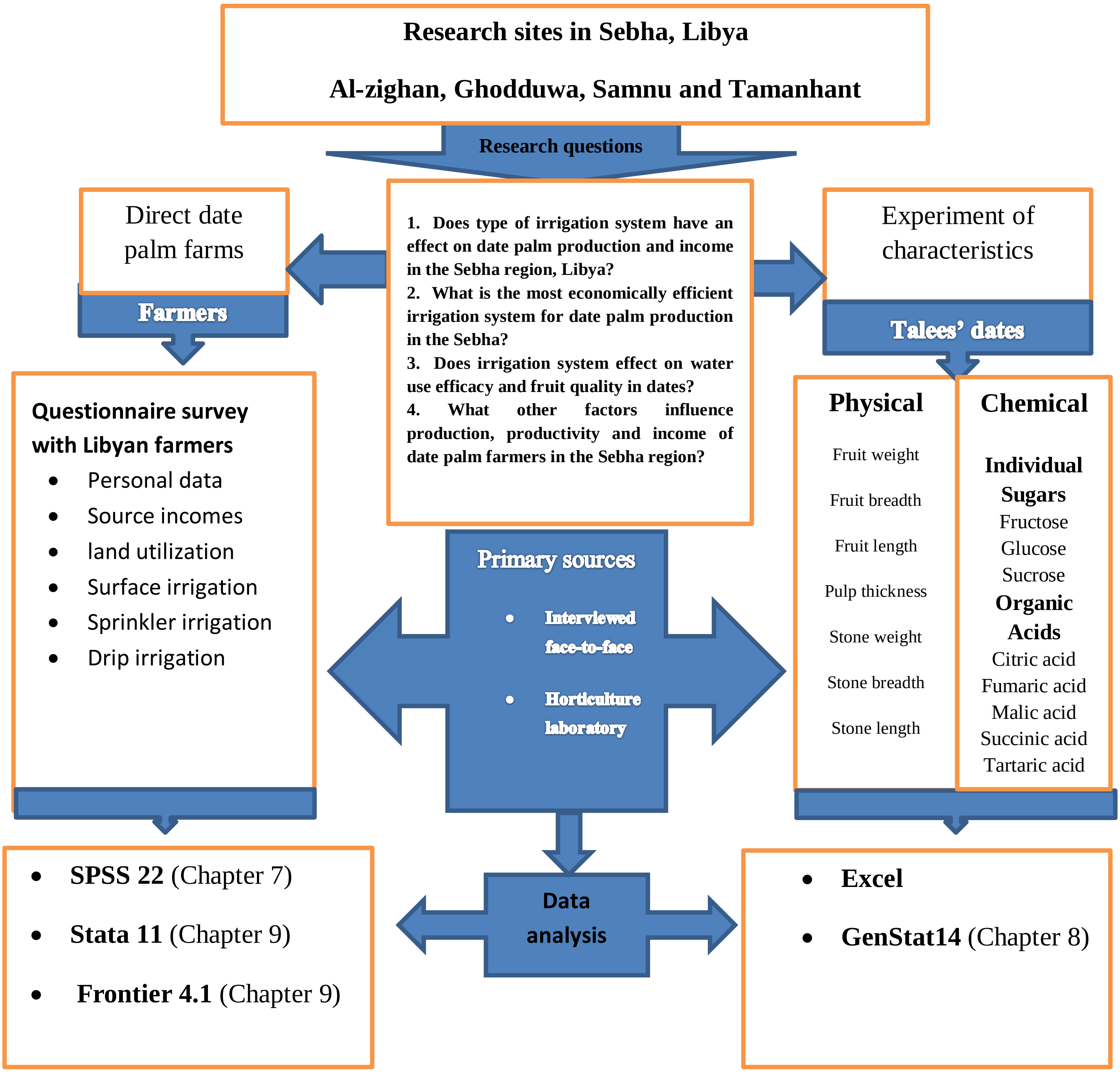

Figure 6-5: An overview of data collection and research method in the study

6.8. Model specification

The method for selecting and measuring variables for the production function vary from one researcher to another. Generally, most studies try to include as many relevant variables as possible based on time and resource considerations and model specification. The variables in this study consisted of variables for the frontier function analysis and variables in the regression analysis. The frontier function was constructed to measure the production of farm-specific technical efficiency, however the regression analysis was utilised to detect significant sources of farm-specific technical efficiency. The variables for constructing the production function are described in the following section.

6.8.1. Production of date palm

Date production is measured as gross production value per hectare of farm before subtracting costs such as wages and cost of irrigation in the study area. Expenditure refers to the real cost of production activities and does not include the cost of purchasing inputs for stocks, shares and rent of land. This variable is applied to express the real effect of all inputs to real farm production. The portion of date palm production consumed by family members, fed to animals and gifts was also included in the production variable measurement. This variable is measured in terms of date harvested in kilograms.

6.8.2. Age of farmers

This variable is measured in years. It is assumed that age indicates the level of maturity of farmers' mentality that in turn will affect attitude towards farming. In rural parts of the country, the real age of farmers is very difficult to record, particularly for those who are older than 50 years. This is because most rural people at that time did not consider it important to record their children's birthdate. However, most of the respondents knew the year they were born. For those who could not remember their birthdate, the approach used was to recall specific events like colonization and rebellions in relation to how old they were at the time, and use that to estimate the year they were born.

6.8.3. Farming experience

The irrigated farming system is common in Sebha area. Length of experience managing the farms is hypothesized to affect the way crops are cultivated and irrigated. The farmer with more farming experience is more skillful at managing their farms. This is anticipated to have an impact on the efficiency of applying farm inputs. As farming is the way of life in most rural areas, most farmers grew up in a farming environment. However, not all the farmers' family has responsibility for a certain amount of the farm. In this study, the number of years' experience refers to the period farmers have been managing their own farms. Some farmers started managing the farm when they inherited their farmland or after they got married. This variable is measured in number of years.

6.8.4. Education

Education is limited to three basic stages such as primary, high school, and university. Other education like vocational courses, participation in workshops at agricultural exhibitions or participation in lectures conducted by extension workers were not taken into consideration as education in this instance. The number of years of schooling completed by the farmer was used as a measure of education. It was hypothesized that a combination of educational level and farming experience may lead towards a better assessment of management decisions and in turn affect the efficiency of farm input use.

6.8.5. Family members

The family member variable is measured by ratio of adults over total family members. The agricultural family consists of a person or group of persons who usually work together or share the same housing; facilities, income and food. They are associated through being blood relatives or by marriage. Family members may separate due to socio-economic factors. Therefore, the size of the household can be reduced, however not the size of the main family. In Sebha region, after marriage, most young individuals live together with their parents however, these young individuals eventually move to a new place or house whenever traditions and customs and the improvement in the economic conditions encourage the couple to live separately in a new house.

6.8.6. Number of date palm trees

The number of trees planted by farmers on their land is registered by the Government. This procedure is to encourage the farmers' tenure over date palm trees. The number of trees per farm is different between farmers. This is because of different date palm cultivars such as Tasfert, Talees, Taghiat and Tdhwi. The farmers in Sebha region cultivate more than five different cultivars. Other farmers choose to grow only one date palm cultivar on their farms. In this study, the total number of date palm was divided depending on ages of trees and type of irrigation system used by farmers.

6.8.7. Distance between date palm trees (planting spacing)

Distance between date palm trees on a farm is also considered to have an effect on output. To select a suitable distance between date palm trees, there are factors that should be taken into consideration such as type of soil, the climate (humidity and sunlight) and access for maintenance and labour. Date palm trees use a square planted system 7 × 7 m with and without any other crops (Zaid & De Wet, 1999). Some private farmers also use 8 × 8 m, however, it is not advisable to utilise a narrower spacing. For many date palm farms, the trend is 10 × 8 m, 10 m between rows and 8 m long (Zaid & De Wet, 1999). As most farmers have different distances between date palm trees in their farms; this variable is stated as number of meters between each tree.

6.8.8. Frequency of irrigation

Frequency of irrigation depends on various factors such as location, soil type, evaporation and farm water usage. However, many date palm farmers recommend two hours irrigation twice per week (from planting till the end of August). From September to March, the following irrigation should be increased to two hours and three times per week. This irrigation timetable usually uses three drippers per palm at a rate between 32 or 40 litres per hour each (Zaid, 2002). The palm will hence receive 96 litres per hour. This variable is measured as the number of irrigation per day/week.

6.8.9. Quantity of water used

Quantity of water is the quantity that is required by crop growth and high production. It is expressed in m^3 per hectare per year. The quantity of water depends on the climate, type of crops and soils. The quantity of water used was calculated by using the data collected with the first survey, according to three different irrigation systems by utilising system operating time records and irrigation system information, for example, 1 hour equals 1 m^3 depending on the pump power for surface and sprinkler and 4 to 5 for drip irrigation (Sager, 2013), or by dividing the volume of water collected in a storage tank on the number of trees (Mosley, 2005).

6.8.10. Size of farm

The size of farm is defined as the total area that is cultivated by farmers. However, farmers may cultivate crops in several parcels of land, the main focus of this cultivation is the farm. Most of the crops are cultivated on the farm, but other areas use housing or livestock shelters. Furthermore, the mix-cropping farming is normally practiced in the Sebha area. Given this situation, the farm size considered as a variable for this study was the total size of the farm measured in hectares.

6.8.11. Labour

Farmers mostly use both family members and hired labour. The labour used in farm management activities is the summation of labour employed for land preparation, planting, fertilizing, weeding, watering, pesticide application, harvesting, packing, transporting and marketing. Labour use in farming is man and machinery. Land preparation is mostly done using human labour as well as machinery. The labour variable is expressed in man-days for human labour and Libyan dinar for machinery costs.

6.8.12. Pesticides

Pesticide is usually used to protect against agricultural pests such as weeds and insects in date palm farms. Most Libyan farmers think that only date palm trees need pesticides. Since there are several forms of pesticides applied by farmers, this variable is included in terms of its use or non-use and price per kilogram or litres. Some farmers apply pesticides before the production stage; some use pesticides several days after harvest. Pesticides used can be liquid, granules, solids and powders. The use of pesticides is part of the input recommended for farmers by the agricultural office in Sebha. The cost of pesticides is defined as the total expense for purchasing all pesticides used for cultivating the crops on the farm.

6.8.13. Fertilizers

Chemical fertilizers commonly used by farmers in the research area were nitrogen in the form of urea (42 per cent N) and phosphorus in the form of SP36 (36 per cent P). In addition, farmers used organic fertilizer such as manure. The amount of fertilizer used is measured in kilograms, but for this analysis, the quantity is converted into kilograms of manure. The analysis only includes the manure that is used or not used by farmers in cultivating crops on their farm. This includes manure purchased from markets and fertilizer produced by the animals on their farm.

6.8.14. Type of soil

Type of soil is considered as a variable for diverse soil types including clay, silt, fine, medium and coarse soils (Blott & Pye, 2001). In date palm farms, different types of soils can be used for sustainable production, however the soils require careful drainage, aeration and fertility. Date palm has a special advantage of being tolerant to high pH, saline and alkaline environmental conditions. Farmers spend large amounts of money on date palm cultivation for keeping sustained growth and for profitable production. It is most suitable to grow date palm on sandy loam soils which has good water-holding capacity and drainage.

6.8.15. Type of irrigation

Irrigation systems play an important role in farm production. Some farmers use more than one irrigation system to manage their crops. However, change of irrigation systems used usually depends on the crops and environmental conditions. The main application systems used for irrigation of date palm farms in Sebha region are surface, sprinkler and drip irrigation. A key performance indicator for irrigation application systems is their ability to supply the desired uniform quantity of water over the irrigated area. Table 6.1 was expected to have both positive and negative signs. These variables broadly fall into four groups:

Table 6-1: Explanatory variables used in the models

Variable	Definition	Measurement / value	Expected sign and explanation
Age	Age of farmer	Years	+/- Older farmers are wealthier and more likely to use improved inputs. However, their wealth and lack of knowledge among older farmers may lead to less inputs use
Experience	Experience of farmers	Years	+ experienced farmers are more likely to procure and use improved farm inputs
Education	Farmer schooling	Years	+ More educated farmers in Libya are less poor, hence more likely to purchase and use better-quality inputs
Family	Number of family	Ratio of adults over total family	+ Small family size in Libya are most likely to purchase and use enhanced farm inputs
Trees	Date palm trees	Number of trees	+ Farmers who have more trees are expected to have improved outputs
Distance	Length of trees	Metres	+ Distance between trees more than 7 or 8 m expected to improve outputs
Time	Irrigation timing	Number of irrigation	+ Increased number of irrigation are expected to improve outputs
Water	Amount of water	Litres per hectare	+ More amounts of water are expected to improve outputs
Land	Size of farm*	Hectare	+ Farmers, who cultivate more area, are anticipated to improve outputs
Labour	Number of labour	Human labour used in days	More labour used in farm are expected to improve outputs
Pesticides	Quantity of pesticides	1 = yes, 0 = no	-/+ Farmers may use pesticides for insects to improve inputs
Manure	Quantity of manure used	1 = yes, 0 = no	-/+ Farmers may use fertilizer to increase outputs or substitute fertilizer for manure as soil nutrient complement
Soil	**Type of soil	A dummy variable to indicate whether farm soil is clay, silt, fine, medium or coarse.	-/+ it is rare to ascertain the expected sign of coefficient owing to different soil types
Irrigation	*** Type of irrigation	A dummy variable to indicate whether farmers used surface, sprinkler or drip irrigation	-/+ it is rare to ascertain the expected sign of coefficient owing to different irrigation system used

*Date palm production was divided on size of farm under different type of irrigation systems for determining the productivity. ** Clay soil is the basic variable for types of soils in the study area
*** Surface irrigation is the basic variable for types of irrigations in the study area

6.9. Analysis of physical and chemical characteristics of 'Talees' dates

6.9.1. Physical analyses

The effects of different irrigation systems on the physical quality parameters of '*Talees*' dates in the Sebha region were also investigated. 'Talees' is one of the most significant date palm cultivars grown in the Sebha region (Ahmodi, 2013; Geddeda & Abdassalam, 2010; Saleh et al., 2012). The experiment was laid out in a randomized complete block design, with treatment comprising three different irrigation systems i) surface irrigation; ii) drip irrigation; iii) sprinkler irrigation with four replications. Each block consists of 40 trees and 10 trees per replicate was used. Adjacent plots were separated by guard trees. The trees were irrigated throughout the year. Two kilograms of fruit was randomly harvested from all the trees from each replication. Dates were imported into Australia with a permit and kept in PC 3 laboratory (quarantine), date fruit from different locations of Sebha were referred to the Horticulture laboratory at Curtin University for analysis.

The fruit used for fruit quality assessment include the following:

- Fruit weight and stone weight were measured by using an electric balance with 0.01 gm sensitivity and average weight per fruit was calculated.
- Pulp stone ratio was calculated by dividing the weight of pulp by stone weight.
- Fruit length, breadth was measured by using a digital Vernier caliper with 0.01mm accuracy.

6.9.2. Chemical analyses

Individual sugars and organic acid were analysed from '*Talees*' dates sourced from four areas at Tamanhant, Samnu, Al-zighan and Ghodduwa in Sebha, Libya during the 2013 cropping season. Date pulp (2 g) was transferred to a falcon tube and grinded followed by addition of 5 ml of HPLC grade water. The reaction mixture was placed in an ultrasonic bath and sonicated for 15 min at 40°C, then centrifuged at 8000 rpm for 15 min at 10°C. The supernatant was filtered through membrane filter (0.45 μM), transferred into a vial and used for analysis of individual sugars and organic acids as detailed by Singh and Singh (2008). A 25 µl sample of filtrate was injected into the HPLC (Waters, USA), and individual sugars were detected using a 2414 RI detector, and organic acids by an absorbance detector (Waters 2487) at 214 nm. The detailed procedure has been reported earlier by Singh and Singh (2008). The concentrations of different sugars and acids in the date fruit were calculated and expressed as $g100g^{-1}$ and $mg\ g^{-1}$, respectively on a fresh weight basis.

After the sugar and organic acids analysis, the dates were disposed of correctly according to import permit no IP13013562 (Appendix B) (see section 8.3.2). After completion of the assessment and the fruit analysis, all data were entered into Excel spreadsheet and the data summarized into mean and standard deviation. The choice of Excel was based on the ease with which the data could subsequently be transferred into packages like GenStat 14th edition or SPSS.

6.9.3. Statistical analysis

The experimental data were analysed by using two-way analysis of variance (ANOVA) using GenStat 14th edition. The effects of various treatments and their interactions with different parameters were estimated and assessed using ANOVA, in particular least significant differences (LSD) along with using a significance level at ($P \leq 0.05$) using F-test. All the assumptions of the analysis were met for ensuring the validity of ANOVA analysis. The physical, chemical and statistical analyses were used for different cultivars of dates in different locations in Middle East and North Africa by several studies (Akasha, 2005; Al-Amoud, Bacha, & Al-Darby, 2000; Shaheen, 2007). However, the current thesis is the first study that used analyses in the Sebha region in Libya. Thus, this provides new insights about the effects of irrigation systems on date palm production in Libya.

6.10. Ethical issues

Ethical considerations were taken into account as follows. The researcher received Form A (high risk) ethics approval from the human research ethics committee (HREC) from Curtin University before the commencement of the data collection (see Appendix C). In line with the ethics approval, respondent's rights, privacy and confidentiality were observed. The researcher also received approval to import quarantine materials from the Department of Agriculture, Fisheries and Forestry of Australia, training industry working group on quarantine and fresh product inspection for samples. These important requirements were observed.

As Morgans and Allen (2012) claimed, the process of obtaining ethics approval is the key step in conducting the study and collecting and analysing data. The data collection began after having obtained ethics approval, following the guidelines, including informing the respondents, the researcher also provided adequate information about the aim of the research project to the respondents and demonstrated a good relationship towards the respondents (Niyibituronsa et al., 2014).

All respondents of this thesis were informed about the study and then given clear instructions; in writing or orally, that respondents had the right to withdraw at any stage of the research process (Ticehurst & Veal, 2000).

6.11. Conclusion

The details of the research design and model description were presented in this chapter. This chapter provided an outline of the most suitable methodology for data collection and analysis of this research. The methodology of this thesis involved collecting primary data through questionnaires due to the unavailability and inaccessibility of secondary data relating to the research questions. However, suitable variables for the models were identified based on an extensive review of literature of previous research and the pre-testing stage of the questionnaire. Farmers (the respondents) were selected randomly based on data collected from the Department of Agriculture in Sebha. To identify other potential date palm respondents who employ different irrigation systems, the snowball sampling technique was subsequently employed. Although the questionnaires were originally prepared in English, these questionnaires were translated from English to Arabic, because most of the respondents do not understand the English language.

Several considerations were taken into account in formulating the questions, carefully selecting words that can be understood by respondents. The procedures for data analyses were carefully designed and selected to meet all of the study objectives. Attention was given to avoid interview fatigue to reduce errors due to biased response.

Appointments were made with potential respondents to arrange a time convenient to them for the interviews in the respondents' houses to reduce the burden on respondents. Conducting interviews at night in a more relaxed situation and drinking coffee and breaks to smoke cigarettes were also some of the things done to ease respondent fatigue.

Finally, data analysis for this study included econometric analysis using OLS regression and stochastic frontier models as the main analytical framework. Physical and chemical characteristics of date palm analysis were also conducted to enhance the robustness of quantitative findings leading to a better understanding of the phenomenon (i.e., production and efficiency) under investigation.

The next chapter will describe and provide an overview of the field study research study site.

Chapter 7
Description of the Farming Systems in the Study Sites

7.1 Introduction

This chapter aims to describe the farming system in the research study site and consists of twelve main sections. Section 7.2 describes the characteristics of farmers and the main background of respondents, including age, schooling, farming experience, family members and salary. Section 7.3 then discusses the key characteristics of farmer households in terms of income, while Section 7.4 includes the description of date palm farms. Section 7.5 compares date palm production according to irrigation systems. Section 7.6 and Section 7.7 includes characteristics of labour used in irrigation systems and characteristics of irrigation. Section 7.8 discusses the inputs that are used in date palm production under different irrigation systems. Section 7.9 provides a description of outputs of date palm farms under irrigation system. Section 7.10 presents the household goals of farmers. Finally, Section 7.11 is devoted to the discussion and Section 7.12 to conclusions.

7.2 Characteristics of farmers

As seen from Table 7.1; the minimum age of respondents was 20 years and the maximum is 97 years old. The mean age of the husband is 53.17 years, which is slightly more than the wife’s mean age of 46.58 years. The number of farmers that are married is about 198 while there are only 12 young, single farmers. Indeed, married farmers who live in the Sebha region represent 94.3 per cent of respondents, while single farmers represent 5.7 per cent. In terms of the educational attainment of farmers and wives, the minimum number of years of schooling of husbands is 3 and the maximum is 25. Meanwhile, of the 196 wife respondents, the minimum number of schooling years is 3 and the maximum is 25 years. The average years of schooling of husbands is about 14 years while for the wife, is about 12 years.

Table 7-1: Characteristics of date growers in Sebha region of Libya

Items	No. of respondents	Min	Max	Mean/ percentage	SD
Husband age	210	20	97	53.2	15.40
Wife age	198	19	85	46.8	13.22
Marital status:					
Married (%)	198			94.3	
Single (%)	12			5.7	
Husband schooling	210	3	25	13.9	4.95
Wife schooling	196	3	25	12.4	4.89
Training:					
Yes (%)	46			21.9	
No (%)	164			78.1	
Family members	210	1	32	5.74	3.91
Farming experience	210	2	60	23.72	12.52
Salary (Libyan dinar)	207	160	5500	723.47	660.54

Source: Survey data, 2013.

Moreover, the data in Table 7.1 shows that 78.1 per cent of farmer respondents do not have any informal training programs, while 21.9 per cent of farmer respondents have informal training. In terms of number of dependents or family members of farmers, the mean number of family members is 5.74, with a minimum of one member, and a maximum of 32 members of the total. Because some farmers have two to three wives in the study area, the number of 32 members from one family is not surprising.

Table 7.1 also reveals that the mean years of farming experience of respondents is 23.72 years, with a minimum of 2 and a maximum of 60 years. Finally, the average monthly salary of farmer respondents is about 723.47 Libyan dinars (US$ 1 equals 1.25 LD according to Central Bank of Libya (CBL), 2013), with the highest salary reported at 5500 Libyan dinars and the lowest at 160 Libyan dinars. In fact, all farmer respondents reported earning salary from different sources, some of them from the government while others were from the private sector.

7.3 Household income

Table 7.2 shows the sources of household income, another important aspect of farm households in this survey. The farmer respondents reported that there are non-agricultural activities that play a role in improving their incomes and standard of living. This aspect gives a knowledge base about the significant sources of income for respondents. Table 7.2 provides more detail about these sources.

Table 7-2: Other sources of income of farm households in Sebha region of Libya

Other income sources	No	%
Subsidy from other family member	125	59.5
Livestock	110	52.4
Services	107	51.0
Rental	99	47.1
Cattle raising	88	41.9
Vegetable	64	30.5
Poultry	50	23.8
Fruit	30	14.3
Commission	13	6.2
Remittances	9	4.3
Other	6	2.9

Source: Survey data, 2013.

As shown in Table 7.2, there are different sources of funds for farmer respondents including subsidies from other family members; livestock such as goats, sheep, cows and camels, services (laundry, labour, etc.); rental (land, house, agricultural equipment, etc.); and cattle raising. There are also some unrelated date farming activities, such as vegetables, poultry, fruit, commission from sales, remittances and other sources.

More than 50 per cent of farmer respondents' reported income from subsidy, livestock or services, while less than 40 per cent of respondents reported that they generate incomes from rental, cattle raising, vegetables, poultry, fruit, commission from sales, remittances and other sources (Table 7.2). On the other hand, it can be seen from Table 7.2 that the farmer respondents relied heavily on subsidies from relatives and family members because the majority of family members are working on farms. Indeed, subsidies represent about 59 per cent when compared with other income sources.

There is a considerable difference between the farm households' source of income by type of household. There are three different groups: owners, workers and others (Table 7.3). In the owner group, subsidies from other family members are the highest source of income at 44 per cent. On the other hand, services is the most popular source in the worker group at 1.9 per cent. In the share (partners) group, livestock activity represents the highest source of supplementary income.

Table 7-3: Other sources of income by type of farmers

Status	Owner	%	Workers	%	Other	%
Vegetables	38	18.1	0	0	26	12.4
Services	38	18.1	4	1.9	65	31.0
Rental	38	18.1	2	1	59	28.1
Subsidy	93	44.3	0	0	32	15.2
Remittances	9	4.3	0	0	0	0
Poultry	24	11.4	0	0	26	12.4
Cattle raising	46	21.9	0	0	42	20
Livestock	37	17.6	0	0	73	34.8
Fruit	17	8.1	3	1.4	10	4.8
Commission	12	5.7	0	0	1	0.5
Other	2	1.0	1	0.5	3	1.4

Source: Survey data, 2013.

Table 7.4 shows the income sources in terms of the contribution of family members. It can be observed from Table 7.4 that the husband has the highest percentage income contribution among the other family members in all income sources. For example, the husband is the largest contributor in the livestock activity 30.5 per cent, services 29, rental 26 and cattle raising 25 per cent. However, for the wife category, it can be noted that the wives play a significant role in subsidies at 34.3 per cent. The next category is the son group, it can be seen that the sons play a key role in the livestock activity of 9 per cent, remittances and fruit 1 per cent. The last two categories are the daughter and relatives groups; it can be seen from the table below that these categories form small proportions in terms of the contribution in all income sources when compared with the other groups or categories.

Table 7-4: Income sources of household income in Sebha region of Libya

Among	Husband	%	Wife	%	Son	%	Daughter	%	Relative*	%	Relative**	%
Vegetable	39	18.6	18	8.6	6	2.9	0	0	1	0.5	0	0
Services	61	29.0	35	16.7	8	3.8	1	0.5	2	1	0	0
Rental	55	26.2	36	17.1	6	2.9	1	0.5	1	0.5	0	0
Subsidy	50	23.8	72	34.3	3	1.4	0	0	0	0	0	0
Remittances	3	1.4	4	1.9	2	1.0	0	0	0	0	0	0
Poultry	31	14.8	12	5.7	4	1.9	1	0.5	1	0.5	1	0.5
Cattle raising	53	25.2	24	11.4	9	4.3	0	0	2	1	0	0
Livestock	64	30.5	23	11.0	19	9	0	0	4	1.9	0	0
Fruit	21	10.0	6	2.9	2	1	1	0.5	0	0	0	0
Commission	9	4.3	2	1.0	2	1	0	0	0	0	0	0
Other	2	1.0	2	1.0	2	1	0	0	0	0	0	0

Source: Survey data, 2013. Relative* = relative of husbands. Relative** = relative of wives.

7.4 Description of date palm farms

7.4.1 Farm managed during irrigation operation

Irrigation operators of date palm growers in this study can be divided into four groups. The results showed that the majority of respondents reported that they depend on family members as irrigation operators with 77.1 per cent of the total respondents; followed by agricultural companies which represent 26 respondents or 12.4 per cent; and then, the government sector, which represents 14 respondents or 6.7 per cent. In the last rank is the other category, which accounts for 8 respondents (3.8 per cent of the total respondents) as shown in the Table 7.5 below.

Table 7-5: Irrigation management in farms in Sebha region of Libya

Items	No.	%
Family members	162	77.1
Agricultural company	26	12.4
Government sector	14	6.7
Other	8	3.8
Total	210	100

Source: Survey data, 2013.

7.4. 2 Information on date palm farming systems

The number of date palm trees is 82.17 trees on average with a standard deviation of 65.54. The results of the data obtained from the questionnaires showed that 1.9 per cent of the respondents estimated the age average of the date trees as less than seven years, while 27.1 per cent of respondents indicated that the average age of their date trees ranges from seven to ten years. In addition, the average age of date trees, which is more than ten years, is reported as 62.4 per cent by the respondent. 131 respondents reported the age average as more than ten years. Meanwhile, 135 respondents said they had other crops in addition to date palm trees (Table 7.6).

Table 7-6: Information on date palm farming systems in Sebha region of Libya

	No. respondents	Mean/ percentage	SD
Number of palm trees (h)	210	82.17	65.54
Age of date palm trees (years):			
Less than seven	9	1.9	
From seven to ten	57	27.1	
More than ten	131	62.4	
All ages	12	5.7	
Crops in conjunction date palm tree:			
No (%)	75	35.7	
Yes (%)	135	64.3	
Type of crops :			
Vegetables (%)	22	10.5	
Fruits (%)	22	10.5	
Forage crops (%)	44	21.0	
Vegetables and fruits (%)	8	3.8	
Vegetables and forage crops (%)	19	9.0	
Fruits and forage crops (%)	5	2.4	
All type of crops (%)	13	6.2	

Source: Survey data, 2013.

When describing the field data in terms of crops, it can be noted that the number of farmers who do not have other crops intercropped with date palm in the same farm, are 75 respondents representing about 35.7 per cent of the growers, while 44 respondents have forage crops representing approximately 21 per cent of the sample and 22 respondents grow vegetables representing about 10.5 per cent. In fact, 22 respondents who grow fruits represented about 10.5 per cent. The number of farmers who grow vegetables and forage crops were 19 respondents, representing about 9 per cent, while 5 respondents who grow fruits and forage crops represented 2.4 per cent. Finally, 13 respondents representing about 6.2 per cent produce all types of crops (Table 7.6).

7.4.3 Types of soils

Table 7.7 reveals that there are five types of soils that form an important feature of the date palm production. About 62 respondents state that the soil in their farm is clay sand while 56 respondents stated that the farm's soil is very fine sand. About 54 respondents indicated that medium sand forms a major part of the farm's land; and finally, 21 respondents said that their farm's land is silt sand, and 17 respondents reported their lands' soils as coarse sand.

Table 7-7: Types of soil in Sebha region of Libya based upon soil classification suggested by Blott and Pye (2001)

Items	No.	%
Clay	62	29.5
Very fine sand	56	26.7
Medium sand	54	25.7
Silt	21	10.0
Coarse sand	17	8.1
Total	210	100

Source: Survey data, 2013.

7.4.4 Sources of water irrigation

It can be seen that most farmers in South-western Libya depend on underground water, for the reason that there is not enough water sources, such as rivers or lakes (Table 7.8). As the Sebha region is located in a semi-arid area; respondents used various sources of irrigation to irrigate their date palms. However, 57.6 per cent of respondents have used private wells as the main source of irrigation, while 33.3 per cent of the respondents utilised shared well water, 7.6 per cent of the respondents utilised dams, and finally, 1 per cent and 0.5 per cent of respondents employed other sources of irrigation and streams, respectively.

Table 7-8: Sources of water irrigation in Sebha region of Libya

Sources of water	No	%
Private well	121	57.6
Shared water well	70	33.3
Dams	16	7.6
Other	2	1.0
Stream	1	0.5
Total	210	100

Source: Survey data, 2013.

7.4.5 Area under sole date palm and date palm with intercropping practice

Growing new date palm trees entails a few years of spending without receiving an income. Due to the length of time required recouping investments, majority of farmers in the area have adopted intercropping practice, where date palm trees are planted with other crops on the same land which is generally termed mixed cultivation. As shown in Table 7.9 below, about 135 farmers grew date palms with intercropping (such as tomatoes, onions, wheat, oranges) representing 64 per cent of the total study population, while 75 farmers did not practice intercropping which represented 36 per cent of the study population. The total area of farmers under date palm cultivation with intercropping was 2006 hectares which represents 77 per cent, while 599 hectares represent 23 per cent of sole date palm cultivation.

Table 7-9: Area under sole date palm and date palm with intercropping practice

Item	No.	%	Area /h	%
Date palm with intercropping	135	64	2006	77
Sole date palm	75.0	36	599.0	23
Total	210	100	2605	100

Source: Survey data, 2013.

7.5 Date palm production under irrigation systems

Table 7.9 shows the number of respondents who use surface, sprinkler and drip irrigation as 131, 119 and 137, respectively. The mean number of years of using surface irrigation by farmers was an average of 21.23 years, while sprinkler and drip irrigation was 11.83, 9.20 years, respectively. The average size of farms under drip irrigation was 3.98 hectares, while for surface irrigation was 4.71 hectares and 4.36 for sprinkler irrigation.

Table 7-10: Number of years used and area under irrigation systems in Sebha region of Libya

Items	Surface irrigation N=131		Sprinkler irrigation N=119		Drip irrigation N=137	
	Mean	**SD**	**Mean**	**S.D**	**Mean**	**SD**
Years	21.23	8.77	11.83	4.82	9.20	3.64
Hectares	4.71	4.56	4.36	5.72	3.98	2.94

Source: Survey data, 2013.

Table 7.10 shows the types of dates that are grown by farmers in Sebha region. Tasfert and Talees cultivars are the most favoured among the respondents for consumption purposes. Taghiat and Tdhwi cultivars are also common in Sebha region. As shown in Table 7.10, the mean number of Taghiat and Tasfert cultivar trees was higher at 168.55 and 124.39 trees, respectively, under surface irrigation when compared to sprinkler and drip irrigation. However, Tasfert has a slightly higher tendency to be grown on farms using drip irrigation (127.44). Other dates (i.e. Asbeer, Agleen, Tamage etc), Tdhwi and Tasfert cultivars have a higher mean yield of 43.33, 37.18, 35.58 kg per tree, respectively, under surface irrigation compared to other methods. The average values of Taghiat, Tasfert and other dates (such as Asbeer, Agleen, Tamage etc) were 5410.80, 4137.30, 3428.10 Libyan dinars, respectively with surface irrigation, while, the value of Talees dates was 3917.58 Libyan dinars with drip irrigation. Under sprinkler and surface methods, the values are 2674.51 and 3517.10 Libyan dinars, respectively.

Table 7-11: Type of date palm trees under various irrigation systems in Sebha region of Libya

Various irrigation systems						
Cultivars	**Surface irrigation**		**Sprinkler irrigation**		**Drip irrigation**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Number of trees						
Tasfert	124.39	241.18	104.63	124.72	105.04	136.57
Talees	106.42	145.32	82.10	78.38	127.44	187.34
Taghiat	168.55	313.75	114.92	190.68	112.91	121.37
Tdhwi	85.72	163.95	92.35	148.59	87.41	92.47
Other	83.78	103.65	75.00	35.36	63.07	41.03
Fruit yield (Kg/tree)						
Tasfert	35.58	17.49	33.30	14.16	32.94	15.33
Talees	34.88	19.01	34.11	16.10	33.14	16.14
Taghiat	35.14	23.46	35.43	23.34	32.56	16.75
Tdhwi	37.18	20.99	31.74	17.45	31.78	17.05
Other	43.33	656.77	37.50	3.54	21.80	16.19
Value (LD)						
Tasfert	4137.30	7198.58	3251.29	4187.89	3287.39	4053.6
Talees	3517.10	4820.23	2674.51	2563.93	3917.59	4947.15
Taghiat	5410.80	12082.18	3713.16	6461.75	3497.52	3669.96
Tdhwi	2598.70	3883.19	2408.02	2656.36	2876.18	3220.27
*Other	3428.10	4845.19	2875.00	1590.99	1298.71	1743.97

*Other date cultivars grown in Sebha such as Asbeer, Agleen, Tamage etc.
Source: Survey data, 2013.

7.6 Characteristics of irrigation labour in Sebha region of Libya

In Sebha, some farmers use workers in their farms in the irrigation process; while other farmer-respondents do not use workers as shown in Figure 7.1. The data show that 96.9 per cent of respondents employ farm workers under surface irrigation, while 94.1 and 93.4 per cent of farmers employ workers in the sprinkler and drip irrigation systems, respectively. On other hand, the percentage of farmers who do not use employed workers during drip, sprinkler and surface irrigation is 6.6, 5.9, and 3.1 per cent, respectively.

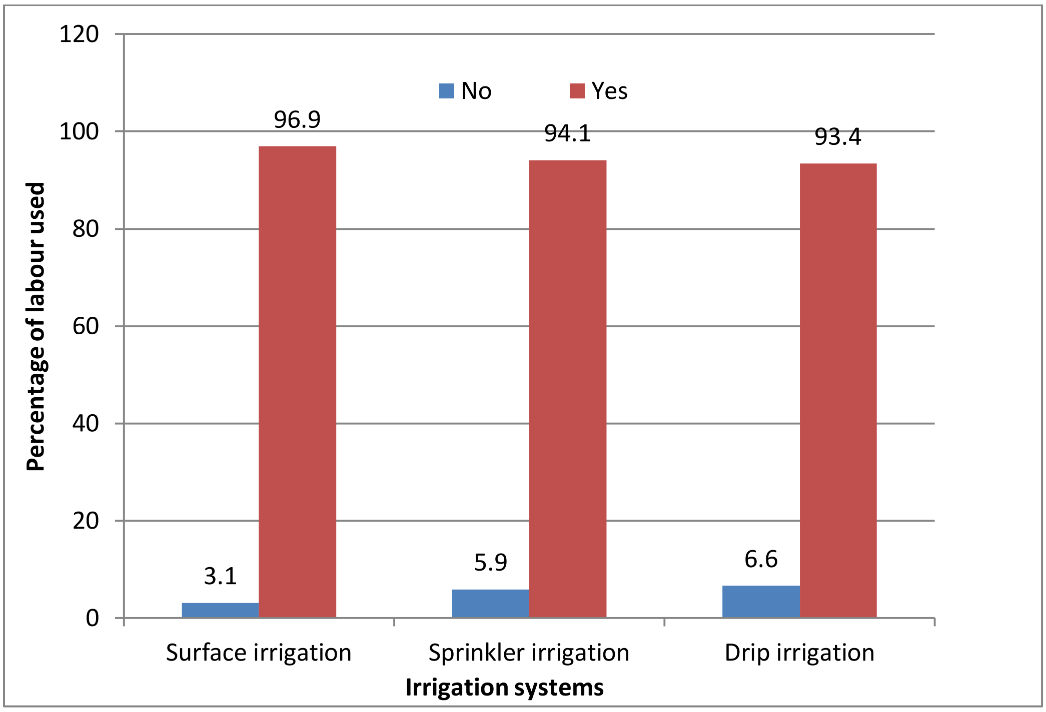

Figure 7-1: Labour used for three irrigation systems in Sebha region of Libya

Table 7.11 shows the type of workers and working hours during irrigation of date palm. The local and family labour consists of males and females who participate in agricultural activities. Due to a shortage of local skilled labour in Libya, Libyan farmers depend on migrant labourers or foreign workers from neighbouring countries, which leads to an increase in wages. As shown in Table 7.11, the family labourers consisting of males and females form a large cost of workers under drip irrigation with an average total cost of 212.08 and 197.63 Libyan dinars, respectively, compared to surface and sprinkler irrigation. On the other hand, the cost of hired labour of males and females under sprinkler irrigation is 272.89 and

308.90 Libyan dinars, respectively. However, the total cost under surface irrigation as a result of utilising family labour is lower than in sprinkler and drip irrigation systems. Therefore, this indicates that the cost of utilising hired and family labour for both male and female is lower when using surface irrigation.

The decline in the female employment category in agriculture is due to the increase in the percentage of women who study and work in non-agricultural sectors in the last ten years, in particular, nursing, education and banking industry. In the past, Libyan women have worked in the agriculture sector and supported their families with their earnings for many decades.

Table 7-12: Type of employees used for irrigation of date palm farms in Sebha region of Libya

Items	**Surface irrigation**		**Sprinkler irrigation**		**Drip irrigation**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Family members						
No. of male	**117**		**94**		**127**	
Male family	1.47	1.47	1.50	1.23	1.15	.58
Working hours	6.61	6.61	6.26	2.07	6.37	2.29
Cash (day)	6.15	6.15	7.88	4.34	8.48	6.02
Number of days	3.63	3.63	4.10	1.50	3.91	1.59
Total hours	23.85	23.85	10.19	6.74	24.85	12.19
Total costs (LD)	150.27	150.27	64.36	51.97	212.08	166.3
No. of female	**29**		**31**		**19**	
Female family	1.24	1.12	1.10	.40	1.21	.42
Working hours	6.38	4.87	5.48	1.91	6.68	2.03
Cash (day)	6.34	3.21	8.73	8.55	8.26	4.53
Number of days	3.10	1.29	3.81	1.30	3.58	1.54
Total hours	18.62	11.99	21.03	10.90	22.74	8.84
Total costs (LD)	124.59	121.30	173.77	148.92	197.63	150.44
Hired members						
No. of male	**117**		**110**		**127**	
Male hired	1.56	1.24	1.57	1.30	1.43	.94
Working hours	7.27	2.48	6.83	1.93	6.97	2.10
Cash (day)	8.59	4.33	8.90	4.58	8.68	4.17
Number of days	3.62	1.66	4.12	1.54	3.99	1.57
Total hours	26.76	17.63	28.87	15.67	27.97	14.09
Total costs (LD)	245.87	235.26	272.89	221.84	261.23	214.86
No. of female	**24**		**21**		**18**	
Female hired	1.38	1.25	1.33	.58	1.39	.98
Working hours	6.46	2.84	6.95	2.87	6.94	3.93
Cash (day)	7.21	3.61	11.14	7.84	10.56	7.11
Number of days	2.96	1.33	3.81	1.40	3.72	1.53
Total hours	20.21	17.71	25.95	12.71	23.94	11.96
Total costs (LD)*	77.04	110.92	308.90	270.73	285.78	303.31

Source: Survey data, 2013. * LD = Libyan dinar

7.7 Characteristics of irrigation systems in Sebha region of Libya

7.7.1 Time of irrigation and distance between each date palm trees

The characteristics of irrigation systems form an important part of this survey. The information in the Table 7.12 shows the characteristics of the surface, sprinkler and drip irrigation in terms of time of irrigation three times in a day, including morning, midday and night per hour and days per week, and distances between each date palm trees for breadth and length. This table presents a solid base to study and assess date palm farmers in terms of their use of surface, sprinkler or drip irrigation. The survey results are shown in Table 7.12 below.

Table 7-13: Time of irrigation and distance between each date palm tree in Sebha region of Libya

Items	**Surface irrigation**			**Sprinkler irrigation**			**Drip irrigation**		
Units	**No**	**Mean**	**SD**	**No**	**Mean**	**SD**	**No**	**Mean**	**SD**
Time of irrigation									
Morning									
days/week	127	3.64	1.76	114	4.46	1.86	133	4.24	1.80
hours	127	5.44	2.34	114	6.89	2.55	133	6.81	2.61
Midday									
days/ week	17	4.35	2.12	14	3.86	1.79	5	5.80	4.71
hours	17	3.24	1.72	14	6.21	3.75	5	4.00	3.39
Night									
days/ week	91	3.69	1.82	96	4.09	1.62	101	4.09	1.72
hours	91	4.67	2.45	96	6.40	2.98	101	6.44	2.91
Distance (m) *									
Breadth	131	6.21	3.40	119	5.85	2.80	137	6.61	8.54
Length	131	6.40	3.28	119	5.99	3.37	137	5.93	3.04
No. of trees (h)	131	85.95	74.61	119	79.61	63.82	137	86.22	65.16
No. of crops	10	2.20	2.30	7	2.00	1.41	8	1.63	.74

Source: Survey data, 2013. * Distance between date palm trees

This table shows both the average and standard error of the selected indicators, where the standard errors indicate the robustness of the mean. The results show that average morning weekly/days of sprinkler irrigation was 4.48 hours, while, the average drip and surface irrigation were 4.24, 3.64 hours, respectively. The average irrigation hours at the morning were 6.89 hours under sprinkle irrigation. The table further shows different averages for the midday period. Drip irrigation has the highest irrigated midday per 5.80 weekly/days while sprinkler irrigation was a higher level of hours irrigation at 6.21 hours compared to surface and drip irrigation systems. At night, sprinkler and drip irrigation were equal at 4.09 weekly/days, while the level time of irrigation was the highest under drip irrigation at 6.44 hours.

The average numbers of date palm trees per hectare were 86.22, 85.95, and 79.61 trees under drip, surface and sprinkler irrigation, respectively. The distance between trees (row to row and plant to plant) under drip irrigation was more for breadth representing 6.61 metres, while, length was more under surface irrigation at 6.40 metres. The average number of intercrops is highest at 2.20 crops under surface irrigation, followed by sprinkler and drip irrigation at 2 and 1.63 crops, respectively.

7.7.2 Irrigation consumption

The water consumption of tree (max) in the research areas ranged from 10 litres to 440 litres. The maximum average water consumption of the tree for surface, drip and sprinkler irrigations were 49.48, 42.11 and 40.83 litres, respectively. Meanwhile, the minimum water consumption of the tree was 5 litres, while the maximum consumption for surface, sprinkler and drip irrigation were 80, 70 and 60 litres, respectively. In terms of lost water (maximum) during irrigation in the research areas, this ranged from 25 litres to of 53 litres. The average (maximum) lost water consumption of the tree for surface, sprinkler and drip irrigation was 14.71, 11.18 and 9.03 litres, respectively; while the lost water (minimum) ranged from 1 litre to 2 litres. The average (minimum) lost water of the tree for surface, sprinkler and drip irrigation were 8.72, 6.28 and 4.93 litres, respectively, as shown in Table 7.13 below.

Table 7-14: Irrigation consumption

Items	No	Min	Max	Mean	SD
Surface irrigation					
Consumption of the tree (max)	131	15	150	49.48	20.54
Consumption of tree (min)	131	8	80	28.79	12.98
Daily temperatures (max)	131	25	48	36.50	3.43
Daily temperatures (min)	131	5	39	28.79	5.51
Lost water (max)	131	5	53	14.71	6.91
Lost water (min)	131	2	20	8.72	4.38
Sprinkler irrigation					
Consumption of the tree (max)	119	10	100	40.83	14.57
Consumption of tree (min)	119	5	70	26.62	10.99
Daily temperatures (max)	119	25	50	36.42	3.49
Daily temperatures (min)	119	10	38	29.15	4.14
Lost water (max)	119	2	25	11.18	5.29
Lost water (min)	119	1	15	6.28	3.74
Drip irrigation					
Consumption of the tree (max)	137	15	440	42.11	36.54
Consumption of tree (min)	137	8	60	24.31	8.95
Daily temperatures(max)	137	25	50	35.85	4.06
Daily temperatures (min)	137	10	50	28.97	5.08
Lost water (max)	137	1	30	9.03	5.52
Lost water (min)	137	1	15	4.93	3.51

Source: Survey data, 2013. max= maximum, min= minimum

7.7.3 Cost of watering

The main benefits of irrigation systems include water savings, high yield, quality improvements leading to increased output prices, labour savings and decreased input costs. The data in Table 7.14 shows that the cost of watering of sprinkler irrigation is higher than surface and drip irrigation, i.e., 2.19 Libyan dinars vs. 1.92 and 2.1 Libyan dinars, respectively. Overall, the minimum cost of watering was 0.5 and the maximum was 10 Libyan dinars per day (hour).

Table 7-15: Cost of watering for irrigation system (day/hours) in Sebha region

Items (Cost/LD)	No	Min	Max	Mean	SD
Surface irrigation					
watering per day (hr)	131	0.15	5.50	1.92	1.18
Sprinkler irrigation					
watering per day (hr)	116	.50	4.00	2.19	1.06
Drip irrigation					
watering per day (hr)	137	1.00	10.00	2.1	1.24

Source: Survey data, 2013.

7.8. Inputs used in date palm production under different irrigation system

7.8.1 Labour used for date production under the irrigation systems

The labour used in various cropping activities is shown in Tables 7.15, 7.16 and 7.17. Labour activities greatly depend on gender roles in performing date palm production. For land preparation, family labour including male and female elements dominated over both hired and exchange labour in clearing land. Family labour respondents participated in this activity and worked for an average of 15 925 hours in the season under surface irrigation, compared with sprinkler and drip irrigation which averaged 15 183 hours, 10 582 hours, respectively during the season, as the labourers worked in the field of activities connected with clearing. Males and females also participated in hired labour. The total hours of hired labour on average was 17 738.5 hours under surface irrigation. However, respondents of hired labour, under sprinkler and drip irrigation spent 15 410 hours and 13 380 hours performing land preparation activities, respectively. However, the total hours of land preparation for male and female labour under surface irrigation represented about 33 663.5 hours in the season, while, drip and sprinkler irrigation were 28 563 hours and 25 992 hours, respectively, in the season. Land clearing is mostly done manually under surface irrigation because it requires less skill; hence, women have greater participation in the land clearing activity.

Family labour also plays a significant role in canal establishment with an average family labour use of about 15 523 hours under surface irrigation, and 12 538 hours under drip and 9 520 hours under sprinkler irrigation. For hired labour (females and males), surface irrigation recorded higher average costs of about 12 657 hours, followed by drip irrigation 12 591 hours, and 10 439 hours for sprinkler irrigation. The total hours of canal establishment labour under surface irrigation is higher, which accounts for 28 180 hours followed by drip and sprinkler irrigation.

Tables 7.15, 7.16 and 7.17, show the average hours of participation in planting activities. Family labour was higher (11 287 hours) for date season crops under surface irrigation, while the contribution was low at 8676 hours under drip irrigation. The same case was observed for hired labour; total participation under surface irrigation was higher at 10 924 hours. The total hours of participation by male and female respondents to family and hired labour are closer to surface and sprinkler irrigation at 22 211 hours and 20 113 hours, respectively.

Fertilization is a specialized male activity for date palm, with only a very small number of female participation. Data in Tables 7.15, 7.16 and 7.17 showed that male family labour was almost the same level of hours compared to hired labour. Females made some contribution in family labour for fertilizing, with an average of 336 hours. Males had a much stronger tendency for both family and hired labour for fertilizing, with an average 9 242 hours for family and 9 983 hours for hired labour in the season as this activity is traditionally a male role.

Table 7-16: Labour used for date production under surface irrigation (hours) in Sebha region of Libya (cropping season)

Activity	Family			Hired			Total labour		
	Male	Female	Total	Male	Female	Total	Total Male	Total Female	Total
Land preparation	12413	3512	15925	13486	4252.5	17738.5	25899	7764.5	33663.5
Canal establishment	11745	3778	15523	12287	370	12657	24032	4148	28180
Planting	9978	1309	11287	10672	252	10924	20650	1561	22211
Fertilizing	9242	336	9578	9983	0	9983	19225	336	19561
Weeding	11961	989	12941	12218	427	12645	24179	1407	25586
Watering	7876	3246	11122	8920	125	9045	16796	3371	20167
Pesticide application	7868	0	7868	9360	0	9360	17228	0	17228
Harvesting	9090	3346	12436	9974	0	9974	19064	3346	22410
Packing & storing	11884	321	12205	11526	0	11526	23410	321	23731
Transporting	2734	0	2734	4268	0	4268	7002	0	7002
Marketing	4313	0	4313	4075	0	4075	8388	0	8388

Source: Survey data, 2013.

Table 7-17: Labour used for date production under sprinkler irrigation (hours) in Sebha region of Libya (cropping season)

Activity	Family			Hired			Total labour		
	Male	Female	Total	Male	Female	Total	Total Male	Total Female	Total
Land preparation	7756	2826	10582	12265	3145	15410	20021	5971	25992
Establishment	9520	0	9520	10439	0	10439	19040	0	19040
Planting	7512	3323	10835	8860	418	9278	16372	3741	20113
Fertilizing	6073	440	6513	8736	208	8944	14809	648	15457
Weeding	9330	3236	12566	11106	100	11206	20436	3336	23772
Watering	5048	498	30044	7396	383	7779	12444	881	13325
Pesticide application	6117	0	6117	8192	0	8192	14309	0	14309
Harvesting	6672	782	7454	7700	170	7870	14372	952	15324
Packing & storing	8731	0	8731	10067	0	10067	18798	0	18798
Transporting	2510	0	2510	4055	0	4055	6565	0	6565
Marketing	3793	0	3793	3159	0	3159	6952	0	6952

Source: Survey data, 2013.

Table 7-18: Labour used for date production under drip irrigation (hours) in Sebha region of Libya (cropping season)

Activity	Family			Hired			Total labour		
	Male	Female	Total	Male	Female	Total	Total Male	Total Female	Total
Land preparation	11265	3918	15183	12583	797	13380	23848	4715	28563
Establishment	9475	3063	12538	12154	437	12591	21629	3500	25129
Planting	7998	678	8676	9836	461	10297	17834	1139	18973
Fertilizing	7526	530	8056	8650	500	9150	16176	1030	17206
Weeding	11840	2488	14328	12055	493	12548	23895	2981	26876
Watering	5588	793	6381	7318	642	7960	12906	1435	14341
Pesticide application	7605	0	7605	8683	0	8683	16288	0	16288
Harvesting	6921	1018	7939	9242	507	9749	16163	1525	17688
Packing & storing	9468	1131	10599	11793	983	12776	21261	2114	23375
Transporting	3699	0	3699	4332	0	4332	8031	0	8031
Marketing	2706	0	2706	3101	0	3101	5807	0	5807

Source: Survey data, 2013.

Date palm trees require substantially high labour for weeding, and this is reflected in the average hours of participation by both genders. In drip irrigation, family labour, males and females on average contributed 11 840 hours and 2488 hours, respectively during the season, while hired labour under surface irrigation also showed dominant proportions spent in weeding, with an average of 12 645 hours during the same season. Drip irrigation had a significant contribution from family and hired labour (men and women), but again, there is only minor hired labour among females.

Watering is predominantly a male activity; family labour recorded differential hours of 30 044 under sprinkler irrigation as against 11 122 hours under surface irrigation in the season. A similar pattern was observed for a higher contribution of hired labour for watering activities and was recorded at 9 045 hours under surface irrigation. The average hours of men and women were 202 167 hours, 14 341 hours, and 13 325 hours under surface, drip and sprinkler irrigation, respectively.

Pesticide application was higher for male family and hired labour. As shown in Tables 7.15, 7.16, and 7.17, there were no recorded female participation for any season. Only male participation was recorded for both family and hired respondents. Males under family and hired labour had higher hours, with 7 868 hours and 9 360 hours, respectively, to apply pesticides under surface irrigation. The total hours of labour was recorded as 17 228 hours under surface irrigation, while, drip and sprinkler irrigation were 16 288 hours and 14 309 hours, respectively. It can be noted that the hours of pesticide application differs according to different irrigation systems. For example, labour hours were high in surface irrigation, because of direct infection of date palm trees, as infection is transferred through water canals, especially underground insects and fungi. They lead to attack of leaves, stems, flowers and dates, so this issue needs to be considered and addressed by the farmers. The use of pesticides under sprinkler and drip irrigation is low.

The highest trend of participation was recorded for harvesting, as shown in Tables 7.15, 7.16 and 7.17. Family labour, males and females, recorded higher at about 12 436 hours under surface irrigation. In the case of hired labour, this figure was 9974 hours for harvesting under surface irrigation, but interestingly, females were involved in higher family labour activities in harvesting. Meanwhile, male family labour had lower cost compared with hired and hired labour.

Male respondents showed markedly higher hours involvement in the packing of dates and storing. The average hours were high for family respondent labourers under surface irrigation at 12 205 hours than for other irrigation for packing and storing dates. However, hired labour was 12 776 hours under drip irrigation. Data presented in Tables 7.15, 7.16 and 7.17 suggest that females also made a lesser but still significant contribution in family labour for packing.

Female participation in transportation activities is one of the lowest of all the activities in the study area, and therefore, transportation can be considered a male-dominated area of production. The lack of driving skills and restricted mobility to storage places cause restrictions for women's contribution in the transport activity. Comparison of data in Tables 7.15, 7.16, 7.17 below showed that male labour for hire and family were higher at 8 031 hours for transport with drip irrigation, compared to the labour under surface and sprinkler irrigation. This is because the date palm farms which used drip irrigation rely on using tractors with their trollies and tracks to transport the dates to the market. However, they do not have easy access between date palm trees to collect the dates and avoid destroying irrigation networks. As result, this leads to increases in the number of hired and family labour, which in turn leads to adding extra transport costs.

Male dominance is clearly visible in the data presented in Tables 7.15, 7.16 and 7.17. Unsurprisingly, the cost of male family labour is significantly higher as compared to hired labour in marketing. No activity was recorded for female hired labour and female family labour for all marketing activities of dates.

7.8.2 Field activities using equipment

Dates were planted in one season with intercropping, which differs from farm to farm. Different field operations undertaken by respondents during crop production, in particular during date production, are addressed in this sub-section.

Field activities start with land clearing and ploughing. Generally, seed bed preparation is done most of the time with the help of a tractor to construct a ridge; however, it is also done manually by some farmers. Planting is mostly done by hand. Fertilizer application is an important part of date palm production, and it requires unique fertilizing equipment. It is also done manually. Farmers in the region are now showing interest in adopting new methods of irrigation such as surface, sprinkler and drip irrigation, which were used by some date farmers in the research area. Insecticide, fungicide and pesticide are applied with manual spray pumps; however, if a large area is under cropping, then a tractor based spray method is used. Loose packing is done in the field, and afterwards, depending on farmers' arrangements, is modified into more refined forms, where the date harvest is packed according to market requirements.

Transportation depends on the production quantities of the crop and ranges from using small shipments to using trucks for bulk transportation. Although most of the farmers sell to the local market, progressive farmers deliver to other places as well.

Table 7.18 depicts field activities by types of irrigation used during the cropping season in 2013. For farms under sprinkler irrigation, the highest equipment use is recorded during land preparation at 8.68 hours, followed by clearing at 8.30 hours, planting 8 hours, ploughing (1) 7.43 hours, harrowing (2) 7.19 hours, harvesting 7.18 hours, watering 7.08 hours, and fertilizing at 6.64 hours. The contribution under drip irrigation is high in weeding 9.63 hours, packing 8.79 hours, pesticide application 6.82 hours, harrowing (1) 6.77 hours, marketing 4.33 hours, and transporting 4.09 hours. Surface irrigation has the lowest farming activity compared to sprinkler and drip irrigation.

Table 7-19: Field activities by equipment use (day/value)

Items	Surface irrigation			Sprinkler irrigation			Drip irrigation		
Units /hired (days)	**No**	Mean Hr/day	Value LD/day	No	Mean Hr/day	Value LD/day	No	Mean Hr/day	Value LD/day
Land preparation	131	7.52	720.30	119	8.68	746.85	136	8.15	690.99
Clearing	130	7.12	565.60	119	8.30	646.70	137	7.71	617.11
Ploughing (1)	130	6.51	556.20	118	7.43	619.21	137	7.26	633.84
Harrowing(1)	129	6.61	514.95	108	6.50	443.70	126	6.77	543.36
Ploughing (2)	0	0	0	0	0	0	0	0	0
Harrowing (2)	123	6.00	441.40	84	7.19	524.02	106	6.57	423.74
Bad preparation	129	6.04	439.80	109	6.84	452.38	128	6.79	454.05
Planting	130	6.39	473.20	118	8.00	602.84	137	7.27	503.32
Fertilizing	130	5.78	484.80	119	6.64	462.13	136	6.54	435.68
Weeding	130	7.65	1032.4	119	9.61	1509.71	136	9.63	1522.35
Watering	130	5.93	382.28	119	7.08	523.32	136	6.72	526.38
Pesticide	130	5.92	407.65	119	6.66	502.71	136	6.82	481.57
Harvesting	129	6.25	489.88	119	7.18	633.77	136	6.79	527.39
Packing	130	6.40	681.58	119	8.76	1170.68	136	8.79	1050.26
Transporting	129	3.66	652.92	119	3.51	666.72	134	4.09	668.99
Marketing	129	3.39	573.98	119	3.78	709.18	133	4.33	725.53

Source: Survey data, 2013.

Table 7.18 also contains data regarding the equipment use in the date palm growing season, and is consistent with the results of the previous means with some minor changes. This time, the highest values of sprinkler irrigation were in packing (1170.68 LD), land preparation (746.85 LD), clearing (646.70 LD), harvesting (633.77 LD), planting (602.84 LD), harrowing (2) (524.02 LD) and pesticide application (502.71 LD). Other results for drip irrigation were weeding (1522.35 LD), followed by marketing (725.53 LD), transporting (668.99 LD), ploughing (633.84 LD), harrowing1 (543.36 LD), watering (526.38 LD) and bed preparation (454.05 LD). The only value of fertilizing per day was highest under surface irrigation with 484.80 LD. A comparative analysis of irrigation systems indicates that in some field activities, depending on the nature of the activity, sprinkler irrigation has a high mean per day. There are also a few activities where the average of drip irrigation per day and values is more than or equal to sprinkler irrigation; however, surface irrigation was mostly those activities that have lower work days and costs. This signifies that the sprinkler and drip irrigation requires more physical activities per day during the date palm season, and this is noticeable and higher than in surface irrigation.

7.9. Output of date palm farms under irrigation in Sebha region, Libya

7.9.1 Distribution and use of dates

The average use of the five types of dates under different types of irrigation systems in Sebha region is presented in Table 7.19.

As shown Table 7.19, under surface irrigation, the mean utilisation of other dates (i.e. Asbeer, Agleen, Tamage etc) in animal food (2091.70 kg) is high compared to Tasfert, Talees, Taghiat and Tdhwi. There is also high use of Talees date for both gifts (415.59 kg) and family (296.04 kg) compared to Tasfert, Taghiat and Tdhwi and other dates (i.e. Asbeer, Agleen, Tamage etc). Furthermore, farmers obtained the highest output (4007.10 kg) and revenue (13 250 LD) from other dates (i.e. Asbeer, Agleen, Tamage etc) when compared to Tasfert, Talees, Taghiat and Tdhwi under surface irrigation system.

Under sprinkler irrigation (Table 7.19), the average use of Talees dates was highest for family use (299.02 kg) when compared to Tasfert, Taghiat, Tdhwi and other dates (i.e. Asbeer, Agleen, Tamage etc). Taghiat was the highest for animal food (841.17 kg) and gifts (360.83 kg) when compared to Tasfert, Tdhwi and other dates (i.e. Asbeer, Agleen, Tamage etc). Also, farmers obtained the highest output from Tasfert dates production; however, Talees had the highest revenue (7220 LD) under sprinkler irrigation system.

In contrast, under drip irrigation, the highest average use was Taghiat for feed for animals (1034.10 kg) compared to other varieties. Taghiat was the highest for family (256.51 kg) as compared to Tasfert, Tdhwi and other dates (i.e. Asbeer, Agleen, Tamage etc). With regard to Talees dates, farmers in Sebha region under drip irrigation system obtained a revenue of 8254.40 LD, outputs of 2968.30 kg and gifts gifts of 328.79 kg.

Table 7-20: Distribution and use of dates (Kg/LD)

Items	Surface irrigation			Sprinkler irrigation			Drip irrigation		
Consumed (Kg)	No	Mean	SD	No	Mean	SD	No	Mean	SD
Tasfert									
Family (kg)	74	147.43	205.29	57	220.20	244.17	76	256.51	259.60
Fed to animals (kg)	82	859.02	1201.40	72	569.58	405.64	86	754.88	823.20
Gifts (kg)	72	282.50	478.97	56	167.86	360.35	63	216.21	408.20
Sold (kg)	98	3066.70	5611.00	95	2709.00	8484.20	108	2335.90	2769.00
Total value (LD)	98	7871.5	15265.00	95	4667.53	4843.80	108	6042.90	6986.00
Talees									
Family (kg)	77	296.04	933.27	66	299.02	403.33	74	241.81	356.2.00
Fed to animals (kg)	98	961.12	1448.70	93	586.40	670.93	90	960.83	1274.00
Gifts (kg)	76	415.59	811.38	54	154.26	203.03	62	328.79	558.50
Sold (kg)	110	3137.90	4388.00	108	2450.48	3787.80	114	2968.30	3990.00
Total value (LD)	110	8983.60	12937.00	108	7220.72	10104.00	114	8254.40	11513.00
Taghiat									
Family (kg)	63	125.89	120.95	40	198.05	284.95	54	186.31	227.20
Fed to animals (kg)	81	1459.40	5666.80	47	841.17	1498.70	73	1034.10	1437.00
Gifts(kg)	57	333.77	506.51	36	360.83	818.66	51	287.94	388.90
Sold (kg)	87	3775.20	6856.00	70	2110.00	2761.40	92	2772.40	3287.00
Total value (LD)	87	8724.10	12892.00	70	4895.02	6180.70	92	6323.50	7179.00
Tdhwi									
Family (kg)	19	208.95	229.76	19	215.58	190.12	22	147.05	123.50
Fed to animals (kg)	25	1121.00	2141.40	22	692.73	832.20	34	884.09	585.30
Gifts (kg)	19	169.47	155.40	14	100.36	60.02	21	247.38	262.00
Sold (kg)	33	1698.80	2242.00	42	1843.69	2350.30	47	2316.20	2998.00
Total value (LD)	33	4763.70	6531.70	42	4234.05	5446.30	47	4604.30	4914.00
Other dates*									
Family (kg)	2	125.00	106.07	1	50.00	1	2	75.00	35.36
Fed to animals (kg)	6	2091.70	2000.10	1	500.00	1	4	700.00	424.30
Gifts (kg)	5	310.00	397.49	1	100.00	1	4	125.00	50.00
Sold (kg)	7	4007.10	5050.60	1	1100.00	1	7	1792.90	2066.00
Total value (LD)	7	13250.00	12873.30	1	4400.00	1	7	4021.40	4550.80

Source: Survey data, 2013. *Other date cultivars grown in Sebha such as Asbeer, Agleen, Tamage etc.

7.9.2 Market of types of date palm

Figure 7.2 shows farmer production dates under sprinkler irrigation, as 92.4 per cent of farmers are engaged in marketing of date palm in local markets; 7.6 per cent of the farmers used other options. However, 90.5 per cent of the farmers, who use drip irrigation, are engaged in market activities; and 9.5 per cent are employed in other activities.

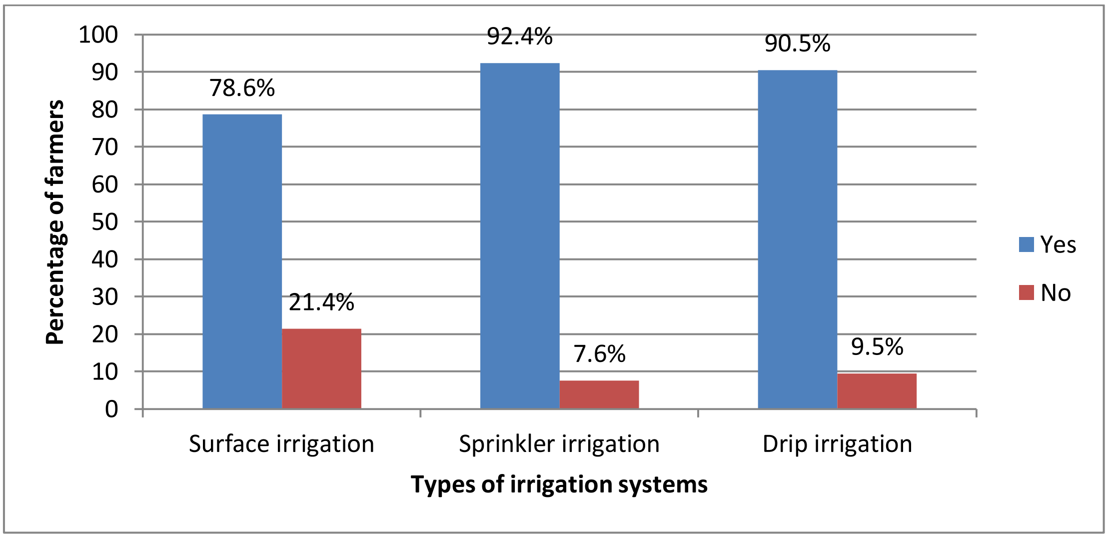

Figure 7-2: Market of types of date palm

In surface irrigation, 78.6 per cent of the farmers are engaged in marketing of dates, against 21.4 per cent who are employed in other activities.

7.9.3 Marketing of dates and other products of date palm tree

The type of dates and irrigation system plays a significant role in terms of marketing and the value per date palm trees for farmers. Table 7.20 summarises the marketing of date palm and other by-products such as seedlings (date palm offshoots)[4] and dry leaves. A comparison of the mean quantities and values between irrigation systems indicates that type of dates has a significant difference in terms of mean quantity and value of types of date palm output sold under different types of irrigation systems.

[4] A seedling is the date palm offshoot. That is, it is generated from the mother palm tree. A date palm offshoot is important for commercial purposes and depends on the type of date palm trees.

Table 7-21: Mean quantity and value of types of date palm output sold under different types of irrigation systems

Items	Surface irrigation			Sprinkler irrigation			Drip irrigation		
	No.	Mean	Value (LD)	No	Mean	Value (LD)	No	Mean	Value (LD)
Tasfert									
Dates (kg)	77	34.25	93.45	86	32.58	94.87	104	34.11	**119.81**
Seedling (No.)	75	139.07	1428.40	85	95.76	1129.76	104	104.97	**1109.52**
Leaves (No.)	64	397.34	665.00	59	192.20	325.08	78	363.27	**746.99**
Lost dates (kg)	10	5.60	0	1	1.00	0	2	3.50	**0**
Talees									
Dates (kg)	93	34.10	97.60	104	31.26	86.87	106	33.64	**94.84**
Seedling (No.)	91	129.42	1459.12	103	94.90	1053.11	106	120.96	**1488.95**
Leaves (No.)	80	462.38	778.13	77	224.03	408.31	82	371.34	**700.97**
Lost dates (kg)	14	11.10	0	0	0	0	4	3.50	**0**
Taghiat									
Dates (kg)	70	35.07	87.60	66	30.67	74.08	92	31.71	**75.28**
Seedling (No.)	67	84.90	710.40	66	71.83	785.86	91	121.14	**1273.96**
Leaves (No.)	64	358.20	619.47	49	229.29	426.33	73	328.29	**535.21**
Lost dates (kg)	24	5.38	0	0	0	0	6	3.83	**0**
Tdhwi									
Dates (kg)	26	36.73	91.90	40	28.75	78.00	38	41.13	**92.00**
Seedling (No.)	24	78.33	687.50	40	100.63	1063.75	38	120.39	**1218.68**
Leaves (No.)	20	175.00	287.50	27	150.37	288.52	28	332.50	**623.21**
Lost dates (kg)	8	12.30	0	0	0	0	4	3.00	**0**
Other dates									
Dates (kg)	7	28.57	107.14	2	37.50	130.00	3	26.67	**53.33**
Seedling (No.)	6	73.33	766.67	2	40.00	470.00	3	116.67	**850.00**
Leaves (No.)	6	116.67	233.30	2	75.00	150.00	3	466.67	**733.33**
Lost dates (kg)	5	10.00	0	0	0	0	4	2.75	**0**

Source: Survey data, 2013. *Other date cultivars grown in Sebha such as Asbeer, Agleen, Tamage etc.

Marketing of types of date in the study area varied with surface irrigation systems. Tasfert has the highest mean number for seedlings (date palm offshoots), and quantity of dates per tree at 139.07 and 34.25 kg, respectively. Talees dates were also marketed by farmers in Sebha region; the number of leaves was more marketed with an average of 462.38 leaves under surface irrigation, while the highest lost dates was an average 12.30 kg for Tdhwi dates. Concerning surface irrigation and Talees dates, the average income is approximately 778.13 LD for leaves, and 1459.12 LD for the seedlings. However, the quantity of dates per tree was highest for other dates (i.e. Asbeer, Agleen, Tamage etc) (107.14 LD).

Under sprinkler irrigation, the results show that Taghiat dates produced an average 229.29 leaves. Tdhwi had higher produce at an average 100 seedlings (date palm offshoots), while other dates (i.e., Asbeer, Agleen, Tamage etc) is 37.50 kg dates per tree. However, there was only 1 kg lost dates for Tasfert under sprinkler irrigation. The mean of the market of types of date palm and other parts achieved in the given sample were higher under sprinkler system. They also have a relatively higher value and income. Regarding the average revenue of Tasfert dates, it was found to be around 1129.76 LD for the seedling (date palm offshoots) and 94.87 LD dates per tree, while, 426.33 LD for leaves.

In terms of drip irrigation, a comparison of the means of various date palm products indicates that Taghiat dates have a much greater output for seedlings (121.14 seedlings) and lost dates (3.83 kg). While Tdhwi was higher per quantity of date per tree by 41.13 kg, however, the highest average was 466.67 kg for other dates (i.e. Asbeer, Agleen, Tamage etc) under drip irrigation. Regarding the average revenue, the results show that the average revenue of Talees for seedlings (date palm offshoots) was 1488.95 LD. In addition, the income of Tasfert is about 746.99 LD and 119.81 LD for quantity of date per tree for those managed under drip irrigation.

7.10 Household goals of farmers

Questions related to household goals were also included in the questionnaire, and data were recorded during the survey. Respondents were asked to answer from a scale of 1 to 7, with 1 = not important and 7 = very important. The results are given in Table 7.21 below.

In Table 7.21, farmers put different levels of importance on household goals. About 22.4 per cent of farmers rated cash income as extremely important, while about 18 per cent and 14 per cent rated household needs and savings, respectively, as extremely important. On the other hand, only few farmers rated environment (8.1 %) leisure (4.3 %), other things (2.9 %) as extremely important. Understanding the priority farmers attach to household needs is critical to empowering them, so that they can effectively manage their household needs, make savings for their households' betterment and concentrate on adequate health facilities for their household members.

Table 7-22: Household goals for farmers

	Rating scale 1-7*													
Goals	**1**		**2**		**3**		**4**		**5**		**6**		**7**	
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Household	3	1.4	7	3.3	4	1.9	42	20	56	26.7	60	28.6	38	18.1
Income	3	1.4	4	1.9	12	5.7	43	20.5	52	24.8	49	23.3	47	22.4
Saving	4	1.9	5	2.4	22	10.5	60	28.6	64	30.5	26	12.4	29	13.8
Education	8	3.8	19	9.0	49	23.3	73	34.8	44	21.0	12	5.7	5	2.4
Health	12	5.7	19	9.0	60	28.6	69	32.9	31	14.8	13	6.2	6	2.9
Social status	18	8.6	30	14.3	62	29.5	47	22.4	31	14.8	20	9.5	2	1.0
Leisure	41	19.5	50	23.8	38	18.1	36	17.1	21	10.0	15	7.1	9	4.3
Environment	19	9.0	33	15.7	26	12.4	36	17.1	40	19.0	39	18.6	17	8.1
Other things	31	14.8	71	33.8	51	24.3	29	13.8	16	7.6	6	2.9	6	2.9

*(1 = Not important at all, 7 = extremely important)

7.11 Discussion

There were different characteristics that could be observed from respondents in Tables 7.1 to 7.9.

In terms of characteristics of farmers, respondents have fewer single farmers. The average ages of husband and wife were more than 50 years, and they have low literacy rates. Most of the farmers have large numbers of family members because they are married to two or three wives during their lifetime. Oladimeji et al. (2013) reported that marrying more than one wife is common in rural settings to ensure a supply of additional family labour. Although farmers have more farming experience, their formal training in agricultural activities was low.

In terms of farmers' income, more than 50 per cent of their income was generated by a subsidy from other family members, livestock and services (see section 7.3.1). Butler and Mazur (2007) reported that diversification of income sources plays an important role in improving food security and income of farmers. For example, subsidies from other family members in small farm holders' contribute to achieving higher production and thus increases and protects their income Nevertheless, it is not uncommon for farm households to be an owner or share in a non-agricultural business, because farm households had relatively high off-farm income compared to farm income. Thus, off-farm income contributed to cover the loss from farming. Family participation is not limited to a particular activity but is distributed along the chain of agricultural activities. Although participation can change with the nature of the activity, husbands' and sons' participation is prominent in agricultural activities as well as in other relevant income-generating activities. Factors responsible for higher male contribution in comparison with female are other sources of income for the family and more experience in agriculture activities. Those factors most effectively contribute to uplifting their social status and developing their incomes.

In the description of date palm farms, farmers in the study area usually managed their farm irrigation or businesses individually. Therefore, agricultural companies and the government sector were lesser participants during farm managed activities. On average, the age of date palm trees is more than ten years on many farms. Farmers indicated that the best age for production is between 20 to 40 years. Contrarily, Chao and Krueger (2007) noted that trees were producing dates at 4 to 6 years of age and reached full production within 15 to 20 years. Besides, farmers prefer crops in conjunction with date palm trees especially trees less than ten years, because they would have a couple of years expenses without revenue (Alshuaibi, 2011). Overall, the investment in date palm trees is a difficult decision by Libyan farmers because there are difficulties in managing water in a sustainable way, as well as the fact that date palms require a long period of time until they can start generating dates.

In terms of type of soil, clay, very fine sand and medium sand were the best for date palm. Palms can be grown in a wide range of soil types. A clay soil has a good water holding capacity and good drainage which is desirable for farmers. However, some farmers have grown date palm in saline soils in the study area, but in such soils the growth and productivity are greatly reduced (Barreveld, 1993).

More than 90 per cent of farmers obtain their irrigation water from private and shared water wells. Date palm farms depend on wells equipped with modern irrigation technologies. They drill their wells and use electric submersible pumps after approval by the Libyan Ministry of Water. Some farmers have drilled wells without a licence due to an expansion of irrigated areas in the study area. This has caused more depletion of water resources because the majority of farmers in the Sebha region are greatly dependent on groundwater resources.

The main irrigation systems used are surface irrigation, sprinkler irrigation and drip irrigation. Many farmers use two or multiple systems on their farms. This is because the adoption of appropriate technologies including the modernization of traditional irrigation systems is needed to achieve efficiency in water usage and productivity (Oweis, Farahani, & Hachum, 2011; Pereira, Cordery, & Iacovides, 2012). The majority of farms under surface irrigation have an area of 4.71 hectares; under sprinkler irrigation the area average is 4.36 hectares, and 3.98 hectares for drip irrigation. Surface irrigation is used for all types of crops and requires high capital investment per hectare, especially for vegetables and fruit trees. Drip irrigation is the method that is of the most of interest to farmers because of its reputation for lower irrigation water requirement (Carr, 2013). Most countries in the North African region including Libya focused on drip irrigation, as the government subsidies cover the cost of drip irrigation (Carr, 2013). There are new technologies, which are designed to improve water productivity; however, these technologies are mainly unknown to most of the date palm growers in Libya.

In terms of labour used for irrigation, the majority of farm households in Sebha utilise different labour in irrigation of date palm. According to percentages of the total labour usages, surface irrigation was highly labour demanding, followed by sprinkler and drip irrigation. Labour was an important input for surface irrigation under date palm (Koech, Smith, & Gillies, 2010; Pereira et al., 2012; Smith, Raine, & Minkevich, 2005). Farmers that apply sprinkler and drip irrigation systems also require labour.

The sources of human labour came from family and hired labour. They are engaged in all types of irrigation processes. Family labour is normally used for light activities such as watering. The reasons for choosing family labour are that the land area is small, family labour is readily available and saves money; while the tradition of helping one another to complete necessary activities as quickly as possible is the main reason that farmers exchange labour. Male and female family labour under drip irrigation systems required more hours and cost higher labour per day for irrigation as compared to those using sprinkler and surface irrigation. Hired labour complemented family labour during times of peak labour demand. The main reason for using hired labour was that the commercial farms have a large number of date palm trees. Sprinkler irrigation required significantly more hours and higher cost per day of hired labour than those under the other irrigation systems, because the sprinkler lines must be moved at regular intervals to irrigate large farms (Wichelns et al., 1996). In Sebha, for example, a sprinkler system operates more than 12 hours in the early morning and early evening. Typically, a separate person is hired to supervise the operation of the sprinklers and the booster pump during the day, and another person is hired to monitor the booster pump during the night. An introduction of sprinkler irrigation may create employment opportunities in Sebha regions. This was attributed to the additional labour requirements for planting and harvesting required for new land brought into production.

Date palm requires both family and hired labour for the whole cultivation process. This is because date farmers required fertilizing, weeding and watering especially in multiple cropping. However, contribution of females of family and hire labour in general remained limited in all irrigation systems, due to the prevailing patriarchal system. It is clear that particular types of work for women, under specific conditions, prevents them from entering other types of work traditionally reserved for men. Family and hired male labour are dominant in almost all irrigation activities especially surface and drip irrigation. This is because of the lack of extension services and other awareness enhancing systems in the study area.

In terms of characteristics of irrigation systems, sprinkler irrigation had higher time of irrigation at morning per weekly/days and hours both morning and midday times. The highest irrigation at midday per weekly/days was drip irrigation. Sprinkler and drip irrigation were equal at night per weekly/days, but drip irrigation used more irrigation hours. To counter the water evaporation, seepage and runoff losses, farmers increase the hours of irrigation. Respondents concluded that most drip irrigation was applied only for date palm tree cultivation. As a result, average date palm trees per hectare recorded highest compared to surface and sprinkler irrigation. According to distance between trees, drip irrigation required more width than the other irrigation systems. The tapes were applied by the width of each date palm tree, while surface irrigation required more length. This may be due to allowing other plants to grow as intercrops in date palm farms.

Regarding water consumption, a farmer who used surface irrigation consumed more water compared to sprinkler and drip systems. Due to the width of canals, a higher number of hour's irrigation is required. Therefore, farmers believe that intercropping with date palm trees requires more water. On the other hand, the water requirements through surface irrigation for date palm are almost double the amounts of water required in summer. El-Juhany (2010) reported that the amount of water consumed by date palm was between 150 to 200 litres per day in winter and summer. Furthermore, surface irrigation was more wasteful than sprinkler and drip irrigation. The significant water losses may be due to evaporation, deep drainage to soil layers underneath the canals, surface runoff, and water leakage from holes of canals. However, Abul-Soad, Mahdi, and Markhand (2015) reported that the amount of water used depends on the development stage of the crop, the degree of maturity and atmospheric issues for example, temperature, wind and humidity. Sprinkler irrigation had higher cost of watering in the irrigation system. This is due to high cost of labour used for maintaining sprinkler irrigation pipes and pumps.

Labour used for date production under irrigation system is found to be family and hired male dominated. Women's participation in pesticides application, transporting and marketing activities was also found to be nil in all irrigation systems; with only participation in packing and storing in sprinkler irrigation. This is because the rural area in Sebha is restricted by socio-cultural issues and mobility. Tenge, De Graaff, and Hella (2004) point out that females are less efficient at adopting soil and irrigation water conservation since women may be constrained to access agricultural information due to traditional social barriers. This result differed in the findings of Upadhyay, Samad, and Giordano (2005) who found that women play a predominant role by contributing 88 per cent of the total farming labour.

In other activities, female work was found to be concentrated in land clearing, canal establishment, planting, weeding, watering, and harvesting activities while there was minimal participation for fertilizing activities. The operations in date production which are physically very tough and require frequent mobility such as input purchase (i.e., sacks of fertilizer are heavy) are therefore operations that are mainly male-dominated. Asfaw and Admassie (2004) note that farms managed by males have a higher likelihood of getting information about new farming technologies than female managed farms.

In terms of marketing of types of dates, there were significant differences between marketing under various types of irrigation technologies. In general, the average annual income of harvest season by drip irrigation was significantly higher compared to the incomes under surface and sprinkler irrigation. For this reason, drip irrigation was more likely to employ less labour as compared to surface and sprinkler. Consequently, the cost of production of dates was lower.

Other aspects not taken into consideration were that farmers rarely have access to information on inputs, outputs and markets. Eskola (2005) reported that lack of market information, and inefficient institutional frameworks in the industry sector and water management are the major barriers in date palm production. Farmers do not have skills and knowledge because they lack strategic information (Concepcion & Digal, 2007). Because of the lack of suitable knowledge, farmers in developing countries have faced difficulties in knowing what the current quality requirements are and what quantity is needed by the market. Therefore, the majority of Libyan farmers have continued to produce the same date product. In the same way, Ata, Shahbaz, and Ahmad (2012) stated that farmers have a very low level of knowledge about the production technology of date palms. Their lack of awareness about production technology of date palm was found as one of the major factors hindering the yield and profit for date growers. On the contrary, some farmers have sold their dates at higher prices under different irrigation systems. This is because farmers use recommended rates of inputs for their date palm trees and achieve attractive prices of their produce due to the quality parameters (Jari & Fraser, 2009). Date palm farmers in this region are well aware of the production and marketing patterns and execute entrepreneurial skills according to the situation to earn high net returns.

7.12 Conclusion

This chapter provided the results of the fieldwork survey held in 2013 on the background of respondents in the study, including the respondents' age, schooling, farming experience, family members and salary in date palm production. It also presented the analysis of the characteristics of farmer's incomes from farm and other business activities. Date palm farms were described in terms of the number of trees, age and crops grown. Comparisons of date palm production under different irrigation systems were made. Labour used under surface irrigation; sprinkler irrigation and drip irrigation were presented. The results showed that surface, sprinkler and drip irrigation were significantly different in terms of time of irrigation, distance between date palm trees, irrigation consumption and cost of watering. The results of the analysis of inputs used, and labour per hours and important field activities in date palm production under different irrigation systems were also presented and discussed. Dates were utilised for food for member of family, fed to animals and gifted to poor people or relatives. The outputs of date palms were dependent on the types of dates.

In Chapter 7 the different characteristics of farmers and farms were analysed and discussed utilizing data obtained from farmers' interviews. The next chapter will explain the effects of types of irrigation systems on fruit quality.

Chapter 8
Effects of Different Irrigation Systems on Physical and Chemical Characteristics of *'Talees'* Dates at Different Locations in Sebha Region, Libya

8.1 Introduction

This chapter focuses on the effects of different irrigation systems on fruit quality of the commercially important date palm cultivar, '*Talees*', at different locations in Sebha, and is divided into six sections. Following this introduction, Section 8.2 provides a brief literature review of studies related to the subject, including studies specifically carried out on dates. Descriptive materials and methods of physical and chemical analysis are presented in Section 8.3 while the physical and chemical analyses results are presented in Section 8.4. Section 8.5 discussed findings finally, Section 8.6 concludes the chapter.

8.2 Literature review

There are many investigations that have been conducted in different countries about which irrigation system has a significant effect on the physical characteristics of date palm fruit. Tafti and Fooladi (2005) reported significant differences in the fruit weight, fruit length, fruit breadth and fruit volume by using different irrigation systems in 'Muzafati' dates in Iran. Shaheen (2007) reported that surface, sprinkler and drip irrigation in Saudi Arabia resulted in significantly different lengths, breadth and size and fruit weight of 'Rabia' dates. Al-Abdoulhadi et al. (2011) reported that fruit weight differed significantly between Khalas and Reziz cultivars under different irrigation systems. Said et al. (2014) evaluated the length, diameter and weight of 54 Algerian date cultivars and only 18 cultivars had the best characteristics of dates compared to other cultivars using different irrigation systems. In Pakistan, Ullah (2011) reported effects of different cultivars such as Azadi, Dhakki, Gulistan, Khudravi, Shakri and Zahdi and irrigation systems on the physical characteristics of fruits. Al-Amoud et al. (2000) examined whether different irrigation systems have an impact on the yield of date palm trees. Their results showed that drip irrigation has the maximum effect in terms of increasing the yield of date palm tree, followed by the basin irrigation system. In addition, the drip irrigation has been proven to have the water use efficiency, followed by the basin plots. This was confirmed by Ahmed, Hashmi, and Ghumman (2011); Hussein and Hussein (1982); Mazahrih et al. (2012); Saker et al. (2013); Al-Rawi and Al-Mohemdy (2001); Al-Hooti, Sidhu, and Qabazard (1997); Akasha (2005); El-Alwani and El-Ammari (2001); Geddeda and Abdassalam (2010) and Elahmer et al. (2006); Ahmodi (2013); and Pundir and Porwal (1998) in Emirates, Egypt, Iraq, Saudi Arabia, Pakistan, Libya and Tunisia, respectively.

Meanwhile, in Saudi Arabia, Basahi (2006) and Rahnama, Abdol, and Mohebi (2012) showed there were no significant effects of irrigation treatments on weight, length, diameter and volume and bunch weight of Sukariah and Barhee date fruit grown in Saudi Arabia, but fertilization treatments had more significant effects. Ismail et al., (2006) and Al-Qurashi (2010) reported that different irrigation treatments improved fruit weight, length and diameter but the differences were not significant in five cultivars grown in the Emirates. Furr (1951) studied the effect of irrigation on Khadrawy date palms. His findings demonstrated that date palm yield and leaf growth rate were not significantly decreased by water shortage, however there was a slight decrease in leaf growth of treatments. Alihouri and Torahi (2013) reported that different irrigation regimes significantly affected yield, fruit weight, volume; length and diameter but there was no significant difference between fruit quality parameters of dates in Iran. Hussain (1993) reported that irrigation systems did not significantly affect fruit volume, fruit weight, fruit diameter and leaf growth. Al-Bouwarthan, Alsfr, and Al-Kars (2007) observed a similar result from the means of production of date palm by drip irrigation and they also found there were no significant differences in date palm production between surface and drip irrigation. Soad, Jatoi, and Markhand (2013) evaluated three cultivars of date palm Ajwa, Safawi and Ruthana from different locations at Al-Madina in Saudi Arabia and Khairpur, Sindh in Pakistan under similar agro-climatic conditions. The findings of Soad et al. (2013) indicated that changing the place of origin of date palm tree is not correlated to date quality. In other words, date quality in the new place (i.e., Pakistan) is similar to date quality that is obtained from the origin place (i.e., Saudi Arabia). The findings also showed that the length and diameter of Ajwa, Safawi and Ruthana dates are 3.16 and 4.25 and 3.52 cm for length, respectively; and 2.31, 2.05 and 2.38 cm for diameter, respectively. The average fruit's weight and stone's weight of Ajwa, Safawi and Ruthana dates were 11.42, 10.49 and 12.42 g, and 1.23, 0.88 and 1.1 g, respectively. The percentage of fruit flesh in the three types: Ajwa, Safawi and Ruthana are 89.14, 90.84 and 90.92 per cent, respectively. It has been demonstrated that the climatic conditions of Khairpur locations are suitable for the cultivation of Ajwa, Safawi and Ruthana dates (Soad et al., 2013). Kenna and Mansfield (1997) tested four date cultivars Medjool, Barhee, Deglet Noor and Thoorty under different conditions in Australia including irrigation systems. They found no differences between fruit weight, but there were differences in length, diameter and breadth of fruit among cultivars under different irrigation systems. Ismeil, Al-Qurashi, and Awad (2014) reported that fruit quality characteristics including fruit weight, fruit length and diameter flesh and stone weight were not significantly affected by the water regime. They suggested that date palm may give a higher production in western locations in Saudi Arabia by supplying (34 m^3) water per year.

Irrigation has also an effect on sugar and organic acid. Among the several studies Jurikova and Gazdik (2009) reported there was a change in organic acids and sugar for berries under irrigated variants. Nadeem, Anjumand, and Bhatti (2011) reported that there were significant differences in sugar for date palm by irrigated variants. Ismail et al. (2006) studied five date cultivars and they reported that sugars were reduced from 76.2 per cent to 68.4 per cent. Bacha, Nasr, and Shaheen (1987) analysed four date cultivars grown in Saudi Arabia and reported that sugars were reduced from Kimri stage to tamar stage by irrigation. In another study, Ibrahim (2008) noticed that during the growing season under irrigation, there was a decrease in sugars in four Egyptian date cultivars in terms of the chemical and physical characteristics. Osman (2010b) indicated that reducing sugar content in the fruit were significantly different between Samany and Zaghloul date palm cultivars grown at different locations in Egypt.

Al-Amoud et al. (2000) found significant differences in organic acid in drip irrigation compared with other irrigation systems. Mirabad, Lotfi, and Roozban

(2013) found that irrigation treatments had a significant effect on levels of sugars in the fruit yield. Souza et al. (2015) observed that organic acids, such as tartaric and malic acid, were much lower for vines under irrigation compared to glucose and fructose contents. Nadal and Arola (1995) reported that there are high levels of malic acid in grapefruit with sprinkler irrigation in Spain due to a high level of potassium. Ismail et al. (2006) analysed five varieties of dates in the Emirates and found that dates have higher levels of fructose and glucose, while sucrose is present only in small quantities. The levels of sugars were not significantly different among all dates, except Barhee dates which showed significantly higher levels compared with other cultivars. The Barhee type also showed a significantly high content of fructose. Compared with fructose, the variation in glucose levels among cultivars was higher. Al-Yahyai and Al-Kharusi (2012) found that irrigation had a direct impact on the chemical quality attributes of dates at different stages in the Sultanate of Oman.

Sucrose was not significantly different among irrigation treatments (Hussein, 1972; Sahari, Barzegar, & Radfar, 2007). De la Hera-Orts et al. (2005) examined the impact of irrigation systems on grapes in south eastern Spain. The results showed that irrigated grapes reached higher weights, however the irrigation systems have not shown an effect on sugar content. Titratable acidity was to some extent impacted by irrigation; as the titratable acidity was higher in the most irrigated grapes, mainly due to higher malic acid content. Al-Barak (2012) studied the effect of irrigation on productivity and quality properties of Berhi date palm fruit in AL-Grna and Al-Faw locations. The results showed a significant superiority of the AL-Grna location in physical properties such as fruit and pulp weight, fruit length and diameter than the Al-Faw location. The results also showed a significant superiority of the Al-Faw location in chemical properties such as TSS, total acidity, total sugars and reducing sugars than the AL-Grna location. Sahari et al. (2007) noted that sucrose levels did not differ significantly among cultivars, but the differences in levels of fructose and glucose were significant among cultivars. Selim et al. (1968) reported reducing sugars ranged from 9.92% to 47.24% and non-reducing sugars varied from 6.03% to 47.24%; and found total sugars ranged from 39.17% to 56.45%. Hussein (1972) reported that under different irrigation systems, there is little or no sucrose in the fruits of soft date cultivars, however there is a relatively high proportion of sucrose in the dry cultivars. Hasanaoui et al. (2011) examined date cultivars from different locations from three countries Algeria, Morocco and Tunisia. The findings showed that there were high sugar levels in all examined date cultivars (54.14 - 75.56 g/100g). For example, in Deglet Nour and Aziza bouzid cultivars in Tunisia and Morocco, it has been shown that sucrose was dominant, while the fructose and glucose were rich and comparable proportions in the majority of other cultivars.

Ayesy (2006) reported that sugars and organic acids in the fruit were influenced by the cultivar and growing location in Saudi Arabia. Sakr et al. (2010) examined the chemical composition of nine date cultivars from different places in Egypt. Zaghloul cultivar had total phenols, and high levels of low sugars. However, there were high levels of total soluble solids in Samany cultivar.

The researcher in this thesis has noted that no research work has been reported on the effects of different types of irrigation systems on date fruit quality grown in Libya. It was surmised that irrigation systems may influence water use efficiency and fruit quality in date palm grown in Libya. Therefore, the effects of different irrigation systems such as surface, sprinkler and drip irrigation on *'Talees'* date fruit quality from Sebha region at four locations (Al-zighan, Ghodduwa, Samnu and Tamanhant) were investigated.

8.3 Materials and Methods

This component of the research was conducted in Sebha region at Al-zighan, Ghodduwa, Samnu and Tamanhant, Libya in 2013 to investigate the effects of irrigation systems on fruit quality in *'Talees'* date palm. Three irrigation systems were used: surface, sprinkler and drip irrigation at all four locations. The experiment was laid out by following a two-factor (irrigation system and location) factorial randomized complete block design with six replicates and two trees per replication. All experimental date palm trees were separated by guard trees. The trees were irrigated throughout the year at all locations. Data were collected for one year. Two kilograms of fruit were randomly harvested from all the trees from each replication.

8.3.1 Physical analysis

The fruit were used for fruit quality assessment including fruit weight, length, breadth, pulp thickness, stone weight and stone length and breadth. The fruit and stone length were measured using Vernier callipers. Meanwhile, fruit and stone weight were recorded on a sensitive scale. The data were statistically analysed using ANOVA and the means were tested by LSD test at 5% level of significance.

8.3.2 Chemical analysis

Date pulp (2 g) dry weight of the ground sample was weighed and was transferred to a falcon tube and grinded followed by the addition of 5 ml of HPLC grade water (see chapter 5). The reaction mixture was placed in an ultrasonic bath and sonicated for 15 min at 40°C, and then centrifuged at 8000 rpm for 15 min at 10°C. The supernatant was filtered through a membrane filter (0.45 μM), transferred into a vial and used for sugar analyses. A 25 μl sample of filtrate was injected into the HPLC (Waters, USA), equipped with a 2414 RI detector and absorbance detector (Waters 2487) for determination of individual sugars and organic acids, respectively as detailed by Singh and Singh (2008). The concentrations of different sugars and organic acids in the date fruit were calculated and expressed as $g100g^{-1}$ and $mg\ g^{-1}$, respectively on a fresh weight basis. Data were analysed using ANOVA and the means were tested using LSD test. The level of significance used was 5%.

8.4 Results

Talees variety is the main date cultivar in the Sebha region. This study focused on talees variety for a number of reasons. Firstly, there is high demand for Talees variety because of the high level of sugar in talees compared to other varieties. Secondly, the variety is suitable for the weather conditions around the Sehba region and has become the preferred choice for farmers in the region. Thirdly, Talees varieties have long-term storage capabilities compared to other varieties. As Akasha (2005) and Ahmodi (2013) reported, there are more than 50 date varieties in the Sebha region; and Talees variety has become the most preferred choice for farmers especially for commercial purposes.

Although majority of the farmers prefer to cultivate Talees variety, the area of Talees differs under different irrigation systems as shown in Table 8.1. The data shows that 36.08 per cent of Talees area are under surface irrigation, while 32.94 and 30.98 per cent of Talees area are under the drip and sprinkler irrigation systems, respectively.

Table *1-8* : Total of area under irrigation systems in Sebha region

Items	Area	Share (%)
Suface irrigation	210.00	36.08
Drip irrigation	191.75	32.94
Sprinkle irrigation	180.30	30.98
Total	582.05	100

Source: Survey data, 2013.

8.4.1Effect of different irrigation systems on physical characteristics of '*Talees*' dates grown at different locations

The analysis of the physical characteristics of date palms is presented below.

Surface irrigation Sprinkler irrigation Drip irrigation

Figure 8-1: Fruit morphology of *Talees* cultivar under different types of irrigation systems

Analyses of fruit weight, fruit length, breadth, pulp thickness, stone weight and stone length are given below.

8.4.1.1. Fruit weight

All the irrigation treatments significantly affected the fruit weight ($p \leq 0.05$) irrespective of the location. Surface irrigation resulted in the highest fruit weight (10.48g fruit^{-1} and 9.67g fruit^{-1}) compared to all other irrigation systems used at Samnu and Al-zighan, respectively. At Tamanhant, the fruit weight was highest

(9.34 g fruit^{-1}) under drip irrigation compared to all other methods of irrigation tested. The fruit weight was highest (8.86g fruit^{-1}) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa. When averaged over locations, the mean fruit weight (9.25g fruit^{-1}) was significantly highest ($p \leq 0.05$) in surface irrigation compared to the drip and sprinkler irrigations, but the fruit weight did not differ significantly between drip (7.73 g fruit^{-1}) and sprinkler irrigations (8.12 g fruit^{-1}) respectively. When averaged over all irrigation treatments, the mean fruit weight was highest at Samnu location (8.93g fruit^{-1}) as compared to Tamanhant location (8.43 g fruit^{-1}) and other locations as shown in Table 8.2. The interaction between treatments and their location was found to be significant ($p \leq 0.05$) for fruit weight.

Table 8-2: Effects of different types of irrigation systems on the fruit weight of Talees dates grown at different locations

	Fruit weight (g fruit^{-1})				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	6.97	6.76	7.86	9.34	7.73 b
Sprinkler irrigation	7.30	8.86	8.44	7.87	8.12 b
Surface irrigation	9.67	8.74	10.48	8.11	9.25 a
Mean (Location)	7.98b	8.12 b	8.93 a	8.43 b	
LSD ($p \leq 0.05$)					
Treatments			0.42		
Location			0.48		
Treatments ×Location			0.84		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant; n = six replicates (10 fruit per replication)

8.4.1.2 Fruit breadth

All the irrigation treatments did not significantly affect the fruit breadth irrespective of the locations. Surface irrigation resulted in the highest fruit breadth (17.50 mm and 17.22 mm) compared to all other irrigation systems used at Ghodduwa and Tamanhant, respectively. At Samnu, the fruit breadth was highest (16.65 mm) with drip irrigation compared to all other methods of irrigation tested. The fruit breadth was highest (17.00 mm) with sprinkler irrigation compared to all other methods of irrigation evaluated at Tamanhant. All the treatments did not significantly increase the fruit breadth ($p \leq 0.05$) irrespective of the location. When averaged over locations, the mean fruit breadth was higher in drip irrigation (16.24 mm) as compared to sprinkler irrigation (16.22 mm) and surface irrigation (16.16 mm). When averaged over all treatments, the mean fruit breadth was significantly highest at Tamanhant location (16.93mm) as compared to Ghodduwa (16.56 mm) and other locations (Table 8.3). The interaction between treatments and their locations was found to be significant for fruit breadth.

Table 8-3: Effects of different types of irrigation systems on the fruit breadth of *Talees* dates grown at different locations

	Fruit breadth (mm)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	16.06	15.66	16.65	16.57	16.24
Sprinkler irrigation	15.51	16.53	15.62	17.00	16.22
Surface irrigation	13.39	17.50	16.77	17.22	16.16
Mean (Location)	14.99 b	16.56 a	16.35 a	16.93 a	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			1.12		
Treatments × Location			1.94		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant, n = six replicates (10 fruit per replication)

8.4.1.3 Fruit length

The irrigation treatments did not significantly affect the fruit length irrespective of the locations. Surface irrigation resulted in highest fruit length (37.28 mm) as compared to all other irrigation systems tested at Ghodduwa. At Tamanhant, the fruit length was highest (34.91mm) with drip irrigation compared to all other methods of irrigation tested. The fruit length was highest (36.75mm) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa. When averaged over locations, the mean fruit length was higher with sprinkler irrigation (35.26 mm) compared to surface irrigation (33.54 mm) and drip irrigation (33.45 mm). When averaged over all treatments, the mean fruit length was significantly highest at Tamanhant location (35.83 mm) as compared to Ghodduwa (35.21 mm), Samnu (34.73 mm) and Al-zighan (30.56mm) as shown in Table 8.4. The interaction between treatments and locations was found to be significant ($p \leq 0.05$) for fruit length.

Table 8-4: Effects of different types of irrigation systems on the fruit length of *Talees* dates grown at different locations

	Fruit length (mm)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	33.86	31.58	33.43	34.91	33.45
Sprinkler irrigation	34.98	36.75	33.92	35.38	35.26
Surface irrigation	22.84	37.28	36.85	37.19	33.54
Mean (Location)	30.56 b	35.21 a	34.73 a	35.83 a	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			2.16		
Treatments × Location			3.75		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant, n = six replicates (10 fruit per replication)

8.4.1.4 Pulp thickness

The irrigation treatments did not significantly affect the pulp thickness irrespective of the location. Surface irrigation resulted in the highest pulp thickness (2.75 mm) compared to all other irrigation systems tested at Al-zighan. The pulp thickness was highest (2.69 mm) with drip irrigation at Samnu compared to all other methods of irrigation tested. The pulp thickness was highest (2.73 mm) with sprinkler irrigation compared to all other methods of irrigation evaluated at Al-zighan. When averaged over locations, the irrigation systems did not significantly affect the mean pulp thickness. Pulp thickness was higher in drip and sprinkler irrigation (2.57mm, 2.57 mm), respectively, compared to surface irrigation (2.51 mm). When averaged over all treatments, the mean pulp thickness was significantly highest ($p \leq 0.05$) at Al-zighan (2.75 mm) as compared to Ghodduwa (2.66 mm) and other locations (Table 8.5). The interaction between treatments and location was found to be significant ($p \leq 0.05$) for pulp thickness.

Table 8-5: Effects of different types of irrigation systems on the pulp thickness of *Talees* dates grown at different locations

	Pulp thickness (mm)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	2.10	2.57	2.69	2.03	2.57
Sprinkler irrigation	2.73	2.67	2.55	2.13	2.57
Surface irrigation	2.52	2.75	2.61	2.39	2.51
Mean (Location)	2.75 a	2.66 a	2.62 a	2.18 b	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			0.20		
Treatments × Location			0.34		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant, n = six replicates (10 fruit per replication)

8.4.1.5 Stone weight

The irrigation treatments did not significantly affect the stone weight irrespective of location. Surface irrigation resulted in highest stone weight (1.07 g fruit^{-1}) compared to all other irrigation systems tested at Samnu. The stone weight was highest (1.14 g fruit^{-1}) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The stone weight was highest (1.18 g fruit^{-1}) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa. When averaged over locations, the mean stone weight was higher with surface irrigation (1.04 g fruit^{-1}) compared to the drip irrigation (1.02 g fruit^{-1}) and surface irrigation (0.97 g fruit^{-1}). When averaged over all treatments, the mean stone wright was significantly highest ($p \leq 0.05$) at Ghodduwa (1.07 g fruit^{-1}) as compared to Samnu (1.06 g fruit^{-1}) and other locations (Table 8.6). The interaction between treatments and locations was found to be significant ($p \leq 0.05$) for stone weight.

Table 8-6: Effects of different types of irrigation systems on the stone weight of *Talees* dates grown at different locations

	Stone weight (g fruit^{-1})				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.89	0.10	1.04	1.14	1.02
Sprinkler irrigation	1.01	1.18	1.08	0.87	1.04
Surface irrigation	0.90	1.02	1.07	0.90	0.97
Mean (location)	0.93 b	1.07 a	1.06 a	0.97 b	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			0.07		
Treatments × Location			0.12		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant, n = six replicates (10 fruit per replication)

8.4.1.6 Stone breadth

The irrigation treatments did not significantly affect the stone breadth irrespective of the location. Surface irrigation resulted in the highest stone breadth (6.92 mm) compared to all other irrigation systems tested at Al-zighan. The stone breadth was highest (7.10 mm) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The stone breadth was highest (7.01mm) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa. Drip irrigation and sprinkler irrigation recorded mean stone breadths between (6.86 mm and 6.73 mm), respectively, while that of surface irrigation was only (6.72 mm). When averaged over all treatments, the mean stone breadth was significantly highest ($p \leq 0.05$) at Ghodduwa location (6.94 mm) as compared to Al-zighan location (6.90 mm) and other locations (Table 8.7). The interaction between treatments and their location was found to be significant ($p \leq 0.05$) for stone breadth.

Table 8-7: Effects of different types of irrigation systems on the stone breadth of *Talees* dates grown at different locations

	Stone breadth (mm)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	6.89	7.05	6.40	7.10	6.86
Sprinkler irrigation	6.89	7.01	6.50	6.49	6.73
Surface irrigation	6.92	6.76	6.86	6.39	6.72
Mean (Location)	6.90 a	6.94 a	6.59b	6.66 b	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			0.17		
Treatments × Location			0.29		

Any two means within each area followed by different letters are significantly different using LSD at $p < 0.05$. NS = not significant, n = six replicates (10 fruit per replication)

8.4.1.7 Stone length

The irrigation treatments did not significantly affect the stone length irrespective of the locations. Surface irrigation resulted highest in stone length (24.62 mm) compared to all other irrigation systems tested at Samnu. The stone length was highest (24.11mm) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The stone length was highest (24.24mm) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa location. Surface irrigation and sprinkler irrigation resulted in mean stone lengths between (23.55 mm and 22.38 mm), respectively. When averaged over all treatments, the mean stone length did not differ significantly at various locations (Table 8.8). The interaction between treatments and their location was found to be non-significant for stone length.

Table 8-8: Effects of different types of irrigation systems on the stone length of *Talees* dates grown at different locations

	Stone Length (mm)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	20.82	21.49	21.42	24.11	21.96
Sprinkler irrigation	22.53	24.24	23.11	19.64	22.38
Surface irrigation	23.26	23.90	24.62	22.43	23.55
Mean (Location)	22.21	23.21	23.05	22.06	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.2. Effect of different irrigation systems on individual sugars of '*Talees*' dates grown at different locations

8.4.2.1 Fructose

All the irrigation treatments did not significantly affect the fructose irrespective of the location. Subsurface irrigation resulted highest in fructose (6.25 g/100g) compared to all other irrigation systems tested at Samnu. The fructose was highest (6.21 g/100g) with drip irrigation at Samnu compared to all other methods of irrigation tested. At the Samnu location, the fructose was highest (6.51 g/100g) with sprinkler irrigation compared to all other methods of irrigation evaluated. Drip irrigation and sprinkler irrigation resulted in mean fructose between (5.60 g/100g and 5.48 g/100g) respectively. When average over all treatments is considered, the mean fructose did not differ significantly at various locations (Table 8.9). The interaction between treatments and their location was found to be non-significant for fructose.

Table 8-9: Effects of different types of irrigation systems on the fructose of *Talees* dates grown at different locations

	Fructose (g/100g)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	4.69	5.43	6.21	6.08	5.60
Sprinkler irrigation	4.90	5.34	6.51	5.15	5.48
Surface irrigation	4.60	5.51	6.25	5.38	5.43
Mean (Location)	4.73	5.43	6.32	5.54	
LSD *($p \leq 0.05$)*					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.2.2 Glucose

The irrigation treatments did not significantly affect the glucose irrespective of the locations. Surface irrigation resulted highest in glucose (8.28 g/100g) compared to all other irrigation systems tested at Samnu. The glucose was highest (8.34 g/100g) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The glucose was highest (8.58 g/100g) with sprinkler irrigation compared to all other methods of irrigation evaluated at the Samnu location. Drip irrigation and sprinkler irrigation recorded mean glucose between (7.51 g/100g and 7.39 g/100g) respectively. When averaged over all treatments, however, the mean glucose did not differ significantly at various locations (Table 8.10). The interaction between treatments and their location was found to be non-significant for glucose.

Table 8-10: Effects of different types of irrigation systems on the glucose of *Talees* dates grown at different locations

	Glucose (g/100g)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	6.30	7.23	8.18	8.34	7.51
Sprinkler irrigation	6.55	7.29	8.58	7.14	7.39
Surface irrigation	6.08	7.51	8.28	7.02	7.22
Mean (Location)	6.31	7.35	8.35	7.50	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.2.3 Sucrose

Sucrose was not detected from *'Talees'* dates irrespective of irrigation system.

8.4.3 Effect of different irrigation systems on organic acids of '*Talees*' dates

8.4.3.1 Citric acid

The irrigation treatments did not significantly affect the citric acid irrespective of the locations. Surface irrigation resulted in the highest level of citric acid (0.29 mg100 $g^{-1\ FW}$) compared to all other irrigation systems tested at Samnu. The citric acid was highest (0.29 mg/100 $g^{-1\ FW}$) with drip irrigation at Samnu compared to all other methods of irrigation tested. The citric acid was highest (0.33 mg/100 $g^{-1\ FW}$) with sprinkler irrigation compared to all other methods of irrigation evaluated at Samnu location. When averaged over locations, the mean citric acid was higher with sprinkler irrigation (0.27 mg/100 $g^{-1\ FW}$) compared to drip irrigation (0.25 mg/100 $g^{-1\ FW}$) and surface irrigation (0.24 mg/100 $g^{-1\ FW}$). When averaged over all treatments, the mean citric acid was not significantly highest at Samnu location (0.30 mg/100 $g^{-1\ FW}$) as compared to Ghodduwa location (0.27 mg/100 $g^{-1\ FW}$) and other locations as shown in Table 8.11. The interaction between treatments and their locations was found to be non-significant for citric acid.

Table 8-11: Effects of different types of irrigation systems on the citric acid of *Talees* dates grown at different locations

	Citric acid (mg 100 $g^{-1\ FW}$)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.16	0.28	0.29	0.27	0.25
Sprinkler irrigation	0.27	0.27	0.33	0.22	0.27
Surface irrigation	0.17	0.28	0.29	0.21	0.24
Mean (Location)	0.20	0.27	0.30	0.23	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.3.2 Fumaric acid

All the irrigation treatments did not significantly affect the fumaric acid irrespective of the locations. Surface irrigation resulted in the highest fumaric acid (0.025 mg/100 $g^{-1 FW}$) compared to all other irrigation systems tested at Tamanhant. The fumaric acid was highest (0.028 mg/100 $g^{-1 FW}$) with drip irrigation compared to all other methods of irrigation tested at Tamanhant. The fumaric acid was higher (0.019 mg/100 $g^{-1 FW}$) with sprinkler irrigation evaluated at Al-zighan, Samnu and Tamanhant, respectively. When averaged over locations, the mean fumaric acid was not significant ($p \leq 0.05$). The highest (0.021 mg/100 $g^{-1 FW}$) was drip irrigation treatment as compared to sprinkler irrigation (0.018 mg/100 $g^{-1 FW}$) and surface irrigation (0.017 mg/100 $g^{-1 FW}$). When averaged over all treatments, the mean fumaric acid was significantly highest at Tamanhant location (0.025 mg/100 $g^{-1 FW}$) as compared to Samnu location (0.019 mg/100 $g^{-1 FW}$) and other locations as shown in Table 8.12. The interaction between treatments and their location was found to be non- significant for fumaric acid.

Table 8-12: Effects of different types of irrigation systems on the fumaric acid of *Talees* dates grown at different locations

	Fumaric acid (mg/100 $g^{-1 FW}$)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.018	0.020	0.020	0.028	0.021
Sprinkler irrigation	0.019	0.019	0.018	0.019	0.018
Surface irrigation	0.018	0.009	0.018	0.025	0.017
Mean (Location)	0.018	0.016	0.019	0.025	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.3.3 Malic acid

All the irrigation treatments did not significantly affect the malic acid irrespective of the locations. Surface irrigation resulted in the highest malic acid (0.24 mg/100 $g^{-1 FW}$) compared to all other irrigation systems tested at Tamanhant. The malic acid was highest (0.10 mg/100 $g^{-1 FW}$) with drip irrigation compared to all other methods of irrigation tested at Samnu. The malic acid was highest (0.07 mg/100 $g^{-1\ FW}$) with sprinkler irrigation compared to all other methods of irrigation evaluated at Tamanhant. When averaged over locations, the mean malic acid was not significant ($p \leq 0.05$). The highest (0.08 mg/100 $g^{-1\ FW}$) was surface irrigation treatment as compared to drip irrigation (0.07 mg/100 $g^{-1\ FW}$) and sprinkler irrigation (0.04 mg/100 $g^{-1\ FW}$). When averaged over all treatments, the mean malic acid was significantly ($p \leq 0.05$) highest at Tamanhant location (0.12 mg/100 $g^{-1\ FW}$) as compared to Samnu location (0.05 mg/100 $g^{-1\ FW}$) and other locations as shown in Table 8.13. The interaction between treatments and their location was found to be significant ($p \leq 0.05$) for malic acid.

Table 8-13: Effects of different types of irrigation systems on the malic acid of Talees dates grown at different locations

	Malic acid (mg/100 $g^{-1\ FW}$)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.03	0.091	0.10	0.05	0.07
Sprinkler irrigation	0.04	0.04	0.02	0.07	0.04
Surface irrigation	0.03	0.02	0.03	0.24	0.08
Mean (Location)	0.04	0.05	0.05	0.12	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.3.4 Succinic acid

The irrigation treatments did not significantly affect the succinic acid irrespective of the locations. Surface irrigation resulted in highest succinic acid (0.18 mg/100 $g^{-1\ FW}$) compared to all other irrigation systems tested at Samnu. The succinic acid was highest (0.25 mg/100 $g^{-1\ FW}$) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The succinic acid was highest (0.25 mg100 $g^{-1\ FW}$) with sprinkler irrigation compared to all other methods of irrigation evaluated at Al-zighan. When averaged over locations, the mean succinic acid was not significant ($p \leq 0.05$). The highest (0.18 mg/100 $g^{-1\ FW}$) was sprinkler irrigation treatment as compared to drip irrigation (0.16 mg/100 $g^{-1\ FW}$) and surface irrigation (0.13 mg/100 $g^{-1\ FW}$). When averaged over all treatments, the mean succinic acid was not significantly ($p \leq 0.05$) highest at Tamanhant location (0.19 mg/100 $g^{-1\ FW}$) as followed Samnu location (0.17 mg100 $g^{-1\ FW}$) and other locations as shown in Table 8.14. The interaction between treatments and their location was found to be non-significant for succinic acid.

Table 8-14: Effects of different types of irrigation systems on the succinic acid of *Talees* dates grown at different locations

	Succinic acid (mg100 $g^{-1\ FW}$)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.06	0.14	0.20	0.25	0.16
Sprinkler irrigation	0.25	0.16	0.14	0.18	0.18
Surface irrigation	0.10	0.10	0.18	0.13	0.13
Mean (Location)	0.14	0.13	0.17	0.19	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.4.3.5 Tartaric acid

The irrigation treatments did not significantly affect the tartaric acid irrespective of the locations. Surface irrigation resulted highest in Tartaric acid (0.04 mg /100 $g^{-1\ FW}$) compared to all other irrigation systems tested at Al-zighan. The tartaric acid was highest (0.07 mg /100 $g^{-1\ FW}$) with drip irrigation at Tamanhant compared to all other methods of irrigation tested. The tartaric acid was highest (0.06 mg /100 $g^{-1\ FW}$) with sprinkler irrigation compared to all other methods of irrigation evaluated at Ghodduwa. When averaged over locations, the mean tartaric was higher with sprinkler irrigation (0.023 mg /100 $g^{-1\ FW}$) treatment as compared to drip irrigation (0.020 mg /100 $g^{-1\ FW}$) and surface irrigation (0.01 mg /100 $g^{-1\ FW}$). When averaged over all treatments, the mean tartaric acid did not differ significantly at various locations Table 8.15. The interaction between treatments and their location was found to be non-significant for tartaric acid.

Table 8-15: Effects of different types of irrigation systems on the tartaric acid of *Talees* dates grown at different locations

	Tartaric acid (mg/100 $g^{-1 FW}$)				
Treatments	**Al-zighan**	**Ghodduwa**	**Samnu**	**Tamanhant**	**Mean (Treatments)**
Drip irrigation	0.07	0.01	0.00	0.00	0.020
Sprinkler irrigation	0.00	0.06	0.04	0.00	0.023
Surface irrigation	0.04	0.00	0.00	0.00	0.010
Mean (Location)	0.03	0.02	0.01	0.00	
LSD ($p \leq 0.05$)					
Treatments			NS		
Location			NS		
Treatments × Location			NS		

NS = not significant, n = six replicates (10 fruit per replication)

8.5 Discussion

Irrespective of irrigation systems, fruit quality parameters tested except fruit size did not differ significantly. Possibly, none of the tested irrigation systems caused water stress, consequently did not significantly affect the fruit quality in *Talees* dates. This is consistent with, Basahi (2006); Ismail et al. (2006); and Al-Qurashi (2010) who reported that irrigation systems have no effect of on date fruit quality. But there were great savings of irrigation water using sprinkler or drip irrigation systems compared to surface irrigation system. Contrarily, research findings reported from the Middle East and North African countries claimed that irrigation systems influence date palm fruit quality (Akasha, 2005; Al-Rawi & Al-Mohemdy, 2001; Hussein & Hussein, 1982; Pundir & Porwal, 1998; Said et al., 2014; Shaheen, 2007; Tafti & Fooladi, 2005; Ullah, 2011). The variations in the findings between this study and the earlier research work conducted by Said et al. (2014), Ullah (2011), Shaheen (2007), Akasha (2005), Al-Rawi and Al-Mohemdy (2001), Pundir and Porwal (1998) and Hussein and Hussein (1982) may be attributed to a number of locational factors. For example, the problem of salinity due to the lack of fresh water and high rate of evaporation hampering date palm farming (Erskine et al., 2004; Zaid & Klein, 2002) in Sebha which is not the case in other date palm producing countries in the Middle East and North Africa. Moreover, there are variations in Libya and the other countries in relation to the soil types, and the capacity of the soil to hold moisture. There were also differences in the volume and level of water usage per date palm tree between Libya and other Middle East regions as well as North African countries. This is exemplified by findings from (FAO, 2007)where they reported that the annual volume of irrigation water usage per date palm tree was high (250 m^3) in Saudi Arabia as compared to Tunisia which requires (100 m^3) volume of water per date tree, whereas Libya requires (212 m^3) volume of water per date tree. Furthermore, different farming practices on cultivation of date palm, such as pollination and pruning in Libya also influence fruit quality (Dowson, 1961, 1982; El-Juhany, 2010; Shamsi & Mazloumzadeh, 2009) date palm producing countries (Abdulla et al., 1982; Al-Obeed et al., 2005; Harhash, 2000; Moustafa, 1998; Osman & Soliman, 2001).

In terms of type of irrigation system, the major factor in using surface irrigation systems in these locations was low cost, suitability for irrigating farms specializing in the cultivation of palms together with other crops, and also suitability for all types of soil (Zaid, 2002). The main factors in using sprinkler and drip irrigation systems in those locations were ease of control of the amount of water used, efficiency and labour reduction (see section 4.5 in chapter 4), suitability for different topography conditions, types of soils and different kinds of crops, and equal amounts of water distributed on the date palm trees (Alvarez et al., 2004; Keller & Karmeli, 1974; Zaid, 2002). Furthermore, sprinkler and drip irrigation protects the agricultural environment by reducing erosion and runoff and can be operated by unskilled farmers because they use simple equipment (Mumtaz & Prathapar, 2012; Zaid, 2002).

The comparison between the different irrigation systems suggest that the development of an irrigation policy framework for irrigation management in Libya can play a significant role in providing support and strengthening the advancement and utilization of drip and sprinkler irrigation systems definitely can be beneficial and advantageous. This strategy will be economically feasible for smallholder's farmers and date palm plantations owned by large companies when they adopt this strategy in the future. However, due to groundwater insufficiency in Al-zighan, Ghodduwa, Samnu and Tamanhant locations, there is the need to ensure efficiency in water usage. Indeed, the optimization of irrigation water usage is needed urgently to increase crop yield per drop of water and to reduce water wastage. It is important to note that the shift from surface irrigation to sprinkler or drip irrigation systems, can lead to providing substantial water-saving potentials without unfavourably impacting characteristics of date fruit quality. However, it has been noted here that it is very useful and helpful to utilise drip and sprinkler irrigations methods, because both drip and sprinkler irrigation systems apply less water when compared with the volume of water required by the use of surface irrigations system (see also Martin, 2006).

In this thesis, an effort has been made to examine and compare the impacts of three irrigation systems on the quality of date fruit. The findings showed that drip and sprinkler irrigation systems are beneficial and suitable for most of the locations tested in Sebha area in Libya. Furthermore, high salinity of water and low levels of groundwater resources coupled with the dry desert climate in Sebha region, as well as the insufficiency of surface irrigation systems, have no significant effect on the quality of fruit. Thus, any method of irrigation that can save water has been suggested as a way of ensuring sustainable use of the limited water resource in Sebha; therefore, the process of shifting from surface to drip and sprinkler in this study is highly recommended.

8.6 Conclusion

The present study introduces important information about the effect of irrigation systems on quality of *'Talees'* dates at different locations in Sebha, Libya. The information is most important in deciding the suitability of different irrigation systems for date palm especially in regions limited in water resources. The results showed that irrigation systems significantly affected only fruit weight whilst fruit breadth and length, pulp thickness, stone weight, stone width and stone length, individual sugars and organic acids were not significantly affected with irrigation systems. When averaged for different irrigation systems, the mean fruit weight, breadth and length, pulp thickness, stone breadth and length were significantly influenced by locations. The interactions between different irrigation systems and locations were found to be significant ($p \leq 0.05$) for fruit weight, breadth and length, pulp thickness, stone breadth and length. In conclusion, the irrigation systems tested do not influence fruit quality but location of growing date palm in Sebha region, Libya does. Further studies are needed to determine water use efficiency using different methods of irrigation in date palm orchards on different date palm cultivars that may be of practical value to find the effect of different irrigation systems on other cultivars in different areas of Libya.

The next chapter will examine the effect of the different irrigation systems on date palm productivity and efficiency.

Chapter 9

Effect of Irrigation on Date Palm Production

9.1. Introduction

Chapter 9 focusses on the effects of irrigation on date palm production, one of the key objectives of this study. It first starts with a description of irrigation systems in the Sebha region in Section 9.2. Section 9.3 then presents the advantages and disadvantages of each irrigation system and the issues faced by farmers under various irrigation methods of date palm cultivation and proposes possible solutions. Section 9.4 presents the effects of irrigation systems on date palm production in Sebha, Libya using econometric models. Section 9.5 presents the determinants of farm level technical efficiency while Section 9.6 discusses the analysis of technical efficiency under various irrigation systems. Section 9.7 then discusses the distribution of technical efficiency of date palm farmers under different irrigation systems. Section 9.8 discusses the findings while Section 9.9 provides the conclusions.

9.2. Irrigation systems in the Sebha region, Libya

The farming systems in Libya can be differentiated based on the location or classification zone. In the northern zone, farmers do not cultivate fruit such as apples, almonds and citrus; however, they instead plant barley, tomato, onion and date palm because the area is mostly dryland. In the southern zone where the soil is diverse and poor in retaining water, farmers prefer to cultivate date palm trees. Consequently, the farming systems in these zones are similar.

9.2.1. Type of irrigation systems (Multiple irrigation systems)

The pattern of irrigation systems used by respondents is shown in Table 9.1. As can be seen from the table, there are differences among the types of irrigation methods used in the area. As can be seen in Table 9.1, the majority of respondents prefer to use sprinkler and drip irrigation together, which forms 32.4 per cent of the whole sample with an average area of 7.47 hectares. Meanwhile, 25.7 per cent of respondents prefer to utilise both surface and drip irrigation at the same time with an average area of 7.94 hectare. Similarly, 20.5 per cent of respondents prefer to utilise both surface and sprinkler irrigation simultaneously because of intercropping. However, there are also respondents who only utilise a single irrigation system in their farms - either surface, drip or sprinkler irrigation (3.3%, 1% and 4.3%, respectively). A significant number of farmers (respondents) used multiple irrigation systems in Sebha region, especially in intercropping date palm farms. This is because, one irrigation system in some cases is not suitable for different crops. In addition, the use of multiple irrigation helps farmers reduce water use which consequently reduces costs. Finally, the use of multiple irrigations systems is necessitated by the different soil types (infiltration rate), crops and scarcity of water in the area.

Table 9-1: Types of irrigation systems used in the Sebha region of Libya

Items	No	%	Mean area	SD
Sprinkler and drip irrigations	68	32.4	7.47	5.05
Surface and drip irrigations	54	25.7	7.94	6.85
Surface and sprinkler irrigations	43	20.5	7.72	7.89
Surface irrigation	28	13.3	6.39	4.83
Drip irrigation	9	4.3	7.22	3.96
Sprinkler irrigation	2	1.0	11	1.41
All irrigation systems	6	2.9	7.67	7.15
Total	210	100	7.92	

Source: Survey data, 2013.

The number of farmers who use drip irrigation (either by itself or in combination with other types of irrigation system) is 137, representing 65.2 per cent of the total sample. Surface irrigation is used by 131 farmers representing 62.4 per cent, while sprinkler irrigation is used by 119 farmers representing 56.7 per cent of the total samples (Figure 9.1)

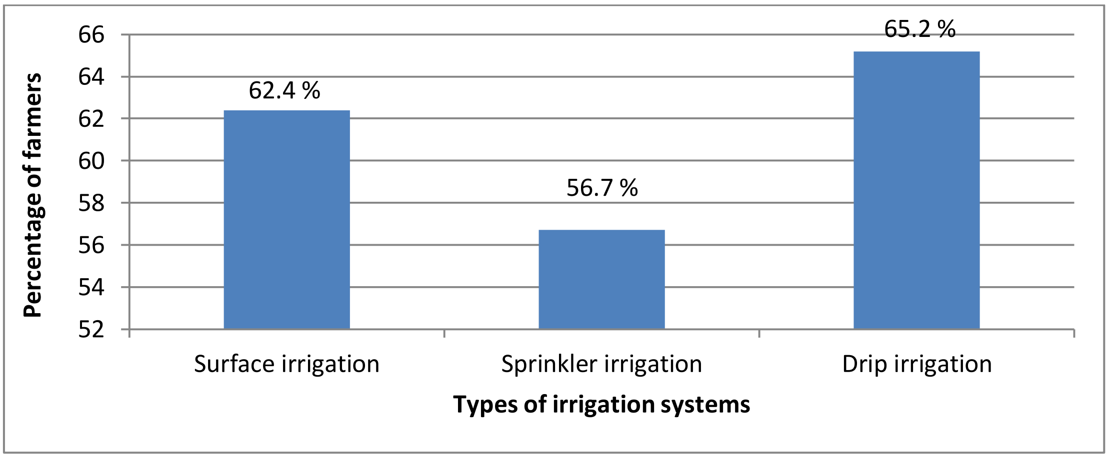

Figure 9-1: Main irrigation systems used by farmers in the Sebha region of Libya

9.2.2. Input expenditure of farms by irrigation system

A summary of the inputs used by farms under the various irrigation systems is presented in Table 9.2. The inputs used are varied in terms of surface irrigation systems. Farms under surface irrigation have high and low input quantity in date production. The high input means include 14,353.6 litres of water, 2,936.6 kg of manure, 257 litres of petrol, 182.75 kg of organic, 117.4 of number of seedling, 104 kg of phosphate, 72.50 kg of potassium, 24.46 of fertilizer. However, the low input means included 9 of liquid fertilizer, 7.18 litre of oil, 3.92 litre of insecticide, 3.78 of number of canals, 3.43 litre of nematicide, 3.42 litres of herbicide, 3.34 litre of fungicide and 3 kg of lime.

Table 9-2: Average input used under various irrigation systems (Unit/Value)

Name of Input	Surface irrigation			Sprinkler irrigation			Drip irrigation		
Units	**No**	**Mean (units)**	**Value (LD)**	**No**	**Mean (units)**	**Value (LD)**	**No**	**Mean (units)**	**Value (LD)**
Fertilizer (kg)	59	24.46	307.37	114	26.90	126.60	135	63.90	65.23
Phosphate (kg)	11	104.00	224.27	11	92.70	169.10	7	160.70	258.57
Potassium (kg)	4	72.50	172.50	2	75.00	175.00	3	13.00	86.67
Lime total (kg)	2	3.00	100.00	0	0	0	0	0	0
Herbicide (li)	77	3.42	72.53	69	2.43	67.01	96	3.64	106.28
Nematicide (li)	103	3.43	87.77	101	2.73	80.65	122	3.20	83.04
Insecticide (li)	130	3.92	103.26	118	2.75	78.89	137	3.38	95.00
Fungicide (li)	125	3.34	85.98	110	2.86	78.75	121	3.26	81.29
Organic (kg)	89	182.75	207.36	77	166.30	198.10	93	144.30	165.45
Manure (kg)	131	2936.60	395.01	118	1882.20	341.80	136	2568.60	503.86
Liquid* (li)	2	9.00	115.00	2	70.00	110.00	3	30.00	96.67
Canal (No)	128	3.78	147.23	112	7.12	429.20	136	54.10	192.68
Seeding (No)	131	117.40	299.74	119	66.13	194.90	136	31.73	100.44
Water (li)	131	14353.6	3.59	119	6605.40	1.65	137	9.89	2.50
Oil (li)	95	7.18	15.14	113	6.15	13.01	107	8.06	17.48
Petrol (li)	131	257.00	38.55	119	333	49.95	107	321.50	48.23

Source: Survey data, 2013. LD = Libyan dinar, Liquid* = liquid fertilizer

For farms under sprinkler irrigation, the results show that the five top input used in date production are water (6605.4 litres), manure (1882.2 kg), petrol (333 litres), organic fertilizer (166.3 kg) and phosphate (92.7 kg).

In terms of amount of inputs used for farms under drip irrigation system, key inputs include manure (2568.6 kg), petrol (321.5 litres), phosphate (160.7 kg), organic fertilizer (144.3 kg) and fertilizer (63.9 kg).

In terms of the value of inputs, the amounts were slightly higher for farms under surface irrigation compared to farms under drip irrigation with the quantity of water. This is because: 1) the area under surface irrigation is more extensive 2) farmers who planted more than one crop (e.g., intercropping fodders and vegetables between date palm trees) tend to use surface irrigation (FAO, 2007; Shirazi et al., 2008). As a result, this led to increasing quantity of water consumption for irrigation. The quantity of water, as an input, was also highly used under the sprinkler irrigation. This is due to the high level of water evaporation or non-uniform water distribution due to changing water direction to other areas by high speed wind, This leads to increasing hours of irrigation by date palm farmers in study area. The manure, as an input, was highly used under the drip irrigation system. This is because the price of manure is very low compared to other types of fertilizers. In addition, date palm farmers can make the manure in the same farm with lesser cost.

In terms of input value, for farms under surface irrigation, the average mean values of input purchased by number of farmers were 307.37 LD for fertilizer, 299.74 LD for number of seedling, 207.36 LD for organic fertilizer, and 115 LD for liquid fertilizer, followed by insecticide, lime, nematicide, fungicide and water at 103.26 LD, 100 LD, 87.77 LD, 85.98 LD and 3.59 LD, respectively. In contrast, farmers who used sprinkler irrigation purchased canal (i.e., spare parts) at an average of 429.2 LD, followed by potassium and petrol (175 LD and 49.95 LD, respectively).

For drip irrigation, the value of input used on average are 503.86 LD purchased manure, 258.57 LD for phosphate, 106.28 LD for herbicide, and 17.48 LD for oil. Overall, though, the purchases of farm inputs under sprinkler and drip irrigation are lower than for surface irrigation. This is because of weak financial ability of farmers to purchase agricultural inputs.

FAO (2002) has consistently reported that farmers have limited access to short-term credit, required for buying seedlings, insecticides, fertiliser and other agricultural inputs, as well as long-term credit for buying land and mechanical equipment for agricultural activities. One of the problems associated with low input purchases is the low mobility of farmers and inadequate access to agricultural input markets. Limitations associated with the Libyan dinar exchange rate against foreign currency also affect farmers' purchasing ability as prices have increased significantly after adjusting the Libyan dinar exchange rate against foreign currencies, where they had increased production costs (Aridah & Shaloof, 2014). Limited technical knowledge regarding the use of fertilisers and other supplies for date production also inhibited their use. Despite these constraints, expenditure on irrigation systems made a considerable contribution in input purchases for each type of irrigation system.

9.3. Advantages and disadvantages of irrigation systems for palm trees production

9.3.1. Surface irrigation

Farmers' response regarding the advantages of surface irrigation is presented in Figure 9.2. The results show that about 67.9 per cent of respondents believe that one of the advantages of surface irrigation is its low cost, while 67.2 per cent indicated that it is suited to intercropping. About 63.4 per cent of farmers mentioned that type of soil can be an advantage; this is surface irrigation can suit different types of soil. According to Brouwer (1988), surface irrigation is more suitable for all types of soil compared to sprinkler and drip irrigation, especially soil that is easily broken into small pieces, as is the case in the study area. Surface irrigation helps to limit soil erosion especially in agricultural land (Larry & James, 1993), while only 29 and 0.8 per cent indicated time saved and other advantages, respectively.

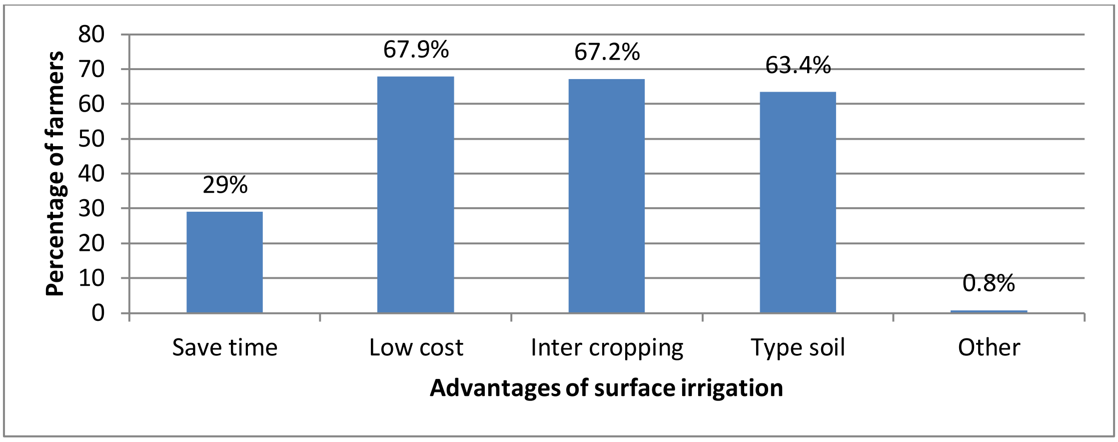

Figure 9-2: Advantages of surface irrigation

Farmers' responses regarding the main disadvantages of surface irrigation are shown in Figure 9.3. As shown in the figure, the main disadvantage mentioned by farmers is labour 70.2 per cent, as surface irrigation is labour intensive (i.e., it requires more number of workers) with higher skills for maintenance, construction and irrigation operations when compared with sprinkler and drip irrigation systems that require less labour and maintenance-cost (H. Ali, 2011; James, 1993; Liebenberg & Zaid, 2002). Thus, the labour intensiveness leads to increasing the costs of surface irrigation per farm or hectare, thus, the number of labour required and their cost are one of the disadvantages of this system. However, there is about 66.4 per cent of farmers mentioned erosion and evaporation of water. About 29 per cent of farmers indicated that it is less efficient compared to other irrigation methods.

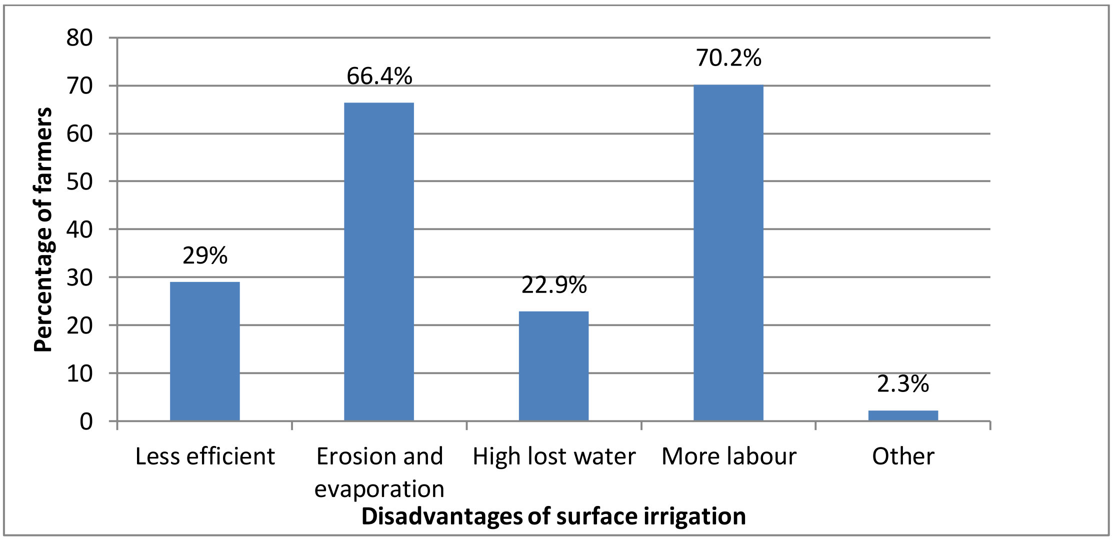

Figure 9-3: Disadvantages of surface irrigation

Some studies (Khanna & Malano, 2006; Maisiri et al., 2005) are inconsistent with the perceptions of farmers in this study about the cost of surface irrigation. The studies of Hakimian and Nugent (2005) and Raine and Foley (2002) however, are consistent with this study that extensive labour use and erosion and evaporation of water were disadvantages of surface irrigation. Surface irrigation require more labour to manage channels, change hoses and to guide the maintenance.

9.3.2. Sprinkler irrigation

Figure 9.4 shows the advantages of sprinkler irrigation according to farmers using this method in the Sebha region. It appears that time saving was the top advantage of the sprinkler irrigation system identified by farmers. About 88 per cent of respondents said sprinkler irrigation saves time, 76.5 per cent said it is easy to manage, and about 52 per cent of the respondents claimed it causes less erosion.

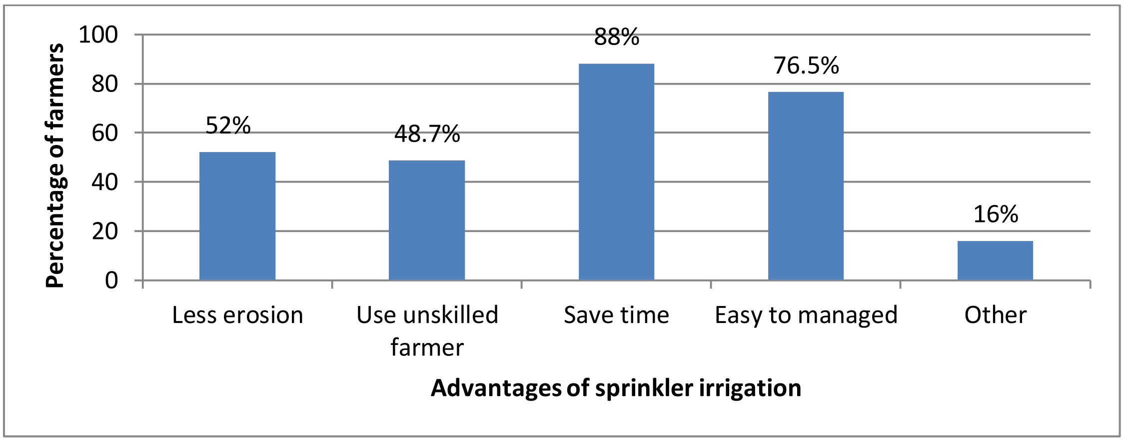

Figure 9-4: Advantages of sprinkler irrigation

Sprinkler irrigation used by farmers also has disadvantages as shown in Figure 9.5. Close to 96 per cent of the respondents perceived non-uniform water distribution as the main disadvantage; 91.6 per cent perceived that sprinkler irrigation was not appropriate for small palms; 75 per cent mentioned lost water; while 59.7 per cent indicated high cost as a disadvantage of sprinkler irrigation. This shows that non-uniform water distribution around date palm trees still influenced the choice of sprinkler irrigation use for date palm

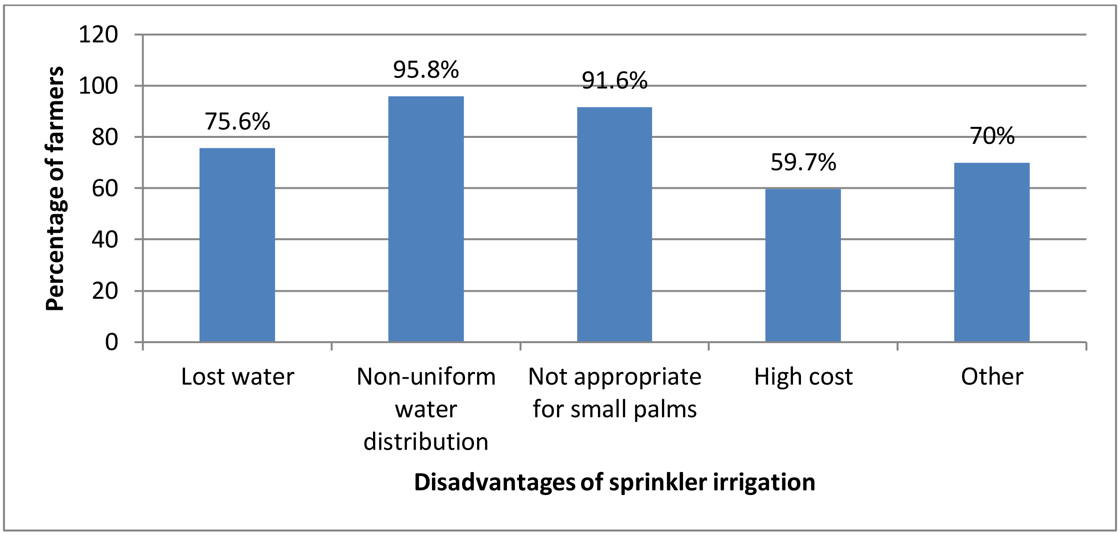

Figure 9-5: Disadvantages of sprinkler irrigation

In terms of advantages of sprinkler irrigation, previous studies are consistent with the current study, for instance, Whiting (1991) reported that sprinkler irrigation plays a role in saving time in farms. Scheumann (2012) confirmed that sprinkler irrigation can be easily managed compared to surface and drip irrigation during cropping season.

In terms of disadvantages of sprinkler irrigation, some studies (Mantovani et al., 1995; Stern & Bresler, 1983) are consistent with the results of the current study, for example, the issue of non-uniform water distribution. Azevedo et al. (2000) reported that speed and wind direction are a dominant factor that affects uniformity or otherwise of water distribution, followed by the pressure and speed of rotation of the sprinkler. Non-uniform water distribution can lead to low production of date palm trees (Ludong, 2008). Moreover, the current study found sprinkler irrigation is not suitable for the irrigation for small palms, because water can enter from above into the growth point of the plant; this result is consistent with the results of Zaid (2002).

As previously discussed, time saving is one of the key benefits of sprinkler irrigation to farmers, however, the weather, especially wind drift associated with water loss and low water distribution, makes it unattractive to date palm farmers in the study area.

9.3.3. Drip irrigation

About 89 per cent of the respondents indicated that reduced water waste is one of the advantages of drip irrigation; 83.9 per cent of respondents indicated less labour used and 70.1 per cent noted time savings. Meanwhile, 46 per cent said that efficiency is an advantage of the drip irrigation system. There seems to be wide acceptance among farmers that drip irrigation is a more appropriate technology for farmers. Figure 6.9 shows the benefits of using drip irrigation.

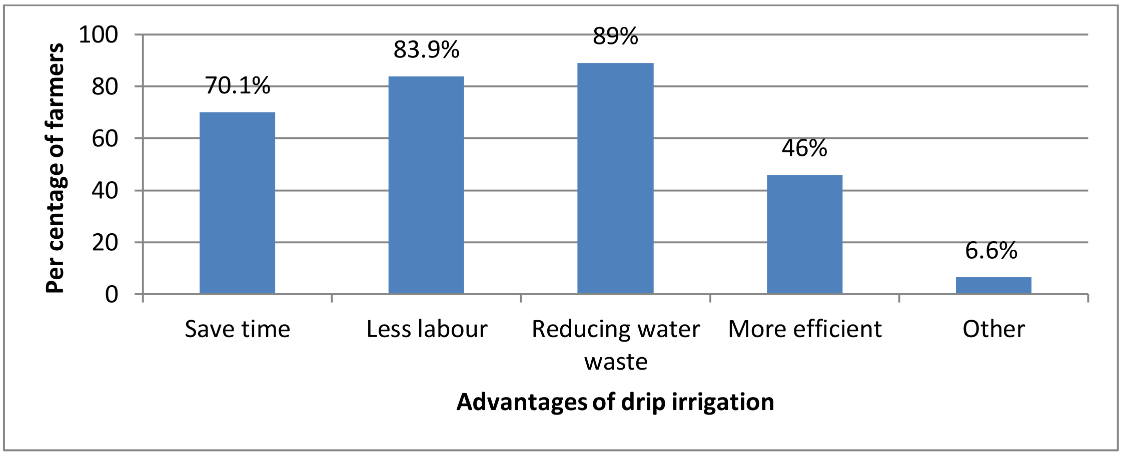

Figure 9-6: Advantages of drip irrigation

The positive characteristics of drip irrigation mentioned by farmers in this study are similar to studies by (Bernstein & Francois, 1973; Camp, 1998; Narayanamoorthy, 2004; Phene et al., 1986). Drip irrigation has lower water wastage because it is applied directly where the palm trees need it. Using drippers maintains an optimum moisture level in the soil at all times. Drip irrigation is timer automated which allows a great deal of control over trees behaviour (deficit irrigation) and saves irrigation time as well (Molle & Berkoff, 2007). Labour is thus reduced as a result of extensive automation.

On the other hand, farmers felt drip irrigation was not efficient in the current study because it required extra costs of cleaning water, high skilled workers and spare parts as well as it required extra maintenances costs. Despite drip irrigation's potential benefits, converting to drip irrigation can increase production costs; consequently, the economic advantages of implementing drip irrigation by farmers were reduced as shown in the study.

Farmers' perceptions on the disadvantages of drip irrigation are shown in Figure 9.7. About 82 per cent of the respondents indicated short life as a key disadvantage, while about 70 per cent of the respondents indicated poor distribution, and 69 per cent of the respondents answered damage of pipe network by sunlight or tractors etc.

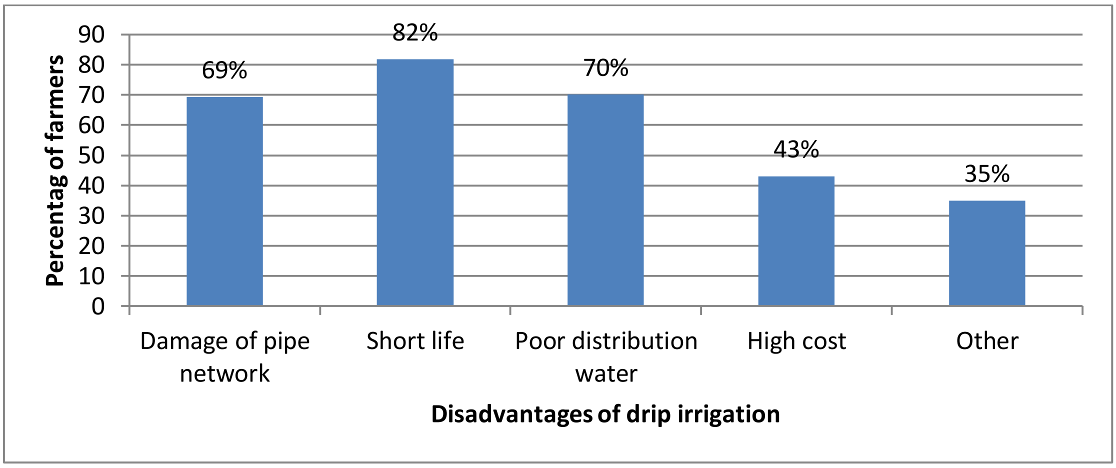

Figure 9-7: Disadvantages of drip irrigation

While majority of farmers indicated that the short life of the system is a disadvantage of drip irrigation, this may be perhaps because most farmers did not perform maintenance of their drip irrigation system. In addition, the low distribution of water might be attributed to the poor experience of farmers especially regarding management and maintenance (Acar, Topak, & Direk, 2010). Damage of drip lines by rodents, livestock and farming machinery are potential sources of leaks (Thomas, Pang, & Li, 2009). Hence farmers often substitute their conventional drip irrigation methods by surface or sprinkler systems to meet the date palm trees' requirements.

9.4. Issues with irrigation systems

9.4.1. Factors that reduce the quality and quantity of irrigation water

The study results obtained from the survey revealed farmers' perceptions on the factors that affected date production by irrigation method. These factors are shown in Figure 9.8. For surface irrigation, the key issues identified by farmers are the incidence of agricultural pests (insects and weeds), quantity of water irrigation, and low maintenance which accounted for 84.7 per cent, 41.2 per cent, and 35.1 per cent of farmers. This is, followed by timing and hours of irrigation (28.2%), unskilled and number of labourers (18.3%), power outages (9.9%), type of soil (7.6 %) and amount of pesticide (6.1%).

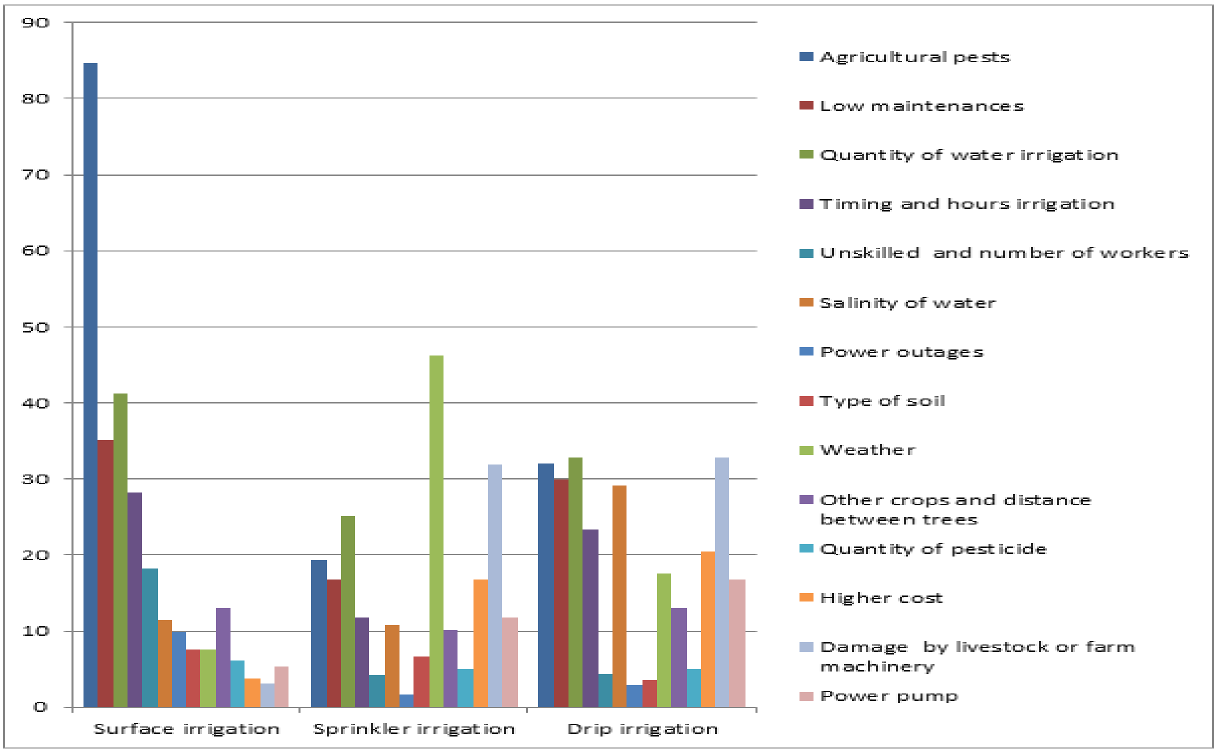

Figure 9-8: Factors that reduce the quality and quantity of irrigation water

As shown in the figure 9.8, farmers who used drip irrigation have greater problem with damage by livestock or farm machinery (32.8% of farmers); this is because drip irrigation systems are more exposed to sunlight or destruction by farm machinery and livestock during grazing or ploughing periods, while farmers under sprinkler irrigation (Figure 9.8) indicate that weather such as rain and wind was the key factor influencing production, with 46.2 per cent of farmers mentioning this issue.

9.4.2. Proposed solutions to issues in palm production

Farmers were asked about their proposed solutions to overcome the factors affecting their palm tree production. Farmers under surface irrigation suggested combatting agricultural pests such as insects and weeds (51.9%), followed by use of other irrigation systems and more labour (14.5% and 12.2%, respectively). Meanwhile 50.4 per cent of farmers under sprinkler irrigation suggested controlling quantity of irrigation water, while 28.6 per cent and 14.3 per cent, respectively, suggested better scheduling of irrigation and provision of generators. Farmers under drip irrigation, on the other hand, suggested renewing wells, proper maintenance, fertilizing and applying pesticides, training farmers on irrigation more efficiently, and not ploughing or breeding during irrigation as shown in Figure 9.9. Farmers suggestions were consistent with Ata et al. (2012) who reported the need to train date palm farmers on modern irrigation methods, fertilizers and pesticides application and agricultural pests management.

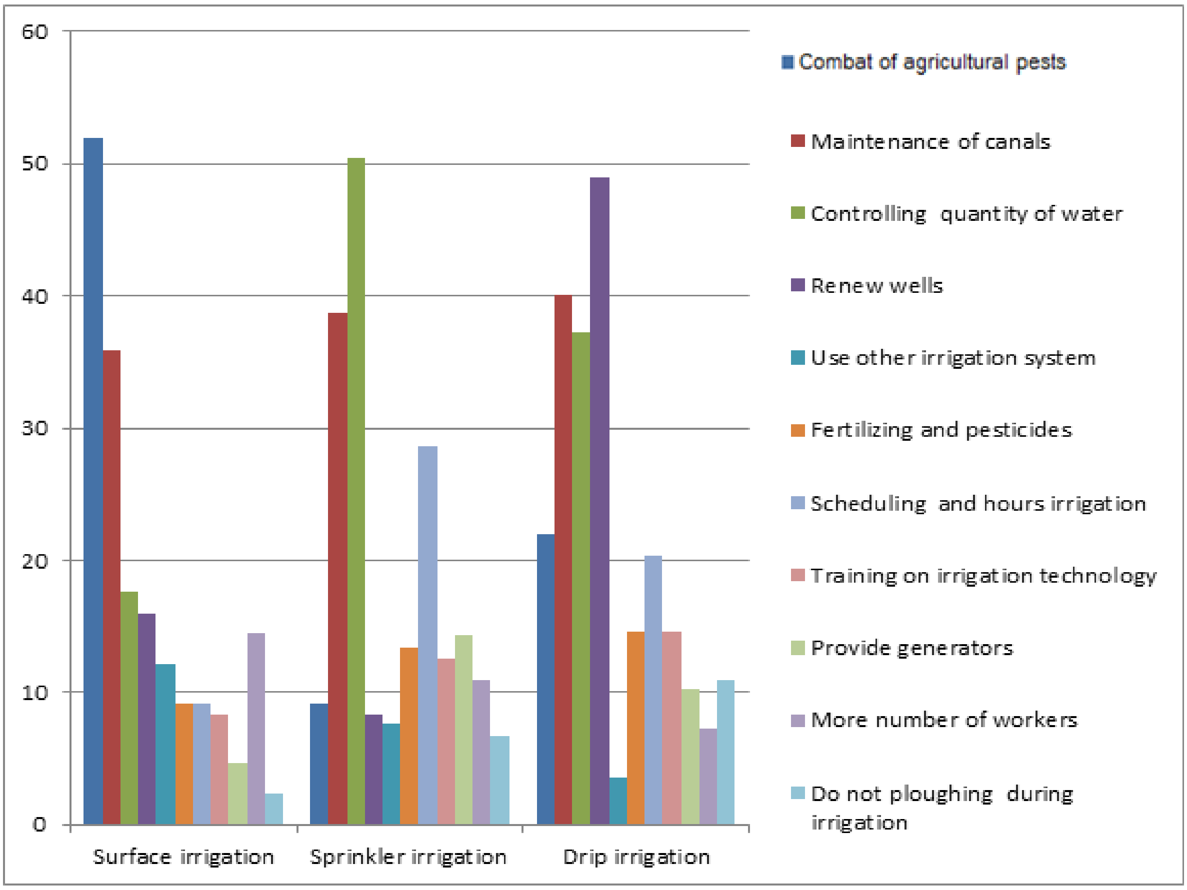

Figure 9-9: Farmers' proposed solutions to issues in palm production

9.5. Modelling the effect of irrigation system on date palm production

Apart from eliciting farmers' opinion on factors influencing their production of date palms, the determinants of date palm production were also modelled in this study. This section discusses the results of the coefficients of the four estimated models -

linear, Cobb-Douglas, quadratic and translog models. Table 9.3 shows that the estimated coefficients of the four models. The variance inflation factor (VIF) showed a high degree of correlation between date palm production and inputs under different irrigation systems. Some of the input variables were dropped due to multicollinearity. The results of the analysis are as follows.

Table 9-3: Estimated coefficients of date production models

	Model 1 (Linear)		Model 2 (Cobb-Douglas)		Model3 (Quadratic)		Model 4 (Translog)	
Variables	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**	**Coeff**	**SE**
Constant	-156.26	1249.50	-3.512	0.61	-3.573	0.098	-3.634	0.582
Age	-3.04	7.78	-0.023	0.098	-0.044	0.053	-0.048	0.099
Schooling	28.06	26.99	0.033	0.053	0.021	0.064	0.024	0.053
Family members	-60.23	247.69	0.058	0.041	-0.058	0.111	-0.063	0.064
Soil(fine)	-14.10**	613.13	-0.038	0.111	-0.076	0.061	-0.079	0.111
Soil(med)	-370.16	325.21	-0.075	0.062	-0.071**	0.071	-0.070	0.062
Soil(silt)	-606.95	388.14	-0.112	0.073	-0.129**	0.080	-0.120**	0.072
Soil(coarse)	-330.73	364.48	-0.026	0.087	-0.022	0.065	-0.021	0.081
No. trees	34.46	8.23	0.810***	0.067	0.825***	0.055	0.833***	0.077
Distance (tree)	3.45**	54.84	0.059	0.057	0.065	0.057		
Time of irrigation	-5.32	28.16	-0.025	0.059	-0.020	0.043	-0.023	0.057
Amount of water	0.06	0.11	0.157***	0.045	0.152***	0.076	0.142***	0.045
Sprinkler irrig	476.39	399.22	0.262***	0.077	0.254***	0.074	0.260***	0.076
Drip irrig	-633.39**	344.58	-0.120**	0.068	-0.135**	0.043	-0.129**	0.074
Labour	41.49	106.37	0.124***	0.044	0.124***	0.048		
Pesticides	317.05**	167.57	0.044	0.048	0.074	0.033		
Manure	-0.22	0.46	-0.058**	0.034	-0.058**	0.042	-0.059**	0.033
Family members2					-0.082**	0.026	-0.086**	0.041
Labour2					-0.022	0.029	-0.020	0.026
Pesticids2					0.078**	0.098	0.084**	0.032
MA× Ln TR							-0.000	0.000
DI× Ln PE							0.036	0.051
TR× Ln PE							0.004	0.021
WR × Ln DI							0.009	0.007
LA× Ln TI							0.051**	0.018
R-squared	**0.50**		**0.685**		**0.694**		**0.695**	
Sig	**0.000**		**0.000**		**0.000**		**0.000**	

**** Significant at 5 % level and ** significant at 10 %. Notes: DI= distance between tree, PE= pesticides, TR= number of trees, WR= amount of water, LA= labour, TI= time of irrigation. MA= manure.*

** Surface irrigation is the basic variable for type of irrigation, while, clay soil is the basic variable for type of soils in study area.*

The first model, which is the linear production function model, was estimated and its estimated coefficients are shown in Column 1 of Table 9.3. The results showed that soil type (very fine sand) and distance between trees, are significant at 10 per cent level of significance. There is a direct relationship between distance between trees and palm production; however the coefficient of very fine sand is negative indicating lower productivity compared to clay sand at 10 per cent level of significance. On the other hand, in the second model, the Cobb-Douglas model, the number of trees, amount of water, drip irrigation, sprinkler irrigation labour and manure were found to be significant and positive at 5 per cent level for date palm production (Table 9.3). As the variables are expressed in natural logarithms, their coefficients are interpreted as output elasticities. Sprinkler irrigation has a higher effect on productivity compared to surface irrigation at 5 per cent level; however, drip irrigation has lower effect on productivity compared to surface irrigation at 10 per cent level of significance.

In Column 3 of Table 9.3, the results of the third model (Quadratic model) is presented and estimated by square terms. In the third model, the number of trees, amount of water, and labour were found to be positive and significant at 5 per cent level, while pesticides square had a positive and significant effect on date palm productivity at 10 per cent level of significance. Farms under sprinkler irrigation have higher productivity compared to surface irrigation at 5 per cent level; however, drip irrigation has a lower effect on productivity compared to surface irrigation at 10 per cent level. On the other hand, manure and family member square have negative relationship on productivity at 10 per cent level. In addition, the coefficient of medium sand and silt sand are significant and negative indicating lower effect on productivity compared to clay sand at 10 per cent level.

The fourth model is the Translog production function that was estimated and tested by the interaction and square terms in Column 4 of Table 9.3. The number of trees, amount of water and sprinkler irrigation are positive and significant at 5 per cent level, while pesticides square and the interaction between labour and time of irrigation is also positive and significant at 10 per cent level. However, silt soil, drip irrigation, manure and family members are negative and significant at 10 per cent. The negative coefficient of silt soil signifies that farms with silt soils have lower productivity compared to those with clay sand at 10 per cent level of significance. When comparing the results of the translog production function with the results of the Quadratic model, it can be concluded that in both models, sprinkle irrigation performs better in terms of productivity at 5 per cent level compared to surface irrigation, while drip irrigation has a lower effect on productivity at 10 per cent levels when using surface irrigation as a basis. The results of the analysis indicate that the type of irrigation system significantly influences productivity of date production. The standard errors and p-values of the estimated coefficients are also shown in Table 9.3.

Thus, Table 9.3 shows that productivity can be improved by a number of factors including farmer characteristics, agronomic characteristics, irrigation characteristics and other inputs. From a statistical perspective, the OLS estimates of the production function effect models show that the Cobb-Douglas model best represents the relationship with a high adjusted R-square at 0.70 for date palm production. This means that 70 per cent of the variance of date production can be explained by the variables included in the Cobb-Douglas model, indicating that the model has a good fit. The estimates of farm specific variables in the Cobb-Douglas model are discussed further in section 9.8.2.1.

9.6. Determinants of farm level technical efficiency of irrigation systems

To analyse the determinants of farm level technical efficiency, stochastic frontier production function analysis was conducted. A description of the variables included in the model is described below.

9.6.1. Output, input and farm- specific variables

Output (y) is the yield defined as date production (kilograms) per hectare during the survey period. The independent variables include amount of water (X_1) which represents the total water used (liters) per hectare; labour (x_2) which includes both family and hired labour and represents the number of labour used per hectare (man day); pesticides (x_3), the quantity of pesticides (liters) used per hectare; and manure (x_4) which includes all animal fertilizer used per hectare during the survey period (see Table 9.4).

Table 9-4: Summary statistics of output, input and farm-specific variables of different irrigation system

Variables	Description
Output	
Date production	**Amount of date production, kg/hectare**
Input variables	
Number of trees(X_1)	Number of trees/ hectare
Amount of water (X_2)	Amount of water applied, liters / hectare
Labour (X_3)	Amount of hired and family labour,
Pesticides (X_4)	Amount of pesticides used, kg/hectare
Manure (X_5)	Amount of farmyard manure applied, kg/hectare
Farm-Specific Variables	
Age (Z_1)	Number of years
Schooling of farmers (Z_2)	Number of years of education
Family members (Z_3)	Ratio of adults over total family
Soil(fine) (Z_4)	Value = 1 if soil type is fine, 0 otherwise
Soil(med) (Z_5)	Value = 1 if soil type is medium, 0 otherwise
Soil(silt) (Z_6)	Value = 1 if soil type is silt, 0 otherwise
Soil(coarse) (Z_7)	Value = 1 if soil type is coarse, 0 otherwise
Time of irrigation (Z_8)	Number of irrigation per week
Distance between (Z_9)	Length between trees per meter

Source: Survey data, 2013.

The average productivity of date palm farms per hectare was significantly different across the various irrigation systems. The average yield under sprinkler irrigation was 3603.5 kilograms. For surface irrigation, the yield was 3163.46, while for drip irrigation, the yield was 2745.66. In terms of the farm-specific variables, in farms under surface irrigation, the mean age of the farmers is 51.3, while schooling is about 14 years. In farms under sprinkler irrigation, the average age of farmers is 53.92, while schooling is about 13.6 years. Finally, in farms under drip irrigation, the average age of farmers is 54.99, while average schooling is 13.4 years.

Table 9-5: Summary statistics of output, inputs and farm-specific variables

Variables	Surface irrigation		Sprinkler irrigation		Drip irrigation	
	Mean	**S.D**	**Mean**	**S.D**	**Mean**	**S.D**
Output						
Date production	3302.68	4067.66	3603.52	3830.19	2745.66	2548.95
Input						
Amount of water	3163.46	3212.69	2677.70	2496.25	11.43	5.13
Labour	1.31	1.49	1.39	1.51	1.41	0.32
Pesticides	1.19	1.22	0.97	0.73	1.04	0.89
Manure	693.05	687.63	630.53	602.09	691.85	561.91
Number of trees	81.32	72.38	78.72	60.81	85.88	62.96
Farm-Specific Variables						
Age of farmers	51.30	14.99	53.92	14.93	54.99	16.16
Schooling	14.17	5.25	13.58	4.71	13.45	4.77
Family members	0.49	0.42	0.63	0.46	0.57	0.44
Soil(fine)	0.12	0.33	0.06	0.24	0.09	0.28
Soil(med)	0.21	0.41	0.29	0.46	0.31	0.46
Soil(silt)	0.34	0.47	0.20	0.40	0.23	0.42
Soil(coarse)	0.11	0.31	0.10	0.51	0.06	0.24
Time of irrigation	8.95	4.50	12.38	5.35	11.43	5.13
Distance between trees	6.40	3.29	5.93	3.11	5.93	2.98

Source: Survey data, 2013.

9.6.2. Stochastic frontier and technical efficiency analysis

Technical efficiency and the technical inefficiency effects models for date palm production under differing irrigation in the Sebha region can be estimated by using either Cobb-Douglas or Translog production functions or both. Cobb-Douglas and Translog production functions are the most often used functional forms for stochastic frontier analysis (Latruffe et al., 2004). Both the Cobb-Douglas and the Translog functions are tested in this study for adequacy (see Battese et al., 1996; Charoenrat & Harvie, 2013; Coelli et al., 2005; Earfan & Samad, 2013). A Cobb-Douglas production function using cross-sectional data may be expressed as follows:

$$Ln\ Y = \beta_0 + \beta_1\ Ln\ X_1 + \beta_2\ Ln\ X_2 + \beta_3\ Ln\ X_3 + \beta_4\ Ln\ X_4 + \beta_5\ Ln\ X_5 + (v - u) \quad \ldots\ldots \textbf{(9.1)}$$

where:

Y= Production of date palm under different irrigation system, X_1 = amount of water used, X_2 = Labour, X_3 = Pesticides, X_4 = Manure X_5 = number of trees,

Ln = natural logarithm, i = 1,…n. = error term

The translog production function is shown according to model (9.2) in the study. It is a flexible functional form which places no restriction on the elasticity of production, unlike the Cobb-Douglas model (see chapter 5). Other studies have calculated technical efficiency by using the translog function (Naqvi & Ashfaq, 2013).

$$\text{Ln } Y = \beta_0 + \beta_1 \text{ Ln } X_1 + \beta_2 \text{ Ln } X_2 + \beta_3 \text{ Ln } X_3 + \beta_4 \text{ Ln } X_4 + \beta_5 \text{ Ln } X_5 + \beta_6 \text{ Ln } X_1^2 + \beta_7 \text{ Ln } X_2^2 + \beta_8 \text{ Ln } X_3^2 + \beta_9 \text{ Ln } X_4^2 + \beta_{10} \text{ Ln } X_5^2 + \beta_{11} \text{ Ln } X_1 \text{ Ln } X_2 + \beta_{12} \text{Ln } X_1 \text{ Ln } X_3 + \beta_{14} \text{Ln } X_1 \text{ Ln } X_4 + \beta_{15} \text{ Ln } X_1 \text{ Ln } X_5 + \beta_{16} \text{Ln } X_2 \text{ Ln } X_3 + \beta_{17} \text{Ln } X_2 \text{ Ln } X_4 + \beta_{18} \text{Ln } X_2 \text{ Ln } X_5 + \beta_{19} \text{Ln } X_3 \text{ Ln } X_4 + \beta_{20} \text{ Ln } X_3 \text{ Ln } X_5 + \beta_{21} \text{ Ln } X_4 \text{ Ln } X_5 + (v - u) \ \ldots \ldots\ldots\ldots \textbf{(9.2)}$$

The model to explain inefficiency is specified as follows:

$$\mu = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + \delta_7 Z_7 + \delta_8 Z_8 + \delta_9 Z_9 \ldots\ldots\ldots \textbf{(9.3)}$$

The variables are defined in Table 9.4.

9.6.3. Hypothesis tested

The estimation of the stochastic frontier production function can be used to test the validation of three hypotheses as follows: (1) adequacy of the Cobb-Douglas production functional form; (2) absence of technical inefficiency effects; and (3) significance of joint inefficiency variables. Formal hypotheses tests associated with the stochastic production function and technical inefficiency effects models are presented in Table 9.2. Three hypothesis tests are conducted by using the generalised likelihood-ratio test (LR test), which can be defined as follows (Coelli et al., 2005; Idiong, 2007; Kamruzzaman & Islam, 2008; Onumah et al., 2013; Shahid & Munir, 2014):

$$\lambda = -2 \{\log [L (H_0)] - \log [L (H_1)]$$

where log [$L (H_0)$] and log [$L (H_1)$] are the values of a log-likelihood function for the frontier model under the null hypothesis (H_0) and the alternative hypothesis (H_1). The LR test statistic contains an asymptotic chi-square (χ^2) distribution with parameters equal to the number of restricted parameters imposed under the null hypothesis (H_0) 0 H, except hypotheses (2) and (3) which contain a mixture of a chi-square (χ^2) distribution (Kodde & Palm, 1986). Hypotheses (2) and (3) involve the restriction that λ is equal to zero which defines a value on the boundary of the parameter space (Coelli, 1996).

9.6.4. Cobb-Douglas function validation

Frontier 4.1 can be used in estimating the Translog and Cobb-Douglas function. Subsequent to equation 9.1, the null hypothesis ($H_0 = \beta_1 = \beta_2 = \beta_3 = 0$) was tested at 5% level of significance for both drip irrigation and surface irrigation owing to the fact that the LR test statistic is less than the critical value at 5% significance level. This suggests that the Cobb-Douglas model provided sufficient specification for both drip irrigation and surface irrigation system. On the other hand, the study further found that Translog production function provided sufficient specification for the sprinkler irrigation system compared to the Cobb-Douglas specification (see Table 9.6).

In order to test for the absence of the inefficiency effect of the model, the study tested the model against the alternative hypothesis. Table 9.6 suggests that the LR tests are greater than the critical value at 5% significance level under the drip irrigation system. This therefore indicates that the null hypothesis specifying the model effect is absent ($\gamma = \delta_0 = \delta_1 \ldots\ldots \delta_9 = 0$) and as such, the study rejects it at 5% significance level implying that the inefficiency effect of the model exists under drip irrigation system. Both sprinkler and drip irrigation system recorded the absence of model inefficiency effect (Table 9.6).

Table 9-6: Statistics for hypotheses test of the stochastic frontier model and inefficiency effect model under different irrigation methods

	Surface irrigation			**Sprinkler irrigation**			**Drip irrigation**		
	Hypothesis 1: CD with half-normal versus Translog with truncated	**Hypothesis 2**: No technical inefficiency versus with inefficiency	**Hypothesis 3**: No joint inefficiency variables	**Hypothesis 1**: CD with half-normal versus Translog with truncated	**Hypothesis 2**: No technical inefficiency versus with inefficiency	**Hypothesis 3**: No joint inefficiency variables	**Hypothesis 1**: CD with half-normal versus Translog with truncated	**Hypothesis 2**: No technical inefficiency versus with inefficiency	**Hypothesis 3**: No joint inefficiency variables
H_0	-119.65	-119.65	-119.65	-72.59	-53.12	-53.12	-65.12	-65.12	-52.57
H_1	-109.75	-116.27	-119.64	-53.12	-49.19	-53.12	-55.79	-52.57	-63.5
	-9.89	-3.38	-0.01	-19.47	-3.93	0.00	-9.33	-12.55	10.93
LR	19.79	6.75	0.01	38.94	7.86	0.00	18.66	25.10	21.86
DF	15	10	1	15	10	1	15	10	1
CV	24.38	16.27	2.70	24.38	17.67	2.7	24.38	17.67	2.7
Decision	Fail to Reject H_0	Fail to Reject H_0	Fail to Reject H_0	Reject H_0	Fail to Reject H_0	Fail to Reject H_0	Fail to Reject H_0	Reject H_0	Reject H_0
	-119.65	-119.65	-119.65	-53.12	-53.12	-53.12	-65.12	-52.57	-52.57

Note: All critical values of the test statistic are presented at the 5 % level of significance, obtained from a x^2 distribution, except were indicated by*, which contain mixture of a x distribution obtained Table 1 of (Kodde & Palm, 1986)

To test for the significance of firm-specific variables and inputs variables (joint inefficiency variables) of the model, the study conducted the null hypothesis to show that the inefficiency effects of all explanatory variables is not a linear function. The null hypothesis specified that all parameters of the explanatory variables equal to zero is tested against the alternative hypothesis and as such the explanatory variables are not equal to zero other words the null hypothesis specifying that all parameters of the explanatory variables are equal to zero is tested against the alternative hypotheses that the explanatory variables are not equal to zero. Table 9.6 suggest that the LR test statistic is greater than the critical value which could be approximated with the chi-square distribution at the 5% significance level. This means that the coefficients of the explanatory variables are equal to (0) $(H0= \delta_0 = \delta_1 \ldots\ldots \delta_9 = 0)$ and as such is rejected at the 5 per cent level of significance for drip irrigation when compared to sprinkler and surface irrigation.

9.6.5. Stochastic frontier efficiency results for different types of irrigation systems

Based on the variables from Table 9.5, farm specific technical efficiency is calculated using maximum likelihood estimation (MLE) method using the econometric software package, Frontier 4.1. The coefficients estimated in the (MLE) method are shown in Table 9.7.

9.6.5.1. Surface irrigation

For date palms under surface irrigation, the Cobb-Douglas model seems to be able to explain the variance of farm level technical efficiency for date palm efficiency the best.

Results showed that the number of trees, amount of water and human labour are significant and positive in the model for technical efficiency of date palm production at 5 per cent level of significance (Table 9.7). This indicates that for farms under surface irrigation methods, productivity increases with the increased number of trees, amount of water and human labour. The estimated elasticities of mean output with respect to number of trees, amount of water and human labour inputs are 0.618, 0.275 and 0.149 respectively. This means that for a 10 per cent increase in each of these inputs, dates output will increase by 61.8 per cent, 27.5 per cent and 14.9 per cent, respectively. The elasticity estimates of number of trees, distance between trees, amount of water and human labour are statistically significant at 5 and 1 per cent level of significance. Age of farmers, and number of family members were found to be negatively and significantly correlated with productivity. This finding is similar to Al-Subaiee et al. (2013) who found that date palm farmers between 30 and 70 years old tend to be slow in adopting technology and are worried about adopting new technology. Surprisingly, schooling was found to be negatively correlated with productivity, but was not significant.

Table 9-7: MLE estimates models of dates for different irrigation in Sebha region

Variables	Surface irrigation N=131		Sprinkler irrigation *N=119		Drip irrigation N=137	
	Coeff.	SE	Coeff.	SE	Coeff.	SE
Stochastic frontier model						
Constant	3.486	0.635	2.072	0.975	3.586	0.495
Ln Number of trees	0.618***	0.180	1.425**	0.839	0.761***	0.113
Ln Amount of water	0.275***	0.134	0.311	0.523	0.214***	0.105
Ln Labour	0.149***	0.067	0.159	0.789	0.089	0.160
Ln Pesticides	0.133	0.095	-1.076	0.788	0.096**	0.057
Ln Manure	-0.055	0.082	-0.223	0.736	-0.099**	0.052
Ln Number of trees 2			0.266***	0.094		
Ln Amount of water 2			-0.013	0.040		
Ln Labour 2			-0.075	0.059		
Ln Pesticides 2			-0.060**	0.076		
Ln Manure 2			-0.034***	0.019		
Ln N of tees × Ln Amount of water			-0.246***	0.086		
Ln Number of trees× Ln Labour			-0.208***	0.106		
Ln Number of trees× Ln Pesticides			0.310	0.118		
Ln Number of trees× Ln Manure			-0.153	0.101		
Ln Amount of water× Ln Labour			0.052	0.071		
Ln Amount of water× Ln Pesticides			0.065	0.089		
Ln Amount of water× Ln Manure			0.173***	0.072		
Ln Labour× Ln Pesticides			0.042	0.111		
Ln Labour× Ln Manure			0.065	0.095		
Ln Pesticides× Ln Manure			-0.134	0.131		
Technical inefficiency function						
Constant	4.269	2.755	-1.386	1.292	-1.375	2.283
Ln Age of farmers	-1.394**	0.821	-0.387	0.254	0.258	0.345
Ln Schooling	-0.180	0.385	0.369**	0.222	-0.194	0.179
Ln Family members	-1.018**	0.556	-0.349**	0.210	-0.857**	0.466
Soil (fine)	-0.018	0.737	0.232	0.336	1.345	1.223
Soil (med)	-0.174	0.850	0.116	0.163	0.725	0.762
Soil (silt)	-0.773	1.056	-0.248	0.281	1.371	1.140
Soil (coarse)	0.773**	0.444	-0.073	0.112	-0.798	1.076
Ln Time of irrigation	-0.448	0.326	0.042	0.142	-0.515***	0.237
Ln Distance between trees	0.092	0.263	0.583***	0.294	-0.403	0.349
Variance parameters						
Sigma-squared	***0.538***	***0.137***	***0.155***	***0.023***	***0.339***	***0.161***
Gamma	***0.392***	***0.237***	***0.183***	***0.131***	***0.723***	***0.141***
LL function	***-116.527***		***-49.19***		***-52.56***	
Mean efficiency	***0.864***		***0.899***		***0.834***	

******* *Significant at 5 % level and ** significant at 10 %*

***** *One would expect multicollinearity in a production function, especially in its translog form with many parameters (Amornkitvikai, 2011; Coelli et al., 2005; Croppenstedt, 2005; Siry & Newman, 2001; Tozer, 2010). However our real interest is in the technical efficiency.*

For farms under sprinkler irrigation, the translog model was considered as the best based on the hypothesis test conducted (Table 9.6). In the translog model, the number of trees, pesticides square, schooling and number of family members were found to significantly affect technical efficiency at 10 per cent level of significance. The regression coefficients of number of trees and schooling were found to be positive indicating that productivity increases as the number of trees and schooling (level of education) increases. This is because increased number of trees (seedling) will lead to more date palm trees and fruits produced. Likewise, farmers who have a high level of education have more knowledge and thus understand better the use of farm inputs for their farm.

The findings also revealed that the number of trees square, manure square, interaction of number of trees and amount of water, interaction of number of trees and labour, interaction of amount of water and manure, and distance between trees were found to significantly affect productivity at 5 per cent. However, the number of trees square and manure and distance between trees were found to have a positive effect on yield. In addition, the interaction of water and manure has also a significant and positive effect at the 5 per cent significance level. The higher amount of water and manure of the farm, the higher the yield will be. On the other hand, manure square was found to have a negative effect on efficiency. Similarly, a negative relationship was found in the interaction between number of tree and number of labour at the 5 per cent significance level.

The modelling results for farms under drip irrigation is also shown in Table 9.7 The number of trees, amount of water and time of irrigation were found to have a significant and positive influence at 5 per cent level of significance. This means that date production increases in drip irrigation with the increase in the number of trees and amount of water. The estimated elasticities of mean output with respect to number of trees and amount of water inputs are 0.76, and 0.214 respectively. This means that for a 10 per cent increase in number of trees and amount of water, dates output will increase by 76 per cent and 21.4 per cent, respectively. These results indicate the relative importance of the inputs in the productivity of date production. Time of irrigation was found to have a positive and significant effect on efficiency at the 5 per cent level. The coefficient estimates of pesticides, manure and family member are significant at 10 per cent but only pesticides were found to have a positive effect on efficiency under drip irrigation, while, manure and family member had a negative effect on efficiency at a level of 10 per cent.

The gamma parameter (γ) indicates whether the deviations from the stochastic frontier model are due to random error or technical inefficiency. If gamma (γ) is equal to zero this indicates that all deviations from the model are caused by random error. However, if (γ) is equal to one, then all deviations are caused by technical inefficiency (Charoenrat & Harvie, 2013; Coelli et al., 2005; Hamjah, 2014).

Table 9.5 shows the estimate of the gamma parameter (γ) in the different types of irrigation systems in the study area. As drip irrigation and surface irrigation are 0.723 and 0.392, respectively, it can be explained that the variation in the composite error term is mainly due to the inefficiency component. However, the estimated (γ) for sprinkler irrigation is equal to 0.183, meaning that deviations from the model are more attributed to random error.

9.6.6. Distribution of technical efficiency of date palm farmers under irrigation systems

Technical efficiency is the ratio of actual and potential production. In the case of the irrigation system in this study, the values indicate that there are still opportunities for improving on-farm production practices. For example, date palm farmers have an average technical efficiency of 86.4 per cent under surface irrigation. This means that date palm farmers can increase their production by 13.6 per cent without addition of new resources. The same analogy also applies for sprinkler irrigation and drip irrigation used by farmers.

In terms of the proportion of farmer's levels of technical efficiency (Figure 9.10), more than 60 per cent of date palm farmers who used sprinkler irrigation seem to have a high level of technical efficiency (TE > 90). Furthermore, close to 40 per cent of date palm farmers who used surface irrigation have a high technical efficiency score (TE > 90), while about 31 per cent of farmers under drip irrigation had a high technical efficiency score (TE > 90). This finding is different to Belloumi and Matoussi (2006) who compared the technical efficiency for date palm farmers using dam irrigation and groundwater scheme irrigation in Tunisia. The majority of technical efficiency for farmers was between 60 to 80 per cent. Similarly, Alzahrani et al. (2012) reported that drip and sprinkler irrigation were more efficient in improving the efficiency of crops e.g, date palm, wheat and vegetables in Saudi Arabia. Unfortunately, the authors did not elaborate their findings on why this is so. The higher efficiency was not due to sprinkler and drip irrigation; high technical efficiency was also found due to choosing appropriate sowing date, selection of appropriate agricultural density, good and proper fertilization and weed and pest management according to Alzahrani et al. (2012). In Nigeria, Ogundari and Ojo (2007) reported that the technical efficiency of the farmers varied between 0.168 and 0.974 with a mean technical efficiency of 0.81 in cassava crops due to changes in factors such as number of trees, farm size and cost.

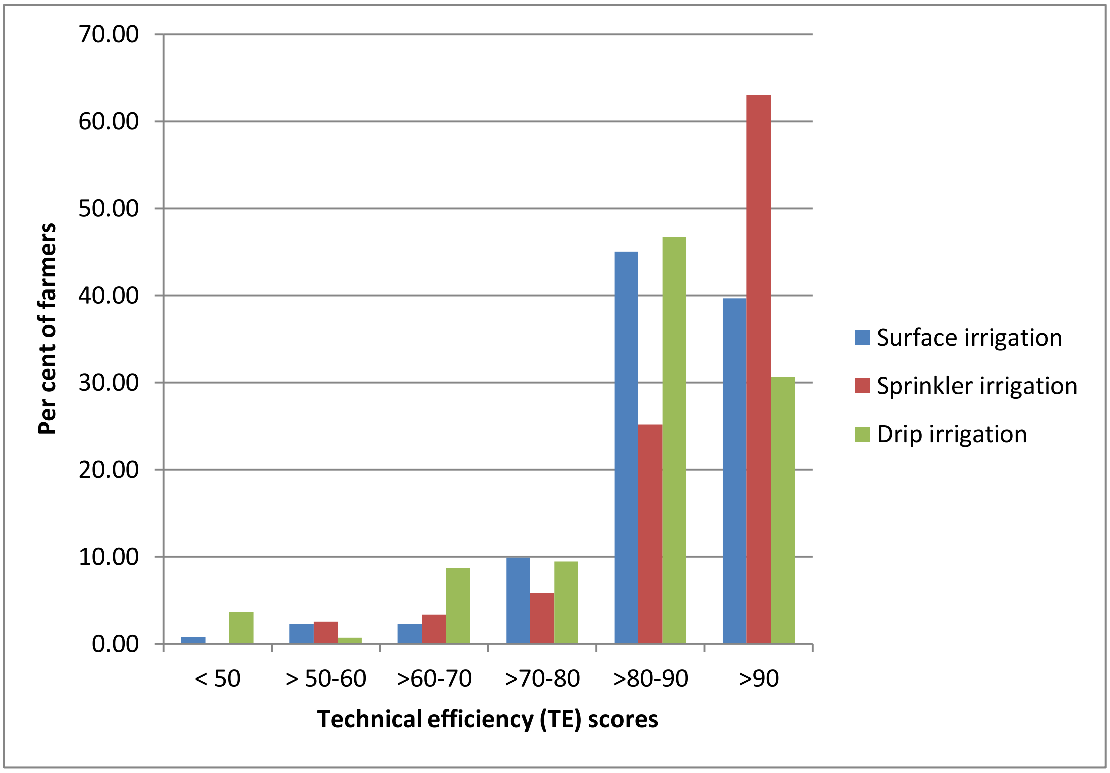

Figure 9-10: Distribution of technical efficiency of date palm farmers under irrigation systems.

In this study, it seems that more than 40 per cent of date palm farmers allocated their resources efficiently, with the value of technical efficiency (<0.80-90). Meanwhile, less than 30 per cent of date palm farmers have technical efficiency

(<0.80-90) under surface irrigation, however, it can be noted that there is no study in Libya to compare with this finding under different irrigation systems and date palm crops. However, the current thesis is similar to Timothy (2005), who found that technical efficiency for oil palm in Nigeria was 23.23 per cent and range from 0.80 to 0.89.

As shown in Figure 9.10, nearly 10 per cent of farmers were found to have technical efficiency score of >70-80 under surface and drip irrigation. Only 5.88 per cent of farmers under sprinkler irrigation had the same technical efficiency scores. Compared to other crops (e.g., potato in Ethiopia), the current finding is different with Bogale and Bogale (2005) who studied technical efficiency of surface, drip and sprinkler irrigation for potato farms. They found that technical efficiency of surface irrigation was higher at 97 per cent and drip and sprinkler irrigation was 77 per cent.

In this study, less than 8 per cent of date palm farmers have technical efficiency scores of >60-70. Finally, less than 4 per cent of date palm farmers have technical efficiency score of >0.50-6) and < 50 under surface, sprinkler and drip irrigation.

9.7. Discussion

9.7.1. Effect of irrigation system on date palm production

The Cobb-Douglas model implied that the improvement in the quantity and quality of number of trees, amount of water, sprinkler irrigation and labour lead to an increase in the date production. The estimated elasticities of mean output with respect to number of trees, amount of water and sprinkler irrigation inputs are 0.81, 0.157, 0.262, -0.120, 0.124 and -0.058, respectively. This means that with 10 per cent increase in each of these inputs, dates output will increase by 68 per cent. The elasticity estimates of number of trees, amount of water, sprinkler irrigation and labour are statistically significant at 5 per cent. These results indicate the relative importance of these inputs in date production. However, the model indicated that yield under drip irrigation is lower than that for surface and sprinkler irrigation. Manure also has a negative effect on date production. Drip irrigation and manure were not used properly by Libyan date farmers. Thus, the current thesis showed that the maintenance costs associated with drip irrigation are high. However, the costs related to manure are low, thus, Libyan farmers extensively used manure that affect negatively on the date production.

The number of palm trees appear to be the most important factor for date production because palm trees are readily available at affordable prices to the date farmers in the study area. In addition, date palm farmers are using quality seedlings for all their farms. This finding is in contrast with Alshuaibi (2011) who found that the number of date palms did not affect date production in Saudi Arabia, while he showed that the age of trees played a significant role in the increase in the date production. In addition, in contrast with Alshuaibi (2011), this thesis did not show ages and variety of date palm trees impacted production, perhaps because most of the date trees' ages are less than seven years, from seven to ten years and more than ten years.

The findings of this thesis also contrasts with the results of Mahmoudi et al. (2008) who reported that type and quality of date cultivars have more effect than number of trees on date palm production per hectare. However, the current findings showed that the number of trees is more effective than the type and quality of date in terms of the increase in the date production. Thus, the current thesis has provided evidence that indicates that the number of date palms plays an important role in increasing date production.

The effect of the number of trees on the date production is different not only from farm to farm, but also from country to country, especially in the Middle east and North Africa region due to prevailing social and environmental conditions (El-Juhany, 2010).

The effect of the amount of water differed according to type of irrigation system and season of the year. The amount of water use differs under the three types of irrigation systems as compared to other countries, e.g., date palm trees in Libya consumed large quantities of water compared to the date palm trees in Algeria, Oman and Egypt (FAO, 2007). In the current study, the quantity of water has a significant and positive effect on date palm production. According to Abusta et al. (2012) using large quantities of water with low palm tree production is the main problem facing the agricultural sector in Sebha, Libya. They attributed the low date production to the insufficient quality and quantity of water e.g., low level of groundwater in recent years (Abusta et al., 2012). However, Al-Khayri et al. (2011) reported that although 65 per cent of farmers irrigated their date palm farms by surface irrigation in Qatar, quantity of water had no effect on date palm yield and production. Similarly, the current findings (see Chapter 6) reported that majority of farmers (62 per cent) still use traditional systems such as surface irrigation including flood, bubbler and bolder irrigation methods. This method led to losing a lot of water by leaching of porous sandy soils, which represented about 29.5 per cent in the study area and also through evaporation.

Human labour had a positive and significant effect on production. Labour is used in different activities in farms and it is a highly significant factor for date palm production in Sebha, Libya. Some date farmers hired labour from outside their location during the season. This is because the majority of farming activities of palm tree farmers in the study area depend on hand manual effort, such as for pollination, pruning and harvesting (Al-Khayri et al., 2011; Shamsi & Mazloumzadeh, 2009). In fact, there were two types of labour in date palm farms in the study area - local labour (family members, friends and relatives) and foreign labour. Because of the civil war in Libya 2011, the majority of foreign labour left farming work in the date palm farms. Thus, the local labour has become the main alternative in Sebha, Libya. Moreover, the local labour is a suitable alternative, because farming activities of palm trees do not require special skills compared with other crops. This thesis showed the importance of human labour as a main input in date palm production in Libya. This is opposite to Pakistan and Iran, where animal labour is the main input in date palm production (Banaeian & Zangeneh, 2011; Ghadiryanfar, Keyhani, & Akram, 2009).

The type of irrigation system has a significant effect on date production, as shown in the Table 9.3; palm production is higher under sprinkler compared to surface irrigation; while farm production under surface irrigation is higher compared to drip irrigation. These findings are consistent with Pelusey (2006); Al-Jamal et al. (2001) and Albaji et al. (2010) who concluded that sprinkler irrigation improved soil and crop productivity. Luhach et al. (2004) reported that sprinkler irrigation method was more economical than drip irrigation, because it reduced the need to hire human labour and operation costs; thus farmers should invest in sprinkler irrigation in the study area. However, the findings in this study is interesting because farmers who use sprinkler irrigation still believed sprinkler irrigation is not suitable for date palm crops. Many farmers think that sprinkler irrigation is more suitable for vegetable crops, such as tomatoes and onion, than to date palm trees. It can be observed that the percentage of farmers who use sprinkle irrigation was only about 56.7 per cent which is less than those who use surface and drip irrigation.

The finding in this study also contrasted with Bond (1998) and Amiri, Panahi, and Aghazadeh (2007) who noted that sprinkler irrigation methods are unsuitable for date palm trees, because, it leads to wetness around the tree trunk, which results in increasing the weed growth and insects. Bruce (2010) reported a large water loss by evaporation with sprinkler irrigation methods. FAO (2007) compared drip irrigation with sprinkler irrigation in terms of reducing water consumption and date palm productivity. The result showed that for drip irrigation, the yield was approximately 145 kg per tree while for sprinkler irrigation; yield was 109 kg per tree. Nonetheless, although Libyan farmers do not heavily use sprinkler irrigation, this thesis provides evidence that sprinkler irrigation still leads to an increase in date palm production.

For drip irrigation system, date palm production is lower compared to surface irrigation. The current study is consistent with Hanson and May (2004) who found that the production of some vegetables increased when surface irrigation was used, while it decreased when drip irrigation was used. However, the current result is in contrast with the results of Rajput & Patel (2006); Skaggs (2001); Cetin et al. (2004) and Zaid & Liebenberg (2002); (Al-Amoud, 2010; Calzadilla et al., 2010; FAO, 2007; Hakimian & Nugent, 2005; Karlberg & Penning de Vries, 2004; Rijsberman, 2003). These researchers found that: (1) drip irrigation is a more common irrigation due to its numerous advantages compared to sprinkler and surface irrigation; (2) drip irrigation is the most appropriate way to irrigate date palm because it enables farmers to control water usage by time management or using different types of emitters; (3) drip irrigation reduces the problem of deep percolation and loss in the soils and saves water in root zone; 4) drip irrigation can create a balance between climatic conditions and growing trees by distributing nutrients and fertilizers, and (5) drip irrigation achieved success in terms of reducing the water usage of irrigation and cost of irrigation and investment in many countries, e.g., USA, Nepal, Turkey and Saudi Arabia.

The reason why the result of the current study differs with the above studies is that first, drip irrigation is a new technology in date palm farms in Sebha, Libya (FAO, 2007). As a result, farmers do not have suitable experience and skills to utilise it when compared with other irrigations, such as surface irrigation, as the majority of Libyan farmers have more than 20 years in using surface irrigation (see Chapter 6). Thus, farmers require training period for drip irrigation management. Second, many date palm farmers have used drip irrigation systems directly after they received it from agricultural companies in study area. That is, they quickly shifted from the surface irrigation system or sprinkler irrigation to drip irrigation without considering the effects of changing from one system to another on the date production. For instance, the sudden shift of irrigation technology can lead to significant decreases in the quantity of water, which has led to decreases in the date production, especially palm trees whose ages are more than ten years, as the older date trees are more vulnerable compared to the young date trees. Palm trees need a few years to develop adaptive mechanisms according to different irrigation conditions e.g., drip irrigation. Finally, drip irrigation requires maintenance before the date season; however, the high costs of maintenance processes have made farmers refuse to maintain the drip irrigation system. This has led to inefficiencies in drip irrigation in Libyan date palm farms. There is a need to improve the efficiency of using drip irrigation to deal with water scarcity by improving irrigation systems and training farmers on how to properly use and maintain the irrigation system, so their cost will go down.

Manure has a negative effect on date palm production. This finding is in contrast to some studies (Aisueni et al., 2009; Narala & Zala, 2010). Indeed, the negative effect may be derived from the resistance to change of old farmers from their previous practice and techniques to more modern and improved methods. One interesting finding is that some date palm farmers did not use fertilisers at all. They believed that the Sebha land is the land of date palm trees, thus the date trees do not need fertilisers. However, some farmers may apply manure without knowledge about requirements of date palm in terms of quantity of manure and timing of application. In addition, foreign labour coming from African countries that do not produce date palm did not have experience of fertilizer programs for date palm trees under Libyan conditions. Therefore strengthening and activation of the weak agricultural extension office in providing information about appropriate use and dosage and other fertilizer options especially for farmers who have lower level of education is important.

It can be noted that date palm farmers tend to apply manure more than any other fertilizers because of the high prices of fertilizers especially after the civil war in Libya in 2011. Many farmers do not have enough financial resources to purchase inorganic fertiliser. This leads to many date farmers using manure as an alternative to fertiliser (as evidenced in survey data). One of the advantages that encouraged the use of manure is that date palm farmers can easily make manure in their farms with relatively small costs. Sometimes farmers can obtain free manure from other farming friends and relatives who have livestock on their farms. Hence, to make the most of this, farmers need to be trained on the appropriate application of manure to maximise production.

Based on the current study, a number of conceptual relationships can be as illustrated in Figure 9.11. In the conceptual framework below, several factors that may affect the productivity of date palms and how they relate to each other are shown.

This framework is developed based on the current empirical evidence from the case of date palm productivity in the Sebha region through the lens of production possibility frontier and Cobb-Douglas production function models. This framework provides the basis to analyse four (4) important characteristics which affect date palm productivity under different irrigation systems (see Figure 9.11). Based on the framework, several factors that may affect the productivity of date palm and how they relate to each other have been identified. The four main characteristics identified within the framework developed include:

(a) Farmer characteristics, such as family members.

(b) Farm and agronomic characteristics, such as distance between trees; distance between trees and pesticides; distance between trees and amount of water.

(c) Irrigation characteristics, such as amount of water; type of irrigation system

(d) Other characteristics, such as pesticides; pesticides with number of trees; labour; labour with number of trees; manure; manure with number of trees.

The current framework can be compared with other frameworks in the relevant literature. For example, Adesiji et al. (2013), Shaloof and Areada (2010),Sperling et al. (2014), developed a conceptual model about the relationship between productivity of date palm cultivar and farmer characteristics and environmental characteristics including farm location, uses of date palm, farming experience, education, income, household size, drought and diseases. The model developed in this study brings new insight and contributes to the existing literature by including four main characteristics (farmer, farm and agronomic, irrigation and other characteristics) into the analysis of date palm productivity. Several studies including Saeed, Sadegh, and Maryam (2014); Adesiji et al. (2013); Alsughayir (2013); Shaloof and Areada (2010); Karami (2006) failed to capture all these factors and characteristics in their research.

In relation to the farm and agronomic characteristics, other previous conceptual models only reported separately the effect of pesticides and water, and the effects without the interaction with distance between trees on the productivity of date palm (Belloumi & Matoussi, 2006; Ismail , Durwish, & Alalaiwi, 2008; Shaloof & Areada, 2010). However, this current study has tested different interactions between various factors under the farm and agronomic characteristics. In particular, the study revealed that the interactions of distance between tree with both pesticides and water have a significant impact on date palm productivity. Thus, including the interactions of distance between tree with both pesticides and water makes a new contribution to the current literature. Moreover, this framework explains how the number of trees and soil type affects productivity, thus adding new insight to the literature.

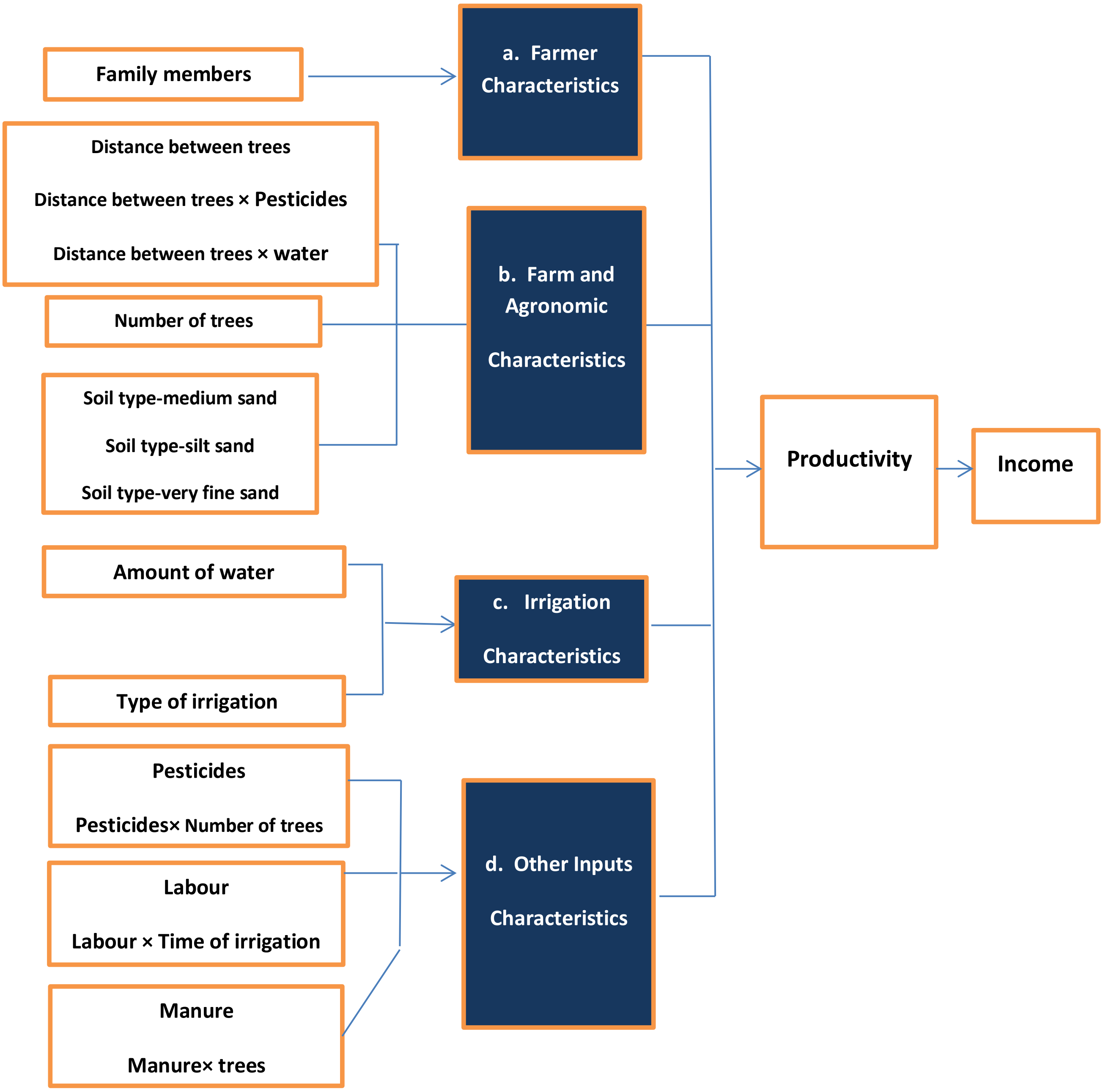

Figure 9-11: Empirical framework of factors influencing crop productivity

In developing this framework, the effects of irrigation systems on dates were examined in terms of productivity and efficiency, in addition to the physical and chemical characteristics. This thesis has considered calls by Karami (2006) who developed a conceptual model of analytic hierarchy process (AHP) for selecting appropriate irrigation systems, such as surface and sprinkler irrigation. The author suggested that future studies need to apply factors or tools which could improve extension programs and farmer decision making processes. This framework considered such factors by capturing how and which type of irrigation systems is suitable for increasing productivity, efficiency and fruit quality in Sebha, Libya.

In Iran, for example, Saeed et al. (2014) developed a model of factors affecting the adoption of new irrigation systems for farmers under five characteristics. They confirmed only social, environmental, economic, support and individual factors that affect irrigation systems and productivity of different crops. However, their study failed to capture the time of irrigation and amount of water in the analysis. However, this model captured the specific characteristics of irrigation systems (i.e., time of irrigation and amount of water) and how they impact on the productivity and adoption of the different type of irrigation systems. Indeed, the current model provides a broader perspective (view) which can support individual farmers to make good decisions that are more appropriate with respect to the selection of different irrigation methods.

9.7.2. Technical efficiency of irrigation systems for date palm farms

As previously presented, the coefficient for the number of trees per hectare is significant and positive under the surface, sprinkler and drip irrigation (at 5 per cent for drip and surface irrigation and 10 per cent for sprinkler). This indicates that the productivity of date under the various irrigation methods increases with the increase in the number of trees. This result is consistent with previous literature presented in Chapter 4 by Altarawneh and Ebraheem (2013) who reported that the number of date palm trees has a significant effect on production and efficiency of date palm in Jordan. Currently, there is an expansion in the cultivation of seedlings (date palm offshoot) in many projects and individual farms by the Libyan Development Date Palm Center under different irrigation systems (Libyan Date Centre, 2007). Kassem and Lairje (2012) reported that Libya has the potential to increase the number of date palm trees due to the availability of land suitable for different cultivation of palm trees. However, this result does not agree with Alshuaibi (2011) and Belloumi and Matoussi (2006) who claimed that farm size, soil type and number of trees and distance between trees negatively affect date palm production and efficiency in Saudi Arabia and Tunisia.

Amount of water. The technical efficiency of amount of water per hectare is also positively and significant in the surface and drip irrigation at 5 per cent. Current findings in this study are in contrast with the results of Al-Jamal et al. (2001) who indicated that sprinkler irrigation water is more efficient compared to drip and surface irrigation. Likewise, Younis and Ahmad (2012) revealed that increasing the quantity of irrigation water by one per cent dropped wheat production in Iraq by 0.81 per cent. This led to a waste of water resources and a decrease in technical efficiency.

Labour. In this thesis it can be seen that the labour under surface irrigation only has positive and significant effect on efficiency compared to sprinkler and drip irrigation. This is because date palm farms in Sebha, Libya totally depend on human labour such as family and hired labour for irrigation options. In Saudi Arabia, Al Kahtani and Ghanem (2013) provided evidence that indicated that an increase by one per cent in labour led to increased date production and efficiency. Narala and Zala (2010) found factors, such as labour in farms affect technical efficiency of individual farms in Gujarat.

Pesticides. The efficiency estimate of pesticides is positive and significant at 10 per cent under drip irrigation only. This can be explained by the fact that the majority of date palm farmers under drip irrigation rely on higher quality of pesticides with specialised labour compared to surface and sprinkler irrigation. Thus, because of the positive effect of pesticides on productivity, it will be beneficial for farmers to apply pesticides.

Manure. Manure has a negative effect on productivity of date palm under drip irrigation. The current results do not agree with the results of Marzouk and Kassem (2011) and Narala and Zala (2010) who reported that higher manure may lead to increasing technical efficiency and production of date palm and rice crops in Egypt and Gujarat. However, the results of this study is similar to the results of Belloumi and Matoussi (2006) who reported that there is a negative relationship between farmyard manure and efficiency of date palms. Drip irrigation is a sensitive system compared to surface and sprinkler irrigation. Most Libyan farmers do not use a filter to reduce blockage of the emitters and remove clay and organic matter, whereas this is important for drip irrigation. Moreover, there is a need to replace emitters every season (Bralts & Wu, 1980; Brinegar & Ward, 2009; Hansen, W, et al., 1980). According to Capra and Scicolone (2007), drip irrigation requires clean water to avoid emitter and filter clogging by suspended solids from different types of fertilizers. Clogging occurs mainly due to the passage of water containing suspended particles, salts and dissolved fertilizers through the very fine pores of the emitters (Skaggs, 2001). Both solutions for the clogging problem require more time and huge running cost to maintain the system (Gilbert et al., 1981). Thus, drip irrigation maintenance is expensive.

Interaction between number of trees and amount of water. In sprinkler irrigation, the interaction between the number of trees and amount of water were found to be negative and significantly affects productivity at the 5 per cent level. According to the Date Palm Centre (2007), each hectare should have 150 palm trees. An increased number of trees leads to a short distance between trees and sprinkler irrigation. Zaid (2002) reported water can enter from above into the growth point of the date palm plant.

This may affect efficiency of palm trees. In previous studies, Zaid (2002) focussed on the effect the quantity of water had on efficacy of date palm only. This thesis provided new information about the interaction between the number of trees and the amount of water that has led to low efficiency in date palm farms in Sebha.

Interaction between number of trees and labour. The interaction between the number of trees and number of labour has a negative and significant effect on productivity at 5 per cent level of significance. The higher the number of trees, the more labour is required for managing sprinkle irrigation. However, the majority of farms have low experience (hired labour) in managing this system, especially with regards to maintenance of the irrigation systems.

Interaction of amount of water and manure. The interaction of the amount of water and manure has a positive impact on the productivity of date palm farms under sprinkler irrigation. Belloumi and Matoussi (2006) reported that there is a positive relationship between quantity of water and efficiency and a negative relationship between manure and efficiency of date palm farms. Al-Jamal et al. (2001) finding is similar to the results of Belloumi and Matoussi (2006), however Al-Jamal et al. (2001)

studied different crops. The implication of the interaction of amount of water and manure is that developing both manure and water management practices of date palm farmers is important as this leads to positive effects on date palm quality and productivity.

Age of farmers. In surface irrigation, the age of farmers has a negative effect on the productivity of date palm farms. This finding is similar to Al-Subaiee et al. (2013) who found that date palm farmers between 30 and 70 years old tend to be slow in adopting technology to improve technical efficiency. This is because surface irrigation requires labour and there are difficulties in managing physical efforts compared to sprinkler irrigation. As date palm farmers become older, their physical effort is reduced, which results to lower level of efficacy according to Zaid (2002) and (James, 1993).

Schooling of farmers. High level of schooling of farmers led to increasing the productivity of date farm under sprinkler irrigation compared to surface and sprinkler. This is because the farmers have used the sprinkler irrigation for date palm and other crops in the same farm and they have more experience in managing this system. In addition, farmers who are more educated, are more likely to access and obtain information from the Office of Agricultural Extension which encourages them to adopt and use improved inputs (Ezebilo et al., 2013; Khan et al., 2009). This thesis does not agree with Khan et al. (2009) and Adesiji et al. (2013) who found a negative relationship between farmers who have less education and date production in Pakistan and Nigeria. However, the finding of the current thesis is consistent with Wang et al. (1996), Perz (2003), Tabi et al. (2010) and Sherif and Dar (1996). Wang et al. (1996) suggested that farmers who have higher education are more efficient than those with lower education in improving agricultural practices and outputs. Khan et al. (2009) demonstrated a significant role for both formal and agricultural education in raising the efficiency and date palm cultivation in Pakistan.

Family members. The number of family members has a negative and significant relationship with the productivity of farms at the 5 per cent level of significance. This result is inconsistent with the findings of Das et al. (2010), Adesiji et al. (2013) and Ezebilo et al. (2013). On the other hand, the current thesis is consistent with Al-Yahyai (2006). This result is interesting for date palm farms in Libya, due to the different cultures in the Middle East. Date palm farmers in the study area have two or three wives and an average of more than 6 members (see Chapter 6, Section 6.2). Farmers in the Sebha region spend large incomes on basic needs of their families such as food, housing, rent and electricity (Yasmeen et al., 2011). The higher prices especially after the Libyan civil war in 2011 has also led to increased prices of agricultural inputs such as fertilizer and hired labour used in farms.

Type of soil (coarse sand). Productivity of farms with coarse sand is higher than that of farms under clay sand (the base soil type) in surface irrigation**.** This finding of the thesis is inconsistent with Belloumi and Matoussi (2006) and Shaloof and Areada (2010). Saline soil type had a negative impact on date palm production, also reported by El-Juhany (2010). Jaradat and Zaid (2004) and Chao and Krueger (2007) considered the type of soils for example as the key constraints of date palm production in Libya. Wollni and Brümmer (2012) reported that technical efficiency of farms is positively influenced by the quality of the soil. This represents an important implication to government projects and private farmers in terms of expansion in lands that have a type of coarse sand.

Time of irrigation. This thesis confirmed that the time of irrigation has a significant impact on efficiency in the study area in Sebha, Libya, but the effect is negative. The time of irrigation has a negative effect on efficiency under drip irrigation, because farmers do not have enough knowledge about this method especially for date palm. In addition there is a wide difference in the number of hours in drip irrigation from farm to farm. Given the significance of this variable, it is important for farmers to be trained in this areas particularly new farmers who are preparing to cultivate palm trees.

Distance between trees. The distance between trees has a positive and significant effect on productivity, so can improve date palm efficiency. This findings is in agreement with Puri and Bangarwa (1992), Puri et al. (1994) and Latifian et al. (2012). This is because the increase in distance between trees leads to decreased pests and weeds in the study area. Some authors such as Shaloof and Areada (2010) and Belloumi and Matoussi (2006) and Jaradat and Zaid (2004) and Chao and Krueger (2007) confirmed that distance between trees has a positive effect on efficiency.

9.7.3. Cost and returns of date palm per hectare

The cost and returns of date palm production differ under the three different types of irrigation systems in Sebha region, as expected. Table 9 presents data on the average cost of date palm production. As shown in the table, total costs under sprinkler irrigation system was higher at about 13 148 LD when compared to surface and drip irrigations. The income generated under surface irrigation is higher, which is estimated at about 6835 LD followed by drip irrigation at 3661 LD and 2814 LD for sprinkler irrigation.

Table 9-8: The average cost of income from the different irrigation systems (per hectare) in Sebha region

Items	Surface irrigation	Sprinkler irrigation	Drip irrigation
Total cost (LD)*	11390.00	13148.45	12664.67
Area (h)	4.71	4.36	3.98
Cost of hectare	2418.25	3015.69	3182.07
Income per hectare(LD)	9253.30	5829.65	6843.34
Net income (LD)	6835.05	2813.96	3661.27

* Includes the fixed and variable costs

9.8. Conclusion

The goal of Chapter 9 was to examine the effect of a set of variables, such as irrigation methods and farmer characteristics on the productivity and efficiency of date palm production. This chapter started discussing the irrigation systems used by farmers in Sebha, Libya. The chapter has provided new insights into the advantages and disadvantages of the various irrigation systems, problems encountered by farmers in Libya and the factors that affect the productivity of palm tree production under various irrigation systems. The solution suggested by farmers to deal with the problems including e.g., timing of irrigation, canal maintenance, repair of wells and water control were examined. Furthermore, the chapter analysed and discussed the effects of irrigation systems on date palm production models and the technical efficiency of farms under various irrigation systems. Finally, the chapter discusses the distribution of technical efficiency of date palm farmers who used surface, sprinkler and drip irrigation in the study area.

Chapter 10

Conclusion and Policy Implications

10.1. Introduction

This chapter is devoted to the summary, conclusion and implications of the research. The next section summarises each chapter of the thesis. The main findings of the study to answer the research questions about date palm production in Sebha, Libya are also presented. The contributions, implications, limitations and future research are then presented.

10.2. Summary of the thesis

The aim of this thesis is to analyse the effect of irrigation systems on date palm production in Sebha, Libya. The research problem this thesis focused on is on what irrigation system is more effective in increasing farmers' productivity and on how date palm farmers can improve the productivity of their date palm production to increase their income and contribute to the Libyan agricultural sector and fight poverty. Hence, the main objectives of this research were:

1. To determine the variables affecting the productivity of date palm and income of date palm farmers in the Sebha region
2. To assess the effects of different types of irrigation system on fruit quality of an commercially important cultivar of dates (Talees dates) in South Libya
3. To assess the economics of date palm production under different types of irrigation system
4. To assess the pros and cons of different types of irrigation system for date palm production

Chapter 1 provided an introduction and covered the background which was followed by an elucidation of the research problem, comparison of irrigation systems, research questions, objectives, and research approach, significance of the study and thesis outline. The main issues faced by date palm farmers in the Sebha region are the limited irrigation water and technology. The current Agricultural Centre and the Date Palm Centre in Sebha concentrated more on how to increase production with small quantities of water.

Chapter 2 provided detailed information regarding the farming systems in Libya. It also described the impact of oil revenues on the economic development of the Libyan economy, especially on the domestic agricultural sector. A general background of Libya was also provided in the chapter. Chapter 2 also discussed the Libyan economy before and after the discovery of oil, and the importance of agriculture to the Libyan economy. This chapter described the major agricultural crops and the farming systems and agricultural societies in Libya.

Chapter 3 provided detailed information about the economic importance and production of date palm in Libya. The chapter described the botanical structure of date palm and importance of dates. The economics of date production in Libya and constraints of date palm tree production were discussed.

Chapter 4 is an overview of irrigation systems currently used in Libya. This chapter focused on the importance of managing water, water resources, and water balance in Libya, as well as the water requirements which help in determining the water needs of date palm trees. It also compared date palm irrigation technologies used in Libya.

Chapter 5 is an overview of development of the conceptual framework. The chapter commenced with a review of the literature on the variables that influence crop production. This chapter presented the existing literature on the factors influencing crop productivity of date palm. Farmer characteristics, farm and agronomic characteristics, irrigation characteristics and other input characteristics were discussed. Finally, the conceptual framework was presented and discussed.

The methodology was outlined in Chapter 6. The chapter outlined the study paradigm and provided an overview of the rationale of the methodology employed in this study. Data gathering method included the type of data, the data collection methods and a design of the questionnaire. The limitations of data collection processes were outlined. In addition, economic analysis of date palms production under irrigation systems was discussed. The analytical methods (procedures) that were employed for the estimation to obtain reliable results were outlined. The model specification including required data and variables according to the conceptual framework were discussed. The physical and chemical characteristics of “Talees” dates were analysed and finally, the ethical issues considerations in the research were also discussed.

Chapter 7 then presented part of the results. This chapter described the research study site, characteristics of farmers and the main background of respondents, especially age, schooling, farming experience, family members and farm household income. This chapter also discussed characteristic of farmers' income, described date palm farms and compared date palm production under the three irrigation systems. In addition, the characteristics of irrigation and characteristics of labour used under various irrigation systems and the output of date palm farms under different irrigation systems. The household goals of farmers were also discussed in this chapter.

Chapter 8 then addressed objective 4 examining the effects of different irrigation systems on fruit quality of date palm cultivar ‘Talees’ at different locations in the Sebha region, Libya. It discussed the results of the thesis with the existing literature related to the study, including studies about dates. The findings of the materials and methods of physical and chemical analysis were discussed.

Chapter 9 was an overview of the irrigation systems used by respondent farmers in Sebha, Libya. This chapter presented the advantages and disadvantages of irrigation systems and the issues faced by farmers using the various irrigation systems for date palm production and the proposed possible solutions. Chapter 9 addressed objectives 1, 3 and 4 by analysing and discussing the effects of irrigation system on date palm production models and the stochastic frontier analysis for examining technical efficiency under different irrigation systems. In addition, the distribution of technical efficiency of date palm farmers who used surface, sprinkler and drip irrigation in the study area was discussed.

10.3. Summary of main findings

The thesis findings addressed the research questions below and were answered in Chapters 7, 8 and 9:

1- Does type of irrigation system have an effect on date palm production and income in the Sebha region, Libya?

2- What is the most economically efficient irrigation system for date palm production in the Sebha region, Libya?

3- Does irrigation system have an effect on water use efficiency and fruit quality in dates?

4- What other factors influence production, productivity and income of date palm farmers in the Sebha region?

The sections below provide more details: about the findings of the study.

1. Does type of irrigation system have an effect on date palm production and income in the Sebha region, Libya?

This study divided the findings related to the first research question into two segments. The first segment provided empirical evidence of the Libyan irrigation system with the aid of aggregate level data through an empirical regression model and descriptive statistics techniques.

This study examined the effect of irrigation system on date palm production and provided an indication of changes to productivity in Sebha, Libya. The factors were statistically significant for all three irrigation systems such as type of soil and amount of water. However, some factors did not have any statistical significance on production such as the age of farmers, time of irrigation, number of family members and schooling of farmers under OLS model. This robustness of the study results is driven by the statistical approach employed in the analysis of the data. Primarily, the regression used provided a more detailed explanation of the variables that affect date palm production under the different irrigation systems in Libya within the study period.

The other part of the first research question was to investigate the relationship between quality of date variety and irrigation systems using experiments in one season. This study applied two analytical techniques; the researcher considered the chemical and physical composition to examine date fruit quality. Clearly, the findings suggest that the different irrigation systems do not have any significant effect on the quality of Talees dates.

The thesis's findings provided direct and indirect evidence about the effects of type of irrigation systems on date palm production. These findings also provided contributions to the date palm and irrigation literature. For example, the findings revealed that, the type of irrigation system, type of soil and distance between trees have an effect on productivity. In addition, the findings showed that interaction between some variables (e.g., number of trees and labour, and amount of water and manure), have an effect on productivity.

2. What is the most economically efficient irrigation system for date palm production in the Sebha region, Libya?

The findings regarding the second research question suggested that the performance of irrigation systems are different in Sebha, Libya. The main irrigation systems used were surface irrigation, sprinkler irrigation and drip irrigation. Many farmers used two or multiple irrigation systems in their farms. This is because the use of proper farming techniques such as modernizing traditional irrigation schemes, which focused on prudent water use and water saving techniques is a requirement for the adoption of agricultural irrigation (Oweis et al., 2011; Pereira et al., 2012).

The average area of the majority of farms under surface irrigation is 4.71 hectares, while the average area of farms under sprinkler irrigation is 4.36 hectares. Meanwhile, the average area for farms under drip irrigation is 3.98 hectares. Further, surface irrigation is used for all types of crops and has high capital investment per hectare, especially for vegetables and fruit trees. Due to the benefit of reducing irrigation water requirements levels, drip irrigation system has become the most commonly use irrigation system among farmers in Libya (Carr, 2013). The Food and Agricultural Organization (2008) and Monteiro, Kalungu, and Coelho (2010) observed that in most North African countries including Libya, governments are supporting farmers with subsidies to apply sprinkler and drip irrigation systems for agricultural crops.

The first objective under the fourth research question sought to investigate date palm efficiency production among the various irrigation systems in date palm farms. The researcher conducted fieldwork in a total of 210 farmers to gather farm-level data. The fieldwork was conducted in one of the drought prone regions in Libya, which is the Sebha region.

Stochastic frontier analyses technique (SFA) was used to analyse the data. This research found dissimilarities in the efficiency level among date palm farmers in the Sebha region. Measuring technical efficiency through the lens of the SFA frontier suggested that farmers who use sprinkler irrigation systems shows that the technical efficiency was higher for date palm farms using sprinkler irrigation.

An estimate of the mean technical efficiency score suggests that on average, date palm farmers achieve a technical efficiency score of about 89 per cent. It can be concluded that date palm farmers using sprinkler irrigation achieved a high level of technical efficiency (TE > 90).

In this study, the researcher used the translog model to analyse technical efficiency of date palm farms using sprinkler irrigation systems (see Chapter 9). This thesis found that the number of tree squared, the interaction between the quantity of manure and water used, and the number of trees are positively related to technical efficiency, whereas, the number of trees and labour, manure squared, pesticide squared, interaction of number of trees and quantity of water are negatively related to technical efficiency. However, overall technical efficiency is positively correlated with the schooling of farmers and distance between trees and negatively correlated with family members.

In date palm farming, drip irrigation was found to have a lower effect on productivity of date palm farms compared with surface irrigation at 10 per cent levels, however, the sprinkle irrigation was found to have a higher effect on productivity of date palm farms compared to surface irrigation at 5 per cent level in Sebha, Libya. However, the average irrigation consumption date per tree in the season by sprinkler irrigation of about 40.83 litres was less than surface (49.48 litres) and drip irrigation (42.11 litres) (see Chapter 7 in section 7.7.2).

This research provided empirical support about the implications of the different irrigation systems on the efficiency among date palm farmers in the Sebha region. For example, dummy variables in this study observed that the different irrigation systems have different effects on date production as these dummy variables were statistically significant. This study also provided evidence and comparisons that are important for date palm farmers and date palm projects in Sebha, Libya for adoption of irrigation technology.

3. Does irrigation system have an effect on water use efficiency and fruit quality in dates?

The thesis also sought to document date palm farmers' perceptions of irrigation systems as well as exploring the determinants of date palm farmers' adaptation strategies within the different irrigation schemes. The analyses were determined by the type of irrigation and locations of date palm farms. The present study introduced important information about the effectiveness of irrigation systems on 'Talees' dates at different locations in Sebha, Libya. The information is most important in deciding the suitability of different irrigation systems for date palm especially in regions limited in water resources. The results showed that irrigation systems significantly affected only fruit weight whilst fruit breadth and length, pulp thickness, stone weight, stone width and stone length, individual sugars and organic acids were not significantly affected by irrigation systems. When averaged over different irrigation systems, the mean fruit weight, breadth and length, pulp thickness, stone breadth and length were significantly influenced by location. The interactions between different irrigation systems and location were found to be significant ($p \leq 0.05$) for fruit weight, breadth and length, pulp thickness, stone breadth and length. In conclusion, the irrigation systems did not influence fruit quality whilst, location of growing date palm in Sebha region, Libya influenced fruit quality. Thus, farmers also took other adjustment of irrigation mechanisms including use of irrigation system with less quantity of water (water saving) and low cost of energy. Knowledge inadequacy and lack of information on fruit quality were identified by farmers as barriers to appropriate irrigation adaptation strategies.

4. What other factors influence production, productivity and income of date palm farmers in the Sebha region?

Different models were applied to examine potential explanatory (dependent) variables to analyse the determinants of productivity. The explanatory variables in this model included farmer characteristics, farm and agronomic characteristics, irrigation characteristics and other inputs. The model was tested using different empirical models to test for the effect on date palm production. The model was free from multicollinearity problems as confirmed by the Variance Inflation Factor (VIF). Other factors such as age, education, farm size and farming experience were all important determinants of productivity.

In general, the fourth research question addressed other factors that affected date palm production under surface, sprinkle and drip irrigation. The researcher found other factors that have not been studied before, in particular for date palm trees in Sebha, Libya, which include type of soil, number of trees, amount of water, sprinkler irrigation, drip irrigation, labour and manure. All these factors were applied and analysed in Middle Eastern and North African countries and some results are consistent with the current thesis while others are not consistent with this thesis.

Results of this study showed that distance between trees was found to have a significant effect on production. In addition, all models showed that sprinkler irrigation has a higher effect on productivity of date palm per hectare compared to surface irrigation technology, which included border, basin or furrow irrigation at 5 per cent level. The interesting finding is that drip irrigation has a lower effect on productivity of date palm compared to surface irrigation at 10 per cent level.

Moreover, the interaction between labour and time of irrigation has an effect on production of date palm in the study area. The number of trees, amount of water, sprinkler irrigation, drip irrigation, labour, pesticide and manure were all important variables that can impact on date palm production. However, in terms of quality of fruit of Talees, all irrigation systems were found to not have a significant effect on both physical characteristics and chemical characteristics of date palm in the Sebha region (Al-zighan, Ghodduwa, Samnu and Tamanhant), Libya.

10.4. Contribution of this research

The contributions of this study are discussed below:

10.4.1. General contribution

Libya is one of the countries that is most vulnerable to lack of water irrigation systems. Date palm is important for the Libyan economy (Edongali & Aboqilh, 2005; Harris, 2003). It is a source of food for the Libyan community, cultural value and even other industries depend on date products (Edongali & Aboqilh, 2005; Harris, 2003). The date production is influenced by different irrigation systems, yet there is no known comprehensive research conducted that examined the effect of different irrigation systems on date palm production using econometric, physical and chemical analysis. The contribution of this thesis is based on the fact that it is among the first to be conducted in Libya looking at these three aspects, thus the findings will have both policy and practical implications for date palm production in Libya. This analysis was significantly enhanced by using both survey and experimental data. Thus, this shapes an important contribution to the literature and to the local authorities as well as state agencies in charge of the date palm sector in Libya.

10.4.2. Methodological contributions

This study is among the first known study in Libya to apply econometric models using cross section data in the analysis of date palm productivity. This is the first study that combined both statistical methods and experimental methods to analyse data about date palm in Libya. Thus, this is a significant contribution in date literature. By examining the most popular irrigation systems in Libya, this research has uncovered that different irrigation schemes have dissimilar effects on date palm crop yields which implies a need for specific crop variety studies. Previous literature mostly used panel data set to examine irrigation schemes effect on crop yield without considering the dissimilar impact of the different irrigation schemes on crop yield. This thesis has addressed this literature gap.

Although a number of empirical studies have been conducted through the lens of the stochastic frontier model as an estimation of technical efficiency (Bravo-Ureta & Pinheiro, 1997; Henningsen & Henning, 2009; Klemme, 1985; Llewelyn & Williams, 1996; Onumah et al., 2013), no known studies have applied the input-specific concept of technical efficiency to estimate irrigation systems use efficiency in date palm farms in Libya. In this regard, this research is amongst the first to advance the input-specific concept of technical efficiency to estimate irrigation system use efficiency in date palm farming in Libya.

10.4.3. Sample of study contribution

This thesis also contributed to gaps in previous literature differentiating the diversity of samples as some studies failed to acknowledge the diversity in the samples in their analysis. This thesis analysed the samples under three different categories including surface, sprinkler and drip. In addition, the thesis also sought to examine the extent of date palm farmers' perception about the use of the various irrigation systems. It was relevant to include this in the study because adaptation of irrigation systems may be strengthened if the issues and constraints for each system is well understood. This study has provided a clear comparison of the type of irrigation systems for local farmers and the Libyan Agricultural and Water Ministry. In particular, comparison results include for example, type of dates, characteristics of irrigation labour, irrigation systems, inputs used and outputs of dates including market of type of date under different irrigation systems. In addition, the thesis provided findings about advantages and disadvantages under different irrigation systems for date crops. Finally, the thesis provided findings about important effects of factors on performance of irrigation systems and proposed solutions. For example, the comparison of average revenue from Talees dates between surface irrigation, sprinkler and drip irrigation implies that the government should facilitate support to irrigation systems that have higher profitability than others with lower productivity of date palm. Moreover, the majority of variables, for example distance between trees and type of soil, that are examined here have not yet been examined within the date palm and irrigation systems literature. Comparing the determinants of variables using different model regression makes the regression results even more robust.

10.4.4. The economics of irrigation system contribution

Indeed, this research is among the first to explore factors that influence farmers adaptation of irrigation systems in Libya using econometric models and contributes to the understanding of irrigation systems. The thesis has provided new evidence and contributes to the date palm literature in Libya. This thesis also provides information on economic benefits individual farmers in their choice of the different irrigation systems. Economic policies that will guarantee access to low interest rate credit facilities have the potential to increase date farmers financial capabilities to meet adaptive measure expenditure. Availability and accessibility to timely extension services could strengthen and enhance date palm farmers' level of irrigation schemes awareness and knowledge related to adaptation measures in Libya. The above mentioned policies can contribute to the reduction of vulnerabilities among date palm farmers. Finally, promoting farm level adaptation strategies provide avenues to boost and increase food security.

10.4.5. Overall theoretical contribution

Overall, this thesis has provided theoretical contribution in terms of bringing to light previously unrecognised variables that influence productivity of date palms as discussed above. This research has corroborated the use of the theories within individual date crop farming and different irrigation systems within a developing economy's context.

10.5. Implications

The impact of the irrigation system on date palm farming by different irrigation systems has been examined in this research. Econometric techniques were used, and the results were reported and summarized from Chapters 7 to Chapter 9. The following recommendations and implications are made based on the empirical evidence provided on Libyan date palm industry under the different irrigation systems used by farmers.

10.5.1. Implication for irrigation system

The irrigation technology such as sprinkler irrigation has been used successfully for date palm in North African such as Libya, Tunisia and Egypt (Monteiro et al., 2010). However, this technology is still used to a limited extent by date palm farmers in Libya and especially in Sebha. Therefore, the government and policy-makers should disseminate information about drip systems to the farmers, as this technology can play a role in helping farmers use low quantities of water without any adverse effects on fruit quality of dates. The researcher, therefore, recommends the establishment of a training program targeting date palm farmers at the districts of Al-zighan, Samnu, Tamanhant and Ghodduwa which could be part of the agricultural extension services unit. A study looking into the provision of plumbing and field water tubes by the government through the agricultural extension service unit, may also be worth investigating.

10.5.2. Implication for date palm farms

This study found that although many farmers have high technical efficiency scores, several farmers are still operating inefficiently, hence there is still room for improvement. Areas where farmers can improve efficiency include improving efficiency of water use, training the labour force, improving availability of pesticides, updating irrigation systems and training farmers on the use, care and maintenance of their irrigation systems. Farmers' knowledge on various aspects also need to be improved, for example the proper use of organic fertilisers including manure. Many farmers use manure for fertilizing date palm because organic fertilizer is expensive. However, farmers need to know the proper application rates to improve their productivity. Proper use of manure is likely to have a positive impact on production and will also help diversify risk and increase their income sources to improve their living standards.

10.5.3. Implication for education

Primarily, date palm farmers' level of awareness has also proven to be an important determinant in the different irrigation adaptation; hence more farm level visits are needed by officers in charge of agricultural extension services as this could be an avenue to educate farmers on the benefits of the use of irrigation schemes in date palm farming. Overall, the government through the Libyan Ministry of Agriculture can develop an informal educational program to target young farmers without any formal education. This can be a platform to develop the interest of the youth and attract them into date palm farming.

10.5.4. Implication for different characteristics

According to the result of the models, there are important determinants, which are human labour, level of education, and numbers of trees which have significant impacts on productivity. The researcher recommends government develops a policy that seeks to improve these determinants to enhance the abilities of farmers to work effectively in difficult conditions, that is, reduce their vulnerability. Thus, there are three policies that should be made: firstly, providing enough inputs at affordable costs to date palms farmers; second, creating more agricultural banks to provide financial resources to small farmers at four locations, which are Al-zighan, Samnu, Tamanhant and Ghodduwa. Finally, facilitating farmers to form co-operatives to share knowledge and experiences that could also help improve their level of awareness and make it easy to receive support in the form of training or credit facilities to expand their production.

10.5.5. Implication for physical characteristics

The physical analysis on date palm revealed that the type of irrigation had no significant effect on fruit quality of Talees dates. However, weight of fruit has been influenced by three irrigation systems, which are: surface, sprinkler and drip irrigation. These results are very important to the industrial sector and marketing of dates for farmers. The physical analysis can play a significant role in enabling industrial engineers to design appropriate containers that should be suitable during storage, transportation and market distributions for both public and private date palm farms. Although, there is an ongoing date palm production particularly in desert areas in South Libya, policy makers should provide financial resources to researchers to examine different characteristics of other types of dates in these projects. This can lead to building databases about the Libyan dates in Sebha, region. The different irrigation systems, such as drip, sprinkler and surface systems, have no significant effects on various fruit quality characteristics of Talees dates, as shown in Chapter 8; thus, the Libyan farmers must give a priority of using irrigation systems that uses less quantity of water or results to higher productivity.

10.5.6. Implication for chemical characteristics

The chemical analysis on Talees dates revealed that irrigation system does not have any significant effect on levels of individual sugars and organic acids in different locations in Sebha, Libya. Thus, policy makers should focus on date palm varieties, especially Talees in different locations in Libya for finding which varieties have better fruit quality in terms of chemical characteristics that are important in the importing processes. Therefore, Libyan farmers should give a priority of using irrigation systems that use less water or results to the highest productivity levels, because the different irrigation systems have no significant difference on the chemical characteristics of Talees dates.

10.5.7. Implication for different varieties and locations in Sebha, Libya

In Sebha, Libya, there are different locations that have significantly affected fruit quality irrespective of irrigation systems tested in the study. Thus, policy makers in these locations in Sebha should take the leading role in developing Talees dates and other varieties by disseminating information on these varieties among farmers; this can be achieved by field visits. This is because field visits can play a vital role in enhancing the abilities of farmers to improve wide varieties of dates. Moreover, government agencies such as the Centre of date palm and Agricultural Research Centre must operate in locations of Sebha region and encourage farmers to adopt quickly the varieties of dates. Agricultural extension should play a role in training local and foreign workers on the use of the internet based technologies to disseminate information. Dissemination of information to local farmers should be strengthened to ensure timely and modern irrigation systems technologies get to local farmers at the right time.

10.6. Limitations of the study

This thesis provided insights into the effect of irrigation systems on date palm production in Sebha, Libya. However, there are certain limitations inherent in the thesis that should be acknowledged like other research:

10.6.1. Findings after field work period

Findings from this thesis are based on data collected from August 2013 to October 2013, thus the subsequent analysis is based on data for one region and one year. Therefore, there is a possibility that the recent climatic conditions, economic, governmental and social developments from the end of 2013 to 2015 may affect the finding and explanations and conclusions drawn from this thesis. Moreover, economic and experimental analysis usually fails to consider inter-seasonal differences in the quantity of water irrigation required. It could well be that during the cropping season, the required survey data irrigation was higher due to climatic conditions. In this regard, further research within the different irrigation schemes must control for the differences in the inter-seasonal demand for irrigation water.

10.6.2. Data collection

The main problems faced by the researcher during collection of the data included the non-availability of written farm records from the Department of Agriculture in Sebha, Libya, and the time, budgetary constraints and illiteracy of date palm farmers. Sometimes farmers refused to give financial information due to illiteracy or fear of paying taxes. However, the memory recall process was used to collect the primary data from the farmers. This method is adopted to assist the farmers in thinking back to the agricultural operations; farmers were also asked about costs of farming activities and revenues from date palm production in previous answers to help in their memory recall process. Consequently, the memory recall process was the most practicable and reasonable way to obtain the primary data with less time and effort for this study.

10.6.3. Security of field work

Because of the safety concerns and travel restrictions to Libya, (traveling to Libya had an alert level of "do not travel" as assigned by the Department of Foreign Affairs and Trade) (DFAT), the Human Research Ethics Committee (HREC) and the Risk Management team at Curtin University recommended to the researcher to collect data during a very short time. It was recommended that the time should not be more than three months, as well as the research area should be restricted only in the Sebha region. Thus, this has led to reducing the sample size and locations. The HREC decision is due to post-civil war security conditions. The Risk Management at Curtin University followed and monitored the researcher every week by telephone and email. However, the researcher sought to minimise the impacts of this limitation through engaging some students who were from the Faculty of Agriculture, the University of Sebha as Research Assistants.

10.6.4. Experiment procedures

The experiment procedure included two parts:

10.6.4.1. Laboratory analysis

The researcher conducted the experiment under complex routines. The researcher needed to do laboratory training and free disease test for all dates sampled before starting the experiment. Sugar and organic acid analysis of dates applied in quarantine laboratory were compared to other crops, which were conducted in the Horticulture laboratory. After that, sugar and organic acid analysis were disposed correctly according to the researcher's import permit from the Department of Agriculture, Fisheries and Forestry (DAFF no. IP13013562). This is because the dates came from out of Australia. The researcher was not able to travel to Libya before the date palms were harvested to measure the humidity and temperature due to the post-civil war security conditions.

10.6.4.2. Water measurement

There are potential errors of the quantity of water consumption due to the way groundwater use was computed. This is because farmers have not installed meters to measure the level of water usage. Therefore the formula used to measure the amount of groundwater extractions was based on an assumption. The current thesis assumed that one hour equates to $1m^3$ depending on the pump power for sprinkler and surface whereas 4 to 5 is assumed for drip irrigation (see Chapter 6). On the one hand, Mosley (2005) suggests dividing the quantity of water collected in a storage tank by the number of trees. This formula failed to account for the variations in efficiency associated with water extraction with the different types of water pumps. There is, therefore, the likelihood of either under-estimation or over-estimation of water consumption.

10.7. Suggestions for future research

For the survey approach, this study develops a closed-ended questionnaire to collect data from date palm farmers. Questionnaires can be developed in future after discussion with officials of the agricultural sector at the field level particularly agricultural extension, the Agricultural Research Centre and the Libyan Date Centre officers, in the areas surveyed. The peace and order situation at that time precluded such consultation, but future studies can factor this in. Furthermore, the production analyses of date palm were based on data collected from the fieldwork survey; future research could also consider other strategies such as case studies to examine the effect of different irrigation schemes on farmer's date palm yields in Sebha.

The literature indicates that some MENA countries e.g. Egypt, Saudi Arabia, Tunisia and Algeria have a strong interest in date palm production and irrigation technology in their locations that are impacted differently by those characteristics. However, the survey part of this thesis focused on only one region in Libya. There are other areas that have different characteristics. This indicates that there is a need for more research in different parts of Libya to ensure both Libyan policy makers and researchers have a holistic understanding of the effect of the different irrigations systems on date palm production in Libya under varying farming systems. Hence, further studies should be carried out in this field to understand the different date varieties in another area in Libya. Studies in this area could generate interesting implications to influence policy directions towards the implementation of adaptation measures to address the issues with irrigation systems more effectively. Other agricultural crops such as vegetables, barley and wheat were also not included in this study; further studies on these crops could also generate interesting policy and practical implications for the Libyan government. Moreover, inter-cropping with date palms such as vegetables and fruit could be an integral component of the whole horticulture and agriculture sector; these need to be investigated. Therefore, different clusters of research could be the way forward to compare between date palm crops and other crops especially intercropping with date palm, irrigated by different irrigation systems.

Further studies are also needed to determine water use efficiency using different irrigation systems in date palm orchards on different date palm cultivars, such as Tasfert, Taghiiat and Tdhwi dates that represent a practical value to find the effects of different irrigation systems on other cultivars in different areas of Libya including specific physical and chemical characteristics. Moreover, the impacts of irrigation systems on date palm quality also requires future research attention, this area of research could look at disaggregate or aggregate levels.

Libya is currently experiencing a major challenge in water supply due to the reduction in the groundwater table, especially around the Sebha region. This problem is likely to create challenges for irrigation development. Considering the scarce nature of water resources in Libya, the researcher recommends further studies to explore the effect of the differential irrigation schemes on date palm yield in other areas in the country.

Finally, on the methodological side, the thesis employs the parametric technique, the one-stage stochastic frontier analysis (SFA), which presumes a specific functional form on the technology. The study has not employed other parametric frontier techniques, e.g., DEA approach (as mentioned in Chapter 6) to obtain alternative sets of efficiency estimates. Therefore, further research is recommended to use DEA approach to see the sensitivity of the results, especially for date palm farms.

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Appendices

Appendix A. Questionnaire

Questionnaire

EFFECTS OF TYPE OF IRRIGATION SYSTEM ON PRODUCTIVITY AND INCOME OF DATE PALM GROWERS IN SEBHA, LIBYA

For Libyan Growers Using Irrigation System for Date Palm in Sebha, Libya

Area ……………………. Data of interview ……………… ID No………………………….

1. Personal data

1.1 Date of survey ------------------------------------

1.2 Family name (optional)---

1.3 Address ------------------------------

1.4 Age of respondent ------------------ Wife's Age------------------

1.5 Marital status-------------------. ( ) Married ( ) Single

1.6 What is the education attainment of the farmer and wife (no. of years schooling)? _____ years

1.7 Do you have any informal training in farming? Yes No

1.8 How many dependent family members do you have? ------------ (members)

1.9 How many experience do you have……………… years

1.10 If you have paid occupation, how much is your salary every month? --------- (Dinar Libyan)

2. Sources of income

2.1 What are the major sources of income of your family? (Encircle primary sources)

2.2 What are the other sources of income of the family?

Sources of income	Status	Who among the family?	Income earned per year					
			Average income/Month			Months Relatively Higher		
			Husb	Wife	Others	Husb	Wife	Other
01 Vegetable Gardening								
02 Services (Laundry, haircut, labour etc.)								
03 Rentals (Land, house, room, agricultural equipment)								
04 Subsidy from other family members								
05 Remittances from abroad								
06 Poultry raising								
07 Cattle raising								
08 Other livestock(Goats, Sheeps)								
09 Fruit trees or other perennial crops								
10 Commission from sales								
99 Others, Specify								

2.2.1. Status: 01 Owner 02 Worker 99 others, specify

2.2.2. Who among the family: 01 Husband; 02 Wife; 03 Son; 04 Daughter; 05 relative of 01; 06 relative of 02

2.2.3. How much is the average annual income of your family/HH? ( )

3. Household expenses

3.1 What are the expenses of household and their average cost annually?

	11.1.3 Not Purchased Commodities/ Kinds		
11.1.1 Items	11.1.2. In cash expenses	11.1.3.1 IN Kind	11.1.3.2 Other Sources
01 Food			
02 House/lot rental fee			
03 Tuition			
04 Allowances			
05 Books			
06 School supplies			
07 School uniform			
08 Electricity			
09 Water			
10 Telephone			
11 Allowance of working			
12 Medicine/ health care			
13 Helpers			
14 Laundry			
15 LPG/ wood			
16 Clothing			
17 Furnishing			
18 Appliances			
19 Recreation			
20 Grocery items			
21 Loans			
99 Others, specify			

4. How is the farm managed during irrigation operation? Please, choose one

4.1 Family members ( )

4.2 Agricultural Company ( )

4.3 Sector Government ( )

4.4 Other, please specify (-------------)

5. How many trees do you have by age of tree? (--------) trees

5.1 Less than seven years (---------)

5.2 From seven to ten years (-------)

5.3 More than ten years (---------)

6. Land utilization

6.1What is the size of your entire farm ------------------- (ha)

6.2 Do you grow other crops in conjunction with date palm trees?

Yes ( ) No ( ). If No, go to Q 6.3 ( )

6.2.1 What other crops do you have?

6.2.2 What is the approximate land size for each crop?

6.2.3 How much is the output of crops planted?

6.2.4 What is the value?

No.	Type (6.2.1)	Area (ha) (6.2.2)	Output (Kg/h) (6.2.3)	LD/ha (6.2.4)
1				
2				
5				
4				
5				

6.3 What is the type of soil in your farm?

(1) Clay	(2) Silt	(3) Very fine sand	(4) Medium sand	(5) Coarse sand

6.4 What is your irrigation water source? Please, choose:

(1)Private well ( )

(2) Dam ( )

(3)Shared water well ( )

(4) Stream ( ).

(5) Other, please specify

6.5 What types of irrigation do you use? Pls. choose all applicable.

(1)Surface irrigation ( )

(2) Sprinkler irrigation ( )

(3) Drip irrigation ( )

(4) All of the above ( )

7. Surface irrigation

Please answer Section 3, if you use surface irrigation:

7.1. How long have you been using surface irrigation system (years)?

7.2. How many hectares of date palm do you grow under surface irrigation?

7.3. What type of date palm do you grow under surface irrigation and what is output?

No	*Type of date	Output (kg/ tree)	No. of trees	Total value
1	Tasfert			
2	Talees			
3	Taghiat			
4	Tdhwi			
5	Other (please specify)			

*This is main cultivar of data palm in Sebha region.

7.4. Do you use labour in surface irrigation? Yes ( ) No ( )

If yes, please complete this table:

Employees and payment		
Male	Family members	Hour
		Ksh/day
	Others	Hour
		Ksh/day
Female	Family members	Hour
		Ksh/day
	Others	Hour
		Ksh/day

7.5. Time of irrigation and distance each date palm trees

7.5.1 What is the time period and how long did it take you to irrigate date palm by surface irrigation?

Morning		Midday		Night	
Weekly days for irrigation	Hrs /days for irrigation	Weekly days for irrigation	Hours / day for irrigation	Weekly days for irrigation	Hrs /day for irrigation

7.5.2 How much distance usually between each date palm tree?

Tree / ha	Distance/breadth/mater	Distance/length/mater	Number of crops between each tree

7.6. Irrigation and cost

7.6.1 What is the maximum daily water consumption of the crop/tree/ pot?

Consumption of the crop /tree/pot		Daily temperatures		Daily evaporation (lost water)	
Max	Min	Max	Min	Max	Min

7.6.2 How much does it cost you per day/ hour for watering? --------- Dinar / hour

7.6.3 Fill in the following table for doing irrigation:

1	2	3	4	5	6
No. of people lifting water	Hrs per day spent lifting water	No. of days/week spent lifting water	No. of weeks/month doing irrigation	No. of months /yrs. irrigation	Total hours (1.2.3.4.5)

7.7. How much input did you use for production under surface irrigation system?

Type	Amount			Unit	Price/ Unit	Total Value
	Owned	Purchased	Hired			
Granular Fertilizer						
Complete						
Phosphate						
Potassium						
Lime						
Herbicide						
Nematicide						
Insecticide						
Fungicide						
Organic Fertilizer						
Manure						
Liquid Fertilizer						
Canal establishment and maintenance						
Seed						
Water (irrigation)						
Oil						
Petrol(Gasoline, diesel)						
Specify Equipment’s						
Synthetic Sacks						
Others						

Note: For commercial products such as fertilizer, Lime, herbicide, seed, seeds, specify name and brand

7.8. Labour utilization. How much labour did you use for your date production under surface irrigation?

	Family(3.2.1)				Hired(Daily Wage) (3.2.2)				Cost of wages(3.2.5)				
	Male		Female		Male		Female		Cash	Kind			
Land Preparation	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Days	Wage/ day	Total Cost	Type	Value
Land preparation													
Canal establishment and maintenance													
Planting													
Fertilizing													
Weeding													
Watering													
Pesticide application													
Harvesting													
Packing and storing													
Transporting													
Marketing													

Note: Children are those who are less than 18 years old.

7.9. What equipment's were used in your date production under surface irrigation?

Activity	Machinery					
	Owned		Hired			
	Hrs	Days	Hrs	Days	Price/day	Value
Land Preparation						
Clearing						
1st plowing						
Harrowing						
2nd plowing						
2nd harrowing						
Bed preparation						
Planting						
Fertilising						
Weeding						
Watering						
Pesticide Application						
Harvesting						
Packing and storage						
Transporting						
Marketing						

7.10. Date palm production under surface irrigation

Type	Harvested area	Total output (kg)	Consumed by family(kg)	Fed to animals(kg)	Gifts (kg)	Sold(kg)	Price/unit (p/kg)	Total value

7.11. Do you market your type of date palm: Yes ( ) No ( )

If yes, please complete this table

No	Type	Kg/trees	Price /kg/tree	Seedlings	Price/one seedlings	Other	Price	Lost of dates
1								
2								
3								
4								
5								

7.12. What is the main reason to choose surface irrigation for date palm trees? (Tick all applicable)

(1) Save time ( )

(2) Low cost ( )

(3) Suitable for inter cropping ( )

(4) Suitable for all types soil ( )

(5) Other, please specify……………

7.12 What are the disadvantages of surface irrigation? (Tick all applicable)

(1) Less efficient ( )

(2) More erosion and evaporation ( )

(3) High lost water ( )

(4) More labour ( )

(5) Other, please specify……………

7.13. Production constraints

7.13.1. What are the three most important factors that reduce the quality and quantity of your field under surface irrigation?

a.____
____

b.____
____

c.____
____

7.13.2 How do you think these problems can be overcome?

____
____

____
____

8. Sprinkler irrigation

Please answer section4, if you use sprinkler irrigation:

8.1. How long have you been using the sprinkler irrigation system?

____

8.2. How many hectares of date palm do you grow under sprinkler irrigation?

8.3. What type of date palm do you grow under sprinkler irrigation and what is output?

No	*Type of dates	Output (kg/ three)	No. of trees	Total value
1	Tasfert			
2	Talees			
3	Taghiat			
4	Tdhwi			
5	Other (please specify)			

*This is main cultivar of data palm in Sebha region.

8.4 Do you use labour in sprinkler irrigation? Yes ( ) No ( )

If yes, please complete this table:

Employees and payment		
Male	Family members	Hour
		Ksh/day
	Others	Hour
		Ksh/day
Female	Family members	Hour
		Ksh/day
	Others	Hour
		Ksh/day

8.5. Time of irrigation and distance each date palm trees:

8.5.1. What is the time period and how long did it take you to irrigate date palm by sprinkler irrigation?

Morning		Midday		Night	
Weekly days for irrigation	Hrs /days for irrigation	Weekly days for irrigation	Hours / day for irrigation	Weekly days for irrigation	Hrs /day for irrigation

8.5.2 How much distance usually between each date palm tree?

Tree / ha	Distance/breadth/mater	Distance/length/mater	Number of crops between each tree

8.6. Irrigation and cost:

8.6.1 What is the maximum daily water consumption of the crop/tree/ pot

Consumption of the crop /tree/pot		Daily temperatures		Daily evaporation (lost water)	
Max	Min	Max	Min	Max	Min

8.6.2 How much does it cost you per day/ hour for watering? --------- Dinar / hour

8.6.3 Fill in the following table for doing irrigation:

1	2	3	4	5	6
No. of people lifting water	Hrs per day spent lifting water	No. of days/week spent lifting water	No. of weeks/month doing irrigation	No. of months /yr. Irrigation	Total hours (1.2.3.4.5)

8.7. Input use. How much input did you use for production under sprinkler irrigation system?

Type	Amount			Unit	Price/ Unit	Total Value
	Owned	Purchased	Hired			
Granular Fertilizer						
Complete						
Phosphate						
Potassium						
Lime						
Herbicide						
Nematicide						
Insecticide						
Fungicide						
Organic Fertilizer						
Manure						
Liquid Fertilizer						
Establishment and maintenance						
Seed						
Water(irrigation)						
Oil						
Petrol(Gasoline, diesel)						
Speicify Equipment’s						
Synthetic Sacks						
Others						

Note: For commercial products such as fertilizer, Lime, herbicide, seed, seeds, specify name and brand

8.8. Labour utilization. How much labour did you use for your date production under sprinkler irrigation?

	Family (3.2.1)				Hired (Daily Wage) (3.2.2)				Cost of wages (3.2.5)				
	Male		Female		Male		Female		Cash	Kind			
Land Preparation	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Days	Wage/ day	Total Cost	Type	Value
Land preparation													
Canal establishment and maintenance													
Planting													
Fertilizing													
Weeding													
Watering													
Pesticide application													
Harvesting													
Packing and storing													
Transporting													
Marketing													

Note: Children are those who are less than 18 years old.

8.9. What equipment's were used in your date production under sprinkler irrigation?

Activity	Machinery					
	Owned		Hired			
	Hrs	Days	Hrs	Days	Price/day	Value
Land Preparation						
Clearing						
1st plowing						
Harrowing						
2nd plowing						
2nd harrowing						
Bed preparation						
Planting						
Fertilising						
Weeding						
Watering						
Pesticide Application						
Harvesting						
Packing and storage						
Transporting						
Marketing						

8.10. Date palm production under sprinkler irrigation

Type	Harvested Area	Total Output (kg)	Consumed by family(kg)	Fed to animals (kg)	Gifts (kg)	Sold (kg)	Price/unit (p/kg)	Total value

8.11. Do you market your type of date palm: Yes ( ) No ( )

If yes, please complete this table

No	Type	Kg/trees	Price /kg/tree	Seedlings	Price/one seedlings	Other	Price	Lost of date palm
1								
2								
3								
4								
5								

8.12. What are the advantages of sprinkler irrigation?

(1) Less erosion ( )

(2) Use unskilled farmer ( )

(3) Save time ( )

(4) Easy to managed ( )

(5) Other, please specify ………….

8.13. What are the weaknesses of sprinkler irrigation?

(1) Lost water ( )

(2) Non-uniform water distribution ( )

(3) Not appropriate for small palms ( )

(4) High cost ( )

(5) Other, please specify……………

8.14. Production constraints

8.14.1 What are the three most important factors that reduce the quality and quantity of your field under sprinkler irrigation?

a.____
____

b.____
____

c.____
____

8.14.2. How do you think these problems can be overcome?

____
____

____
____

9. Drip irrigation

Please answer section 5, if you use drip irrigation:

9.1. How long have you been using the drip irrigation system (years)?

9.2. How many hectares of date palm do you grow under drip irrigation?

9.3. What type of date palm do you grow under drip irrigation and what is output?

No	*Type of date	Output Kg/ three	No. of trees	Total Value
1	Tasfert			
2	Talees			
3	Taghiat			
4	Tdhwi			
5	Other (please specify)			

*This is main cultivar of data palm in Sebha region.

9.4. Do you use labour in drip irrigation? Yes ( ) No ( )

If yes, please complete this table:

<table>
<tr><th colspan="3">Employees and payment</th></tr>
<tr><td rowspan="4">Male</td><td rowspan="2">Family members</td><td>Hour</td></tr>
<tr><td>Ksh/day</td></tr>
<tr><td rowspan="2">Others</td><td>Hour</td></tr>
<tr><td>Ksh/day</td></tr>
<tr><td rowspan="4">Female</td><td rowspan="2">Family members</td><td>Hour</td></tr>
<tr><td>Ksh/day</td></tr>
<tr><td rowspan="2">Others</td><td>Hour</td></tr>
<tr><td>Ksh/day</td></tr>
</table>

9.5. Time of irrigation and distance each date palm trees:

9.5.1. What is the time period and how long did it take you to irrigate date palm by drip irrigation?

Morning		Midday		Night	
Weekly days for irrigation	Hrs /days for irrigation	Weekly days for irrigation	Hours / day for irrigation	Weekly days for irrigation	Hrs /day for irrigation

9.5.2. How much distance usually between each date palm tree?

Tree / ha	Distance/breadth/mater	Distance/length/mater	Number of crops between each tree

9.6. Irrigation and cost:

9.6.1 What is the maximum daily water consumption of the crop/tree/ pot?

Consumption of the crop /tree/pot		Daily temperatures		Daily Evaporation (lost water)	
Max	Min	Max	Min	Max	Min

9.6.2 How much does it cost you per day/ hour for watering? --------- Dinar / hour

9.6.3 Fill in the following table for doing irrigation:

1	2	3	4	5	6
No. of people lifting water	Hrs per day spent lifting water	No. of days/week spent lifting water	No. of weeks/month doing irrigation	No. of months /yr. Irrigation	Total hours (1.2.3.4.5)

9.7. Input use. How much input did you use for production under drip irrigation system?

Type	Amount			Unit	Price /Unit	Total Value
	Owned	Purchased	Hired			
Granular Fertilizer						
Complete						
Phosphate						
Potassium						
Lime						
Herbicide						
Nematicide						
Insecticide						
Fungicide						
Organic Fertilizer						
Manure						
Liquid Fertilizer						
Establishment and maintenance						
Seed						
Water(irrigation)						
Oil						
Petrol(Gasoline, diesel)						
Speicify Equipment’s						
Synthetic Sacks						
Others						

Note: For commercial products such as fertilizer, Lime, herbicide, seed, seeds, specify name and brand

9.8. Labour utilization. How much labour did you use for your date production under drip irrigation?

	Family(3.2.1)				Hired(Daily Wage) (3.2.2)				Cost of wages(3.2.5)				
	Male		Female		Male		Female		Cash		Kind		
Land Preparation	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Hrs	Man Days	Man Days	Wage/ day	Total Cost	Type	Value
Land preparation													
Canal establishment and maintenance													
Planting													
Fertilizing													
Weeding													
Watering													
Pesticide application													
Harvesting													
Packing and storing													
Transporting													
Marketing													

Note: Children are those who are less than 18 years old.

9.9. What equipment's were used in your date production under drip irrigation?

Activity	Machinery					
	Owned		Hired			
	Hrs	Days	Hrs	Days	Price/day	Value
Land Preparation						
Clearing						
1st plowing						
Harrowing						
2nd plowing						
2nd harrowing						
Bed preparation						
Planting						
Fertilising						
Weeding						
Watering						
Pesticide Application						
Harvesting						
Packing and storage						
Transporting						
Marketing						

9.10 Date palm production under drip irrigation

Type	Harvested Area	Total Output (kg)	Consumed by family(kg)	Fed to animals(kg)	Gifts(kg)	Sold(kg)	Price/unit (p/kg)	Total value

9.11. Do you market your type of date palm: yes ( ) No ( )

If yes, please complete this table

No	Type	Kg/trees	Price /kg/tree	Seedlings	Price/one seedlings	Other	Price	Lost of date palm
1								
2								
3								
4								
5								

9.12. What are the most benefits when use drip irrigation for your field?

(1) Save time (   )

(2) Less labour (   )

(3) Reducing water waste (   )

(4) More efficient than other methods (   )

(5) Other, please specify………………….

9.13. What are the most problems can be effect on drip irrigation?

(1) Damage of pipe network ( )

(2) Short life ( )

(3) High cost (   )

(4) Poor distribution water (   )

(5) Other, please specify …………. ( )

9.14. Production constraints

9.14.1 What are the three most important factors that reduce the quality and quantity of your field under drip irrigation?

a.____
____

b.____
____

c.____
____

9.14.2 How do you think these problems can be overcome?

____
____

____
____

10. Household goals

Please rate how important the following goals are to you and your household using a rating scale of 1 to 7(with 1= not important at all; 7=extremely important)

	Not important at all	Neutral					Extremely important
1 Meet household food needs	1	2	3	4	5	6	7
2 Cash income	1	2	3	4	5	6	7
3 Savings	1	2	3	4	5	6	7
4 Education	1	2	3	4	5	6	7
5 Health	1	2	3	4	5	6	7
6 Social status	1	2	3	4	5	6	7
7 Leisure	1	2	3	4	5	6	7
8 Environment	1	2	3	4	5	6	7
9 Other ____________________	1	2	3	4	5	6	7

End of the questionnaire: Thank you for your cooperation

Appendix B

Australian Government
Department of Agriculture, Fisheries and Forestry

Quarantine Act 1908 Section 13(2AA)

Phone: 02 6272 3917
Fax: 02 6272 3745
File Ref:

Permit to Import Quarantine Material

Permit: IP13013562 **Valid From:** 23 Jul 2013 **Valid To:** 23 Jul 2015 **Page** 1 of 3

Importer	Exporter
Mr Ahmad Aridh Curtin University Curtin University Department of Environment and Agriculture Kent Street Bentley WA 6845 Attn: Prof. Zora Singh	Various suppliers/exporters Various addresses in Libya

You are authorised to import the following material under the listed conditions
Note: This permit covers DAFF quarantine requirement only.
All imports may be subject to quarantine inspection on arrival to determine compliance with the listed permit conditions and freedom from contamination. Imports not in compliance or not appropriately identified or packaged and labelled in accordance with the import conditions they represent may be subject to seizure, treatment, re-export or destruction at the importer's expense.
Additionally, all foods imported into Australia must comply with the provisions of the *Imported Food Control Act 1992*, and may be inspected and/or analysed against the requirements of the Australia New Zealand Food Standards Code.
All imports containing or derived from Genetically Modified material must comply with the *Gene Technology Act 2000*.

It is the importer's responsibility to identify, and to ensure it has complied with, all requirements of any other regulatory organisations and advisory bodies prior to and after importation including The Australian Customs and Border Protection Service, The Department of Health and Ageing, Therapeutic Goods Administration, Australian Pesticides and Veterinary Medicines Authority, Department of Sustainability, Environment, Water, Population and Communities, Food Standards Australia New Zealand and any state agencies such as Departments of Agriculture and Health and Environmental Protection authorities. Importers should note that this list is not exhaustive.

This permit is granted for the purposes of the *Quarantine Act 1908* and *Quarantine Proclamation 1998* of the Commonwealth of Australia. The laws of Australian States and Territories may also impose restrictions on the import of animals, plants and other goods into those States and Territories. This import permit does not prevent the application of those State and Territory laws. The importer should seek its own advice on any restrictions that may apply in any State or Territory into which it is proposed to import the animals, plants or other goods to which this permit relates.

Import conditions are subject to change at the discretion of the Director of Quarantine. This permit may be revoked without notice.

Notification of the import must be provided to DAFF for all imported goods other than goods imported as accompanied baggage or goods imported via the mail and not prescribed under the *Customs Act 1901*. Notification must be consistent with *Quarantine Regulations 2000* (examples include a Quarantine Entry or a Quarantine declaration).

Commodity Name	Condition Number(s)	Country	End Use
Phoenix dactylifera : Dates - Fresh (Phoenix dactylifera for research purposes)	PC0600	Libya	In-vitro

Condition	Condition Text
PC0600	This permit allows for the importation for in-vitro analysis, of the following: 60 kg of Phoenix dactylifera (fresh dates) from Libya Importer's Responsibilities

This permit is granted subject to the condition that fees determined under Section 86E are paid

Stamp: DEPARTMENT OF AGRICULTURE, FISHERIES & FORESTRY QUARANTINE AUSTRALIA Q950

Delegate of Director of Quarantine
Printed Name Jutta Tuerck **Date** 23 Jul 2013

Appendix C

Curtin University

Memorandum

To	Professor Fay Rola-Rubzen, Curtin Business School (CBS)
From	Professor Stephan Millett, Chair, Human Research Ethics Committee
Subject	Protocol Approval **HR 76/2013**
Date	7 June 2013
Copy	Mr Ahmad Mohamed Ahmad Aridah, Curtin Business School (CBS) Professor Zora Singh, Curtin Business School (CBS)

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784
FACSIMILE 9266 3793
EMAIL hrec@curtin.edu.au

Thank you for your application (4468) submitted to the Human Research Ethics Committee (HREC) for the project titled "*Effects of Type of Irrigation System on Productivity and Income of Date Palms Growers in Sebha, Libya*". Your application has been reviewed by the HREC and is **approved**.

- You have ethics clearance to undertake the research as stated in your proposal.
- The approval number for your project is **HR 76/2013.** *Please quote this number in any future correspondence*.
- Approval of this project is for a period of 4 years **11-06-2013** to **11-06-2017**.
- Your approval has the following conditions:
  - (i) Annual progress reports on the project must be submitted to the Ethics Office.
  - (ii) Please ensure that the researcher reports to their supervisor on a weekly basis when in Libya.
  - (iii) Please follow the university travel policy.
- **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.**

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

The attached **Progress Report** should be completed and returned to the Secretary, HREC, C/- Office of Research & Development annually.

Our website https://research.curtin.edu.au/guides/ethics/non_low_risk_hrec_forms.cfm contains all other relevant forms including:

- Completion Report (to be completed when a project has ceased)
- Amendment Request (to be completed at any time changes/amendments occur)
- Adverse Event Notification Form (If a serious or unexpected adverse event occurs)

Yours sincerely

Professor Stephan Millett
Chair Human Research Ethics Committee