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Water Quality Problems in Irrigated Agriculture in Libya

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This thesis is dedicated to soul of my parents.

Abstract

The Kufra region of south eastern Libya comprises an area about 850 km south to north, and some 500 km wide rising to 450 m above sea level. Rainfall is low and agriculture depends on irrigation. Most of the population of Kufra are private farmers who use flood irrigation from shallow wells (19-60 m), but there are co-operatives of farmers that have shared the cost of deeper wells (120 - 150 m) and sprinkler irrigation. The Kufra Agricultural Project (KAP) state farm is made up of 100 circles (farms) each having its own deep well (220 – 352 m) and rotary sprinkler.

The experimental work was conducted in three phases.

An initial study was made of soil profiles and irrigation water on 4 private and 4 state farms. An inter laboratory study compared results in the KAP and Glasgow University (GU) laboratories. The third phase was a survey of top soils, irrigation water, crop yield and questionnaires for a much larger number of farms.

Chapter 3 describes the comparison between chemical analysis results of 33 soils in the KAP and GU laboratories. There was a good level of agreement between the two laboratories. The high correlation coefficients indicate a high level of precision in both laboratories. However there were systematic differences between the two laboratories, results for EC, Ca^{2+}, Mg^{2+} and Cl^- were 2% to 6% lower in the KAP laboratory. There were no significant differences in the results for Na^+ and K^+ between the laboratories. It is important that all analyses were carried out in one laboratory, so all subsequent samples were sent to the KAP laboratory.

Chapter 4 evaluates the quality of irrigation water from 86 wells in the Kufra region in line with FAO and USDA standards for irrigated agriculture. pH, EC, Ca^{2+}, Mg^{2+}, Na^+ and SAR were not significantly affected in state farms by well depth or age, but were significantly affected in the private farms by well depth, where the values were higher in shallow wells and significantly related to well age. There are two responses to well age related to well depth shown by two distinct lines. The shallow wells (<30 m) show a significant ($p< 0.001$) increase in EC, Ca^{2+} and Na^+ and significant ($p< 0.01$) increase in Mg^{2+} as well age decreases. The deeper wells (>30 m) exhibits no significant effect of well age ($p> 0.05$). USDA classification indicates that the water of all the wells of private farms is unsuitable for irrigation purposes. The FAO criteria showed that all private wells had limitations on use due to salinity and SAR. (EC: 78% severe, 22% slight/moderate ; SAR: 35% severe, 65% slight/moderate)

Chapter 5 describes a survey of soil profiles from state and private farms. Irrigation lowered the salinity of the virgin soil profiles, with a clear distinction observed between the virgin and irrigated profiles for EC and water soluble Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and SO_4^{2-} in state farms, and for EC and water soluble Na^{+}, Cl^{-} and SO_4^{2-} in private farms. In the virgin soil profiles, these parameters showed a clear decrease with depth, while in the irrigated soil profiles they were much lower in concentration and more uniform with depth. There was no clear trend with depth in irrigated soil profiles for pH, HCO_3^{-}, $CaCO_3$%, exchangeable cations, and ESP % in the state farms and for pH, water soluble Ca^{2+}, $Mg^{2+}$and K^{+}, $CaCO_3$%, exchangeable cations, and ESP% in the private farms. The profile averages for pH, EC, ESP%, water soluble Na^{+}, Cl^{-}, HCO_3^{-} and SO_4^{2-} and exchangeable sodium were significantly greater (t-test, $p \leq 0.05$) in the irrigated profiles of private farms than in KAP farms. The irrigated topsoils (0–25 cm) showed similar results except that bicarbonate and sulphate were not significantly different.

The second part of chapter 5 describes a larger survey of irrigated topsoils. This showed that the pH, EC, ESP% and exchangeable Na^{+} were much higher in the private farms compared to state farms soils. According to the USDA classification all state farm soils were classed as normal, while 70% of private farm soils were classed as saline alkaline, 15% normal, 10% saline and 5% alkaline. There was no significant effect of crop type on any soil parameter for state or private farms. There was no significant correlation in the combined data for state and private farms between irrigation water and soil for pH, Ca^{2+} and Mg^{2+} but there is for EC, Na^{+} and SAR. In all the graphs there are 2 clusters of points separating the state and private farms which masks the correlation relationship.

Chapter 6 compares the yields of alfalfa and potatoes in the state and private farms. The mean values for dry yield of alfalfa from state (6.32 t/ha) and private (3.06 t/ha) farms were significantly different ($p<0.001$, pooled t-test). The age of the alfalfa crop had a significant ($p<0.001$) positive effect on yield in the state farms, but a significant ($p<0.001$) negative effect in private farms. Crops on the private farms were 2 to 8 years old compared with under 2 years on the state farms. Although there were low yields at high values of water and soil parameters (private farms) and high yields at low values of water and soil parameters (state farms) plotting yield against these parameters shows 2 clusters. Looking

at the private farms alone there was no significant correlation between alfalfa yield and any of the quality parameters for soil or water.

No potatoes were grown on state farms when the samples were collected, so historical data was used (average yield 40 t/ha). The mean yield of potatoes from private farms was significantly lower ($p<0.001$) 23.16 t/ha. None of the correlation relationships between crop yield with soil and water quality parameters for private farms was significant.

Despite the large differences in soil and irrigation water chemistry between state and private farms, there was no evidence that poor irrigation water quality or soil salinity currently limits production on private farms.

Chapter 7 describes the survey of private farmers and shows that 81% of respondents did not consider farming as a professional activity they could rely on, but rather an activity to fill their free time. The study also examined other aspects including the farmers’ education level, the farms’ age, irrigation and the impact of water salinity, types and sources of fertilisers. The study concluded that traditional agricultural systems in this region are not built on a scientific basis, or an adequate knowledge of economic feasibility. Consequently, the production rates of agricultural crops are very low.

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Author's Declaration

I declare that the work described in this thesis is my own, and has not, in whole or part, been submitted for any other degree.

Aiad A. A. Alzway

Chapter 1 General Introduction & Literature Review

1.1 Irrigation water

It is important to highlight that more than 90 % of the fresh water resources are located underground; making it a significant reserve of good quality water. In case of insufficiency or scarce rainfall, groundwater becomes the only natural water resource due to its buffer capacity (Mandl et al., 1994). With the steady rise of the world's population and the consequent expansion at the expense of the agricultural land, increasing the demand for agricultural products, in turn, led to an increased use of intensive agriculture and resulted in damage to the soil due to the widespread use of chemical fertilizers and irrigation with saline water on non-saline and saline soils. Soil degradation has become an environmental problem which limits the sustainability of agriculture and decreases soil productivity throughout the world. This degradation is the result of negative changes in physical and chemical soil properties (Barut and Celik, 2009). Irrigation can have adverse effect on soil properties thereby on sustainable productivity if not regularly monitored (Henry and Hogg, 1997). This means Irrigation should be managed so that it could minimize adverse effects on soil quality. Moreover, the effects of irrigation on soil physicochemical properties in arid and semi-arid environments were well documented. Importance of maintain soil due to the good management and understanding how to apply agricultural practices (Negassa and Gebrekidan, 2004). Arid and semiarid regions are particularly susceptible to soil degradation and often show low resilience (Bravo-Garza and Bryan, 2005.

One of the most serious challenges facing currently countries of arid and semi-arid districts is how to balance the demands for fresh water between industrial, urban-domestic, and agricultural needs. Increasing stress for irrigation water (to provide food for rising populations in the face of limited water resources) lead to consideration of reuse of the available water (Bouwer, 1994; Ragab, 1996).

At the present time, scientists in general and environmentalists in particular are seriously concerned by the increasing scarcity of water worldwide, and consequently the need for alternative water resources is more urgent than ever. Irrigation in agriculture draws disproportionately on freshwater and as global demand for water increases; the agricultural sector will face competition from other sectors for water. Possible alternative water sources include waste water from landfills and water originating from composting processes. Water and plant nutrients, such as nitrogen, potassium, magnesium and calcium, contained in landfills leach out and can be utilised to reduce water stress and to enhance plant growth (Zupanc and Justin, 2010; Zalesny et al., 2008).

Reduced water supplies induce restrictions on water uses and allocation policies among different user sectors. In such regions, rivalry for limited water resources among users will inevitably decrease the supplies of freshwater available for crop irrigation. If the water resources are available (as they are in the study area in the Kufra region of Libya see page 22) the depths of wells is often related to the financial means of the farmers because the digging cost of wells is relatively high. As a result, cultivation will increasingly be forced to use marginal waters such as saline water or reclaimed effluent to meet its increasing demands, which in turn increases the risks of soil salinisation and yield reduction. Accumulation of salts in the root zone affects plant performance through the development of a water deficit and the disruption of ion homeostasis (Zhu, 2001; Munns, 2002). These stresses change hormonal status and impair basic metabolic processes (Loreto et al., 2003).

It is a fact which cannot be disputed that irrigation is an essential and indispensible practice in dry land agriculture. However, nowadays, despite unanimous agreement about the vital need for water in agriculture, there is huge competition for the use of fresh water in the development of urbanisation, industry, leisure, and other fields which provokes a net decline of fresh water for irrigation (Bergez andNolleau, 2003; Zwart and Bastiaanssen, 2004). According to figures provided by the Food and Agricultural Organisation (FAO) agriculture is responsible for 69% of the world’s water consumption (FAO, 2002). It is also predicted that the area under irrigation will increase by 25–30% until the year 2025 and competition for fresh water among the agriculture industry, environment and services will continually increase. In order to make the necessary improvements for the future in agricultural production, or even only to maintain present day production levels, it is required to consider seriously the reuse of irrigation water.

The efficient management of water is of considerable importance, in particular when it is meant to prevent soil salinization, losses from deep percolation, soil and water contamination and over-exploitation of natural water resources. In Portugal Castanheira and Serralheiro (2010) suggested that mulching was a promising soil management practice that can increase soil water storage, especially in arid regions. However, it is important to observe that, despite the beneficial effects of mulching in water-limited environments, there is a lack of adequate information on the effects of mulching on soil quality and crop productivity when saline water is used as an irrigation source. Several mulching studies have addressed soil salinity dynamics (Deng et al., 2003; Qiao et al., 2006; Pang et al., 2010) but Pang et al., (2010) suggested more work is needed.

Recently, plant breeders have improved the tolerance to salinity of some crops, using plant health or seed yield as their main selection criteria, through normal selection and breeding techniques. These results rely on the phenotypic characteristics of the plants, though there isn’t a complete understanding of the underlying biochemical mechanisms. There is a consensus that selection is more convenient if the species tested possesses distinctive indicators of salt tolerance, whether at the level of the entire organism, at the tissue, or cellular level. Therefore, it is necessary to understand these cellular mechanisms, in order to aid plant breeders. Despite numerous studies, neither the metabolic sites where salt stress damages plants, nor the adaptive components of salt tolerance are completely understood. Consequently, there are no definitive plant indicators for salinity tolerance which can be utilised by plant breeders in their breeding programs (Ashraf and Harris, 2004).

In arid and semi-arid areas, both surface irrigation water and rainfall supplies are not reliable and insufficient to meet crop water requirements. Saline groundwater could be exploited to meet crop water requirements if no adverse effects on crops and land resources occur. In their studies of winter wheat in India Chauhan et al, (2008) found that saline groundwater with an EC of 6–8 dS m^{-1} could be used for wheat cultivation to supplement all irrigations, except for the pre-sowing irrigation. Saline water with an EC of 12 dS m^{-1} could be utilised for at least two additional irrigations. The fresh water available should be applied during the initial growth stage, and supplemented with saline water at later growth stages. This method produced wheat using saline water with an EC up to 12 dS m^{-1}, giving a yield as high as 90% of the optimum crop yield which could be achieved with water of low salinity. It is quite relevant to notice that the salinity of the soil increased to reach 14.5 dS m^{-1} at the surface where all irrigations happened to be with 12 dS m^{-1} water. Additionally, most of the salts were leached due to the fact that the climate was a monsoon one. However, it is not sure if such a method is sustainable on a long-term basis and if it would be practiced in Libya where the climates are known to be dry. The concerns about negative effects has often restricted the utilisation of naturally occurring saline groundwater, and salinity is at present one of the most important abiotic factors limiting agricultural production in dry land areas. The high rates of human population development and global warming are expected to further exacerbate the risk of salinity, particularly in semi-arid regions like the Mediterranean area. Malash et al., (2008) consider that there are several factors which should to be taken into account when using saline water for irrigation: plant tolerance, the irrigation system, water management strategies, irrigation frequency and soil properties.

1.2 Water Quality Parameters and Evaluation.

The evaluation of water quality for irrigation could be done by considering its parameters and connected problems. There are various available guidelines to assess the quality of the water. Richards (1954) stated that when classifying irrigation water, the assumption is that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of crop. Significant variations from the average for any of these variables could make it unsafe to use what would otherwise be suitable water. Conversely, water which would be unsafe to use under average conditions could be appropriate. The irrigation water quality criteria developed by the USDA classification (Richards, 1954; National Engineering Handbook, part 623, 2013) has received wide acceptance in several countries. The most important characteristics to determine the quality of irrigation water are discussed below;-compatible

1.2.1 Total concentration of soluble salts

The total concentration of soluble salts in irrigation water can be adequately expressed for purposes of diagnosis and classification in terms of electrical conductivity. The conductivity is useful because it can be readily and precisely determined. Following his experimentation, (Richards, 1954) noticed that the irrigation waters with conductivity values lower than 2250 micromhos cm^{-1} were used efficiently for a substantial period in arid and semi-arid agriculture soils. On the other hand, waters of higher conductivity are used occasionally, however, crop production, except in unusual situations, has not been satisfactory. The saline soils are those with electric conductivity of saturated paste extract higher than 4 dS m^{-1}, or 4000 micromhos cm^{-1} (Richards, 1954).

On the other hand, waters of higher conductivity are used occasionally, however, crop production, except in unusual situations, has not been satisfactoty.

1.2.2 Relative proportion of sodium to other cations

The reaction with soils of the soluble inorganic elements present in irrigation water occurs under the form of ions rather than molecules. The calcium, magnesium and sodium, are the main cations with usually the presence of small amounts of potassium. The most present anions are bicarbonate, sulphate and chloride, while the fluoride and nitrate appear only in low concentrations. If the quantity of sodium is high, the alkalinity hazard is high, and, equally, the hazard is low when calcium and magnesium are preponderant. Alkali soils are made through the accumulation of exchangeable sodium and are regularly characterised by poor tilth and low permeability.

1.2.3 Concentration of other elements that may be toxic.

Boron is an element present in almost all natural waters and its concentrations varies from traces (less than 1 $mg1^{-1}$) to several mgl^{-1}. It is an essential micronutrient which means it is essential for plant growth and development, but is required in very small quantities. Although Boron requirements vary among crops, the optimum boron content of the leaf tissue for most crops is 20-100 mg/kg (Plank, 1989). It is absolutely essential to take into account the boron, when assessing the water quality, knowing that this element occurs in toxic concentrations in some irrigation waters.

Rhoades (1972) showed the needs to assess the suitability of irrigation water based on criteria which reveal their potentials to make soil conditions hazardous to crop growth or to human and animals consumption (of those crops). Moreover, the particular situations under which irrigation water is used consist of grown crops, soil properties, irrigation management, cultural practices, and climatic conditions. The fundamental criteria of irrigation water quality and their possible threats to crop growth are:

Salinity:

Generally, it is believed that salt effects on crop growth is mostly of an osmotic nature and is linked to the whole concentration of salts and not only to individual concentrations of particular salt constituents.

Sodicity:

Sodicity results from an excessive quantity of exchangeable sodium in the soil on soil permeability, soil structure deterioration, and a direct toxic impact of exchangeable sodium in plants particularly sensitive to sodium.

Toxicity:

Toxicity results from the effects of a particular ion of solutes (other than sodium) of a nutritional nature, especially those of chloride and boron.

1.3 Irrigation Water Quality Problems

According to Ayers and Westcot (1985) irrigation water might vary significantly in terms of quality, and this depends principally on the nature and amounts of dissolved salts in irrigation water. They result from liquefaction of rocks and soil, including liquefaction of lime, gypsum and other soil materials which dissolve gradually. Therefore, it can be said that it is by knowing the total amount as well as the type of salts that determine whether or not the water is suitable for irrigation purposes. Furthermore, it is also by assessing the eventual severity of problems likely to appear on the long-term use that the quality of water is evaluated. In fact, the potential difficulties or problems vary both in kind and degree, with not only the influence of the soil, the climate and the type of crop, but as well as by the farmers’ skills and methods of irrigation.

1.3.1 Water quality problems in irrigated agriculture

1.3.1.1 Salinity:

Salt accumulation in the root zone leads to poor crop growth and low yield, salts often come either from a saline, high water table or from salts which are in applied water. The salts accumulate in the root zone so much so that the crop is unable to get enough water from the salty soil solution and this causes a water stress for a substantial period, and results in a reduction in yield. Therefore, the lessening in water absorption affects the growth of the crop by slowing its rate. The symptoms at the level of the crop appear similar to those of drought such as wilting, or a darker, bluish-green colour and sometimes thicker, waxier leaves. However, the variety of symptoms is more observable when salts affect the crops during the early growing phases (Ayers and Westcot, 1985).

Another researcher, Rhoades (1972) observed that salt effects on the growth of crops are usually confirmed by below average growth with small size canopies and appearance of smaller plants (few and small leaves). Alawi et al. (1980) assessed the effects of irrigating water in a soil over a 3 year period, so they used three types of waters in terms of chemical characteristics. In fact the waters salinity content varied from EC, of 3.2 to 0.55 dS m^{-1}. The results obtained allowed them to state that the use of various waters gave different soil salinity contents, e. g., values of EC for the surface 30 cm were 3.50 to 2.13 dS m^{-1} for the high to low salt waters respectively. Moreover, exchangeable sodium percentage (ESP) varied from 18.4 to 24.0 in the surface 30 cm of soil, though it was the highest when using the less saline water.

1.3.1.2 Water infiltration rate

A problem of infiltration linked with the water quality occurs due to the decrease of the infiltration rate for the applied water. Consequently, the water remained on the surface of the soil for a long period or infiltrated in a very slow rate in order to give to the crop an adequate amount of water to preserve the harvests. The water salinity and its sodium content relative to the calcium and magnesium content could be considered as the most common water quality factors which contribute to a normal infiltration rate.

Nevertheless, it is highly possible to see both factors operating simultaneously. High salinity water will undoubtedly increase infiltration while low salinity water or water with high sodium to calcium ratio will likely decrease the infiltration. In case the irrigation is prolonged for a lengthier period to facilitate adequate infiltration, secondary difficulties might appear such as crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rooting of seeds and poor crop stands in low-lying wet spots.

In general, infiltration difficulties linked to the quality of the water happens in the surface few centimetres of soil and is due to the structural stability of the soil and the low amount of calcium compared to the sodium (Ayers and Westcot, 1985). Rhoades (1972) stated that the sodicity effects on soil are shown by puddling and by a reduced rate of water consumption.

Park and O'Connor (1980) used four various types of soils from sand to clay with five saline-sodic waters in order to determinate both the saturated hydraulic conductivity and the infiltration rate. The waters varied in total dissolved solids from 1.9 to 23.4 dS m^{-1} and in SAR from 16 to 57 and were from New Mexico’s saline groundwater. The results of their experiments show that the water quality does not affect significantly the saturated hydraulic conductivities of soils if the waters used were the only source of irrigation. Following the use of irrigation water with a high SAR (due to dispersion of the clays and increased soil pH as Na replaces other cations on the exchange complex of the soil), there is a reduction in water movement in the soil. Costa et al., (1991).

1.3.1.3 Specific ion toxicity

The risks of toxicity occurrence materialise when some soil or water constituents (ions) are absorbed by the plant and accrue to a level of concentrations that either harm the crop or reduce the harvests. The ions gather to the highest amount where the water loss is the highest. Generally, the more resistant crops are not affected by low concentrations, although if practically all crops will be harmed or affected if concentrations are very high. Similarly, the climate has an impact, since in a hot weather conditions, accumulation is faster than when the same crop grew in cool conditions when it could either show slight or no damage Ayers and Westcot, (1985).

1.3.1.4 Miscellaneous effects

There are also various other problems linked to the quality of water irrigation water that due to their frequent occurrence, deserve some attention. For instance, the concentrations of high nitrogen in the water which when transferred to the crop might provoke an excessive vegetative growth. The normal pH range for irrigation water varies from 6.5 to 8.4. An unusual value is a sign that the water needs more assessment. Irrigation water with a non-standard pH might contain a toxic ion or be responsible for a nutritional imbalance. Low salinity water ($EC < 0.2\ dS\ m^{-1}$) sometimes has an irregular pH due to its very low buffering capacity. In this case, the water generally causes problems for either soils or crops. Moreover, due to its very corrosive characteristic, it might quickly rust pipelines, sprinklers and monitoring devices Ayers and Westcot, (1985).

1.3.2 Poor quality water impact on irrigation water.

Irrigation plays a significant role in crop production, and agricultural development in arid and semi-arid regions, (Bouwer, 2002; Hillel and Vlek, 2005), and water quality problems in irrigation include salinity. Salinity affects crop production because crop roots have great difficulty extracting enough water and nutrients from saline solution. Consequently, crop production is limited because sufficient water cannot reach the root zone of particular consequence is the ratio of sodium to calcium and magnesium. When sodium-rich water is applied to soil, some of the sodium is taken up by clay and the clay gives up calcium and magnesium in exchange. Clay that takes up sodium becomes sticky and slick when wet and has low permeability.

The constant growth of water requirements for agriculture worldwide is due to two main reasons; firstly there is an increasing demand for food from the fast-increasing population and secondly there is a need to improve living standards for a large part of the population (FAO, 2011; Marcoux, 1994) .

For crop production in arid and semi-arid areas, the major source of water is rainfall, which is often limited and unreliable. Generally, in irrigated agriculture, farmers, planners and policy decision makers place greater emphasis on short-term crop productivity than on long-term soil resource sustainability. However, recently there is more awareness among the people involved and an increasing appreciation of the importance of soil resource sustainability has occurred.

The use of poor quality water, particularly high saline water for irrigation necessitates new approaches that simultaneously address the short-term productivity concerns and long-term sustainability issues of soil resources. Moreover, the decreasing supplies of quality water for irrigation and the competition from other users induce most farmers to use saline water for irrigation (Shani and Dudley, 2001; Dehghanisanij et al., 2004). Although several studies exist on the salinity tolerance of plants, neither the metabolic sites at which salt stress damages plants nor the adaptive mechanisms used by plants to tolerate saline situations are well understood.

During the second half of the twentieth century the lands under irrigation in arid areas increased considerably. However, experts consider that, any further expansion should depend, or be based, on annual renewable freshwater resources, which have largely been allocated already to various water-use sectors in many places. Another undeniable factor is the permanent competition among domestic, industrial, environmental and agricultural sectors, which not only exist but is expected to inevitably increase, and will cause a continuing decrease in freshwater allocation to cultivation (Tilman et al., 2002). Qadir and Oster (2004) highlight the fact that such conditions are expected to continue and to intensify in less developed countries in dry areas that already have high population growth rates and suffer environmental degradation. Another author, (Thomas, 2008) believes that, with the occurrence of freshwater shortage, most countries in the North Africa and Central and West Asia will face similar challenges. As an alternative to freshwater resources, water resources of marginal quality such as saline water produced by agricultural drainage methods or pumped from saline aquifers can be used to reduce the gap between freshwater demand and supply (Rhoades et al., 1999; Dıaz and Grattan, 2009).

High water tables are often associated with salinisation of shallow groundwater and soil due to a reduction in water percolation and an increase in the capillary rise (Wang et al., 2008). The adverse effects of salinity result from the inhibition of water uptake because of the low soil water potentials and the toxicity effects of specific ions at cellular level (Ebert, 2000). The use of non-conventional water resources and opportunities for achieving food security in water-scarce countries are presented (Qadir et al., 2007). Conventional crops are not halophytes; thus, their yield and even their life might be threatened under such saline conditions and this is the main cause for the destruction of farming systems in societies where saline water is used for irrigation (Khan et al., 2009).

Salinity and porosity of composted sewage sludge were studied to evaluate their effect on vegetable seedlings. It showed negative seedling performances, possibly due to its high acidity of pH 4.7, a severe problem for growing cucumber, tomato, and pepper seedlings. These vegetables need an acidic–neutral environment (pH 6–8) to promote growth in China. (Cai et al., 2010). To determine optimal conditions for irrigation of processing tomatoes, which were planted on a sandy soil, they were drip irrigated with saline and fresh water. It has been found that the salinity had no effect on chloride concentration in leaves but more than doubled the concentration of sodium. On the other hand, salinity had little effect on leaf calcium content but reduced levels of potassium and phosphorus (Pasternak et al., 1986).

The excessive use of fertilisers, the increase in macronutrient accumulation in the soil could aggravate the soil salinity problem in the future, and could affect negatively the economic revenues from agricultural production in the area. For instance, in the particular case of Jordan Al-Zúbi (2007) considers that, the increase in salt accumulation could control the soil's fertility and this could lead to a reduction in its fertility. Additionally, groundwater contamination by nitrate NO_3 has been attributed to excessive use of N fertiliser, while the misuse of nitrogenous fertilisers was found to be the source of serious nitrate (NO_3) pollution in many flood-irrigated districts of the western parts of the USA. Various writers consider that a reduced rate of irrigation practices such as drip irrigation can offer an approach to control NO_3 leaching and agricultural water use, (Gheysari et al., 2009; Cassel Sharmasarkar et al., 2001).

The other potential consequences of the use of poor water is the impact on soil chemical properties like salinity and sodicity (Gros et al., 2006; Bhardwaj et al., 2008; Loncnar et al., 2010). Several writers acknowledge the fact that, an assessment of the effect of the poor quality water on the environment, specifically on soil characteristics, is extremely difficult due to the variability of soil properties (Müller et al., 2007). As mentioned earlier, soil salinity represents a major challenge facing irrigated agriculture worldwide, especially in dry and semi-dry areas. The consequences are quite dire since soil salinity can lead to total or partial loss of productivity on account of accumulation of salt, which is a limiting factor for the growth of vegetation (Ashraf and McNeilly, 2004, Boivin et al., 2002; Corwin and Lesch, 2005). The use of poor water may alter the physical properties of the soil, such as bulk density and soil porosity (Abedi- Koupai et al., 2006; Wang et al., 2003), as well as incidence of soil water repellence (Wallach et al., 2005; Tarchitzky et al., 2007).

1.4 Soil Salinization

There are some soluble salts within all soils. These are essential nutrients for plants, but excessive amounts cause soil salinity, which inhibits plant growth (Shrivastava and Kumar, 2015). Saline or salt-affected soils are often found in arid and semi-arid regions. The weathering of minerals in the soil causes the release of ions, whether due to natural or human induced causes. Primary salinisation occurs as a result of natural causes, while secondary salinisation is caused by human agency such as irrigation water or fertilisers (Sheith, 1998). Soil salinity is a major environmental factor which affects agricultural productivity, by causing land degradation and affecting food crop harvests (Mostafazadeh-Fard, 2007). This problem decreases crop yield, but placing the livelihood strategies of small farmers in jeopardy (Tanwir et al., 2003). Increase in salinity in closer proximity to drier areas is an effect of soil texture, relief and soil age. Deep, fine textured soils tend to be more saline than coarse textured or shallow soils, given that the other environmental factors are similar (Al-Turki, 1995). Naturally occurring saline soils are common in arid areas, due to evaporation of the soil far surpassing the quantity of water that reaches it. As a result, salts accumulate near the surface (Franchis, 2003). This mainly happens as a result of arid to semi-arid climates; poor irrigation management and water quality (Dregne, 1986 and Ragab, 2010).

Nowadays, it is estimated that around 380 million hectares (ha), of potentially usable agricultural land, across the world, have their productivity severely constrained due to salinity considerations. Such salt-affected areas represent a real and widespread problem, especially in arid and semi-arid regions. It has been established that the development of agriculture into arid zones with high evapotranspiration rates, leads to rising saline water tables, a concept known as ‘‘dry land salinity’’(Lambers, 2003). For instance, in southern Portugal, soil salinity is becoming a serious problem, since saline groundwater continues to increase in catchments, causing a decline in the quality of water resources and consequently affecting the traditional agro-ecosystems in the Mediterranean area (Ben-Asher et al., 2002).

1.4.1 Impact on soil condition.

About 20 million hectares of agricultural lands are saline. Although more frequent in dry land areas, salt-affected soils are also present in fertile moderate regions including many coastal plains of southern Italy, where soil salinity is frequently caused by the poor quality of the irrigation water (Sifola and Postiglione, 2002). According to several agricultural experts soil salinisation is one of the most severe causes of yield reduction in modern agriculture (Paranychianakis and Chartzoulakis, 2005). The excessive salt concentration affects adversely between 4 to 7% of arable land surface (Ebert, 2000). Soil salinity represents a real challenge for agricultural productivity (Munns, 2002, 2005). Since 7% of the world’s land surface is affected by the salinity it is considered as one of the main limiting constraints to the agricultural productivity worldwide. Soil salinity, which is either the result of natural processes or of crop irrigation with saline water, happens generally in arid and semi-arid areas, impacting on the plant growth due to water deficit or salt specific damages. The same authors mention the fact that more that 20% of all irrigated lands are salt-affected. According to figures given, Martinez Beltran and Licona-Manzur (2005), state that approximately 830 million hectares worldwide are salt-affected soils.

The expansion of irrigated areas, partially on salty and poorly structured soils, resulted in development of salinisation of effluents and the fluvial network. The trend towards larger fields and farms in both dry farming and irrigated systems has resulted in a relaxation of soil conservation practices in Spain García-Ruiz, (2010). (Patterson, 1999) showed that loss of soil permeability commenced as low as sodium adsorption ratio of 3 when the electrical conductivity was about the same as that in domestic wastewater. Internationally, a sodium adsorption ratio of 6 is accepted as a level above which soil permeability and structural stability may be affected. Studies conducted by (Travis et al., 2008; Gross et al., 2005) show that, long-term irrigation of arid loess soil with groundwater may cause an accumulation of salts and surfactants in the soil, and alter soil properties and add toxicity to the plants. Waste waters, despite containing necessary nutrients, might not be appropriate due to their potential effects on the quality of the soil and the people’s health (Wang et al., 2003a; Chen et al., 2005; Wang et al., 2003b; Li et al., 2009).

The total area of agricultural land which is affected by salinity worldwide is about 400 million hectares. The most common causes of salinity are high rates of evaporation, low rainfall and using low quality irrigation water (Kenan and Sinan, 2007). These authors also estimate that about 830 million hectares worldwide are salt-affected soils. For example in Sudan alone there are about 4.8 million hectares of salt-affected soils (Ahemd et al., 2012). Low quality irrigation water plays an important role in changing productive soil into salinised soil. Knowing only the quality of irrigation water is far from sufficient for assessing the eventual salinity. Therefore, it is also essential to study carefully soil, climate and irrigation methods, because rapid development of irrigated agriculture has created multiple environmental problems relating to soil salinity or irrigation water, which mostly relates to lack of discharge.

Salinity may arise from irrigation using poor quality (high in salts) water, or by salts existing in soil due to higher levels of groundwater level, or both of these (Crown and Lesch, 2005). Poor irrigation practice may raise the level of groundwater in agricultural soil, changing it into saline soil and promoting the growth of salt tolerant weedy species such as harmful plants like cane (Arundo donax). Moreover salinisation is a major factor for soil degradation because it leads to physic-chemical changes in soil properties and because high levels of ions such as sodium in the soil obstruct the growth of vegetation and affects the soil permeability (Slavich et al., 2002).

1.5 Physiological effects of salinity on crop plant growth

Excessive sodium present in the rhizosphere, apart from its own toxic behaviour in plant metabolism, causes physiological drought in plant tissues through osmotic processes. Sodium also reduces the entry of other ions into root plants provoking a deficiency of other mineral elements, indispensable for normal development. An immediate reaction of a salinity induced water imbalance is the closure of stomata (Ahmad and Jabeen, 2005). The maximization of crop yields when the salinity of irrigation water is high depends on plant transpiration requirements and evaporative losses, as well as on maintaining minimum soil solution salinity through leaching. To identify safe and effective ways of using salty water, field experiments were conducted to assess the result of saline water irrigation and plants on soil salinity and yield in a winter wheat – summer maize crop system in North China (Pang et al., 2010). Another study to determine the effects of drip irrigation with saline water on emergence, vegetative growth, yield of waxy maize and the effects on soil salinity was also carried out. It has been observed that, while the seedling emergence rate of waxy maize was not affected by drip irrigation with saline water, the seedling biomass such as plant height, fresh mass and dry mass decreased with the increase in salinity of irrigation water (Kang et al., 2010).

The interaction between four chloride levels (10, 20, 40, 80 mgl^{-1}) in irrigation water and three nitrogen fertilizer forms (NO_3–N 100%, NH_4–N 100% and NO_3–N 50%:NH_4–N 50%) had an impact on growth of tobacco crop, agronomic and chemical characteristics in the Virginia tobacco especially for Cl > 40 mg/l lead to reduction in yield, depending on the tobacco type, methods of fertilization, cultivation and harvesting used in the Drama, North Greece (Karaivazoglou et al., 2005). The shortage of rain and good quality waters in semi-arid regions makes essential use of waters of low quality for irrigation. These waters, the majority of which come from subterranean aquifers, are very often saline, and their use may be limited by the salt acceptance of the crop. New strategies in the use of water for irrigation is important for keeping high-quality waters in those districts, where the availability of water resources of high quality is a limiting factor in agricultural production. Melon is an important crop in arid and semiarid areas with salinity difficulties (Botía et al., 2005)

1.6 Salinity treatment by using irrigation methods and the management

There is a consensus as regards to the fact that, without suitable management, irrigated agriculture can be harmful ecologically and can impact on the sustainability aspect. Therefore, the aims of the most recent irrigation methods are to keep the more appropriate water for irrigation, to distribute the saline irrigation water within the roots zone, and to preserve good soil structural conditions. In clay soils it is expressly recommended to avoid irrigation systems affecting soil structure and altering macropores continuity. It is by dealing with the available data (or by collecting new information), by determining the quality of the irrigation water, and by being able to characterise the topsoil electrical conductivity remotely (using remote sensing), that it is possible to determine subsoil salinity conditions in irrigated soils and also evaluate the return flow from such irrigated land (Crescimanno et al., 2007; De Clercq et al., 2009).

Nowadays, agricultural systems, either in arid or semi-arid regions are increasingly dependent on irrigation and fertilisers. For sustainable agricultural production in these systems, it is necessary to understand the role irrigation plays in the transport of soluble chemicals in soils; in particular in no-till or reduced-till farming. The other essential point relates to the understanding of the influence of irrigation methods on solute transport in order to properly manage chemical use in agricultural soils (Nachabe et al., 1999). The selection of irrigation methods is extremely significant, especially when using poor quality of irrigation water. Using sub-irrigation or drip irrigation methods with a saline solution is an attractive strategy to limit the yield decrease of saline water and to obtain improved water use efficiency (Rouphael et al., 2006).

Surface irrigation with saline water is possible only with salt-tolerant crops or if used alternately with limited clean water resources. However, in dry agricultural areas in Canada, the sub-irrigation method is used to overcome the limitations of salty water. Such a system is used to produce potatoes, one of the world's main food crops (Patel et al., 1999). In Iran, two irrigation methods, surface irrigation and subsurface irrigation with a porous pipe have been used to determine the effect of treated wastewater on soil chemical characteristics in arid areas (Heidarpour et al., 2007). Saline water is often used to drip-irrigate crops: the practice being to use deep sandy soils (96% sand) to avoid soil salinisation.

In some countries of Africa, saline groundwater could be an abundant and insufficiently used resource; though, there is a lack of statistics to prove this assumption. Saline water is intentionally and successfully used for irrigation of field and garden crops in several countries. The water saving characteristics and the distribution patterns of water in the soil under drip irrigation makes this water use method suitable for use in combination with saline water. Low-cost drip irrigation proved to be successful when implemented in sub-Saharan Africa. It is suggested that the use of low-cost drip irrigation with saline groundwater for the cultivation of horticultural crops can be achievable under conditions of water shortage and has the potential to contribute to the improvement and sustainable crop production for smallholder farmers (Karlberg et al., 2004).

Successful production of potatoes using saline water (salinities from 1 to 9 dS m^{-1}) indicates the possibility of using salty water having salinity even higher than this. Sub-irrigation methods may prove to be quite helpful for food production with reduced quality irrigation water in regions, where torrential rains can flush-out salts accumulated in the crop root zone (Patel et al., 2001). The highest root yield was obtained using surface drip irrigation and sewage (Hassanli et al., 2010). On the other hand, in areas where water shortage prevails, depth of irrigation can be lowered up to 75% of its full supply for the production of green pepper under normal planting method; with 25% water saving and 22.8% yield reduction. Thus, drip irrigation is widely regarded as a suitable system for applying saline water to crops (Gadissa and Chemeda, 2009; Malash et al., 2005; .Kang et al. 2004; Kang and Wan, 2005).

Production of spring potato on a deep sandy soil in the central highlands of Israel under drip irrigation with saline water was examined by (Bustan et al., 2004). The aim was to determine the effects of saline water irrigation on potato production in an arid environment, with a special focus on interactions with weather conditions. Although yields were often high, salinity effects were evident in some years. The water evaporation rate was about 10 times lower at night than during the day, so irrigating at night was found to be beneficial in maize in terms of reduced leaf Na^+ and Cl^- accumulation and increased yield, in NE Spain (Isla and Aragüés, 2010).

1.7 Management approaches

In Africa, water managed areas include 14.3 million ha, and surface irrigation techniques are used in more than 80% of this area (Ragab and Prudhomme, 2002), suitable soil management combined with good water management is essential for sustainable crop production in arid areas. The objectives of management practices to be followed for optimal crop production, with saline water include the prevention of salt increase to levels which limit the productivity of soils and, control of salt balances in the soil-water system, as well as minimising the harmful effects of salinity on crop growth (Minhas, 1996).

Saline groundwater is frequently established at shallow depths in irrigated regions of arid and semi-arid areas and is associated with problems of soil salinisation and land degradation. The standard management approach to consider when facing such an issue is to maintain a deep water-table through the provision of engineered wastewater disposal methods. However, experts do not agree unanimously regarding the efficiency of this approach and the sustainability of such methods is still disputed. The continuing expansion of irrigation with related water scarcity problems, plus the increasing use of groundwater of marginal quality, has resulted in a new challenge that is difficult to handle at the farm level. Examples locations suffering from this problem are the Fatnassa oasis in Tunisia or in the lower Chelif, in Algeria (Gowing et al., 2009; Bouarfa et al., 2009).

An autumn irrigation system used a large quantity of water in the Hetao Irrigation region of China, with the objective of decreasing salinity levels in the root zone and raising water accessibility for the following spring crops. However, the autumn irrigation caused a major amount of NO_3 to filter from the plant root zone into the groundwater (Feng et al., 2005). Water availability often limits crop production in rain fed agriculture. Consequently, rain fed crop production in regions of low or variable rainfall may be maximized by ensuring water is extracted thoroughly from the soil profile and/or by minimizing the loss of water (Ogola et al., 2002).

Good quality water is a necessity for crop production, although in the private farms there is an increasing use of highly saline water for irrigation. This practice is mainly witnessed in the arid parts of Libya, where the demand for agricultural expansion is increasing, due to the pressure to create more jobs and improve the income of the rural population.

1.8 Other impacts

The use of saline waters in Mediterranean regions is an alternative for the irrigation of salt tolerant ornamentals as competition for high quality water increases. However, the increase in external NaCl led to an increase in Na and Cl in the roots and leaves of the different species (Cassaniti et al., 2009; Oenema et al., 2005). It has been suggested that, with the nutrient balance of agricultural land it is easy to evaluate proxies for nutrient release from agricultural land. Furthermore, the relationships between nutrient balances and nutrient discharges into surface water and groundwater are not well-founded; as it has been found when examining the effects of small N and P extras in Netherlands agriculture regarding the quality of surface water and groundwater. Limited water ease of use and the continuous increase and demand for good water quality for urban use has restricted the use of fresh water for irrigation. Ben-Ahmed et al. (2009) mention a field experiment in Tunisia, which has been used over two successive seasons to determine the effect of the different levels of salinity of the irrigation water. This experiment aimed to improve fruit characteristics; as well as the yield and virgin olive oil quality in that country.

1.9 Country case study Libya

Libya, a North African country (Figure 1.1), lies along the southern coast of the Mediterranean, approximately between latitude 18° and 33° North and 9° and 25° East. The country of Libya covers an area of about 1,800,000 square kilometres spanning three climatic zones: the Mediterranean, the semi-desert and the vast desert zone of the northern Sahara with its sprinkling of oases. The present population in Libya is about 6 million, living mainly in the Mediterranean coastal zone with a large proportion in its principal cities of Tripoli and Benghazi. The fertile lands of the Jeffara Plain in the northwest of the country, Jebel Al-Akhder in the northeast and the coastal plain east of Sirt, all support a flourishing agriculture which is dependent upon rainfall. To the south separated by a strip of semi-desert, the desert is encroaching ever nearer upon the Gulf of Sirt. The prevailing climatic conditions near the coast are typical of the Mediterranean region characterized by variability and unpredictability. The rainfall is erratic in quantity, frequency and distribution Bulugma and Ghaziri, (1995) In the semi-desert, which serves primarily as pasture, rainfall is slight and irregular and the natural balance of plant life is fragile. As more and more livestock feed within this diminishing area, the plants disappear or fade under the twin impacts of overgrazing and scarcity of water. Low rainfall and a high evaporation rate characterise the desert zone. Extremes of temperature and lack of vegetation have resulted in erosion of the soil, leaving rock, sand and dust.

Records of rainfall distribution show 500 millimetres falling annually on Jebel Al-Akhder, falling to 150 millimetres in the coastal region around Benghazi, while between 200 and 250 millimetres fall annually along the Jebel Nefussa and the western coast. Along the coast of the Gulf of Sirt, the annual rainfall decreases rapidly with distance inland and south of Jebel Nefussa and in Jebel Al-Akhder it similarly gradually diminishes until it reaches only a few millimetres annually at Sarir in the southeast and Sabha in the southwest. Consequently, Libya relies heavily on groundwater for its water supply. In the north of Libya the demand for water is rapidly increasing, forcing the intense exploitation of groundwater resources, particularly in the fertile lands of the Jeffara Plain in the northwest and Jebel Al-Akhder in the northeast of the country.

1.9.1 Location of the study area

Kufra is located in south eastern Libya, comprising an area of 850 km long from south to north (20 – 27°50’ N) and some 500 km wide (18 – 25^{o} E), lying at approximately 450 m above sea level. The political border of the Kufra region is the Chad Republic and Sudan to the south and Egypt to the east, as well as the Oases region of Libya to the North (Figures 1.1 and 1.2). With a total area of some 352 000 km^2, Al-Kufra occupies about 20% of Libyan land, while its population is estimated to be around 60,000 people, according to the most recent census (2006).

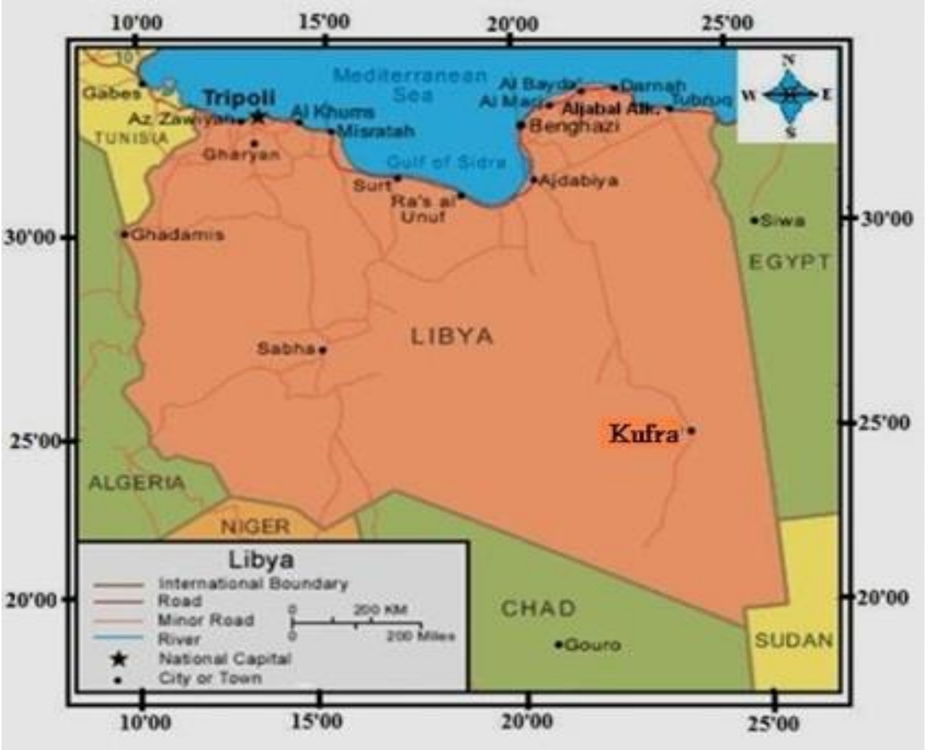


Figure 1—1 Map of Libya 1980 (Source; Ph.D. Bradford University, 2011)

Figure 1—2 Image for aerial photograph of kufra region 2010 googlesightseeing.com/2005/06/desert-farming

1.9.2 Climate

Desert climate conditions are typical for the Kufra region (the study area), with dry hot weather all year round (very hot summer days and cold winter nights). Values from the meteorology station at Kufra are given below. The average monthly temperature for the last twenty years has ranged from 3 ^{o}C to 27 ^{o}C degrees in January and from 22 ^{o}C to 43 ^{o}C in June. The annual average is 14 ^{o}C degrees, with 32 ^{o}C in June, and the annual average daily variation in temperature is about 23 ^{o}C. Continental winds prevail, with the wind in summer blowing from east and north eastern directions with averages speed of between 7 and 19 knots (rarely calm). In winter, westerly winds prevail (4.9–14 knots). During spring, dry hot Gibly (local name south wind) winds blow from the south, carrying sand and dust. The region is arid with relatively low humidity. The average annual rainfall does not exceed 6.5 mm, with no more than 1 mm in most months. Humidity is also low, not exceeding 31% – 66% as a maximum in January and a minimum in July of 17% – 26%. Evaporation rates are highest in the summer months. In summary, the area is classified as hot dry desert with rare rains.

1.9.3 Soil

Pedological data for the Kufra region indicates that it supports poorly-developed new formation desert sandy soils (with little thickness and showing weak resistance to wind erosion) covered by a salty crest in some areas. The soil of the area is light-yellowish with different salt crystals on the surface, especially in low-lying areas. Sand constitutes 96% of the soil, which mainly consists of non-adhesive single or grouped particles, due to lack of colloids. Its pH is either neutral or alkaline, and salt contents vary considerably (some soils having only low salt content, with others naturally high in salt). Sometimes, salts accumulate to form a salty crest, but the absence of a crest does not necessarily imply absence of salt. Groundwater levels in some areas are not stable, leading to chemical and physical deterioration of the soil which, in turn, can affect crop growth. Accumulation of salt has a relation to the depth of groundwater and concentration of salt therein. Insufficiency of discharge keeps extra water longer in the soil, which increases salinisation and constitutes solid stratums due to mismanagement of irrigated soils.

The dry hot climate plays an important role in specifying the quantity of organic material because the area is poor in vegetation cover. High temperatures affect all physical, chemical and biological reactions in soil because high temperature encourages quick disintegration and disappearance of organic residuals from soil. In addition, hot conditions reduce the positive ion exchange capacity of the soil, due to the deficiency of enough clay particles and organic material (whose content of important different nutritional elements differs according to its location). Though Kufra is a desert, in which case the soil is generally low in nutritional elements, its productivity is increased by adding fertilisers, which is a major element of agricultural practice in the region.

1.9.4 Groundwater resources

The Kufra basin is part of a major groundwater area covering hundreds of thousands of square kilometres of southeast Libya and adjacent areas, where the porous Nubian sandstone is saturated to depths of several hundred metres with water of excellent quality. Swailem et al., (1983) stated that the age of the groundwater has been determined by radiocarbon dating to be about 25,000 to 30,000 years old. Dating of this kind is not definitely determined, but serves to indicate that the groundwater is not related to recent hydrologic events, but is a relic of an ancient period of relatively high rainfall in North Africa when the infiltrating waters flushed and saturated the sediments. The groundwater is flowing out of the Kufra basin at a very slow rate, in a generally northerly direction, and is also discharging through evaporation and transpiration from the oases areas, where the water table approaches or intersects the land surface.

At the present time recharge to the Nubian sandstone is negligible in the Kufra Basin; the groundwater of the Kufra Basin is,in effect, irreplaceable. Groundwater is the only source of water in the area consisting of public and private wells for people’s consumption (drinking and daily life utilities) plus economic and agricultural activities. The number of wells exceeded 2,000 in 1990. The Libyan Secretariat of Agriculture reports stated that in 1991, that average groundwater consumption was 85.1 million m^3 per year and was expected to reach 100 million m^3 per year upon expansion of agricultural projects. As for water consumption via private wells, this is estimated to be about 289.08 million m^3 per year, irrigating about 1,320 private farms. Chemical composition of groundwater shows that it contains multiple dissolved elements and minerals.

1.10 The contents of the chapters

This thesis contains seven chapters. This first one is a general introduction followed by the aims of the research and review previous studies which dealt with the impact of water quality on soil physical and chemical properties and plants in different regions of the world and contain a description of the study area. Chapter two contain a detailed presentation of the experimental work and analytical methods. In chapter three entails a comparison between soil sample analyses in two laboratories, Kufra agricultural project in Libya, and the environmental chemistry laboratory at the University of Glasgow, UK. This analysis was conducted in two phases. The first survey was conducted in the summer of 2010, and the second in 2013. A total of 312 soil samples and 82 water samples were analysed at the Kufra Agriculture Project (KAP) laboratory. To confirm the results, soil samples were selected randomly then taken to the University of Glasgow laboratory to conduct similar analyses for the same parameters in the saturation extract (pH, EC, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+).

Chapter four will to investigate the groundwater salinity of the Kufra area and comparison between groundwater and shallow water which used in both state and private farms.

Information on water quality is sparse, but groundwater across Libya tends towards salinisation as a result of irrigation use (El-Trriki, 2006). The increase in demand for groundwater at Kufra is due to agricultural activity. Most of the population are private farmers who were able to buy desert land cheaply. Sinking wells is relatively expensive compared to the cost of land, and increases with well depth (Ebrik, 1981). As a result, most privately dug wells are shallow (15-60 m), but farmers co-operatives have shared the cost of deeper wells (120-150 m) and modern irrigation methods. In the early 1970s, Libya launched a desert agriculture project in Kufra, using deep groundwater for irrigation.

Most of Kufra population are working in the agriculture, produced by both private and state farms, so chapter five to evaluate the chemical properties of virgin soil profiles in the study area and classify soils, also assess the effect of irrigation water quality on chemical properties of the soil in both state and private farms. Widely study of topsoil to compare the irrigated soils of state and private farms and evaluate the effect of different crops on soil chemical properties, and classify them, also to evaluate the relationship between soil chemical properties and irrigation water quality.

Chapter six to assesses two crops alfalfa crop and potatoes in state and private farms. In the state farms soils are irrigated with good quality water under adequate supervision of fertilisation, tillage, and prevention. In private farms where people rely on agriculture as their primary economic activity, cultivation is based on grain (cereals, legumes, palm trees, and vegetables. These farms are irrigated using water from shallow wells. The shallow water wells have the salinity.

Chapter seven survey to identify farming practices and farm characteristics in the study area, and the major problems facing small farmers and the measures they have taken to overcome them. The questionnaire consists of 21 questions encompassing all circumstances related to agricultural activities in the area.

1.11 Aims of the study

1. Evaluate the relationships between the year of establishment, well depth and the spatial variability of the wells with the concentration of salts in the irrigation water for the study area. Compare the quality of the irrigation water from shallow and deep aquifers used by private and state farms using a standard classification of irrigation water.
2. Investigate the soil in two phases. The initial phase investigated a small number of profiles to evaluate the chemical properties of virgin soil profiles in the study area and compare these with irrigated soil profiles on state farms and private farms, and classify them according to USDA Salinity Laboratory Handbook No. 60 (Richards, 1954).
3. In the second phase a large number of irrigated topsoil samples were collected to evaluate if the findings from aim 2 were representative of the whole region, and evaluate the effect of different crops on soil chemical properties. Evaluate the relationship between topsoil chemical properties and irrigation water quality over the Kufra region.
4. Evaluate the relationship between crop yield, and irrigation water and soil quality. Compare the yield of alfalfa and potatoes in the state and private farms.

5. Attempt to identify the form of agricultural operations exercised by the private farmers.
6. To provide important baseline information for any future studies of the Kufra region.

Chapter 2 Materials and Methods

2.1 Experimental work:

The experimental work was in three phases.

The initial phase was a survey of the soil profiles and well water of 8 farms. A total of 192 soil samples and 8 well water samples were analysed at the Kufra Agricultural Project (KAP) laboratory. The details for this are in chapters 4 and 5.

The second phase involved taking 33 of the soil samples from the initial survey to the Glasgow University laboratory to be analysed for a selection of parameters so that a comparison between the two laboratories could be made. The details for this are in chapter 3.

The third phase was a survey of top soils, irrigation water, crop yield and questionnaires on a much larger number of farms. There were 36 farms for top soil samples, 30 farms for crop yield, 82 farms for irrigation water samples and 212 farm questionnaires were responded from 215. All the chemical analysis was carried out in the KAP laboratory and the results for these are shown in chapter 4, 5, 6 and 7.

2.2 Analytical methods.

This section describes the methods for the chemical analysis of soil and water samples. Most of the analysis was carried out at the Kufra Agricultural Project laboratory. But some soil analyses were carried out at the Glasgow University laboratory as a comparison between the two laboratories. Where different equipment or methods were used in the 2 labs the 2 procedures are described separately. The methods are based on those described in USDA handbook No 60 (Richards, 1954) and Methods of analysis for soils, plants and waters (Chapman and Pratt, 1961).

2.2.1 Saturation percentage of soil from volume of water added.

Saturation percentage of soil according to Richards (1954)

200 g of air-dry soil was transferred to a porcelain dish and distilled water was added from a graduated cylinder while stirring by glass rod. At saturation the soil paste shines as it reflects light but free water should not collect on the surface. After mixing, the sample was allowed to stand for an hour or more and the saturation status checked and adjusted if required. Initially, the sample can be air-dry or at the field-moisture content, but the mixing process is generally easier if the soil is first air-dried and passed through a 2 mm sieve. Finally the volume of water added was recorded.

S. P.= 100 x (total volume of water added) / (weight of oven-dry soil).

S.P.= Saturation Percentage

2.2.2 Saturation extract of soil.

The saturated soil paste prepared as above was transferred to a Buchner funnel with a Whatman No. 42 filter paper in place and vacuum was applied. The extract was collected in a bottle or test tube. It was terminated when air begins to pass through the filter. The amount of soil required depends generally on the measurements to be made (i. e., on the volume of extract desired). A 200 g sample is convenient to handle and provides sufficient extract for most purposes.

2.2.3 Measurement of pH.

Measurement of pH is one of the most important and frequently used tests in water and soil chemistry. At a given temperature, the intensity of the acidic and basic character of the solution is indicated. Measurements were made by Mettler Delta pH meter in the Glasgow laboratory and Jenway 3020 pH meter in the KAP laboratory. The pH meter was standardised with buffer solutions of pH 7.0 and pH 4.0.

Method for water.

The samples were collected in plastic bottles. No preservation was required, and the samples were analyzed for pH within twenty four hours of sampling. The electrode was swirled in sample and the reading was taken after it had remained constant for 1 min.

Method for soil.

A saturated soil paste was prepared with distilled water and paste was allowed to stand at least 1 hour. The electrode were inserted into the paste and raised and lowered repeatedly until a representative pH reading was obtained.

2.2.4 Measurement of the electrical conductivity.

The conductivity values are useful to estimate the total dissolved solids in a filtrate in milligrams per litre by multiplying conductivity in micromhos per centimetre by an empirical factor. Measurement of EC was made by Jenway 4070 EC meter in the Glasgow laboratory, and Wilhelm 8120 EC meter in the KAP laboratory.

Method for water.

The conductivity electrode was swirled in the water sample and the conductivity value was recorded when the reading stabilised.

Method for soil.

Soil conductivity was measured in a saturation extract prepared as described in method 2.2.2 The conductivity electrode was swirled in the filtered solution and the conductivity value was recorded when the reading stabilised.

Results were recorded as dS m^{-1}. This applies to both water and soil.

2.2.5 Determination of sodium and potassium in soil extract and water samples.

Potassium and sodium were determined by flame photometry, a form of flame emission spectroscopy. The flame photometer (Corning Model 410, was used at Glasgow University and Model 400 used at KAP Laboratory) was calibrated using potassium and sodium standards prepared by relevant dilutions of stock solutions. The instrument was set for measuring either potassium or sodium and the solution measured and the emission value noted. Using the standard graph for that particular metal, the emission value was converted to a concentration value.

Sodium

Standards were prepared by appropriate dilution of 1000 mg/l stock solution.

The Glasgow laboratory used a 0 – 50 mg1^{-1} curve. Samples were diluted into this range if required.

The KAP laboratory used two calibration ranges a low range 0 – 10 mg1^{-1} linear, and a high range 0 – 50 mg1^{-1} curve. Samples were diluted into this range if required.

To convert Na mg1^{-1} to mmol$_c$l^{-1} divide by 23.

Potassium

Standards were prepared by appropriate dilution of a 1000 mg/l stock solution.

The Glasgow laboratory used a 0 – 50 mg1^{-1} curve. Samples were diluted into this range if required.

The KAP laboratory used two calibration ranges a low range 0 – 10 mg1^{-1} linear, and a high range 0 – 50 mg1^{-1} curve. Samples were diluted into this range if required.

To convert K mg1^{-1} to mmol$_c$l^{-1} divide by 39.1.

2.2.6 Determination of calcium and magnesium by AAS at the Glasgow laboratory.

Perkin Elmer Atomic Absorption Spectrometers (models 1100B and analyst 100) were used for analysis of samples. The operating conditions are outlined in Table 2.1 below;

Table 2-1 Instrument settings and flame condition for analysis of metals by AAS

Conditions	Ca^{2+}	Mg^{2+}
Wavelength (nm)	422.7	285.2
Lamp current (mA)	10	6
Oxidant	Air	Air
Fuel	Acetylene	Acetylene
Quantification limit (mg l^{-1})	0.05	0.05
Working range (mg l^{-1})	0 – 5.0	0 – 5.0
Background correction	Off	On

Working range standards were prepared from stock solution of each metal (1000 mg l^{-1})

Samples were diluted into range (0 – 5 mg l^{-1}) with deionised water, Strontium chloride was added at a final concentration of 0.1% $SrCl_2$.

To convert Ca mg1^{-1} to mmol$_c$$l^{-1}$ divide by 20 and Mg mg1^{-1} to mmol$_c$$l^{-1}$ divide by 12.2.

2.2.7 Determination of calcium and magnesium by EDTA titration in water and soil extracts at Kufra Agricultural Project laboratory.

Titration with Ethylenediaminetetraacetate (versenate) according to Chapman and Pratt (1961).

Reagents:

A. Ammonium chloride ammonium hydroxide buffer solution.

47.5 g of ammonium chloride were dissolved in 570 ml of concentrated ammonium hydroxide to make 1 litre.

B. Sodium hydroxide, approximately 4M.

160 g of sodium hydroxide was dissolved in 1 litre of water.

C. Standard calcium chloride solution 0.005M.

   0.500 g of pure calcium carbonate (crystals) was dissolved in 10 ml. of approximately 3M (1+3) Hydrochloric acid and was diluted to a volume of exactly 1 litre.

D. Eriochrome black T indicator.

   0.5 g of Eriochrome black T and 4.5 g of Hydroxylamine Hydrochloride were dissolved in 100 ml of 95% of ethanol.

E. Ammonium purpurate indicator.

   0.5 g of ammonium purpurate was carefully mixed with 100 g of powdered potassium sulphate.

F. Ethylenediaminetetraacetate (versenate) solution, approximately 0.01 M.

   3.72 g of disodium dihydrogen ethylenediamine tetraacetate and 0.05 mg of magnesium chloride hexahydrate were dissolved in water and was diluted to a volume of 1 litre. The solution was standardized against reagent C, using the titration procedures given below. The solution was standardized, using each of the indicators D and E, as the molarity with ammonium purpurate indicator is 3 to 5 % higher than with Eriochrome black T indicator.

Procedure:

Calcium

A 5 to 25 ml (depending on sample type) aliquot containing not more than 0.1 mmol of calcium was pipetted into a 3 or 4 inch diameter porcelain dish. It was diluted to a volume of approximately 25 ml with distilled water. 0.25 ml (5 drops) of reagent B and approximately 50 mg of reagent E were added. The solution was titrated with solution F using a 10 ml micro burette. The colour changed from orange red to lavender or purple. When close to the end point, the titrant F was added at the rate of about a drop every 5 to10 seconds, as the colour change is not instantaneous. A blank containing reagents B, E, and a drop or two of F aids in distinguishing the end point.

Calcium plus magnesium

An aliquot (1 to 25 ml depending on sample type) containing not more than 0.1 mmol of calcium plus magnesium was pipetted into a 125 ml Erlenmeyer flask. It was diluted to a volume of approximately 25 ml with distilled water. 0.5 ml (10 drops) of reagent A and 3 or 4 drops of reagent D were added. The solution was titrated with solution F using a 10 ml micro burette. The colour changed from wine red to blue or green. No tinge of the wine-red colour remained at the end point.

Calculations:

$\text{mmol}_c\text{l}^{-1}$ of Ca^{2+} = (ml of versenate solution used x molarity of versenate solution as determined by indicator E x 1000) /(ml in aliquot) .

$\text{mmol}_c\text{l}^{-1}$ of Ca^{2+} Mg^{2+} = (ml of versenate solution used x molarity of versenate solution as determined by indicator D x 1000) /(ml in aliquot) .

$\text{mmol}_c\text{l}^{-1}$ of Mg^{2+} = $\text{mmol}_c\text{l}^{-1}$ of Ca + Mg - $\text{mmol}_c\text{l}^{-1}$ of Ca.

2.2.8 Carbonate and bicarbonate by titration with sulphuric acid.

Titration with sulphuric acid for carbonate and bicarbonate according to Richards, (1954)

Reagents:

A. Phenolphthalein
   1 percent in 60 percent ethanol.
B. Methyl orange
   0.01% in water.
C. Sulphuric acid
D. Approximately 0.005M standardized.

Procedure:

An aliquot containing 0.005 to 0.04 mmol of chloride into a 15 ml (depending on sample type) of water sample or saturation extract of soil was pipetted into a small porcelain dish. Chloride is specified here because the same sample is subsequently used for the chloride determination. 1 drop of indicator reagent A was added. When the solution turned pink, solution C was added from a 10 ml micro burette drop-wise at 5 second intervals until the colour disappeared. This burette reading was designated as y ml. 2 drops of indicator B were added and the titration continued to the first orange colour. The new burette reading was designated as z ml. The titrated sample was saved for the chloride determination.

Calculations

1. mmol$_c$l^{-1} of CO_3^{2-} = (2 **x y** x 2 x molarity of H_2SO_4 x 1000) / (ml in aliquot).
2. mmol$_c$l^{-1} of HCO_3^- = (z – (2 x **y**)) x 2 x molarity of H_2SO_4 x 1000 / (ml in aliquot).

2.2.9 Chloride in soil extracts and water samples by titration with silver nitrate at Kufra Agricultural Project laboratory.

Titration with silver nitrate was used at the Kufra Agricultural Project Laboratory (Richards, 1954).

Reagents:

A. Potassium chromate indicator, 5 % solution.

   5 g of potassium chromate were dissolved in 50 ml of water and 1 M silver nitrate was added drop wise until a slight permanent red precipitate was produced The solution was filtered and made up to 100 ml

B. Silver Nitrate 0.005 M

   0.8495 g of silver nitrate was dissolved in water and diluted to exactly 1 litre, and then it was kept in a brown bottle away from light.

Procedure:

To the sample preserved from the carbonate-bicarbonate determination, 4 drops of reagent A. were added. While stirring, under a bright light solution B was titrated from a 10 ml micro burette to the first permanent reddish-brown colour.

Calculations:

$mmol_c l^{-1}$ of Cl^- = (ml of $AgNO_3$ – ml of $AgNO_3$ for blank) x 0.005 x 1000 / (ml in aliquot).

2.2.10 Determination of chloride in soil extract at Glasgow laboratory.

Chloride was determined at the environmental analytical chemistry laboratory at Glasgow University using a Sherwood MK Π Chloride analyzer 926.

The 926 is a direct reading, digital chloride meter. It is designed for fast and accurate determination of chloride levels in the range 0 - 200 $mg1^{-1}$. Sample volume is 0.5 ml and results are displayed on a digital readout in mg l^{-1} chloride.

To convert Cl $mg1^{-1}$ to $mmol_c l^{-1}$ divide by 35.45.

2.2.11 Determination of sulphate at Kufra Agricultural Project laboratory.

Determination of sulphate according to Richards, (1954) .

Reagents:

A. Methyl orange, 0.01% in water.
B. Hydrochloric acid, approximately 1 M
C. Barium chloride, approximately 0.5 M
   122 g of barium chloride dihydrate were dissolved in water and diluted to 1 litre.
D. Ethanol, 50% by volume.

Procedure:

An aliquot containing 0.05 to 0.5 mmol of sulphate was pipetted into a clean 12 ml conical centrifuge tube of known weight, then it was diluted or evaporated to about 5 ml. 2 drops of reagent A were added, then reagent B drop-wise until the solution became pink, followed by a further 1 ml of reagent B. The sample was then heated in a water bath until it boiled. While twirling the tube 1 ml of reagent C was added drop-wise. It was then returned to the hot water bath for 30 min and then cooled for at least an hour in air. The sample was centrifuged at RCF = 1000 for 5 min. The supernatant was carefully decanted and the tube allowed to drain by inversion on a filter paper for 10 min. The mouth of the tube was wiped with a clean towel or lint less filter paper.

The precipitate was stirred and the sides of the tube rinsed with a stream of 5 ml of reagent D blown from a pipette. If necessary, the precipitate was loosened from the bottom of the tube by means of a wire bent in an appropriate shape. The tubes were centrifuged for 5 min and the supernatant liquid decanted but not drained. This washing and decanting was repeated once more. The outside of tube was wiped carefully with a chamois and any subsequent touch with fingers was avoided. It was dried overnight in an oven at 105°C. The tube was cooled in a desiccator and weighed.

Calculations:

$$\text{mmol}_c\text{l}^{-1} \text{ of } SO_4 = (\text{mg of } BaSO_4 \text{ precipitate x } 8.568) / (\text{ml in aliquot}).$$

2.2.12 Determination of calcium carbonate.

Calcium carbonate was measured using a carbonate meter USDA handbook No 60 Richards, (1954).

Reagents:

HCl 4 M

340 ml concentrated HCl was diluted with distilled water up to 1000 ml

Procedure:

A 4 to 10 g soil sample was weighed out, depending on the concentration of calcium carbonate in the soil. HCl 4M was added and the meter measured the carbon dioxide evolved.

2.2.13 Cation-exchange-capacity.

Measurement of cation exchange capacity according to Chapman and Pratt (1961)

Reagents:

A. Sodium acetate solution, 1 M

   136 g of sodium acetate trihydrate were dissolved in water and diluted to a volume of 1 litre. The pH value of the solution was about 8.2.

B. Ethanol, 95%.

C. Ammonium acetate solution, 1 M

   To 700 or 800 ml. of water were added 57 ml of concentrated acetic acid and then 68 ml of concentrated ammonium hydroxide. The solution was then diluted to a volume of 1 litre and adjusted to pH 7.0 by the addition of more ammonium hydroxide or acetic acid.

Procedure:

4 g samples were weighed and placed in 50 ml centrifuge tubes. 33 ml of reagent A was added; the tubes were plugged and shaken for 5 min. They were then unplugged and centrifuged at RCF = 1000 until the supernatant liquid was clear. This required about 5 min. The supernatant liquid was decanted as completely as possible and discarded. The samples were treated in this manner with 33 ml portions of reagent A, a total of 3 times, discarding the supernatant liquid each time. Next 33 ml of reagent B were added to the tubes, which were stoppered, shaken for 5 min, unstoppered, and centrifuged until the supernatant liquid was clear. The supernatant liquid was decanted and discarded. The samples were washed with 33 ml portions of reagent B a total of 3 times. The adsorbed sodium was replaced from the sample by extraction with three 33 ml portions of reagent C which were combined and the volume made up to 100 ml.

Finally the sodium concentration was determined by flame photometry see section 2.2.5.1. Working range standards were prepared from stock solution of Na (1000 mg l^{-1}). Samples were diluted into range (0 – 5 $mg1^{-1}$) with deionised water.

Calculations:

Cation exchange capacity in $\text{cmol}_c\ \text{kg}^{-1}$ = (Na concentration of extract in $\text{mmol}_c \text{l}^{-1}$ x 10) / (wt. of sample in g)

2.2.14 The mechanical analysis of soil.

Richards (1954), according to the Sieve Analysis Apparatus by the American Salinity Laboratory as follows.

Sieving method

100 g of soil were weighed and placed in a sieve (diameter of the holes 0.25 mm). The sample was washed with water to get rid of silt and clay and only the sand was kept. Then the soil was put in a porcelain dish and dried in the oven at 105 °C. When the soil was dried it was cooled and transferred to a sieve shaker and sieves Fig 2.1 which divides the sand into different categories,

Gravels	> 2 mm
Very coarse sand	2 – 1.18 mm
Coarse sand	1.18 – 0.600 mm
Medium sand	0.600 – 0.425 mm
Fine sand	0.425 - 0.250 mm
Very fine sand	0.250 - 0.150 mm
Silt + clay	0.150 – < 0.150 mm

Figure 2—1 Sieve shaker and sieves

Chapter 3 Comparison of laboratories

3.1 Summary

This study consists of a comparison of the results obtained following chemical analyses of soils in two different laboratories, one located at the KAP in Libya, and the second one in the Environmental Analytical Chemistry Lab at Glasgow University. The first phase involved the selection of 33 soil samples at random, from different soil horizons from 48 soil profiles. They were then divided into two parts, and the following parameters were measured in saturation extracts (pH, EC, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+), initially in the KAP laboratory, and then the same process was repeated in the laboratory at Glasgow. The purpose of this procedure was to assess the accuracy of the KAP laboratory in chemical analyses of soils and water. This laboratory was then used to conduct the analysis of the samples used in this thesis.

Similar instruments were used to measure the pH and Electrical Conductivity (EC) in both laboratories. For the measurement of chloride, calcium and magnesium, the KAP lab used titrimetric methods, while the Glasgow laboratory used electronic instruments, (Chloride analyzer 926 and Atomic Absorption Spectrometer). Sherwood Flame Photometers models 400 and 410 were respectively used for Na^+ and K^+ in the KAP laboratory and in Glasgow. The comparison of the pH values using a paired t-test confirmed that the Glasgow results were significantly higher than the KAP results, at a level of 1%. The results of the regression analysis for EC, Cl^- and also Ca^{2+} (when an outlier Ca^{2+} value is removed), was that the intercept is not significantly different from 0, but the slope is significantly different from 1. However, the intercept is significantly different to 0, and the slope is significantly different from 1 for Mg^{2+}. The difference between the regression slope and the theoretical value of 1 means that one method gives a systematically higher value than the other, probably due to standardisation differences. The regression analysis results for Na^+, K^+ and Ca^{2+} indicate no significant difference from an intercept of 0 or a slope of 1 between the laboratories. This comparison confirmed that there is a good level of agreement between the Kufra agricultural project laboratory and Glasgow University laboratory. The high correlation coefficient indicates a high level of precision in both laboratories for all samples. However as there were systematic differences between the two laboratories it is important that all analyses were carried out in one laboratory, so all the samples were sent to Kufra Agricultural Project laboratory.

3.2 Introduction

The present study entailed a comparison between the results of soil sample analyses in two laboratories, one the Kufra Agricultural Project in Libya, and the other in the Environmental Chemistry laboratory at the University of Glasgow, UK.

The Kufra Agricultural Project laboratory in Libya is used to help agricultural activity through analyses of soil, water and fertilizer, and provides recommendations for the project and for private farmers. In the KAP laboratory there are experienced technical staff who carry out these soil and water tests routinely, and due to the difficulty in transferring the great number of soil samples, each weighing not less than half a kilogram and water samples) from Libya to UK it was decided to conduct most of the laboratory analyses in the Kufra Agricultural Project laboratory. Therefore it is important to compare the results between the two laboratories.

The analysis of soils and water in the Kufra Agricultural Project (KAP) laboratory were conducted in two phases. The first survey was conducted in the summer of 2010, and the second in 2013. A total of 312 soils samples and 82 water samples were analysed at the KAP laboratory.

To compare the results, 33 soil samples were selected randomly from the 192 samples (48 soil profiles 4 layers each) collected for the first survey and taken to the University of Glasgow laboratory to conduct similar analyses for the some of the parameters measured in saturation extracts (pH, EC, Cl^-, Ca^{2+}, Mg^{2+}, Na^+, and K^+). The results obtained in Glasgow laboratory were compared with the ones obtained and recorded in the KAP laboratory.

It is possible to divide analytical methods into two distinct categories, classical and instrumental procedures. The first are called wet chemistry methods, using precipitation, extraction, distillation, titration and qualitative analysis by colour, odour, or melting point. The second one is instrumental ranging from pH meters, EC meters to colorimetry, and flame photometry to AAS GC or HPLC-MS. Many researchers rely on automated equipment for conducting their analyses. These are highly sophisticated instruments which can produce a huge number of laboratory results in a very short time, through the integration of technologies (computer and analytical chemistry). These methods are excellent replacements for methods requiring a larger quantity of equipment such as glassware and repetitive manual work in the laboratory (Karkalousos and Evangelopoulos, 2011). These sophisticated methods are similar to those available at University of Glasgow laboratory. Although the Kufra Agricultural Project Laboratory uses more traditional wet chemistry methods, the results should not differ that much from the results of the Glasgow laboratory.

The following procedure is usually followed for the comparison of two methods for measuring analyte concentrations. The vertical Y axis of a graph plots the results obtained by the new method, while the horizontal axis plots the results obtained by applying the reference or comparison method to the same samples. Therefore, each point on the graph represents a single sample, analysed by two separate methods (Harvey, 1999).

A regression line can be used to compare the two analytical methods, as to whether there is perfect agreement between both methods for all the samples, or results arising from different forms of systematic or random error.

This method is used to calculate the slope (b), the intercept (a) and the product-moment correlation coefficient (r) of the regression line. Evidently, if each sample produces an identical result with both analytical methods, the regression line will have a zero intercept, and the slope and correlation coefficient of 1. In practice, however, this never happens. Even when there are no systematic errors, the presence of random errors means that the two analytical procedures will not result in complete correlation for all the samples.

Deviation from the “ideal” situation ($a = 0$, $b = 1$, $r = 1$) can occur in a variety of manners. For instance, the regression line could have a slope of 1, but a non-zero intercept. In other words, one method of analysis may yield a result that is either higher or lower than the other by a fixed amount. Another possibility is that the slope of the regression line is >1 or <1, indicating the presence of a systematic error in the slope of one of the individual calibration plots.

In practice, the researcher is most often aiming to test for an intercept varying significantly from zero, and a slope varying significantly from 1 and a correlation coefficient of close to 1 (Miller and Miller, 2010)

3.2.1 Aims for this chapter

To assess the degree of agreement between the laboratory of Kufra Agricultural Project and the Environmental Analytical Chemistry Lab at Glasgow University, and to find out if there were any important differences in the results obtained by the two laboratories

3.2.2 Methodology

Different equipment used at the two Laboratories.

Table 3-1 **Methods and instruments used.**

Parameter	Glasgow	KAP
pH	Mettle Delta pH meter	Maker 3020 pH meter
EC	Jenway 4070EC meter	Wilhelm 8120EC meter
Cl	Sherwood MK Π Chloride analyzer 926	Titration by $AgNO_3$
Ca^{2+} Mg^{2+}	Perkin Elmer AAnalyst 100 AAS	Titration by EDTA
Na^{+} K^{+}	Sherwood 410 Flame photometer	Sherwood 400 Flame photometer

Chemical analysis

pH and EC were determined as described in sections 2.2.3 and 2.2.4 respectively.

Sodium and Potassium were determined by the flame photometer as described in section 2.2.5.

Calcium and Magnesium were determined by EDTA titration as described in section 2.2.7 and by AAS as described in section 2.2.6

Chloride was determined by titration with $AgNO_3$ as described in section 2.2.9 and by chloride analyzer 926 as described in section 2.2.10

3.3 Results and Discussion

pH

Both the Glasgow University laboratory and the Kufra Agricultural Project (KAP) laboratory used a pH meter for this measurement.

Figure 3.1 shows a comparison between the two laboratories. Statistical regression analysis is not appropriate for pH data because the range of pH values is small so a paired t-test is more suitable.

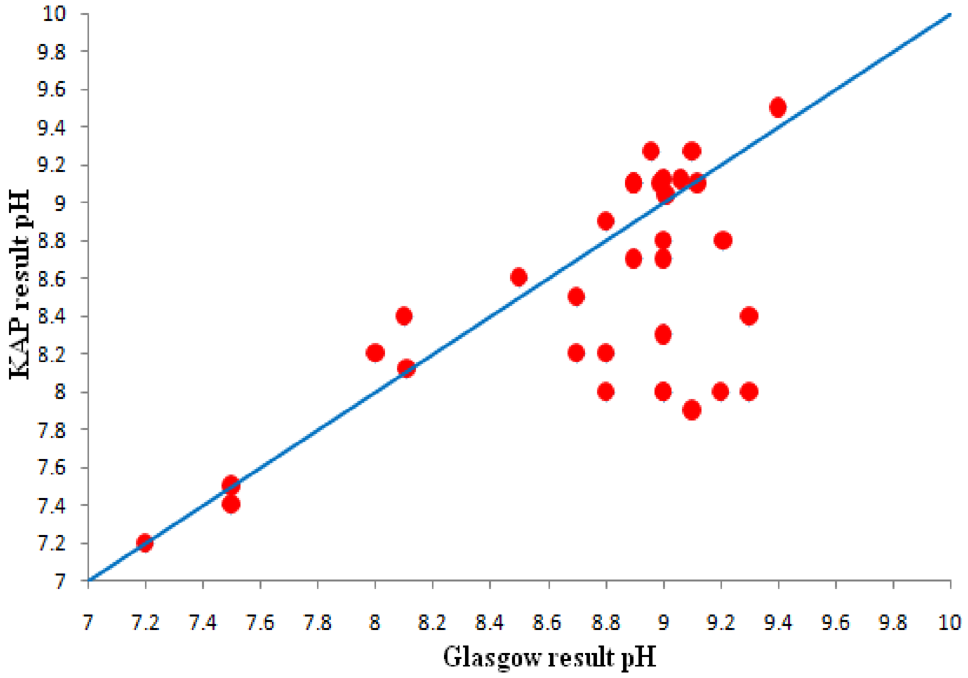


Figure 3—1 Comparison of the pH values in soil between Glasgow laboratory and KAP laboratory.

Statistical analysis using a paired t-test (DF = 31, t value = 3.07 P = 0.004) for pH showing that the Glasgow results were significantly greater than the KAP results, at a level of 1%, and the mean difference of -0.26 but is not considered to be of practical importance.

Electrical Conductivity

Both the Glasgow University laboratory and the KAP laboratory used a conductivity meter for this measurement.

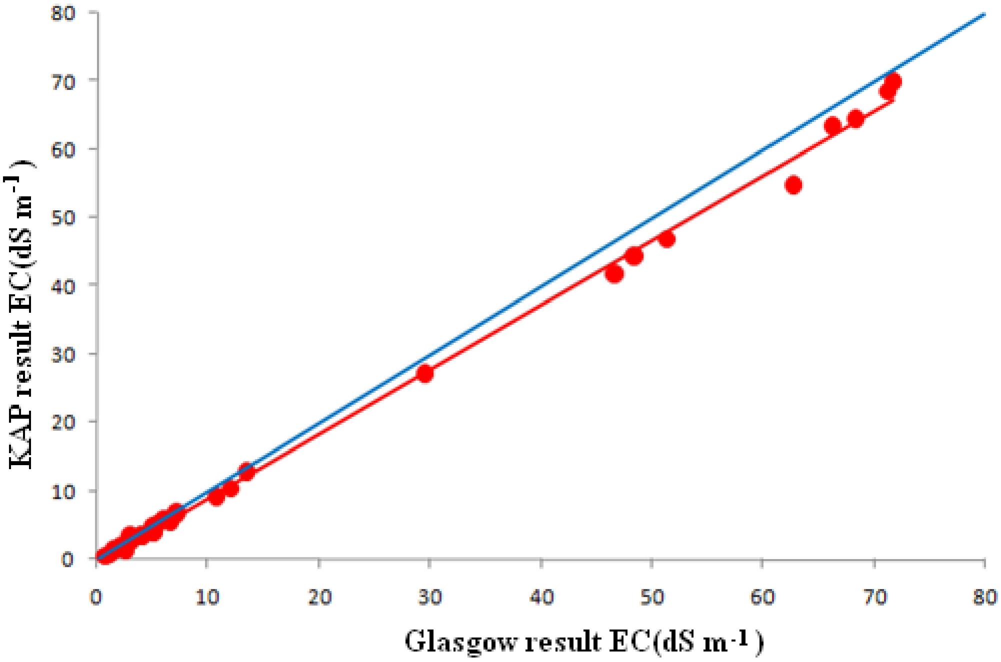


Figure 3—2 Comparison of the EC values in soil samples between labs with the regression line and the line of equality

The results of the regression analysis are shown in Table 3.2. The intercept is not significantly different from 0 but the slope is significantly different from 1. This suggests the difference is related to the calibration of the meters. The high correlation coefficient indicates a high level of precision in the two laboratories.

Table 3-2 Regression and correlation analysis results for EC.

parameter	**Intercept**	***p*≠ 0**	**Slope**	***p*≠ 1**	**r**
EC	0.4492	NS	0.941718	*p*<0.001	0.999

The slope figure produces about a 6% difference between the two laboratories but 6% is not practically significant in terms of identifying the salinity categories of the soils.

Chloride

The Glasgow University laboratory used a Sherwood MK Π chloride analyzer 926 whereas at the KAP laboratory used titration with $AgNO_3$ for chloride measurement.

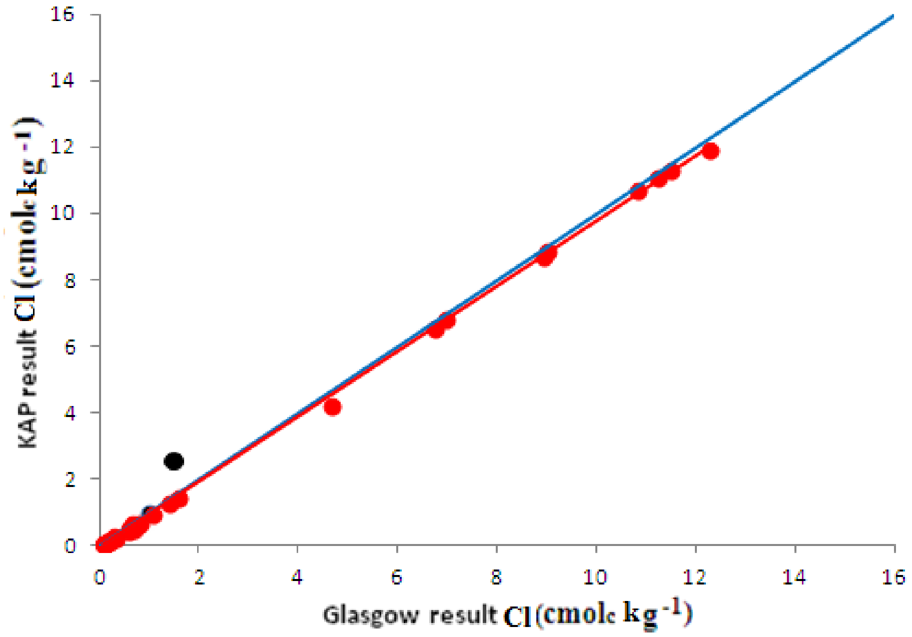


Figure 3—3 Comparison of the Cl^- values in soil samples between labs with the regression line and the line of equality.

The regression analysis results in Table 3.3 show that the intercept is not significantly different to 0 but the slope is significantly different from 1 at $p<0.05$. When the outlier point (soil 12) is removed the significance is unchanged. The high correlation coefficient indicates a high level of precision in the two laboratories. The slope figure produces about a 2% difference between the two laboratories but 2% is not practically significant.

Table 3-3 Regression analysis results and correlation coefficient for Chloride

parameter	n	Intercept	$p\neq0$	Slope	$p\neq1$	r
Cl^-	33	-0.01324	NS	0.982673	$p<0.05$	0.999
Cl^-	32	-0.01302	NS	0.982835	$p<0.05$	0.999

Calcium and Magnesium

The Glasgow University Laboratory used a Perkin Elmer Analyst 100 AAS whereas the KAP Laboratory used titration with Ethylenediaminetetraacetate (EDTA) for Calcium and Magnesium measurement.

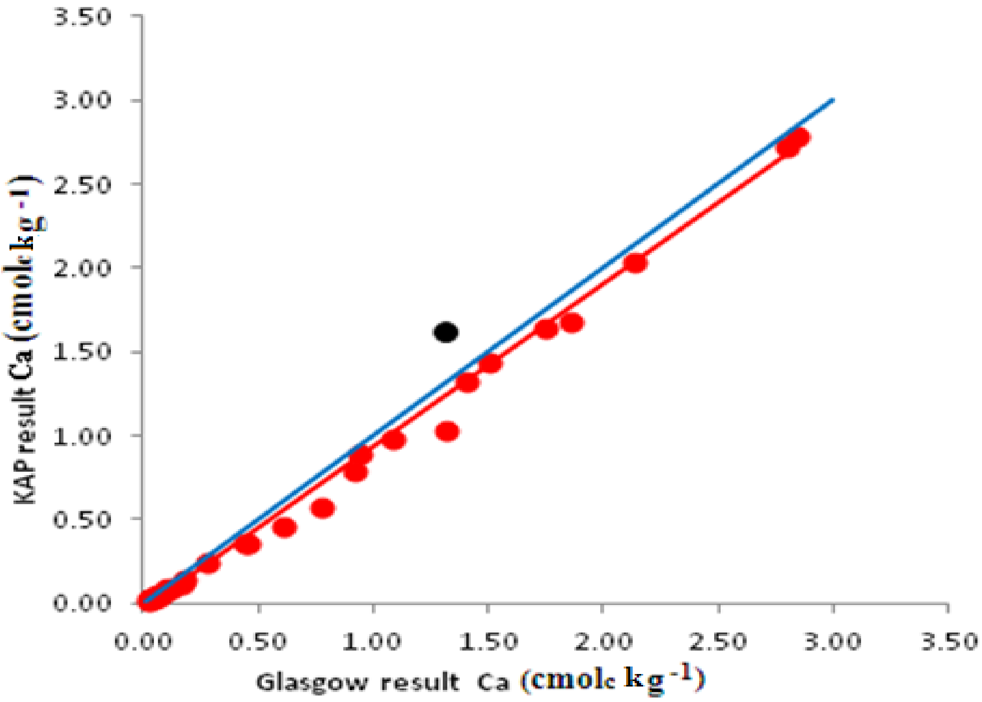


Figure 3—4 Comparison of the Ca^{2+} values in soil samples between labs with the regression line and the line of equality.

Table 3.4 shows that the intercept is not significantly different from 0 and the slope is NSDF1 1. When the outlier point (soil 15) is removed the intercept is still not significantly different from 0 but the slope is significantly difference from 1 at $p<0.05$. The high correlation coefficient indicates a high level of precision in the two laboratories. The difference in slope produces about a 2% difference between the two laboratories but 2% is not practically significant.

Table 3-4 Regression and correlation statistical analyses with and without the outlier point for Ca^{2+}

parameter	n	Intercept	*p*≠0	Slope	*p*≠1	r
Ca^{2+}	33	-0.02953	NS	0.96924	NS	0.998
Ca^{2+}	32	-0.01302	NS	0.982835	$p<0.05$	0.999

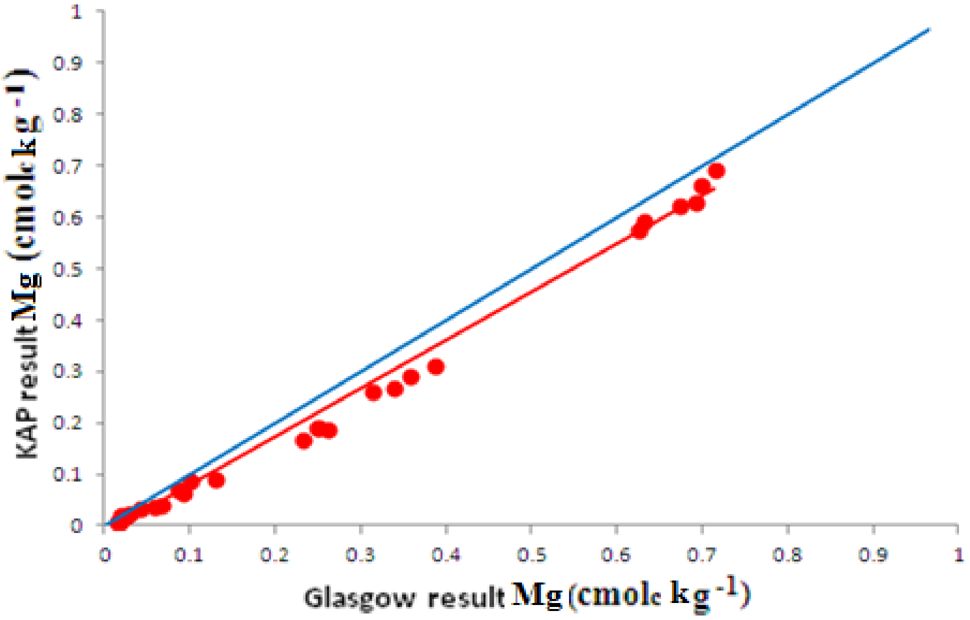


Figure 3—5 Comparison of the Mg^{2+} values in soil samples between labs with the regression line and the line of equality.

The regression analysis results in Table 3.5 show that the intercept is significantly different to 0 at *p*<0.01 and the slope is significant different from 1 at *p*<0.001

Table 3-5 Shows regression and correlation statistical analyses for Mg^{2+} of soil samples.

parameter	n	Intercept	*p*≠0	Slope	*p*≠1	r
Mg^{2+}	33	-0.013263	*p* <0.01	0.93469	*p*<0.001	0.996

The slope figure produces about a 6% difference between the two laboratories for Mg^{2+}, but is not practically significant. The level of precision in both laboratories is high.

Sodium and Potassium

Both the Glasgow University laboratory and the KAP laboratory used a Flame photometer for these measurements.

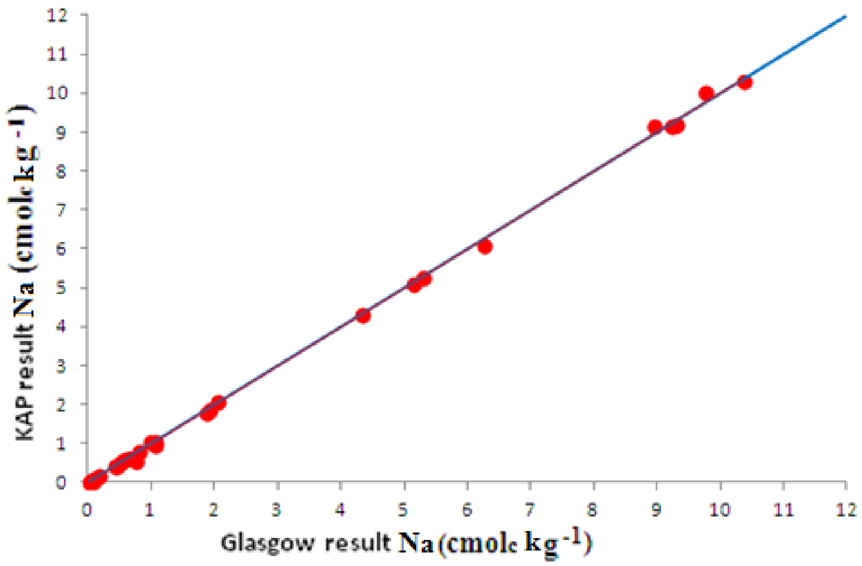


Figure 3—6 Comparison of the Na$^+$ values in soil samples between labs with the regression line and the line of equality.

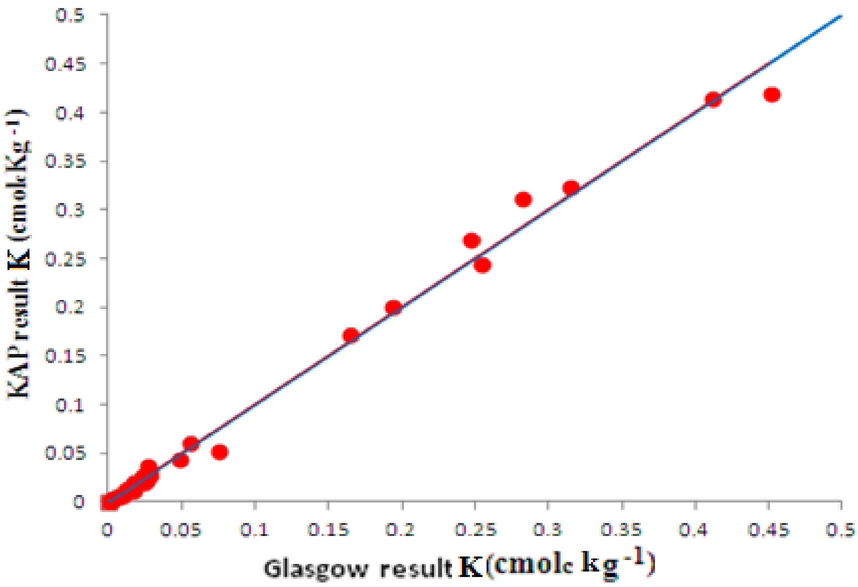


Figure 3—7 Comparison of the K$^+$ values in soil samples between labs with the regression line and the line of equality.

The regression analysis results in Table 3.6 show that no significant difference from an intercept of 0 or a slope of 1 in the results for Na^+ and K^+ between the laboratories. The high correlation coefficient indicates a high level of precision in the two laboratories.

Table 3-6 Shows regression and correlation statistical analyses for Na^+ and k^+ of soil samples.

Parameters	N	Intercept	$p\neq 0$	Slope	$p\neq 1$	r
Na^+	33	-0.02263	NS	1.00235	NS	1.00
K^+	33	-0.001039	NS	1.00034	NS	0.997

3.4 Conclusion

Despite the systematic differences, which are probably due to standardisation, there is a good level of agreement between the two laboratories. However, as there are these systematic differences it is important that all analyses were carried out in one laboratory, so all the samples were sent to Kufra Agricultural Project laboratory.

Chapter 4 Assessment of irrigation water quality

4.1 Summary

This study assesses the quality of irrigation water in the Kufra area of southern Libya, in line with the relevant Food and Agriculture Organization (FAO) standards for irrigated agriculture and the USDA classification (Ayers and Westcot, 1985; National Engineering Handbook, part 652, 1997; Richards, 1954; National Engineering Handbook, part 623, 2013). The samples of irrigation water were collected from 46 private farms and 36 state farms (Kufra Agricultural Project). The depths of the private farm wells were shallow (between 19 and 55 m depth). In contrast, the depth of the wells situated on the state farms varied between 220 and 352 m. At the time of the study, the average age of well from its year of establishment was 23 years for private farms and 40 years for state farms (year of establishment 1973). Several water chemistry parameters were not significantly affected in state farms by well depth or age. However, EC, Ca^{2+}, Mg^{2+}, Na^{+}, and SAR were significantly affected in the private farms by well depth and were significantly related to the well age. Assessment using the USDA and FAO criteria showed that due to the higher levels of EC, and SAR in the shallow wells, many of the private farms using them receive poor quality irrigation water.

4.2 Introduction

Libya, as with the other countries of the Maghreb, relies heavily on groundwater for its water supply. In Libya, demand for water is rapidly increasing, forcing the intense exploitation of groundwater resources, particularly in the fertile lands of the Jeffara Plain in the northwest and Jebel Al-Akhder in the northeast of the country. In desert regions such as Kufra, in the southeast of the Libya, the development of groundwater has increased rapidly during the last twenty years. Most of the water in Libya is used for agricultural purposes, which on average accounts for 83% of the groundwater consumption. Only about 2 % of Libya's land receives enough rainfall to be cultivated without irrigation (Lawgali, 2008). Domestic water use accounts for 14% of the water supplied, and industrial usage makes up the remaining 3% (Laytimi, 2002). However, the rapid increase in groundwater withdrawals has resulted in lowering the piezometric surface, particularly in the northern regions of the country. Furthermore, there is a suspicion that saline intrusion is occurring along the coast in the north (Pallas, 1980). Information on water quality is sparse, but groundwater across Libya is tending towards salinisation as a result of irrigation use (El-Trriki, 2006).

The rapid increase in demand for groundwater in the study area at Kufra is due to agricultural activity. Most of the population of Kufra are private farmers who were able to buy desert land cheaply. Sinking wells is relatively expensive compared to the cost of land, and increases with well depth (Ebrik, 1981). As a result most privately dug wells are shallow (15-60 m), but there are co-operatives of farmers that have shared the cost of deeper wells (120 - 150 m) and modern irrigation methods, located around the Kufra region. At the beginning of the 1970s, Libya launched a large desert agriculture project in Kufra, using deep groundwater for irrigation. The project consists of 100 x 1 km diameter circular irrigated areas (referred to as “farms” here). These farms are divided between five agricultural units, with each farm having its own well (220 – 352 m depth). (Allan, 1976; Metz, 1987).

It has been suggested that this agricultural activity is likely to result in salinisation of the shallow aquifer on which the private farmers rely heavily. A previous study by El-Ramly, (1980) warned that return flow from the KAP farms could cause the development in irrigated fields of a new shallow water table, due to the prevalence of impermeable palaeo-lake deposits at shallow depths (<5 m) within the sandstone strata. However, groundwater levels have fallen. Two salt water lakes are all that remains of a large ancient lake that still existed 30 years ago near the town of Kufra. These are Buhayrit Buwaimah in the North East of Kufra, which had a diameter of about 400 m and was surrounded by palm groves, and Aiet Ghayth in the West, which was a diameter of about 200 m. This lake was relatively deep (4 m in 1977), but has now dried up completely, probably because of the expansion of agricultural water use, which has caused a deepening of the water table to approximately 15 m.

4.2.1 Classification of irrigation waters:

The irrigation water quality criteria developed by the USDA classification (Richards, 1954; National Engineering Handbook, part 623, 2013) has received wide acceptance in several countries. Total dissolved salt concentration (salinity) and the potential sodium hazard of the irrigation water are the two major components of the criteria. Four classes each of salinity hazard and sodium hazard were proposed to assess irrigation water quality. Salinity hazard is based on electrical conductivity (EC) measurements and sodium hazard expressed as sodium adsorption ratio (SAR)

The SAR value is calculated using the formula;

$$\mathbf{SAR}=\frac{\mathbf{Na^{+}}}{\sqrt{\dfrac{\mathbf{Ca^{2+}}+\mathbf{Mg^{2+}}}{2}}}$$

Where concentrations of cations are mmol$_c$/l.

4.2.1.1 Criteria of US Salinity Laboratory (Richards, 1954: also National Engineering Handbook, part 623, 2013).

4.2.1.1.1 Salinity

To find the salinity of the water and classify it in an easy and fast way it is necessary to determine the electrical conductivity which shows the amount of dissolved salts.

Water is divided in to four classes with respect to conductivity:

A. Low salinity water (C_1) – These waters, which have conductivity values below 0.250 dS m^{-1}, can be used to irrigate the majority of crops in most soils, with a low risk of soil salinity. Some leaching is required, especially for soils of slow permeability.

B. Medium salinity water (C_2) – This water, in the range of 0.250 – 0.750 dS m^{-1}, can be used where a moderate amount of leaching is present. Plants with high tolerance to salinity will not require any additional treatments to be cultivated.

C. High Salinity water (C_3) - This water 0.750 – 2.250 dS m^{-1} is unsuitable for soils characterised by moderately slow to very slow permeability. Special management for salinity control may be necessary, even in the event of adequate permeability, and only plants with high salt tolerance should be cultivated.

D. Very high salinity water (C_4) -This water, with conductivity values above 2.250 dS m^{-1}, is generally unsuitable for irrigation. Only crops with very high salt tolerance can be grown with these waters, and only under very particular circumstances, such as excess irrigation being applied to provide considerable leaching.

4.2.1.1.2 Sodium hazard

Sodium Adsorption Ratio (SAR) is used as an index for sodium hazard in water for irrigation purposes based primarily on the effect of exchangeable sodium on soil physical conditions. The expression of SAR was recommended by the USDA classification (Richards, 1954).

Water is divided in to four classes with respect to SAR:-

The boundaries of the SAR classes are not fixed and depend on the electrical conductivity of the water.

A. Low Na^+ water (S_1) little danger.

B. Medium Na^+ water (S_2) Problems may be found with finely textured soils and sodium sensitive plants, especially under low-leaching conditions. Soils should have good permeability.

C. High Na^+ water (S_3) Problems on most soils. Good salt tolerant plants are required, along with special management, such as the use of gypsum.

D. Very high Na^+ water (S_4) Unsatisfactory except with low or medium salinity, and the use of gypsum.

Figure 4-1 is used to determine irrigation water classes in which a given quality of water can be placed using EC and SAR values. This system uses conductivity units of Micromhos/cm (dS m^{-1} = Micromhos/cm divided by 1000) and SAR values for classifying water. It is a simplified diagram developed in the laboratory for use in classifying irrigation waters. SAR values are listed on the left from bottom to top. EC values are shown on both sides top and bottom of the diagram.

Electrical Conductivity EC is measured from low (C_1= EC <250 micromhos/cm) through to very high (C_4 = EC> 2250 micromhos/cm). Sodium hazard is measured from S_1= SAR (low sodium) to S_4=SAR (very high sodium). Each sample can therefore be given a C_{1-4}, S_{1-4} classification e.g. For example category (C_1-S_3) refers to salinity low hazard with sodium high hazard.

In the classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, and drainage, quantity of water used, climate and salt tolerance of crops.

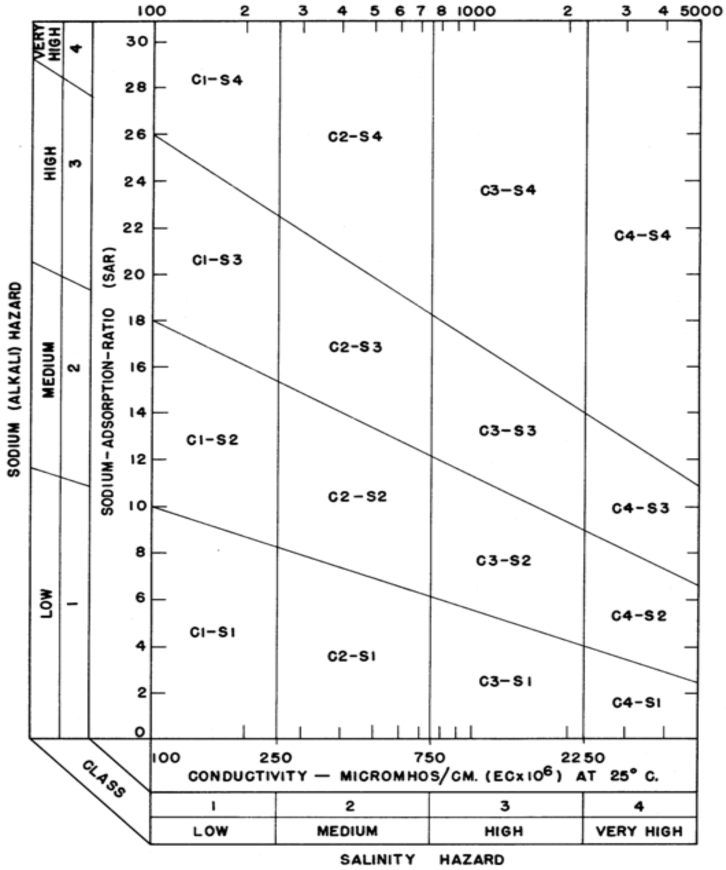


Figure 4—1 Shows the USDA classification of irrigation water according to the relationship between salinity hazard (EC) and sodium hazard (SAR). The classes 1, 2, 3 and 4 refers to low, medium, high and very high respectively, on both the X and Y axis (Richards, 1954).

4.2.1.2 The guidelines for irrigation water of FAO (Ayers and Westcot, 1985; also National Engineering Handbook, part 652, 1997).

Table 4-1 illustrates the FAO guidelines for irrigation water quality.

Table 4-1 Potential Irrigation Problems and the restrictions on use of irrigation water according to (Ayers and Westcot, 1985).

Potential Irrigation Problem		**Units**	**Degree of Restriction on Use**		
			None	**Slight to Moderate**	**Severe**
Salinity*(affects crop water availability)*					
	EC	dS/m	< 0.7	0.7 – 3.0	> 3.0
	TDS	mg/l	< 450	450 – 2000	> 2000
Infiltration (affects infiltration rate of water into the soil. Evaluate using EC and SAR together)			**None**	**Slight to Moderate**	**Severe**
SAR	0 – 3		> 0.7	0.7 – 0.2	< 0.2
	3 – 6		> 1.2	1.2 – 0.3	< 0.3
	6 – 12		> 1.9	1.9 – 0.5	< 0.5
	12 – 20		> 2.9	2.9 – 1.3	< 1.3
	20 – 40		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*					
	Sodium (Na^+)		**None**	**Slight to Moderate**	**Severe**
	surface irrigation SAR		< 3	3 – 9	> 9
	sprinkler irrigation SAR		< 3	> 3	
	Chloride (Cl)				
	surface irrigation	me/l	< 4	4 – 10	> 10
	sprinkler irrigation	me/l	< 3	> 3	
	Boron (B)	mg/l	< 0.7	0.7 – 3.0	> 3.0
	Trace Elements				
Miscellaneous Effects *(affects susceptible crops)*					
	Nitrogen (NO_3 - N)	mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)				
	(overhead sprinkling only)	me/l	< 1.5	1.5 – 8.5	> 8.5
	pH		**Normal Range 6.5 – 8.4**		

Following their study Ayers and Westcott (1985); National Engineering Handbook, part 652, (1997) observed that the quality of irrigation water might vary significantly. Such variation depends upon the type and quantity of dissolved salts which are present in irrigation water, in relatively small but significant amounts. These salts result from the dissolution of soluble substances from soil components, including rocks and other materials in addition to weathering processes. The appropriateness of water for irrigation is determined not only by the total amount of salt present, but also by the type of salt. However, water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. These problems vary both in kind and degree, and are modified by soil, climate and crops, as well as by the skill and understanding of the water user. Water quality problems in irrigated agriculture are:

Salinity

The salinity problem is due to salts which are water soluble and easily carried by water. A certain amount of the salts that gather after the irrigation process might be leached lower than the rooting depth where more irrigation water permeates the soil deeper than is used by the crop during the crop season. Leaching represents the key element for the control of the quality of the water related to the salinity problem. After a certain time, the removal of salt by leaching should equal or exceed the salt additions from the applied water, in order to avert the increase of the level of salt to a harmful concentration. It is essential to highlight the fact that the amount of leaching necessary is subject to both the quality of irrigation water quality and the salinity tolerance of the crop.

Infiltration

The water salinity and its sodium content relative to the content in calcium and magnesium are commonly the water quality factors affecting the infiltration rate. For instance, high salinity water is expected to increase infiltration, while water with high sodium to calcium ratio usually reduces infiltration. The continuous use of water with high SAR leads to a breakdown in the soil aggregates. The sodium replaces calcium and magnesium on ion exchange sites, and causes dispersion of soil particles. This dispersion results in the breakdown of soil aggregates, and causes the soil to become hard and compact when dry, and increasingly resistant and impermeable to water penetration (Hergert and Knudsen, 1977).

Toxicity

The ions that most concern us are chloride, sodium, and boron. They are typically absorbed by the roots, but when the absorption is through the leaves, the rate of accumulation is higher. This direct absorption usually happens in sprinkler irrigation systems at high temperatures and low humidity conditions. Table 4.1 gives general recommendations on the risk of toxic effects. However, toxic effects may be influenced by the kind of crops, state of growth, concentration of the toxic ion or ions, and combination of climate and soil conditions.

Miscellaneous

There are various other problems related to irrigation water quality which happen quite often, justifying their specific mention here. For instance, high nitrogen concentrations, bicarbonate water containing gypsum, or water high in iron.

4.2.2 Aims for this chapter

The purpose of the study was to investigate the groundwater salinity of the Kufra area, with a view to:

1. Evaluate the groundwater physical-chemical quality of the area.
2. Evaluate the relationships between the year of establishment, depth and the spatial variability of the wells with concentration of salts in irrigation water.
3. Compare the quality of irrigation water from shallow and deep aquifers used by private and state farms using a standard classification of irrigation water.

4.3 Methodology

The Kufra region was chosen to study the phenomenon of salinity, concentration of cations and anions, and to calculate the Sodium Adsorption Ratio of irrigation water in both the deep aquifer (state farms) and the shallow aquifer (private farms)

4.3.1 Selection of water samples of the state farms.

Water samples were collected from wells of the state farms. The Kufra Agricultural Project is made up of a total of 100 circles (farms) divided into five agricultural units, each containing approximately 20 farms as shown in figure 4.2. 36 farms were selected blindly from the list of farms for the collection of well water samples. The depth of the wells sampled from these farms ranged from 220 to 352 m.

Agricultural unit	Number of farms	Samples collected
1. Unit A	21	10
2. Unit B	21	5
3. Unit C	19	8
4. Unit D	20	7
5. Unit E	20	6

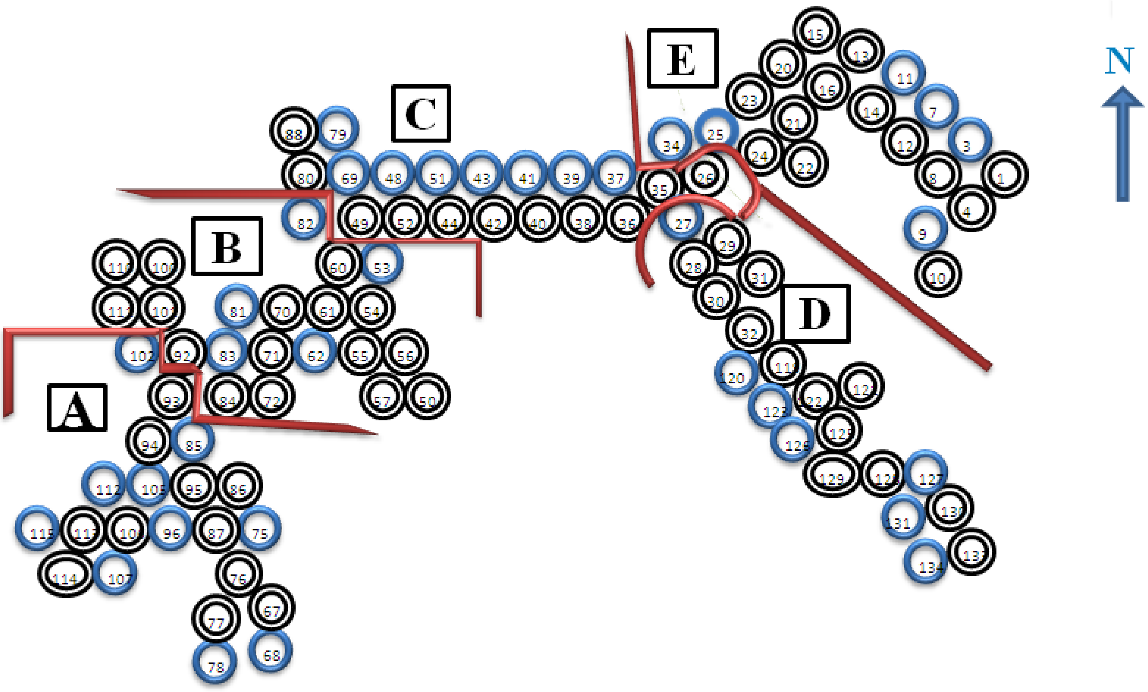


Figure 4—2 The five agricultural units of the Kufra Agricultural Project The farms coloured blue show where the water samples were collected.

4.3.2 Selection of water samples of the private farms.

The area of small private farms is divided into three geographic regions as in Figure. 4.3.

1. Al-Jawf including the western Jawf and Al-Tawbat, until Talaab, which is to the west and south-west of Kufra.
2. Al-Zawriq and Al-Istitaanee are located to the south of Kufra.
3. Hawari, which includes Al- Haweweri, and is located to the north of Kufra.

The average area of the private farms was 3.5 ha. A total of 46 water samples were collected from the wells of private farms. The farms to be sampled were selected blindly from an alphabetical list provided by the Office of Agriculture in Kufra. The 46 farms sampled were based on the ratio of the number of the farmers in each of the 3 regions the depth of the wells for these farms ranged from 19 to 55 m over the three regions.

Agricultural region	**Number of farms**	**Samples collected**
1- Al- Jawf	872	19
2- Al- Zawriq	592	14
3- Hawari	660	13

Water samples from the study area were collected in new plastic containers in the morning after a period of irrigation of not less than an hour from the operating of the pumps. The samples were taken directly to the laboratory for measurement of the conductivity and pH, and other parameters were measured later. The water samples were collected between 2nd December 2013 and 18th December 2013.

A more detailed study was carried out on a small number of wells. The samples of irrigation water were randomly selected (three replicated operations for each sample) at different times from 8 irrigation water wells to ensure an accurate representation of the samples. The depths of the first four wells were respectively 220 m, 245 m, 255 m, and 270 m, and represent the water of the deep wells of state farms. The second group of four wells had depths of 19 m, 27 m, 33 m, and 40 m, and represent shallow wells of the private farms. These samples were collected between 10th July 2010 and 10th August 2010.

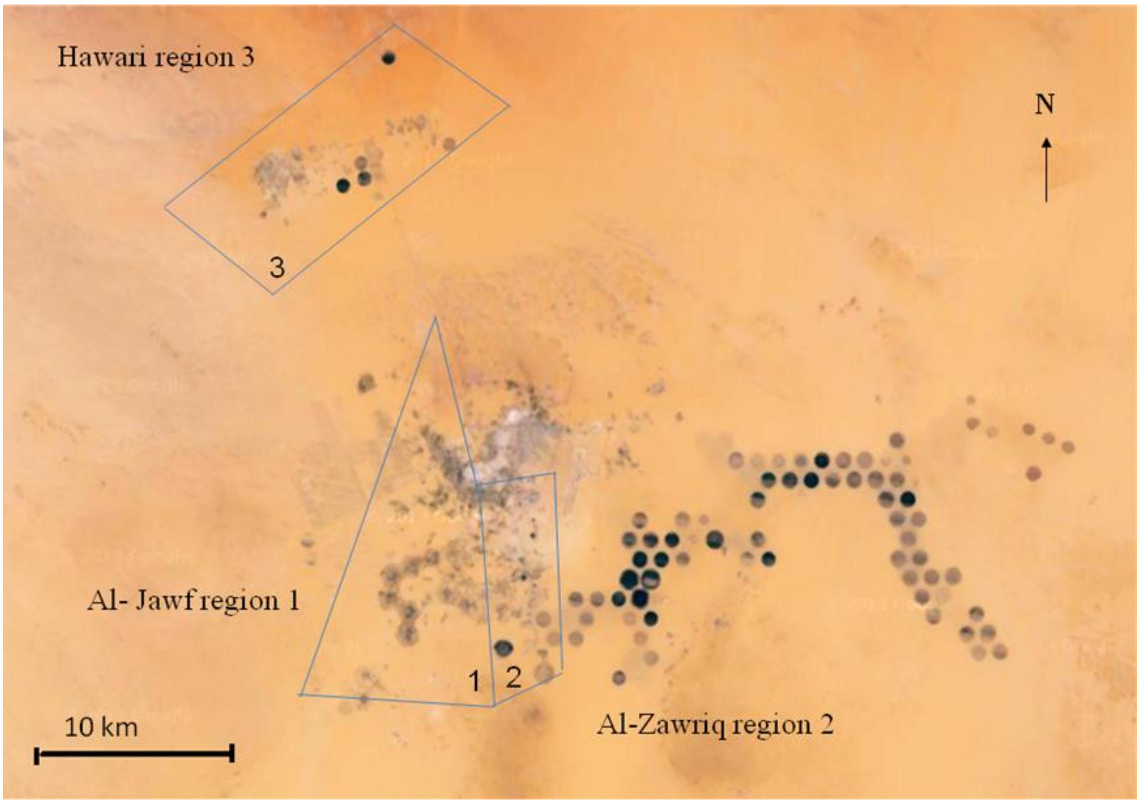


Figure 4—3 The three regions 1, 2 and 3 of private farms where samples were collected.

4.3.3 Chemical analysis

EC and pH were determined as described in sections 2.2.3 and 2.2.4 respectively.

Sodium and Potassium were determined by the flame photometer as described in section 2.2.5.

Calcium and Magnesium were determined by EDTA titration as described in section 2.2.7.

Bicarbonate and chloride were determined by Titration with Acid as described in section 2.2.8 and 2.2.9.

Sulphates was determined by precipitation of $BaSO_4$ as described in section 2.2.11

4.3.4 Statistical analysis and data handling

State farms

The following statistical procedures were carried out using the Minitab statistical package (version 16), General Linear Model to investigate the effects of well depth and agricultural unit, on the water quality parameters as follows:

Well depth under study; range from 220 m to 352 m

Agricultural unit; 5 units, A, B, C, D, E, see figure 4.2.

Well age was not considered because the wells were all established within a 3 year period.

Private farms

The following statistical procedures were carried out, using the Minitab statistical package (version 16) General Linear Model and Linear Regression to investigate the effects of well depth, age of well, and regions, on the water quality parameters as follows:

The effect of well depth which; ranged from 19 m to 55 m was tested using linear regression as a single line or split at 30 m depending on the parameter. pH and Ca were treated as single lines. EC, Mg, Na and SAR were treated as two lines based on the change in slope at 30 m depth.

Age of well; year of establishment ranged from 1975 to 2006

Well age was grouped in to 3 age classes as follows for General Linear Model.

1975 to 1984	age class 1
1985 to 1994	age class 2
1995 to 2006	age class 3

Subsequently the data was split by well depth (<30 m and 30 m and more) and the effect of well age tested using linear regression for all parameters.
Region; 3 regions, see figure 4.3 were tested using General linear Model.

1- Al-Jwaf
2- Al- Zawriq
3- Hawari

4.4 Results and Discussion

4.4.1 pH

The results for irrigation water reveal pH values ranging from 6.3 to 7.5 for state farms and 7.2 to 7.8 in private farms (see Appendix 9.1-4).

Figure 4.4 shows the effect of well depth on irrigation water pH for the state farms. The samples were slightly acidic, there were only two samples in agricultural units A and E where the pH was above 7.

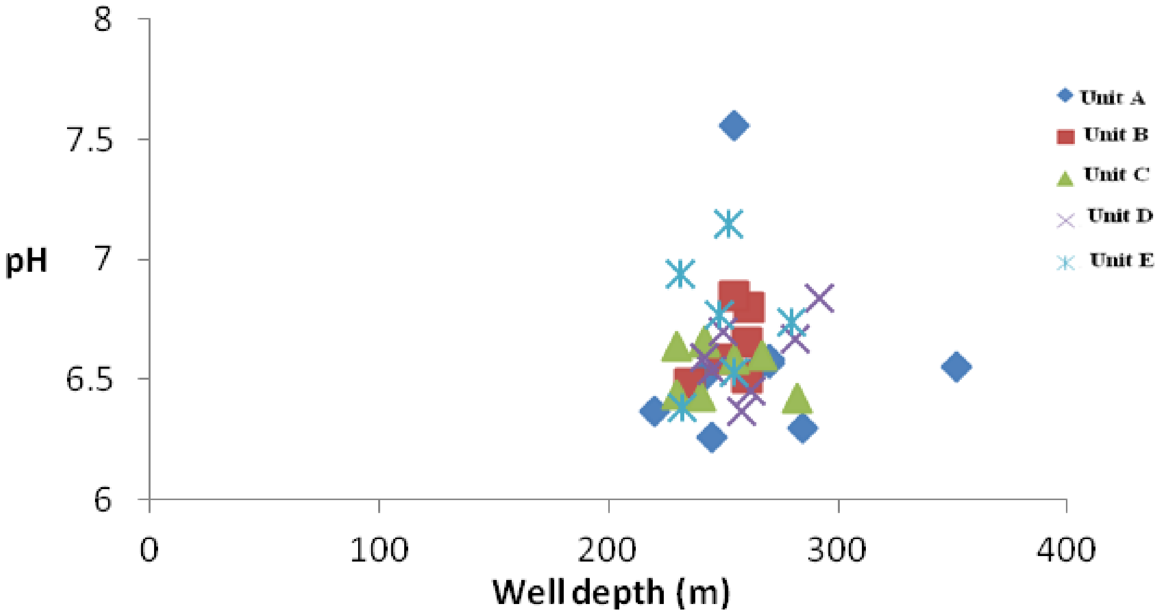


Figure 4—4 The effects of well depth on the pH of irrigation water from farms of the Kufra Agricultural Project subdivided by the five agricultural units.

Statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF= 25, F= 1.06, $p>0.05$) or agricultural unit (DF= 4, F=1.70, $p>0.05$) on pH. Well age was not considered because the wells were all established within a 3 year period.

The pH values recorded in private farms tend toward the alkaline, with all pH values greater than 7. Figure 4.5 shows the relationship between pH and well depth for the private farms.

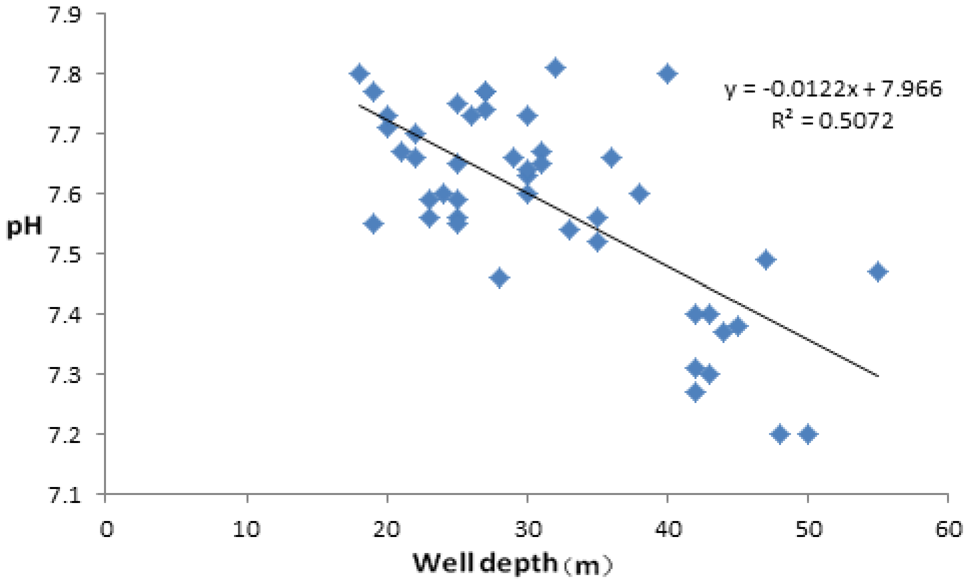


Figure 4—5 The effects of well depth on the pH of irrigation water from the private farms.

There is a trend of decreasing pH with greater well depth. Statistical analysis using linear regression showed that there was a significant effect of well depth on pH (DF= 44, F= 45.29, p<0.001).

The well depths are related with the financial means of the farmers in study area because of their relatively high cost. Namara et al., (2011) suggested that the main factor in the development of shallow wells is the financial cost of increasing the well depth in a study of upper east region of Ghana.

Figure 4.6 shows the relationship between the pH of irrigation water of private farms against the year of establishment, subdivided by the three regions.

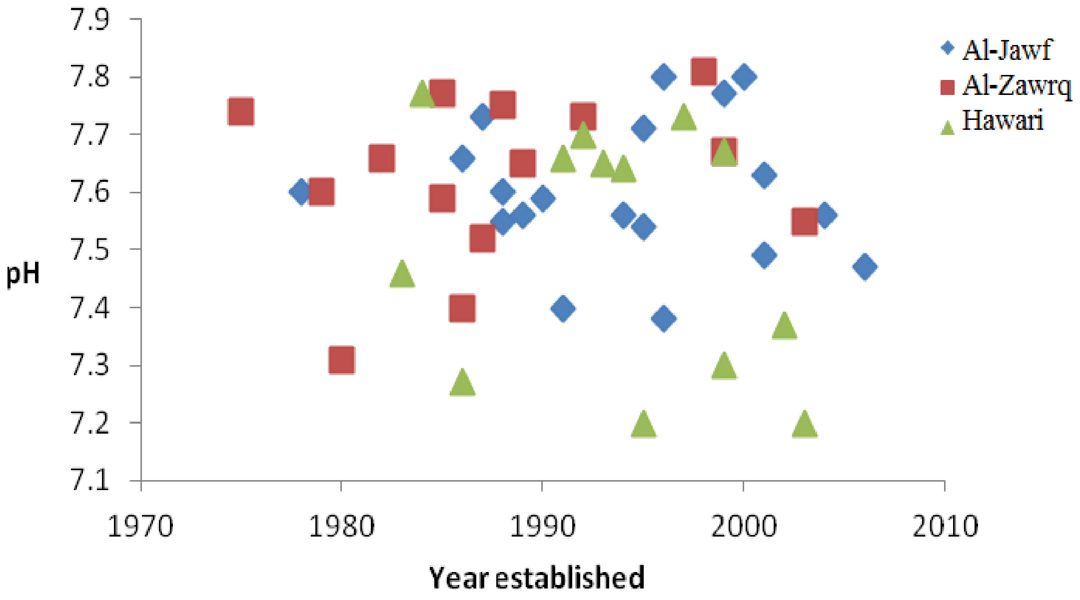


Figure 4—6 The effects of the year of establishment of the well on the pH of irrigation water from the private farms subdivided by the three regions.

The graph shows a scatter of data points for pH values between those established in 1975 and those established in 2007.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of region (DF= 2, F=0.45, *p*>0.05) on irrigation water pH. The statistical analysis regression linear showed that there was no significant effect of well age on pH (DF= 44, F= 0.56, *p*>0.05).

4.4.2 Electrical Conductivity

Analysis of the irrigation water samples for the study area (Appendix 9.1- 4) shows that the conductivity values ranged between 0.12 and 7.8 dS m^{-1}, and in some wells exceeded the category of slight to moderate degree of restriction on use for irrigation water (Table 4.1), which ranges between < 0.7 and > 3.0 dS m^{-1} according to FAO (Ayers and Westcot, 1985).

Figure 4.7 shows the effect of depth on EC values of irrigation water wells of the five agricultural units from the state farms.

All values were in the no restrictions category of the FAO classification (Ayers and Westcot, 1985) except one sample in unit C which was just into the slight to moderate restrictions category.

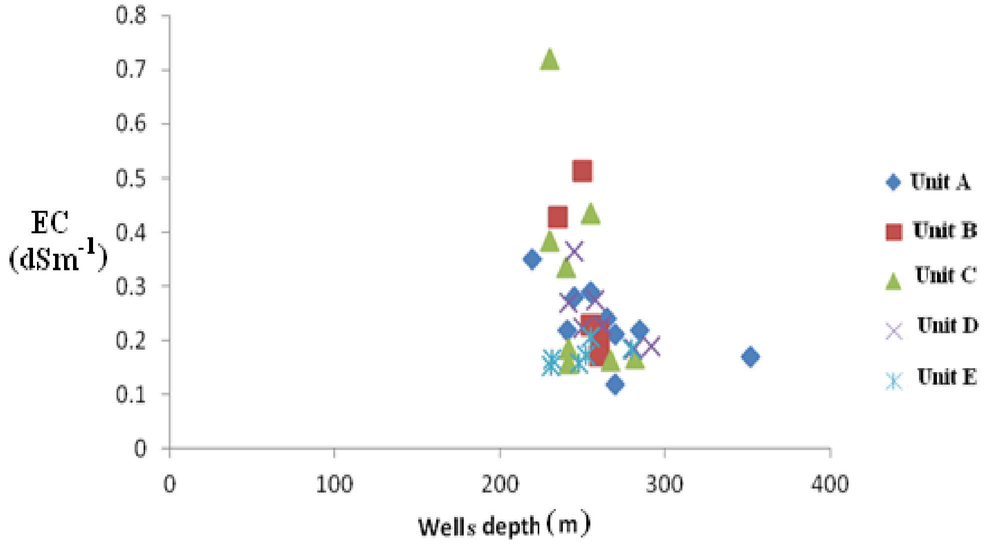


Figure 4—7 The effects of well depth on electrical conductivity of irrigation water in from the farms of the Kufra Agricultural Project Subdivided by the five agricultural units.

The statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF= 25, F=0.57, $p>0.05$) or agricultural unit (DF= 4, F=0.19, $p>0.05$) on EC.

The EC values of 8 wells with values higher than 0.3 dS m^{-1} were identified as being higher than the main body of results. Their spatial distribution is shown in Figure 4.8. A cluster of 6 wells with higher conductivity can be seen in units B and C.

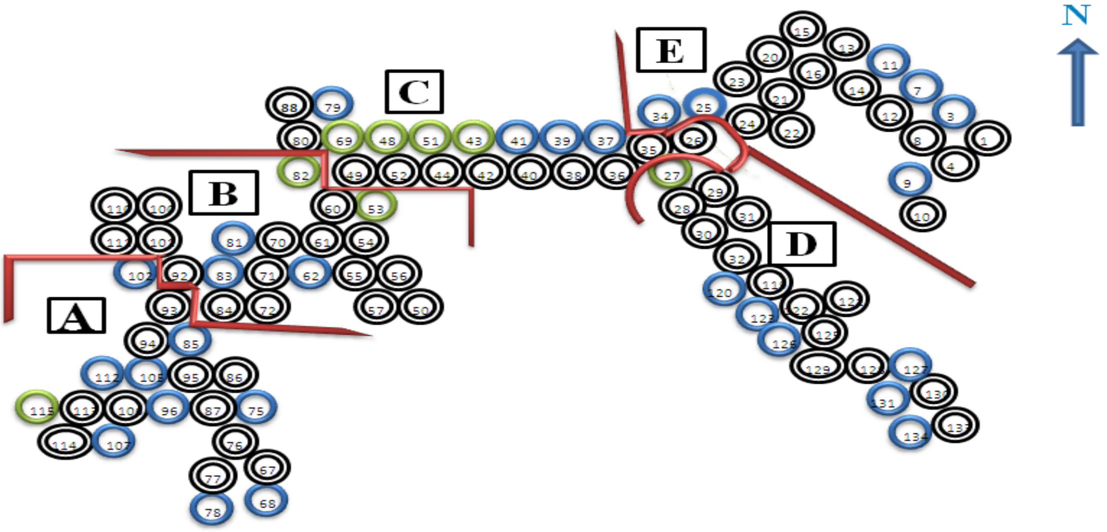


Figure 4—8 Spatial variability in irrigation water electrical conductivity in state farms. High values (>0.3 dSm^{-1}), are represented by the green circles, lower values (<0.3 dSm^{-1}) by blue circles.

Figure 4.9 shows the effect of well depth on Electrical Conductivity (EC) for the private farms.

In contrast to the state farms, these results show that 78% of well water samples from private farms are in the severe category (>3.0 dS m^{-1}) of the FAO guidelines (Ayers and Westcot, 1985).

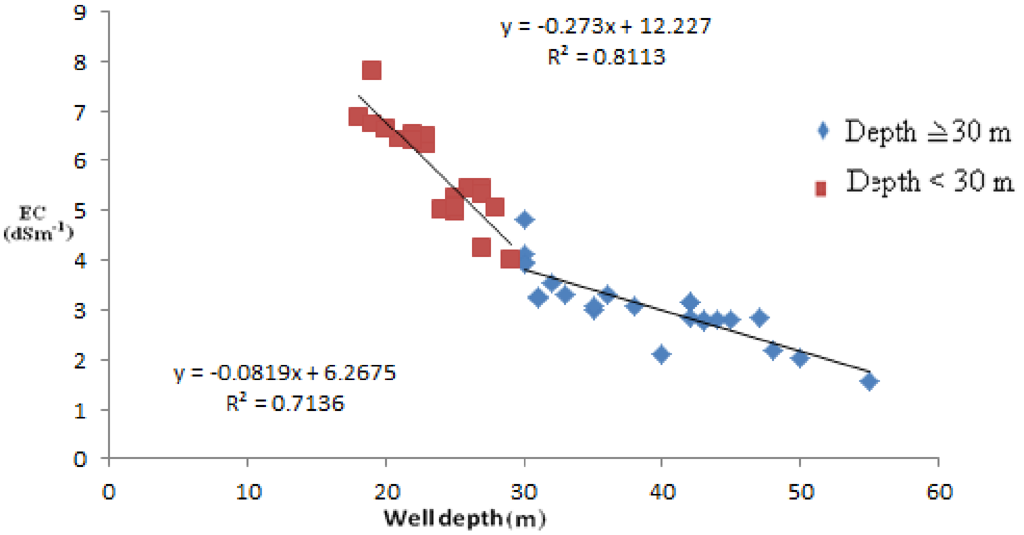


Figure 4—9 The effects of well depth on electrical conductivity of irrigation water from private farms subdivided by the two depths (wells < 30 m deep and wells 30 m or more deep).

Figure 4.9 shows that conductivity fell with increasing well depth and the data points fall into two zones. The graph shows a change of slope at approximately 30 m with a steeper slope with depth seen in the shallower wells.

Statistical analysis using linear regression showed that the shallow wells (<30 m) exhibit a significant (DF = 20, F= 86.01, $p < 0.001$) decrease in EC as well depth increases. In the same manner the deeper wells (30 m or more) exhibit a significant effect of well depth (DF = 22, F= 54.82, $p < 0.001$).

Figure 4.10 shows the relationship between the Electrical Conductivity (EC) of irrigation water of private farms against the year of establishment, subdivided by the three regions.

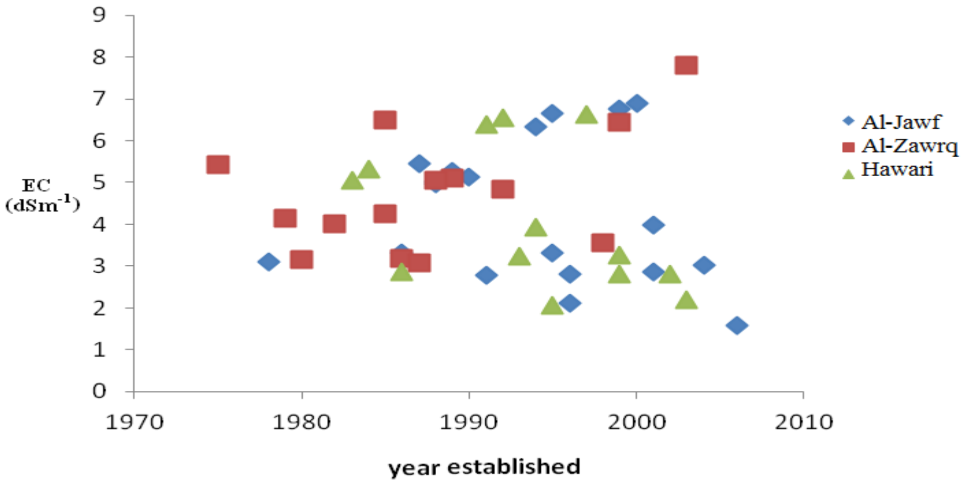


Figure 4—10 The effects of the year of establishment of the well on the EC of irrigation water from the private farms subdivided by the three regions.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of well age class (DF=2, F= 0.95, $p > 0.05$) or region (DF= 2, F= 0.64, $p > 0.05$) on EC.

However, the graph suggests that there were two trends for EC values with well age. One group of wells showed an increase in EC from 4 dS m^{-1} to 7 dS m^{-1} between those established in 1975 and those established in 2007, while the second group of wells showed a small decrease. To investigate this further the data was split into two by depth at 30 m based on the change in slope in figure 4.9.

Figure 4.11 shows the effect of well age on the EC with the data split into those well with depths below 30 m and those wells with depths 30 m or greater.

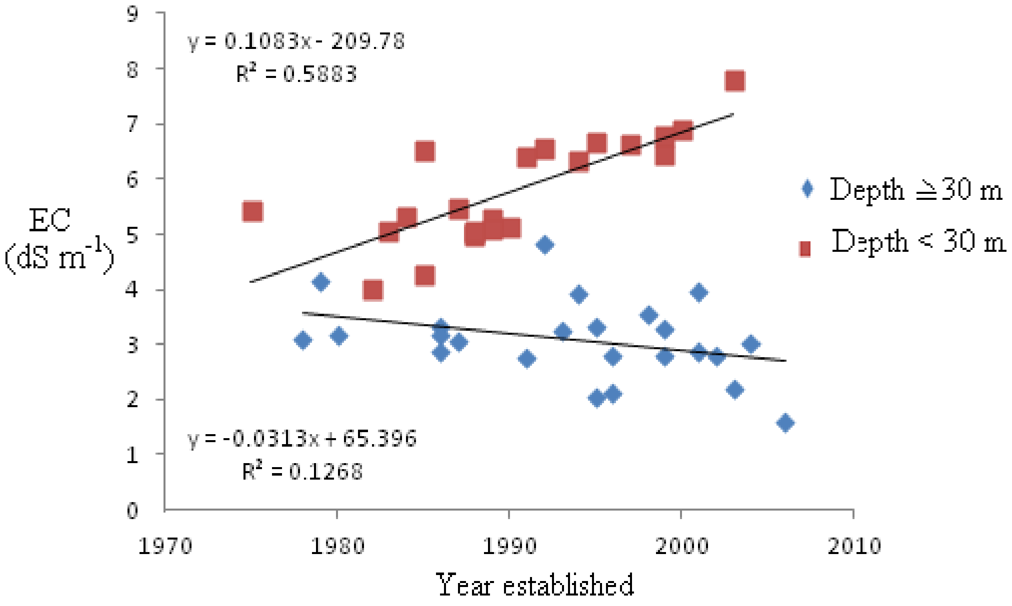


Figure 4—11 The effect of the year of establishment of the well on the EC of irrigation water from the private farms subdivided by well depth (wells < 30 m deep and wells 30 m or more deep).

The graph demonstrates that both responses to well age are related to the well depth, and the change in slope in Fig. 4.9. Both graphs are quite distinct. The shallow wells (<30 m) exhibit a significant (DF = 20, F= 28.58, $p < 0.001$) increase in EC as well age decreases. The deeper wells (30 m or more) exhibit no significant effect of well age (DF = 22, F= 3.20, $p > 0.05$).

There was an effect of well depth on EC for the private farms where the values were high in shallow wells, and low in deeper wells. Figure 4.9 shows a change in slope at 30 m which may be due to leaching of irrigation water to the groundwater as a consequence of the irrigation method and sandy soil texture It has been suggested by Dennis (2002); Dobaradaran et al. (2009); as well as Jeyaseelan et al. (2013), that the majority of groundwater is formed by irrigation water or precipitation soaking into the soil, and passing down to the aquifer, Groundwater may vary in composition from one well to another, as a result of the respective ground waters being in contact with different aquifer materials, or having been in contact with the aquifer minerals for different periods of time and by leaching of irrigation water. Also, researchers have confirmed that in the passage of surface water through soil to the groundwater, its quality will change. This may be due to human or natural phenomena. Anning et al., (2007) suggested that these result from the dissolution of minerals contained in the aquifer rocks and soils, and the quality of the agricultural return water. Generally, it is concluded that shallow groundwater is affected more by contamination than deep groundwater. It has been suggested by Duell and Schroeder (1989); Nolan et al. (2002); and Dubrovsky et al. (2010), in studies in the USA, that shallow groundwater is often considered as more susceptible to contamination than deep groundwater. In contrast, Kent and Landon (2013), in a study done in California, suggested that trends in EC concentrations were not related to well depth.

4.4.3 Calcium

The results of the analysis of water samples under study in (Appendix 9.1- 4) show that the values of the calcium ion concentration ranged between 0.5 mmol$_c$l^{-1} and 2.4 mmol$_c$l^{-1} in the state farms, and 2.6 and 16 mmol$_c$l^{-1} in the private farms.

Figure 4.12 shows the effect of well depth on Ca^{2+} concentration for the state farms.

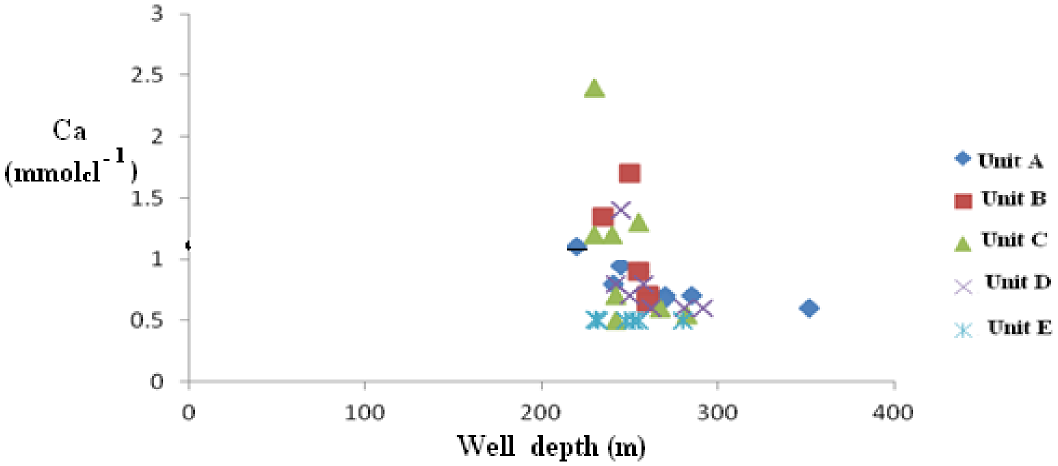


Figure 4—12 The effects of well depth on Ca^{2+} concentration of irrigation water in from the farms of the Kufra Agricultural Project Subdivided by the five agricultural units.

The statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF= 25, F=0.59, p>0.05) or agricultural unit (DF=4, F=0.47, p>0.05) on Ca concentration.

The Ca concentrations of 8 wells with values higher than 1.0 mmolcl^{-1} were identified as being higher than the main body of results. Their spatial distribution is shown in Figure 4.13. A cluster of 6 wells with higher Ca^{2+} concentration can be seen in units B and C.

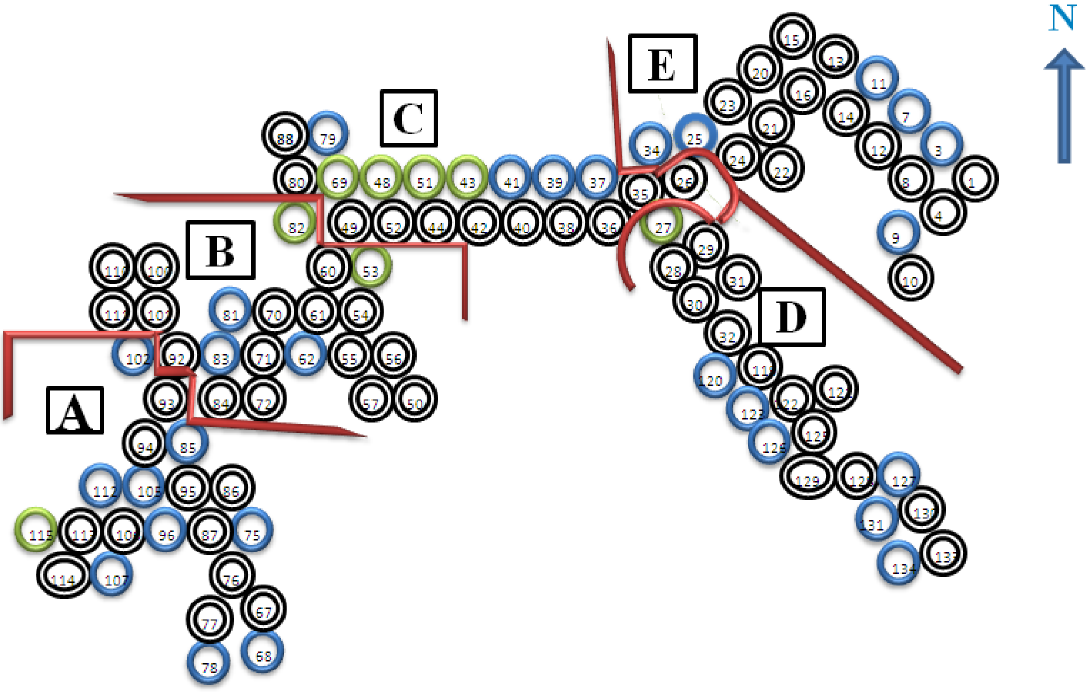


Figure 4—13 Spatial variability in irrigation water Ca^{2+} concentration in state farms. High values (>1. 0 mmolcl^{-1}), are represented by the green circles, lower values (<1.0mmolcl^{-1}) by blue circles.

Figure 4.14 shows the effect of well depth on Ca^{2+} concentration for the private farms. Calcium concentrations in the well water of private farms are higher than in the Kufra Agricultural Project well water.

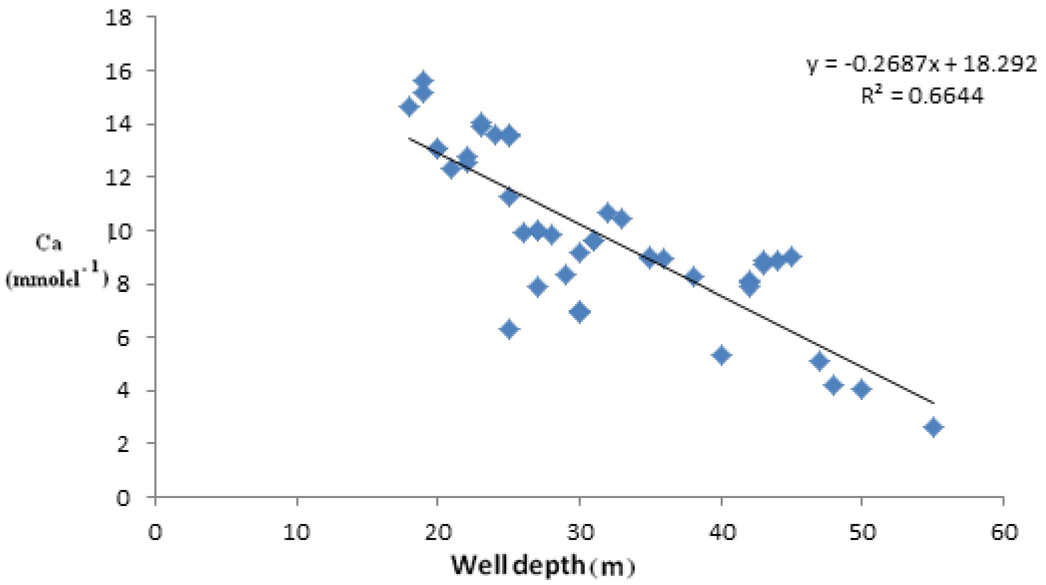


Figure 4—14 The effects of well depth on the Ca^{2+} concentration of irrigation water from the private farms.

The figure shows no clear change of slope at 30 m so the data is treated as a single line. Statistical analysis using linear regression showed that there was a significant effect of well depth on Ca concentration (DF= 44, F= 87.10, p<0.001).

Figure 4.15 shows the effect of well age on the Ca^{2+} concentration of irrigation water from the private farms subdivided by three regions.

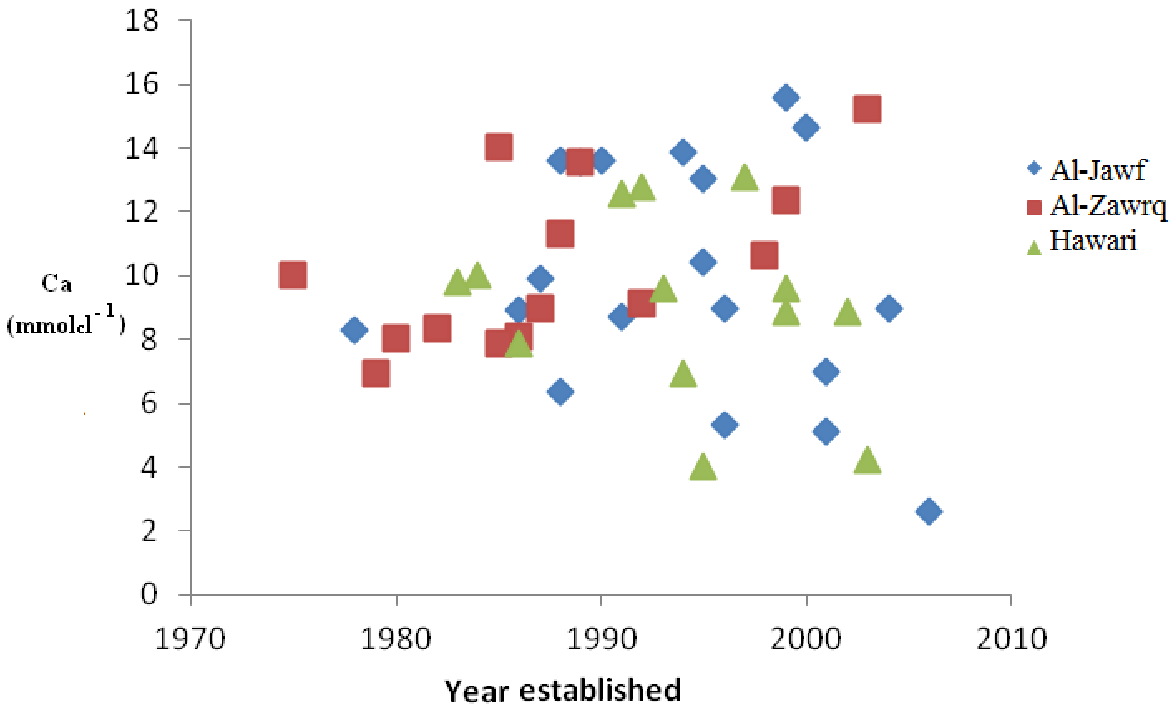


Figure 4—15 The effects of the year of establishment of the well on Ca^{2+} concentration of irrigation water from the private farms subdivided by the three regions.

The figure shows a triangle of data points with a wide scatter of data points among the more recent wells.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of well age class (DF= 2, F=0.04, $p>0.05$) or region (DF=2, F=0.12, $p>0.05$) on Ca concentration.

Figure 4.16 shows the effect of well age on the concentration of Ca^{2+} with the data split into those well with depths below 30 m and those wells with depths of 30 m or greater.

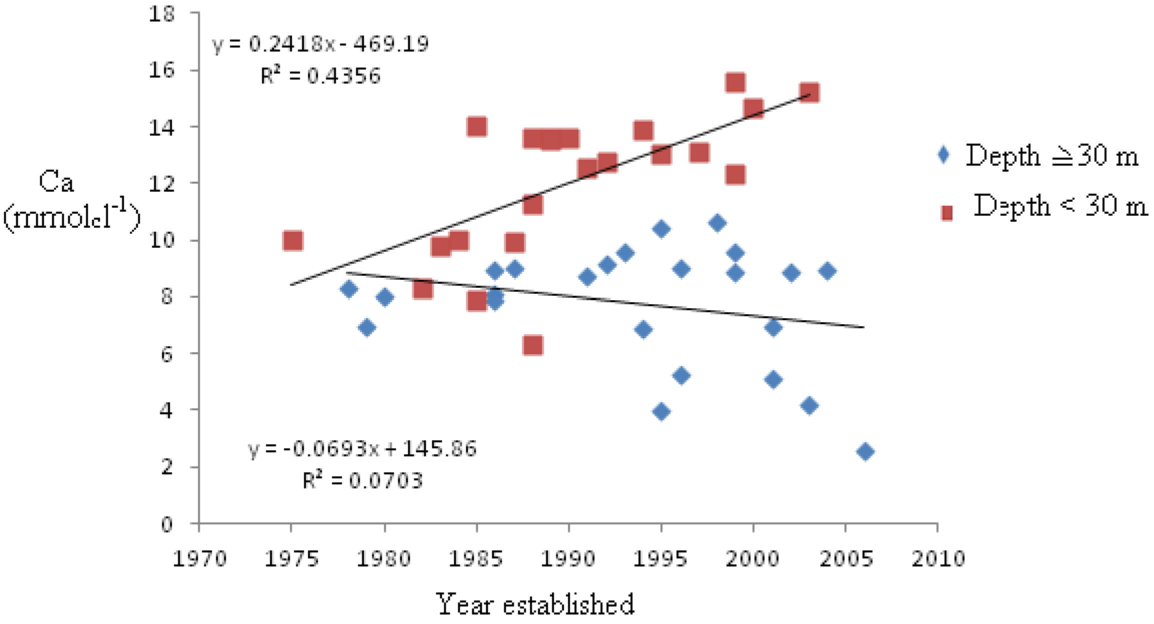


Figure 4—16 The effect of the year of establishment of the well on the Ca^{2+} concentration of irrigation water from the private farms subdivided by well depth (wells < 30 m deep and wells 30 m or more deep).

The graph demonstrates that there are two responses to well age related to the well depth. Each graph is distinct but with several overlapping points among the older wells. The shallow wells (<30 m) exhibit a significant (DF= 20, F= 15.43, $p< 0.001$) increase in Ca^{2+} concentration as well age decreases. The deeper wells (30 m or more) demonstrate no significant effect of well age (DF = 22, F= 1.66, $p> 0.05$).

4.4.4 Magnesium

The results of the analysis of water samples under study in (Appendix 9.1- 4) show that the values of the magnesium concentration ranged between 0.4 and 1.6 $mmol_c l^{-1}$ in the state farms, and 2.2 and 12.8 $mmol_c l^{-1}$ in the private farms.

Figure 4.17 shows the effect of well depth on Mg^{2+} concentration for the state farms.

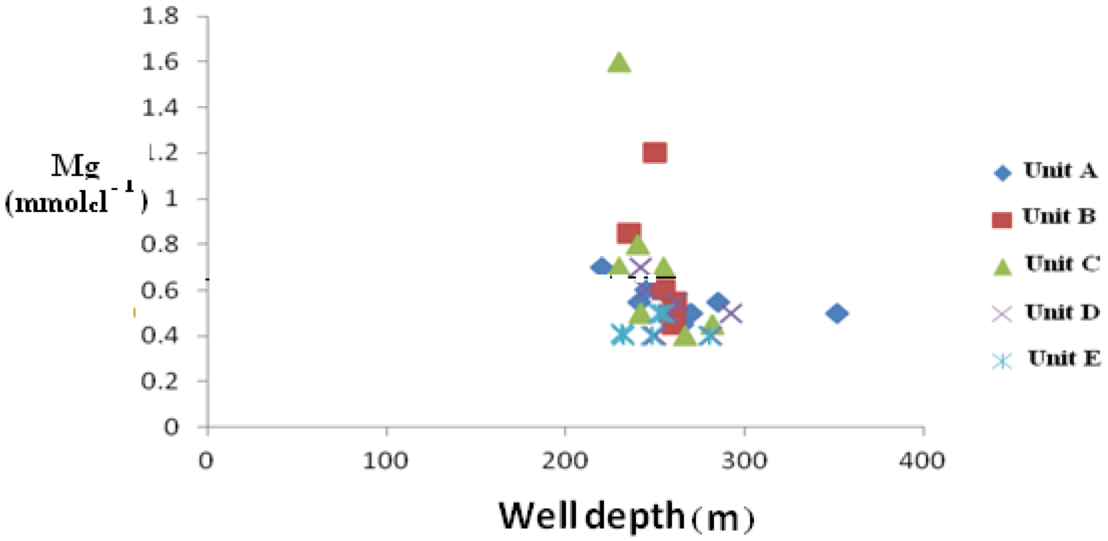


Figure 4—17 The effects of well depth on the Mg^{2+} concentration of irrigation water from the farms of the Kufra Agricultural project subdivided by the five agricultural units.

Statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF= 25, F=0.36, $p>0.05$) or agricultural unit (DF= 4, F=0.33, $p>0.05$) on Mg^{2+} concentration.

The Mg^{2+} concentration values of 8 wells with values higher than 0.65 mmolcl^{-1} including two outliers 1.2 and 1.6 mmol$_c$l^{-1} were identified as being higher than the main body of results. Their spatial distribution is shown in Figure 4.18. A cluster of 6 wells with higher Mg concentration can be seen in units B and C.

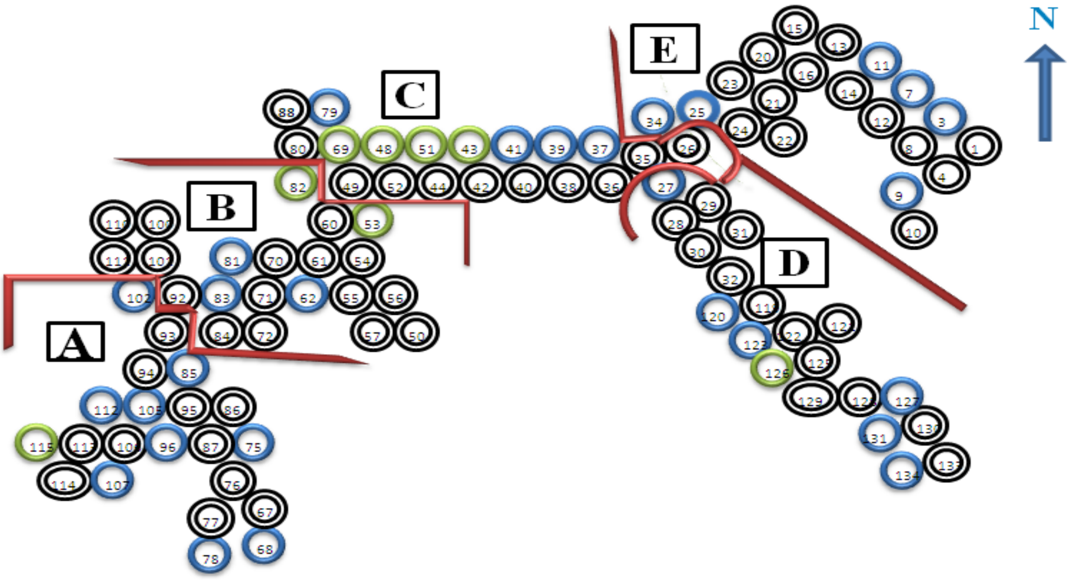


Figure 4—18 Spatial variability in irrigation water Mg^{2+} concentration in state farms. High values (>0.65 $mmolcl^{-1}$), are represented by the green circles, lower values (<0.65 $mmolcl^{-1}$) by blue circles.

Figure 4.18 shows the spatial variability in irrigation water magnesium concentration in the state farms, Most of the green circles (high Mg^{2+}) are located in agricultural unit C, and in nearby farms in unit B. This pattern is similar to the spatial variability for the higher and lower values of calcium.

Figure 4.19 shows the effect of well depth on Mg^{2+} concentration for the private farms.

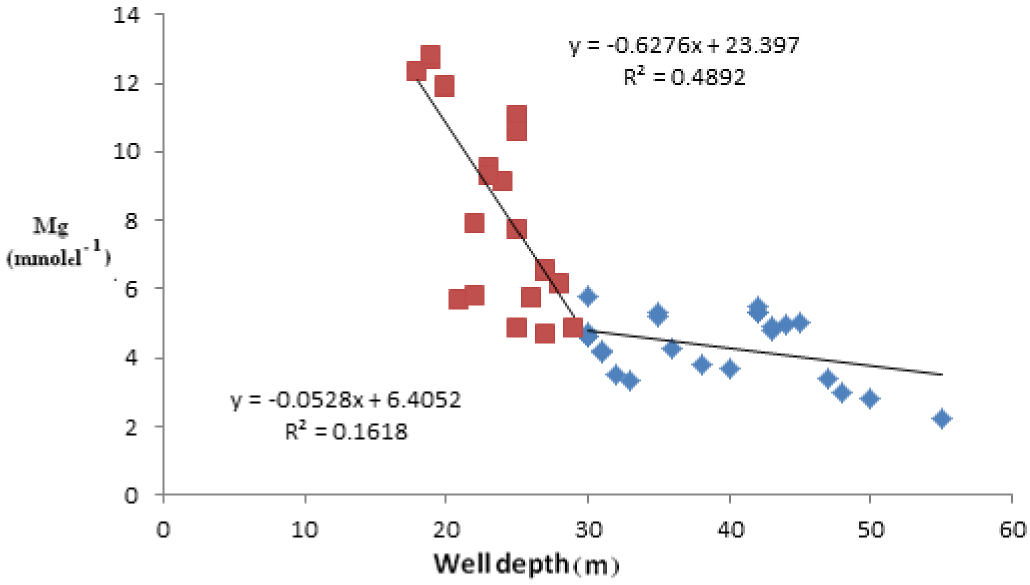


Figure 4—19 The effects of well depth on the Mg^{2+} concentration of irrigation water from the private farms subdivided by the two depths (wells < 30 m deep and wells 30 m or more deep).

The graph shows two groups of data points forming two responses to well depth; a change of slope at 30 m with a steeper slope with depth seen in the shallower wells.

Statistical analysis using linear regression showed that the shallow wells (<30 m) show a significant (DF = 20, F= 19.16, $p<0.001$) decrease in Mg concentration as well depth increases. The deeper wells (30 m or more) exhibit no significant effect of well depth (DF = 22, F= 4.25, $p> 0.05$).

Figure 4.20 shows the relationship between Mg^{2+} $mmol_cl^{-1}$ of irrigation water of private farms and the year of establishment of the farm in three regions of private farms.

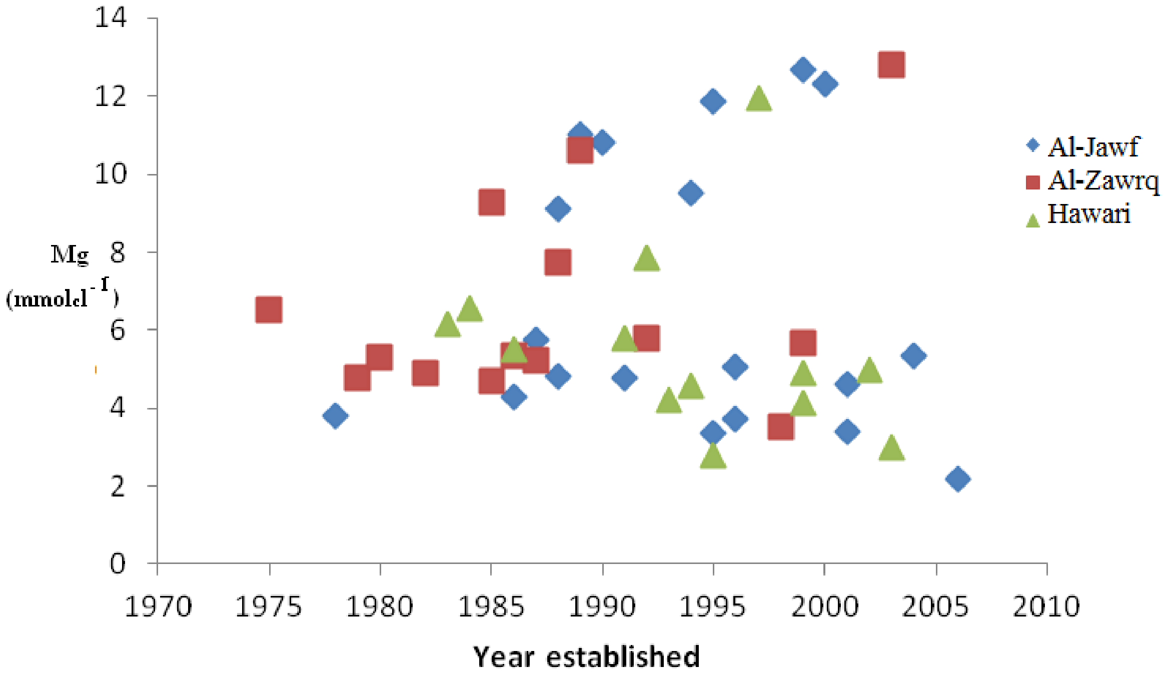


Figure 4—20 The effects of the year establishment of the well on the Mg concentration of irrigation water from the private farms subdivided by the three regions.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of well age class (DF= 2, F=0.10, *p*>0.05) or region (DF=2, F=0.03, *p*>0.05) on Mg^{2+} concentration.

However, the graph shows two groups of data points forming two responses to well age. One group of wells showed an increase in Mg^{2+} concentration from 7.9 to 12.8 $mmolcl^{-1}$ between those established in 1975 and those in 2007, while the second group of wells showed a small decrease. To investigate this further the data was split into two by depth at 30 m based on the change in slope in figure 4.19.

Figure 4.21 shows the effect of well age on the concentration of Mg^{2+} with the data split into those well with depths below 30 m and those wells with depths 30 m or greater.

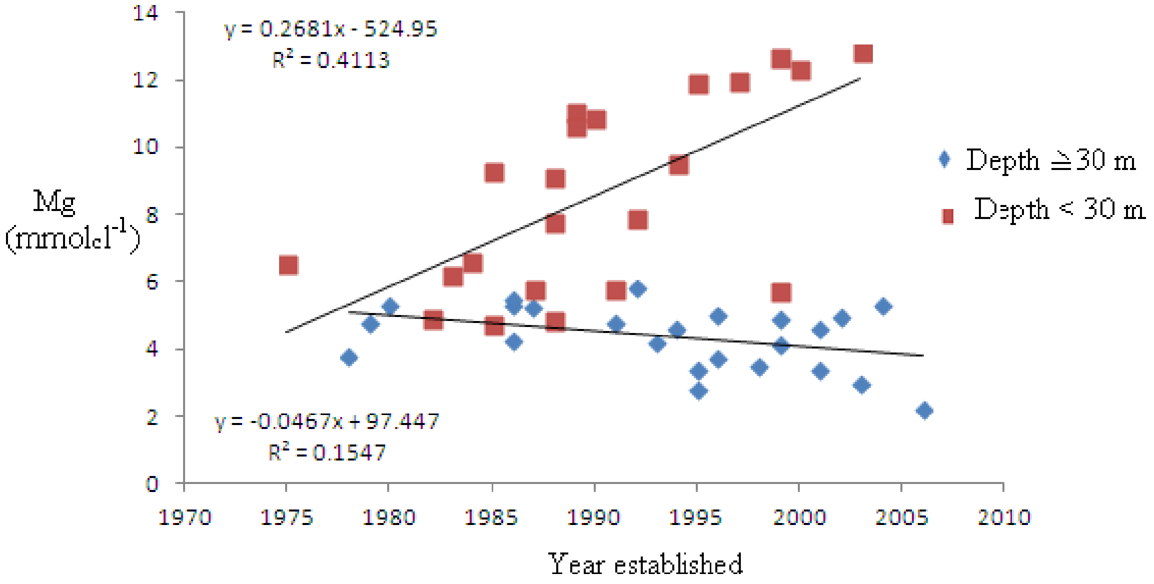


Figure 4—21 The effect of the year of establishment of the well on the Mg^{2+} concentration of irrigation water from the private farms subdivided by well depth (wells < 30 m deep and wells 30 m or more deep).

The graph demonstrates that both responses to well age are related to the well depth and the change in slope in Figure 4.19. Each graph is distinct but with several overlapping points. The shallow wells (<30 m) show a significant (DF = 20, F= 13.97, $p<0.01$) increase in Mg concentration as well age decreases. The deeper wells (30 m or more) exhibit no significant effect of well age (DF = 22, F= 4.03, $p> 0.05$).

4.4.5 Sodium

The results in (Appendix 9.1- 4) show that sodium is the predominant positive ion in the irrigation water of the study area, which agrees with previous data (Ellwood and Hickes, 1991).

In this study, the concentrations of sodium ranged between 0.6 and 2.7 $mmol_cl^{-1}$ in well water from the state farms, and 8.5 and 41.5 $mmol_cl^{-1}$ in the well water of private farms. This results in high values of Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR). The water of the private farms might represent a real danger for the soil, and to plants, if they were used for irrigation purposes (Yousef, 1985). Observations made during water sample collection from private farms indicated a significant degradation of the soil irrigated from these wells, with a white crust of salts (mainly sodium chloride due to the

Na^+ and Cl^- ions being predominant among negative and positive ions in irrigation water) covering the soil (Figure 4.22).

Figure 4—22 White crusts of salts on irrigated soil supplied by shallow wells.

Figure 4.23 shows the effect of well depth on Na^+ concentration for the state farms.

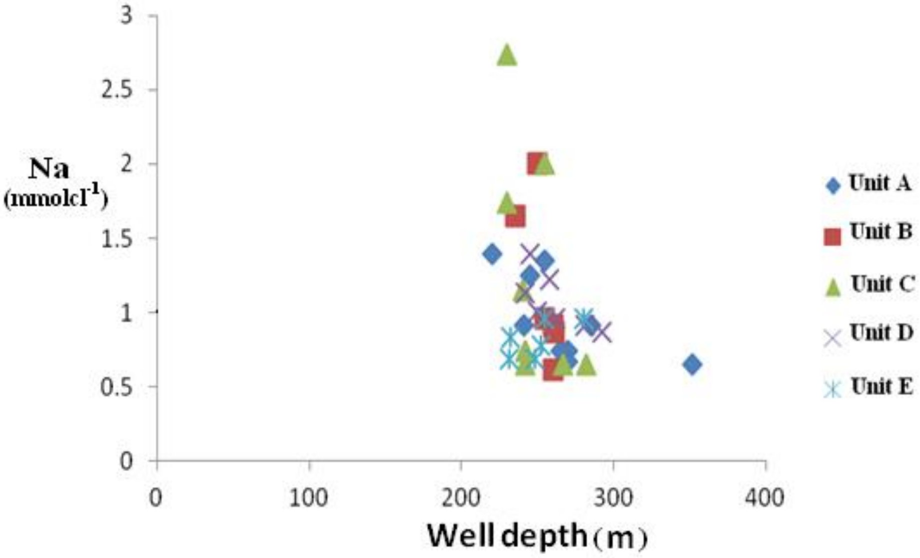


Figure 4—23 The effects of well depth on the Na^+ concentration of irrigation water from farms of the Kufra Agricultural Project subdivided by the five agricultural units.

Statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF=25, F=0.73, $p>0.05$) or agricultural unit (DF=4, F=0.21, $p>0.05$) on Na^+ concentration.

The Na^+ concentration values of 12 wells with values of higher than 1 $mmol_c l^{-1}$, including one outlier in unit C, were identified as being higher than the main body of results. Their spatial distribution is shown in Figure 4.24. A cluster of 6 wells with higher Na^+ concentration can be seen in units B and C.

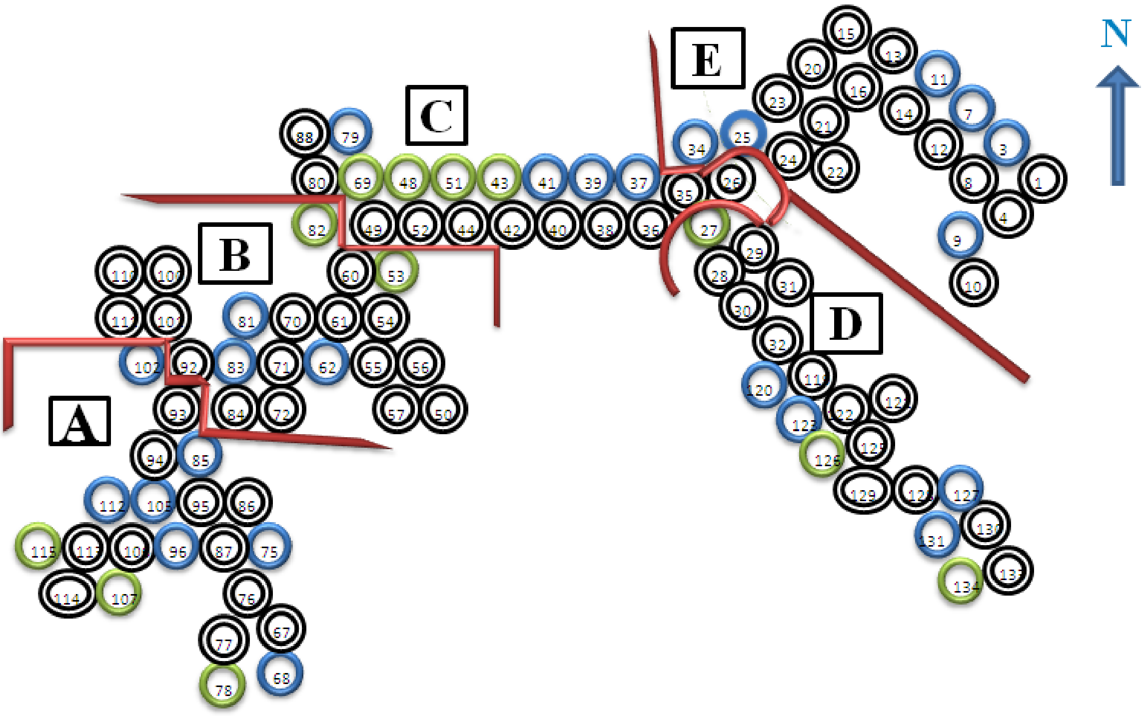


Figure 4—24 Spatial variability in irrigation water Na^+ concentration in state farms. High values (>1.0 $mmolcl^{-1}$), are represented by the green circles, Lower values (< 1.0 $mmolcl^{-1}$) by blue circles.

Figure 4.25 shows the effect of well depth on Na^+ concentration for private farms.

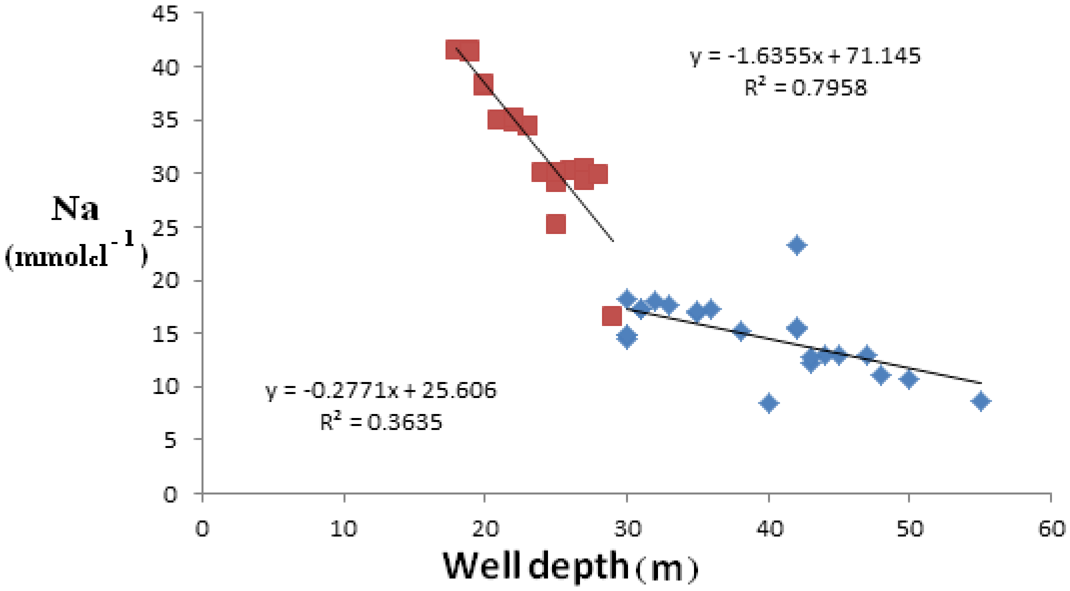


Figure 4—25 The effects of well depth on the Na^+ concentration of irrigation water from the private farms subdivided by the two depths (wells < 30 m deep and wells 30 m or more deep).

The graph shows two groups of data points forming two responses to well depth; a change of slope at approximately 30 m with a steeper slope with depth seen in the shallower wells.

Statistical analysis using linear regression showed that the shallow wells (<30 m) exhibit a significant (DF = 20, F= 77.95, $p < 0.001$) decrease in Na as well depth increases. In the same manner the deeper wells (30 m or more) exhibit a significant effect of well depth (DF = 22, F= 12.56, $p < 0.01$).

Figure 4.26 shows the effect of well age on the Na^+ concentration ($mmol_cl^{-1}$) of irrigation water from the private farms, subdivided by the three regions.

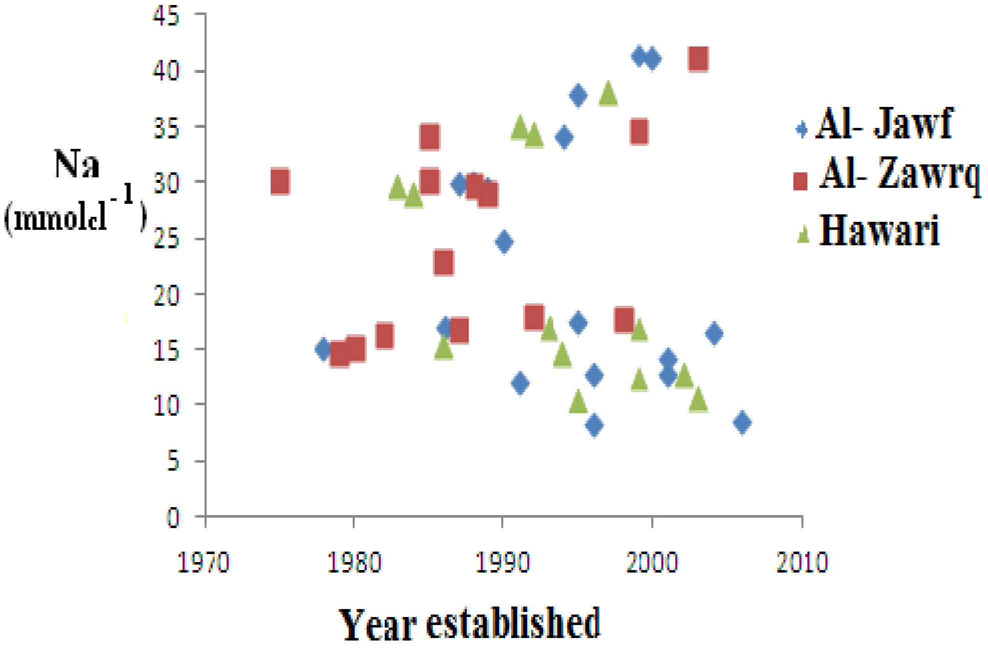


Figure 4—26 The effects of the year establishment of the well on the Na$^+$ concentration of irrigation water from the private farms subdivided by the three regions.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of well age class (DF=2, F=0.98, p>0.05) or region (DF=2, F=0.87, p>0.05) on Na$^+$ concentration.

The graph shows two groups of data points forming two responses to well age. One group of wells showed an increase in Na$^+$ concentration in the more recent wells while the other group show a small decrease. To investigate this further the data was split into two by depth at 30 m based on the change in slope in Figure 4. 25.

Figure 4.27 shows the effect of well age on the concentration of Na$^+$ with the data split into those well with depths below 30 m and those wells with depths 30 m or greater.

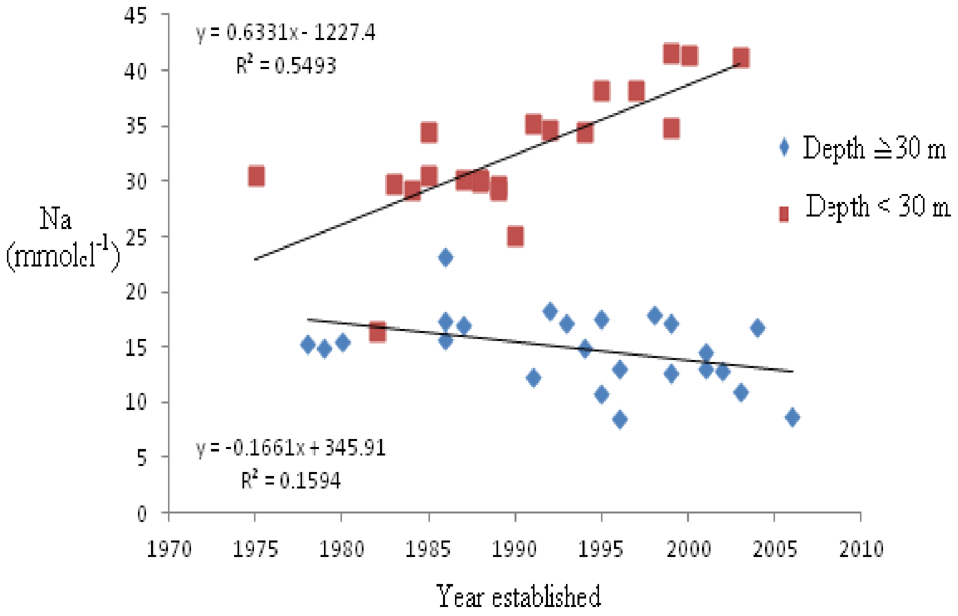


Figure 4—27 The effect of the year of establishment of the well on the Na$^+$ concentration of irrigation water from the private farms subdivided by well depth (wells < 30 m deep and wells 30 m or more deep).

The graph demonstrates that both responses to well age are related to the well depth and the change in slope in Figure 4.25. Each graph is quite distinct. The shallow wells (<30 m) show a significant (DF =20, F= 24.38, $p < 0.001$) increase in Na concentration as well age decreases. The deeper wells (30 m or more) exhibit no significant effect of well age (DF = 22, F= 4.17, $p > 0.05$).

4.4.6 Sodium Adsorption Ratio:

The results of the analysis of water samples under study in (Appendix 9.1- 4) show that the values of the SAR ranged between 0.8 and 2 in state farms and between 4 and 13 in the private farms.

Figure 4.28 shows the effect of well depth on sodium adsorption ratio for the state farms.

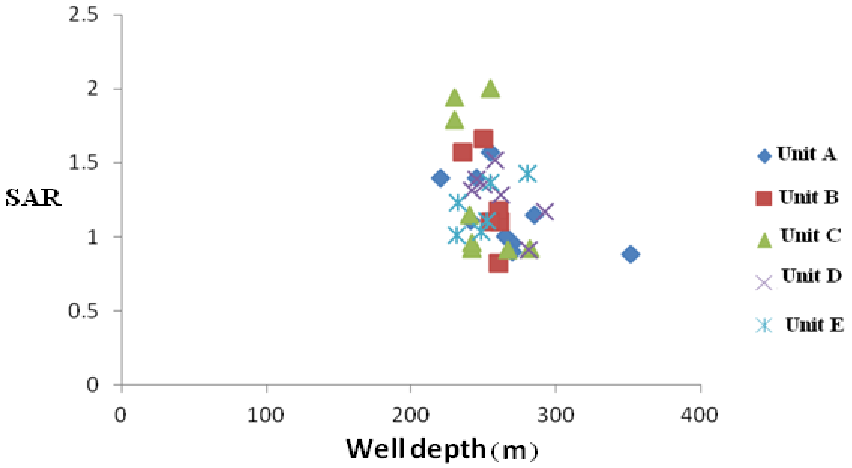


Figure 4—28 The effects of well depth on the SAR of irrigation water from farms of the Kufra Agricultural Project subdivided by the five agricultural units.

Statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (DF=25, F= 1.15, *p*>0.05) or agricultural unit (DF=4, F=0.32, *p*>0.05) on SAR.

Figure 4.29 shows the effect of well depth on Sodium Adsorption Ratio for private farms.

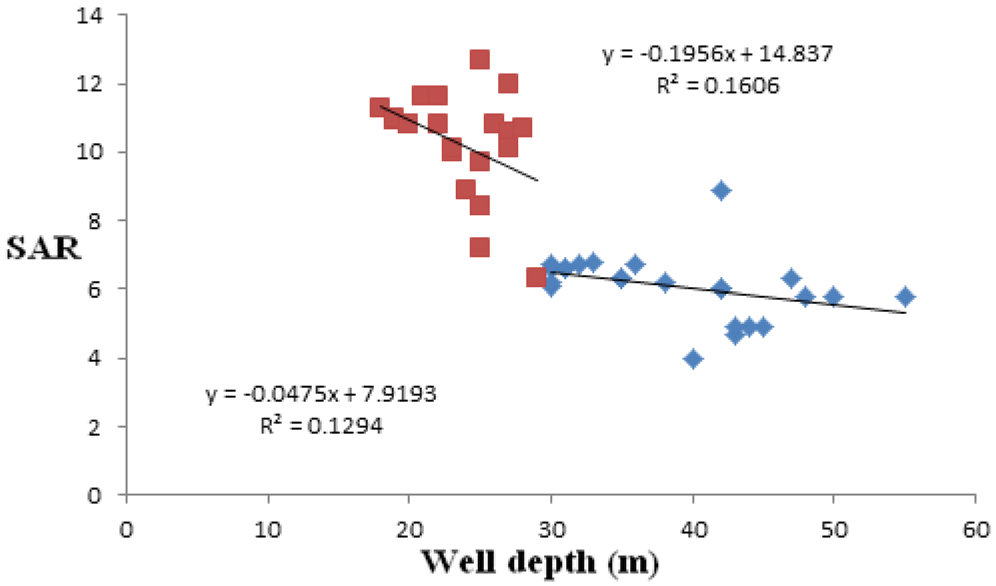


Figure 4—29 The effects of well depth on the SAR of irrigation water from private farms subdivided by the two depths (wells < 30 m deep and wells 30 m or more deep).

The graph shows two groups of data points forming two responses to well depth with different slopes. A change of slope at approximately 30 m with a steeper slope with depth seen in the shallower wells and no effect of depth in wells deeper than 30 m.

Statistical analysis using linear regression showed that the shallow wells (<30 m) show no significant effect of well depth (DF =20, F= 3.83, $p > 0.05$). In the same manner, there is not any influence of well depth (DF = 22, F= 3.27, $p > 0.05$) on the deep wells (30 m or more).

Figure 4.30 shows the effect of well age on the Sodium Adsorption Ratio of irrigation water from private farms subdivided by the three regions.

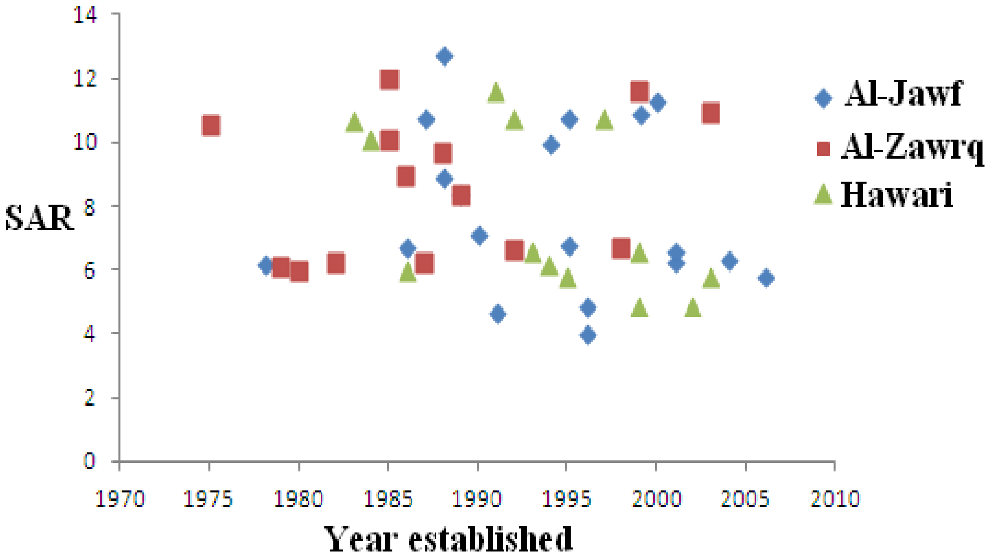


Figure 4—30 The effects of the year establishment of the well on the SAR of irrigation water from private farms subdivided by the three regions.

Statistical analysis (ANOVA general linear model) showed that there was no significant effect of well age class (DF=2, F=1.02, $p>0.05$) or region (DF=2, F=0.87, $p>0.05$) on Sodium Adsorption Ratio.

The graph shows two horizontal lines of data points for the SAR between those established in 1975 and those established in 2007. To investigate this further the data was split into two by depth at 30 m based on the change in slope in Figure 4. 29.

Figure 4.31 shows the effect of the year establishment of the well on the SAR with the data split into those well with depths below 30 m and those wells with depths 30 m or greater.

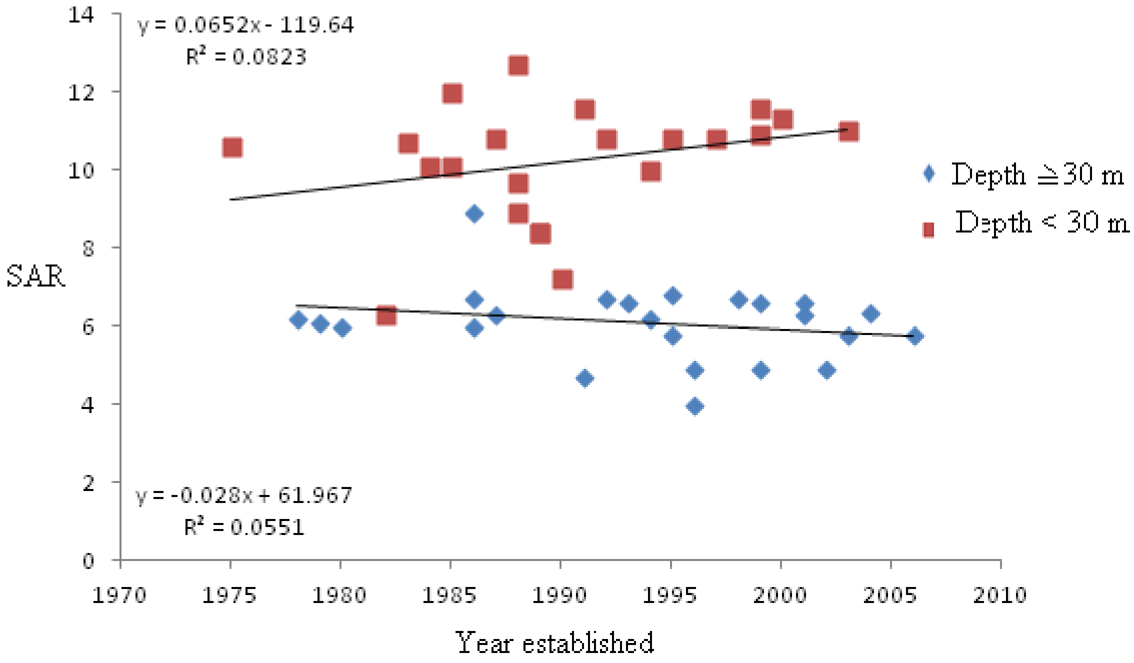


Figure 4—31 The effect of the year of establishment of the well on the SAR of irrigation water from the private farms subdivided by well depth (wells < 30 m deep and wells 30 m or more deep).

The graph shows two horizontal lines of data points with the age of the wells related to the wells depth. The shallow wells (<30 m) show no significant effect of well age (DF =20, F= 1.28, *p*> 0.05). In the same manner, there is not any influence of the wells age (DF = 22, F= 1.79, *p*> 0.05) on the deep wells (30 m or more)

The present study confirmed that the sodium was the predominant ion in the irrigation water. Subba Rao et al., (2002); Qiyan and Baoping, (2002); Kinniburgh and Smedley (2001); Zheng et al., (2004); suggested that sodium is considered to be the main factor in determining the suitability of groundwater for irrigation purposes. The amount of sodium is normally expressed in terms of sodium adsorption ratio. The higher Na concentration is due to the long residence time of water, dissolution of minerals from lithological composition or soil, and the leaching of chemical fertilisers by the irrigation waters.

The sodium Adsorption Ratio (SAR) was not affected by well age, unlike the concentrations of sodium, calcium and magnesium the ratio was unaffected.

4.4.7 Classification of irrigation water quality

Using the FAO guidelines

Irrigation waters in the state farms under study were classified according to the FAO guidelines (Ayers and Westcot, 1985; National Engineering Handbook, part 652, 1997) depending on three degrees of restriction on use (none, slight to moderate and severe) in relation to potential problems in irrigation water quality due to salinity, infiltration rate and toxicity of sodium).

Table 4-2 Classification of irrigation water in the study area from the state farms, following the FAO classification system shown in Table 4.1 (Ayers and Westcot, 1985).

State farms	Degree of restriction on use		
	none (%)	slight to moderate (%)	severe (%)
Salinity	97 %	3 %	Nil
Infiltration. Evaluate using EC and SAR together	3 %	56 %	42 %
Toxicity Sodium Sprinkler irrigation SAR	100 %	Nil	//
Surface irrigation SAR	100 %	Nil	Nil

Table 4.2 shows the results of classification of irrigation water for state farms, following the FAO classification system (Ayers and Westcot, 1985). It appears that, in general, there were no restrictions as regard to the salinity of the irrigation water for irrigation purposes, except for 1 farm with EC above 0.7 dS m^{-1} where the restriction was slight to moderate.

Restrictions on use in terms of infiltration varied from none to severe, with only 1 farm in the no restrictions category. The low EC values (<0.7 dS m^{-1}) caused the wells to be classed as slight to moderate or severe despite the low SAR values. However, reduced infiltration rate due to the effects of Na^+ on soil clays is unlikely to be an issue in such sandy soils.

Regarding the degree of restrictions in irrigation water usage resulting from the risk of sodium toxicity, there were not any restrictions for sprinkler irrigation or surface irrigation in state farms.

Table 4-3 Classification of irrigation water in the study area from the private farms, following the FAO classification system shown in Table 4.1 (Ayers and Westcot, 1985).

Private farms	**Degree of restriction on use**		
	none %	**slight to moderate %**	**severe %**
Salinity	Nil	22 %	78 %
Infiltration. Evaluate using EC and SAR together	100 %	Nil	Nil
Toxicity Sodium Sprinkler irrigation SAR	Nil	100 %	//
Surface irrigation SAR	Nil	65%	35%

Table 4.3 shows the classification of irrigation water for private farms, following the FAO classification system (Ayers and Westcot, 1985), and demonstrates that the restrictions were severe in 78% water samples (EC> 3 dS m^{-1}), and slight to moderate in 22% water samples (EC> 0.7 dS m^{-1}) in terms of salinity, due to the high Electrical Conductivity values. There are no restrictions on use of these water for irrigation purposes in terms of infiltration risk due to the high values of both EC and SAR in irrigation water. Ayers and Westcot, (1985); Ezlit et al., (2010) suggested that there is no risk to leaching when irrigating with saline water if both EC and SAR are high. Values of Electrical Conductivity and the SAR values generate a balance between calcium and magnesium cations on one hand, and sodium on the other.

As for the risk of sodium toxicity, according to the irrigation system used, restrictions were slight to moderate in most samples (65%), under surface irrigation, and severe on the rest of the samples (35%). The wells were classed as slight to moderate for all samples in sprinkler irrigation systems. There are two potential problems that should be considered. The first problem is the uptake by the roots and the second is related to the direct damage to the leaves of the plant when sprinkler irrigation is used. Ezlit et al., (2010) suggested that flood irrigation gives the plants an opportunity to absorb the larger amounts of sodium and cause plant stress while they get a smaller quantity of sodium if the sprinkler technique is used. Under conventional surface drip irrigation, salts can migrate downwards and reach the main root zone during precipitation and uniform distribution of water on the soil surface. This process may inhibit water and nutrient uptake, consequently causing adverse effects on crop growth and yield (Hanson and Bendixen, 1995; Oron et al, 2002). This hypothesis was confirmed for Tunisian conditions.

Using the USDA classification

Table 4.4 shows the irrigation waters in the state farms under study classified according to the USDA system (Richards, 1954; National Engineering Handbook, part 623, 2013) depending on classes of salinity and sodium hazard.

Table 4-4 Classification of irrigation water in the study area from the state farms, following classification system shown in Figure 4.1(Richards, 1954).

Classes	%	Remarks
$C_1 – S_1$	67%	Can be utilised for irrigation of most crops in the majority of soils, with low risk of development of harmful levels of exchangeable sodium.
$C_2 – S_1$	33%	Can be utilised for irrigation if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown, with low risk of development of harmful levels of exchangeable sodium.

They were classified under categories where water can be used for irrigation purposes without problems in this system due to the fact that the values for Electrical Conductivity are lower than 0.7 dS m^{-1}, and SAR values are lower than 2. This means that they do not cause any salinity or infiltration problems in soil.

Table 4.5 shows the irrigation waters in the private farms under study classified according to the USDA system (Richards, 1954; National Engineering Handbook, part 623, 2013) depending on classes of salinity and sodium hazard.

Table 4-5 Classification of irrigation water in the study area from the private farms, following classification system shown in Figure 4.1 (Richards, 1954).

Classes	%	Remarks
$C_3 – S_1$	4 %	Cannot be used on soils with restricted drainage. Plants with high salt tolerance should be selected, special management for salinity control may be required, low chance of development of harmful levels of exchangeable sodium.
$C_4 – S_1$	4 %	Unsuitable for irrigation under ordinary conditions, but may be used under extraordinary circumstances. The soil must be permeable, drainage must be adequate, with considerable leaching, and only crops with very high salt tolerance should be selected.
$C_4 – S_2$	44 %	Not suitable for irrigation under ordinary conditions, but may be used under extraordinary circumstances. The soil must be permeable, drainage must be adequate, with considerable leaching and only crops with very high salt – tolerance should be selected. An appreciable sodium hazard will present in fine textured soils possessing high cation – exchange – capacity, especially under low-leaching conditions.
$C_4 – S_3$	22 %	Not suitable for irrigation under ordinary conditions, but may be used occasionally in very exceptional circumstances. May produce harmful levels of exchangeable sodium in most soils, and will require special soil management.
$C_4 – S_4$	26 %	Generally unsatisfactory for irrigation purposes, except at low and possibly medium salinity, where the calcium solution of the soil, use of gypsum or other amendments may make feasible the utilisation of these waters.

These classifications indicate that the water cannot be used for irrigation purposes as all fall into categories C_3 and C_4 meaning they are unsuitable for irrigation in normal circumstances. The SAR category is less important in sandy soils. Richards, (1954) explained that high values of SAR in irrigation water have the greatest affects on clay soils. Most of the irrigation water in the private farm wells (44%) falls into category C_4 - S_2.

4.4.8 Other parameters of irrigation water

The present section represents a detailed study of a small group of samples of irrigation water, taken from four wells of private farms, as well as four samples from the wells of state farms.

The samples represent shallow groundwater (for the private farms) and deep groundwater (for the state farms), where a larger number of parameters and the calculated ionic balance of the water were examined.

In this section, the parameters which were not considered in the previous section (Ionic balance, potassium, chloride, sulphate and bicarbonate) are reviewed as follows.

Table 4-6 Mean values and standard deviation of mean ((± SD) for Electrical Conductivity (EC), Bicarbonate (HCO_3^-), Chloride (Cl^-), Sulphate (SO_4^{2-}, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), and Potassium (K^+), in water samples from Kufra Libya.

Variables	**State farms**				**Private farms**			
	F 68 (± SD	F 78 (± SD	F 107 (± SD	F 115 (± SD	F1 (± SD)	F 2 (± SD	F 3 ± (SD	F 4 (± SD
Depth (m)	270	255	245	220	33	15	27	40
EC (dS m^{-1})	0.12 ±0.01	0.29 ±0.04	0.28 ±0.06	0.35 ±0.01	3.47 ±0.07	11.42 ±0.05	4.25 ±0.06	2.12 ±0.04
HCO$_3$ (mmol$_c$l^{-1})	0.87 ±0.15	0.92 ±0.10	1.0 ±0.11	0.97 ±0.13	1.67 ±0.03	3.57 ±0.06	2.35 ±0.05	1.28 ±0.03
Cl (mmol$_c$l^{-1})	0.55 ±0.30	1.20 ±0.10	1.20 ±0.29	1.52 ±0.65	19.00 ±0.06	76.20 ±0.69	27.10 ±0.23	9.20 ±0.00
SO$_4$ (mmol$_c$l^{-1})	0.57 ±0.17	0.83 ±0.03	0.69 ±0.10	0.85 ±0.07	12.74 ±0.26	47.35 ±0.95	14.70 ±0.25	7.55 ±0.13
Ca (mmol$_c$l^{-1})	0.68 ±0.11	0.90 ±0.09	0.95 ±0.15	1.10 ±0.27	11.10 ±0.46	32.60 ±0.20	7.90 ±0.12	5.30 ±0.23
Mg (mmol$_c$l^{-1})	0.50 ±0.12	0.59 ±0.03	0.60 ±0.12	0.70 ±0.12	3.70 ±0.10	12.10 ±0.42	4.70 ±0.12	3.70 ±0.26
Na (mmol$_c$l^{-1})	0.67 ±0.12	1.35 ±0.08	1.25 ±0.14	1.39 ±0.44	17.74 ±0.31	80.43 ±0.00	30.43 ±0.00	8.52 ±0.08
K (mmol$_c$l^{-1})	0.11 ±0.01	0.12 ±0.01	0.10 ±0.01	0.11 ±0.02	0.54 ±0.03	1.95 ±0.09	1.02 ±0.00	0.49 ±0.02
Anions	1.99	2.95	2.89	3.34	33.44	127.12	44.15	18.03
Cations	1.96	2.96	2.90	3.30	33.08	127.03	44.05	18.01

Table 4.6 shows the mean values for state and private farms; in state farms all were relatively uniform and small, while in private farms were extremely variable and high. Due to the fact that the wells in state farms are from a deep underground reservoir, far away from pollution by leaching, the parameters in these waters are more constant and low in

concentration. However, the wells of the private farms utilise the upper groundwater reservoir in which the water quality (for this particular type of reservoir) is affected by several factors such as when virgin soils are irrigated (the virgin soil profiles are high in salts), soluble salts are leaching to the upper groundwater due to the fact that the reservoir is close to the surface.

Ionic balance

There is very good agreement between total cations and total anions, meaning that the ionic balance has identified all important cations and anions in the water.

Potassium

The results of the analysis of water samples under study in table 4.6 show that the values of potassium concentration ranged between 0.10 and 0.12 $mmol_cl^{-1}$ in the state farms, and 0.49 and 1.95 $mmol_cl^{-1}$ in the private farms.

Chloride

The results in table 4.6 indicate that values of chloride in the irrigation water ranged between 0.55 and 76.2 $mmol_cl^{-1}$. The concentrations of chloride ranged between 0.55 and 1.52 $mmol_cl^{-1}$ in well water from the state farms, and 9.2 and 76.2 $mmol_cl^{-1}$ in the well water of private farms.

Sulphate

The results obtained show that the concentration of sulphate in the irrigation water from wells under study ranged between 0.57 and 47.35 $mmol_cl^{-1}$ as shown in table 4.6. The results of the analysis indicate that the values of the sulphate concentration ranged between 0.57 and 0.85 $mmol_cl^{-1}$ in the state farms, and 7.55 and 47.35 $mmol_cl^{-1}$ in the private farms.

Bicarbonate

The results obtained in the study area showed bicarbonate contained in the irrigation water ranging between 0.87 and 3.57 $mmol_cl^{-1}$. Table 4.6 indicates that the values of the bicarbonate ranged between 0.87 and 1.0 $mmol_cl^{-1}$ in the state farms, and 1.28 and 3.57 $mmol_cl^{-1}$ in the private farms.

There was no effect of well depth on the water quality parameters on the state farms, because they used the deep aquifer. In the private farms, on the contrary, the use of the shallow aquifer had a clear effect on all the parameters studied, where the values were high in shallow wells (<30 m), and lower in deeper wells (>30 m). The difference between state and private farm is due to the wells tapping different aquifers, the deep aquifer is relatively uncontaminated, while upper part of the shallow aquifer has been impacted due to the leaching of salts from the soil profile.

4.5 Conclusion

Table 4-7 Effect of well depth and well age on water quality parameters in private farms.

Parameter (units)	**Range of values**	**Effect of well depth**		**Effect of well age**	
		shallow <30 (m)	deep ≥30 (m)	shallow <30 (m)	deep ≥30 (m)
pH	7.2 - 7.8	decrease (**$p<0.001$**)		**NS**	**NS**
EC **(dS m^{-1})**	1.59 – 7.81	decrease **($p<0.001$)**	decrease **($p<0.001$)**	decrease **($p<0.001$)**	**NS**
Ca^{2+} **(mmolcl^{-1})**	2.6 - 15.6	decrease **($p<0.001$)**		decrease **($p<0.001$)**	**NS**
Mg^{2+} **(mmolcl^{-1})**	2.2 - 12.8	decrease **($p<0.001$)**	**NS**	decrease **($p<0.01$)**	**NS**
Na^{+} **(mmolcl^{-1})**	8.5 – 41.5	decrease **($p<0.001$)**	decrease **($p<0.01$)**	decrease **($p<0.001$)**	**NS**
SAR	3.9 – 12.7	**NS**	**NS**	**NS**	**NS**

The effect of well depth and well age on EC, Mg^{2+}, Na^{+} and SAR in the private farm wells are shown with the data split into those wells with depths below 30 m, and those wells with depths above of 30 m or greater, because figures 4-9, 4-19, 4-25 and 4-29 clearly show a change in slope at 30 m. pH and Ca^{2+} are treated as single graphs for well depth because the slope of figures 4-5 and 4-14 did not change at 30 m. There is a general decrease in salt concentrations with depth except for SAR because both Na^{+} and Ca^{2+} + Mg^{2+} decrease with depth. A steeper slope with depth is seen in the shallow wells (<30 m) for EC, Mg^{2+} and Na^{+} compared to the deeper (>30 m) wells. The effect of well age was only seen for the shallow wells. (< 30 m) where there was a decrease in EC, Ca^{2+}, Mg^{2+} and Na^{+} concentrations as well age increases.

There were high concentrations of salt in the virgin soil profiles. When the virgin soils are irrigated, soluble salts leach to the upper groundwater as a consequence of the irrigation method used (a lot of water used with the flood irrigation method) combined with a sandy soil texture. The accumulation of these salts has been observed in the shallow ground water rather than in the soil profile. There is less impact on the deeper (> 30 m) wells but the values are still high when compared to the deep wells in the state farms which have depths exceeding 220 m and are consequently far from the effects of leaching.

With the passing of time (age of wells) spanning about 40 years there was a decrease of salts at depths of less than 30 m probably due to these salts penetrating to the deeper groundwater layers between 30 - 60 m depth. Generally, to access good quality irrigation water the farmers may need to dig increasingly deeper wells.

For more than forty years the sprinkler irrigation method has been used in the state farms, according to a scientific irrigation program utilizing water more effectively. A lot of salts have been leached from the top 1 m of soil in these farms. It is necessary to investigate if these salts have leached to the upper groundwater or only leached to more than 1 m depth of the soil profile due to the more efficient use of irrigation water as these salts could impact the quality of the shallow aquifer.

Table 4-8 Range of values for water quality parameters of state farms.

Parameters	Range of value
Well depth (m)	220 – 352
pH	6.3 – 7.5
EC ($dS\ m^{-1}$)	0.1 – 0.7
Ca^{2+} ($mmolcl^{-1}$)	0.5 – 2.4
Mg^{2+} ($mmolcl^{-1}$)	0.4 – 1.6
Na^{+} ($mmolcl^{-1}$)	0.6 – 2.7
SAR	0.8 - 2.0

Statistical analysis (ANOVA general linear model) confirmed that there was no significant effect of well depth (p>0.05) or agricultural unit (p>0.05) on pH, EC, Ca^{2+}, Mg^{2+}, Na^{+} and SAR. Well age was not considered because the wells were all established within a 3 year period.

The results of the classification of the irrigation waters for the state farms following the FAO classification system, show there were no restrictions as regard to the salinity of the irrigation water, except for 3% of samples, where the restrictions were slight to moderate. However, the degree of restriction on use, in terms of infiltration, was slight to moderate or severe, except for 3% of the well waters where there was no restriction. Classification of irrigation water in the state farms according to the USDA system (Richards, 1954) suggested that all water samples can be used for irrigation purposes without problems; as the values for Electrical Conductivity are lower than 0.7 dS m^{-1}, and SAR values lower than 2.

The classification of irrigation water for private farms following the FAO system indicates that the restrictions were severe on 78% of farms (EC> 3 dS m^{-1}), and slight to moderate on 22% of farms (EC> 0.7 dS m^{-1}) in terms of salinity. There are no restrictions on use these wells for irrigation purposes in terms of infiltration risk. As for the risk of sodium toxicity in the private farms, (according to the irrigation system used) restrictions were slight to moderate in most samples (65%) for surface irrigation systems and severe for the rest of the samples (35%), For sprinkler irrigation systems all samples were classed as slight to moderate risk. Classification of the irrigation water on the private farms according to the USDA system (Richards, 1954), indicated that they cannot be used for irrigation purposes as all fall into categories C_3 and C_4 meaning they are unsuitable for irrigation in normal circumstances. Most of the irrigation water on the private farms (44%) falls into category C_4 - S_2, but the SAR category is less important in sandy soils.

The FAO and USDA systems agree with each other in their assessment of the quality of the well water of the private farms regarding the salinity problems, but disagree with respect to the well water of the state farms which have low salinity with low SAR. These well waters were classed as having severe limitations in the FAO scheme due to reduced infiltration, while under the USDA scheme the water can be used for most crops in the majority of soils. The FAO system always gives limitations due to reduced infiltration if the water has low salinity even with low SAR. This means that the USDA scheme is more appropriate to use in Kufra because the data collected from the Kufra area indicate that infiltration into the sandy soil is not affected, therefore, low EC and low SAR water does not cause any worries.

Chapter 5 Soil Survey

5.1 Summary

The study involved a survey of the virgin and irrigated soils of state farms (Kufra Agricultural Project) and private farms according to the soil salinity standard established by the U.S. Department of Agriculture (Richards, 1954). The first survey of the soils was conducted in the summer of 2010, 192 soil samples were collected from 48 profiles at a depth of 0-100 cm and from four layers in each profile; 0-25 cm, 26-50 cm, 51-75 cm, and 76-100 cm. Half of the profiles were collected from virgin soils (not cultivated) while the other half were from irrigated soils. The collected profiles were divided equally between private farms and Kufra Agricultural Project (KAP) state farms. Subsequently, mechanical and chemical analyses were performed.

The soil texture was sandy and the results showed that irrigation lowered the salinity of the virgin soil profiles, There was not a clear distinction between the profiles of the virgin and irrigated soils for pH, HCO_3^-, $CaCO_3$%, exchangeable cations, and ESP % in the state farms and for pH, water soluble Ca^{2+}, $Mg^{2+}$and K^+, $CaCO_3$%, exchangeable cations, and ESP% in the private farms. In contrast, a clear distinction was observed between the virgin and irrigated soil profiles for EC and water soluble Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, and SO_4^{2-} in the state farms and for EC and water soluble Na^+, Cl^-, and SO_4^{2-} in the private farms. In the virgin soil profiles, these parameters showed a clear decrease with the depth while in the irrigated soil profiles they were much lower in concentration and more uniform with the depth. In the virgin soils the salts have accumulated in the upper layers of the soil profile due to evaporation. In the private farms using flood irrigation, a lot of water washes the salts out of the profile but the level of salts remains slightly evaluated, because the water quality is poor. In the state farms that use less water and of much better quality, the salts are washed out of the profile (at least to a depth of more than 1 m) and the residual salts are of much lower concentration.

On the basis of the average values for the profiles pH, EC, ESP%, water soluble Na^+, Cl^-, and SO_4^{2-} and exchangeable sodium were significantly greater (t test $p \leq 0.05$) in the irrigated profiles of the private farms than in the state farms, while bicarbonate was significantly higher (t test $p \leq 0.05$) in the state farm profiles. A similar comparison for the topsoils (0–25 cm) showed similar results except that bicarbonate and sulphate were not significantly different.

The second survey of the soil was conducted in December 2013 with the collection of 120 samples from irrigated soils from both state and private farms at a depth of 0-25 cm. Half of the samples were collected from state farms, and half from private farms. pH, EC, ESP% and exchangeable Na were significantly greater (t test $p < 0.05$) in the private farm samples compared to the state farm samples. There was no significant difference between the crop types for the state or private farms.

There was a significant correlation ($p \leq 0.05$) between the EC of the irrigation water and topsoil EC in both state and private farms. According to the USDA classification (Richards, 1954) all the state farm soils were classed as normal while the private farm soils were classed as normal 15% , saline 10%, alkaline 5% and saline alkaline 70% .

5.2 Introduction

Soil salinity represents a real and grave environmental problem worldwide, particularly in arid and semi-arid areas Pitman and Läuchli (2002). It is serious issue, whether resulting from natural causes or as the result of human carelessness Ghassemi et al., (1995). The increase in levels of soil salinity negatively affects both crop growth and productivity, eventually leading to degradation of the soil (Hillel, 2000). The American Salinity Laboratory points out that if electrical conductivity in the soil extract > 4 deciSiemens m^{-1}, Exchangeable Sodium Percentage (ESP) < 15 and pH (soil reaction) < 8.5 then these soils are referred to as saline soils (Richards, 1954). The salt forms in the soil as a result of the weathering of rocks and primary minerals, or being transported by wind or water (Shrestha and Farshad, 2008).

The United Nations Food and Agriculture Organization (FAO) assessed that saline soils cover 397 million hectares of total land area worldwide (Koohafkan and Stewart, 2008). They cited Africa, Asia, Europe, Australia, Latin America, the Near East and North America as the most affected areas (Koohafkan and Stewart, 2008). According to the latest estimates from a survey of farmers, in Australia an area of about 2 million hectares (20,000 farms) presented signs of salinity (Dennis, 2002).

Thousands of years ago, the richest agricultural lands in the world were already affected by these salts, in what is known presently as Turkey and Iraq, and such a situation induced a change in the culture of farmers, due to the negative effect of the accumulation of salt in the soil, and the inadequacy of the leaching and drainage of irrigation water Oster, (1994). Accordingly, the farmers moved from the traditional cultivation of wheat and barley to the cultivation of barley, which is more tolerant to salinity, and, eventually, the increase of salt forced farmers to abandon the affected lands in Iraq Nikos et al., (2002) whether in arid or semi-arid areas. This salinity problem has been known for thousands of years, due to the lack of rain to leach the salts from the plant root area Miller and Donahue, (1995).

It can be also argued that the effects of soil salinity are not merely confined to the environment, but also impact on the economy. Economic losses due to secondary salinity (salinity from human practices) in a particular region of Oman, called Batinah, amounted to $ 1,604 per hectare (28%) of gross margins when an increase of the salinity from low to medium level was observed, and $ 4,352 per hectare (76%) if the increase was from the lowest to the highest level Naifer et al., (2011).

Soil salinity is a major issue in North African irrigated lands, as about 98.5 million hectares in the continent are affected, and about 2.46 million hectares or 1.4 % of soil in Libya is affected by salinity. These areas are mainly located in coastal Sabkhas (marshland) and in southern areas where rainfall is extremely low and evaporation is high (Ross-Larson, 2003). Irrigated agriculture suffers from the negative impact of salinity, which has become a threat to both production and quality in Libyan agriculture, especially in the southern area Mansour and Latif, (2013). This study focuses on salinity and associated issues in agricultural soils in Kufra (southern Libya), where large saline areas affect agricultural development and cause deterioration of vegetation cover El-Barasi and Saaed, (2013).

Kufra is located in the south-east of Libya and depends mainly on agriculture produced by both private farms and state farms. However, it has been observed that private farms' soils are more affected by salinity than state soils' farms Alzway et al., (2013). In order to study the effect of salinity in this region, soil samples were taken in two phases. The first were collected from areas at a depth of 0-100 cm, while the second samples were taken at a depth of 0-25 cm of virgin and irrigated soils in both private farms and state farms.

5.2.1 Criteria of US Salinity Laboratory (Richards, 1954).

Electrical Conductivity (EC)

Electrical Conductivity is a measure of the ability of a solution to pass an electric current. EC increases as the salinity (salt concentration) of the solution increases. EC is usually measured as the electrical conductivity of a saturated soil-water extract the units are dS m^{-1} (deciSiemens/metre).

EC is the preferred method of estimating soil salinity, because it best reflects how salinity will affect plant growth; furthermore, soil salinity is a major environmental factor limiting the productivity of agricultural lands, causing land degradation and affecting food production (Sharma & Rao, 1998). Conventionally, saline soils are defined as those having an EC value >4 dS m^{-1}, see (Table 5.1).

Table 5-1 Salinity ratings for soil based on EC.

Rating EC	dS m^{-1}	Effect on plants
Non-saline	<2	Salinity effects are mostly negligible
Slightly saline	2 – 4	Yields of sensitive crops are affected
Moderately saline	4 – 8	Yields of many crops are affected
Highly saline	8 - 16	Only tolerant crops yield satisfactorily
Extremely saline	>16	Only very tolerant crops yield satisfactorily

Source: Richards, 1954

Exchangeable Sodium Percentage (ESP %)

Alkaline soil, by definition, is one containing a high level of sodium relative to other exchangeable cations (i.e. calcium, magnesium and potassium). A soil is classified as "sodic" when its Exchangeable Sodium Percentage (ESP) is 15% or greater.

Exchangeable sodium percentage (ESP): The percentage of the cation exchange capacity neutralised by sodium, that is, the proportion of the total cation sites on the surface of a soil material that are occupied by sodium. Water infiltration and leaching rates are very low in sodic soils irrigated with good quality water, because in general they are compacted and the clays dispersed. Sodic soils are low in soluble salts but comparatively high in exchangeable sodium. High levels of exchangeable sodium cause the individual sand, silt and clay particles to be dispersed and not clustered together into larger particles. This dispersion makes the clay soil compact and impervious so that it allows little irrigation water, rain, or air to permeate into the soil. However, irrigation with saline water is less of a problem because there is less dispersion of clays in a high background salt solution. Sandy soils are also less of a problem because of their low clay content.

Reclamation requires restoring the cation balance as well as reducing salinity, initially with more saline water to allow infiltration then with better quality water. The rate of reclamation is dependent on the amount of water travelling through the soil profile, soil salinity, water quality and mineral weathering within the soil Robbins et al., (1991)

$$ESP = (Na^{+} / CEC) \times 100$$

Where; ESP = Exchangeable Sodium Percentage
Na^{+} = Measured exchangeable Na^{+}, meq/100 g soil
CEC = Cation Exchange Capacity, meq/100 g soil

All soils possess the ability to absorb the positively charged constituents of soluble salts, such as sodium, magnesium, potassium, calcium, etc. This is known as their cation exchange capacity. These various absorbed cations can be exchanged for others, with the extent of exchange dependent on their relative concentrations in the soil water.

Affected soils can be classified according to various systems. The most universally applied is that implemented by the USDA salinity laboratory (Richards, 1954), since it is based on easily obtainable parameters such EC and ESP (Table 5.2), and has a demonstrable practical execution in plant growth and tolerance levels of crops. Effect of ESP can be reduced by increasing the concentration of exchangeable calcium or by raising EC to above 4 dS m^{-1}. If saline water containing high amounts of calcium is available, the infiltration rate can be increased by increasing soluble calcium and EC. Then, as the sodium is replaced, higher quality water can gradually be used (Robbins et al., 1991). These mean more saline water may be needed to improve the infiltration rate of alkali soil

Table 5-2 Classification of salt-affected soils by the US salinity laboratory.

Diagnostic parameters	EC ≤ 4 dS m^{-1}	EC > 4 dS m^{-1}
ESP ≤ 15%	Non-saline and non-alkali soil	Saline soil
ESP >15%	Alkali (or sodic) soil	Saline alkali soil

Source: Richards, 1954

Saline soil

Soils where the conductivity of the saturation extract is more than 4 dS $m^{-1,}$ and the Exchangeable Sodium Percentage (ESP) is less than 15%, are classified as saline. Normally their pH is less than 8.5. The amount of soluble salts present controls the osmotic pressure of the soil solution. Sodium rarely amounts to more than half of the soluble cations, and therefore is not absorbed to any significant extent. The comparative quantities of magnesium and calcium present both in the soil solution and on the exchange complex may vary significantly. The main anions are chloride, sulphate, and, occasionally, nitrate. Small amounts of bicarbonate may be present.

Non saline-Alkali Soil

Non saline-alkali soils are those where the exchangeable- sodium-percentage is greater than 15% and the conductivity of the saturation extract less than 4 dS m^{-1}. Their pH readings normally range between 8.5 and 10. They most commonly occur in semiarid and arid regions.

Saline -Alkali soil

Soils can be classified as saline-alkali where the conductivity of the saturation extract is greater than 4 dS m^{-1}, and the exchangeable-sodium percentage is greater than 15%. These soils formation is due to the combined processes of salinisation and alkalisation. While excess salts are present, the appearance and properties of these soils tend to be similar to those of saline soils. Under conditions of excess salts, the pH readings are seldom higher than 8.5.

5.2.2 Aims for this chapter

The specific objectives of the study are to:

Initial survey

1. Evaluate the chemical properties of virgin soil profiles in the study area and compare these with irrigated soil profiles on state farms and private farms.
2. Classify the virgin and irrigated soil profiles according to USDA Salinity Laboratory, Handbook No. 60 (Richards, 1954).
3. Evaluate the effect of irrigation water quality on chemical properties of the soil profiles.

Main survey

1- Take a large number topsoil samples across the study area to specifically compare the irrigated soils of state and private farms and evaluate the effect of different crops on soil chemical properties,

2- Classify the topsoil according to USDA Salinity Laboratory, Handbook No. 60 (Richards, 1954)

3- Evaluate the relationship between soil chemical properties and irrigation water quality.

5.3 Methodology

5.3.1 Initial soil Survey

The current study examined 8 farms, four of them are privately owned (with an average area 3 ha each) from three regions Al-Jawf, Al-Zawriq and Hawari, while the other four are state-owned, under the Kufra Agricultural Project (state farms) from agricultural unit A (figure 5.1), with an area of 100 ha for each circle.

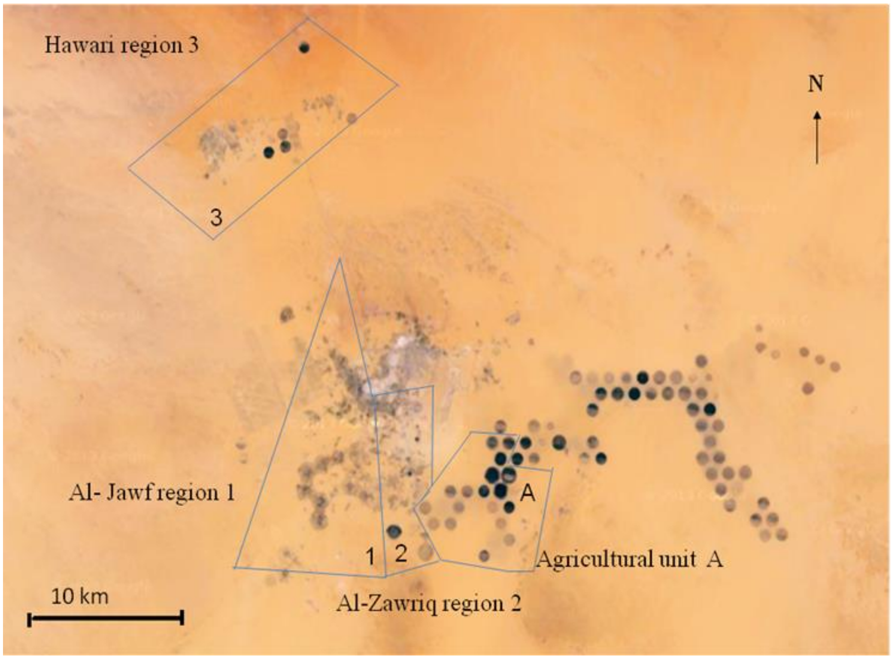


Figure 5—1 The three regions 1, 2 and 3 of private farms and agricultural unit A of state farms where samples were collected. (https://www.google.co.uk/search Images for aerial photograph of Kufra region 2010).

5.3.1.1 State farms

The Kufra Agricultural Project irrigates with pivot irrigation machines, which are the largest kind of pivot irrigation machines used worldwide. Their length is 560 m which represents the radius of a circle covering an area of 1km^2.

Due to the climatic conditions in Kufra such as the high temperatures and insufficient irrigation water for an area of 100 hectares at the higher temperatures in the summer it has been decided to divide the area of the field to an inner and outer area in order to cultivate the two areas (50 hectares each) in the winter but only the inner area in the summer. Crops, such as wheat and alfalfa are only grown in the inner circle.

Figure 5.2 shows the pivot irrigation machine consists of 14 wheel mounted towers (trusses), the distance between towers is 40 m. The length of the irrigation arm from the pivot point at the centre of the circle to the tenth tower is 400 m representing the inner area and covering 50 hectares (0.5 k m^2). The remaining 4 sections of the irrigation machine (towers 10 to 14) are 160 m long representing the outer area and cover 50 hectares (0.5 k m^2).

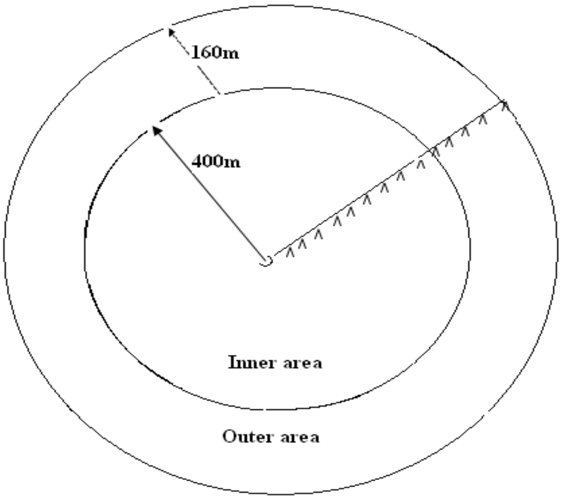


Figure 5—2 Shows the inner and outer areas of state farms.

Four fields were randomly selected from the farms project from agricultural unit A the farm numbers were 68, 78, 107 and 115.

Figure 5.3 shows the sampling method of the farm (circle area), where the farm is divided into 3 radii A, B and C, and radius A is the entrance to the field. 3 irrigated soil sample points were located 10 m outwards from wheel tracks 11, 8 and 5 (there are 14 circular wheel tracks in each farm, starting with track 1 closest to the centre of the field) on radii A, B and C respectively Sample point 11 A was moved 100 m anticlockwise to avoid any effects from the entrance to the field. 3 virgin soil sample points were located 20 m outside the farm on radius A, B, and C (Tables 5.3 and 5.4).

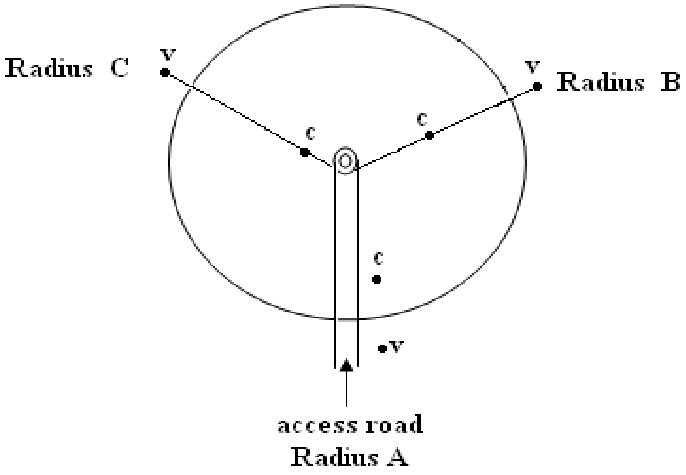


Figure 5—3 The locations of sample sites on state farms.
c = cropped soils, and **v=** virgin soils

Table 5-3 Sampling sites in the circle area (irrigated soil).

Track	Radius	Counter-clock distance from radius (m)	distance out from wheel track (m)
11	A	100	10
8	B	0	10
5	C	0	10

Table 5-4 Sampling sites around the circle (virgin soil).

Radius	Counter-clock distance from radius (m)	Distance out from edge of the circle (m)
A	100	20
B	0	20
C	0	20

5.3.1.2 Private Farms

For the private farms, 4 were selected from the Al-Jawf, Hawari, and Zawriq regions. The names of farmers were randomly chosen from a list of farmers available at the Al-Kufra Office of Agriculture. Two farms were in Al-Jawf since it is the largest area, and one farm each was chosen for Al-Zawriq and Hawari regions. The sites of profiles were chosen to be representative of the area cultivated.

The farms chosen had a rectangular shape and the sampling sites were along a diagonal as figure 5.4. Virgin soil sample points were selected randomly 20 m from edge of the irrigated area.

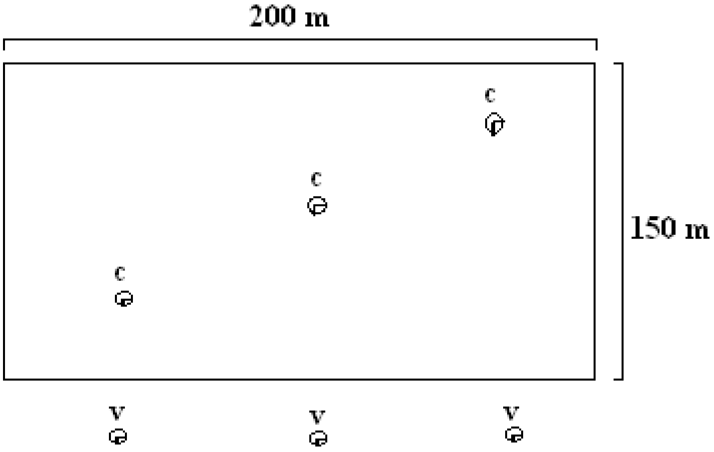


Figure 5—4 Shows the location a samples sites of private farms, the letters **c =** cropped soils and **v=** virgin soils.

Sampling method

At each of the 6 sampling points per farm, a squre profile pit was dig 1 m by 1 m and 1 m deep. Samples were taken at 0-25, 26-50, 51-75 and 76- 100 cm by taking sub samples from four faces of the profile and mixing to produce approximately 500 g pooled sample at each depth. The samples were collected during the summer of 2010.

5.3.2 Main soil survey

During the main soil survey (winter 2013), topsoil samples were collected from a larger number of different sites. The soil samples were taken from the same area as the plant specimens, the method for the selection of the sites was based on the type of crop. In this instance, samples were collected in December (from the 2nd to the 31st of December 2013, which is the winter season in Libya). The winter crops grown within the study area are alfalfa, potatoes, cereals, forage and vegetables. The plan was to collect 10 topsoil samples from alfalfa crops and 10 soil samples from potato crops (from both state farms and private farms).

5.3.2.1 State Farms

The Kufra Agricultural Project contains 100 farms (circles), but due to the recent political upheavals (events of the revolution in Libya in 2011) the electrical connections (power shutdown) for the KAP were interrupted affecting the irrigation pumps and rotary arms. This problem affected the project which had to be suspended for more than a year. Only 57% of the circles of the project were working when samples were collected in December 2013, as shown in Table 5.5.

Table 5-5 Shows cultivated crops in the winter season 2013 in the state farms.

Inner area	**cultivated crop**						
Type crops	Cultivated					uncultivated	Total
	Wheat	Alfalfa	Barley	Forage	total		
Number	19	17	4	2	42	15	57

Outer area					uncultivated	Total
cultivated crop						
Type crop	Barley	forage	potatoes	total		
Number	21	14	0	35	22	57

Wheat; Triticum, durum or aestivum. Alfalfa; Medicago, sativa, Barley; Hordeum, vulgare Forage; Mixed cereals (barley with wheat). Potatoes; Solanum tuberasum L. Spunta

17 fields cultivated with alfalfa in were identified and 10 of them were selected at random from the list. No farms cultivated with crop potatoes were identified. 60 farms cultivated with winter crops such as barley, wheat and forage crops in both the inner and outer areas were identified, and 10 of them were chosen at random from the list.

Table 5.6 shows the locations of the state farms selected for sample collection. Alfalfa was only grown in the inner area. This is due to the perennial nature of the crop (over two years) as well as for other technical factors.

Table 5-6 Soil sampling sites for state farms.

Farm No.	**Agriculture unit**	**Inner or outer area**	**Crop growing**
85	A	Inner	Alfalfa
96	A	Inner	Alfalfa
102	A	Inner	Alfalfa
105	A	Inner	Alfalfa
62	B	Inner	Alfalfa
81	B	Inner	Alfalfa
37	C	Inner	Alfalfa
69	C	Inner	Alfalfa
126	D	Inner	Alfalfa
34	E	Inner	Alfalfa
48	C	Inner	Alfalfa
75	A	Inner	Wheat
53	B	Inner	Wheat
62	B	Outer	Preparation for planting
82	B	Outer	Uncultivated
37	C	Outer	Wheat + barley (mixed)
43	C	Inner	Wheat
51	C	Outer	Barley
69	C	Outer	Barley
27	D	Inner	Wheat

Sampling Alfalfa (inner circle only)

Figure 5.5 shows the sampling method of the inner area of the circle, where the circle is divided into 3 radii A, B and C, and radius A is the entrance to the field. Samples were taken 10 m outwards from wheel tracks 8, 5 and 3 on radii A, B and C respectively Sample point 8 A was moved 100 m anticlockwise to avoid any effects from the entrance to the field. See Table 5.7.

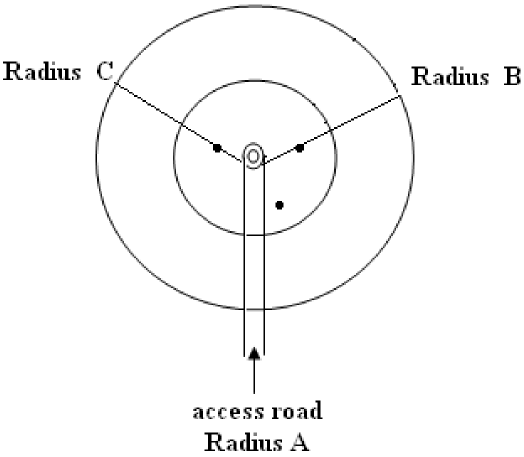


Figure 5—5 The location of sample sites in inner circle.

Table 5-7 Sampling sites in the inner area.

Track	Radius	Counter-clock distance from radius (m)	distance out from wheel track (m)
8	A	100	10
5	B	0	10
3	C	0	10

In order to be able to take a composite sample from an area of 10 m^2 after identifying the location the following method was used. A 2 x 5 m^2 sampling point area was marked out and divided into 10 $1m^2$ areas. Squares 1, 6 and 9 were selected as samples, as shown in figure 5.6. In each metre square 3 auger samples (0–25 cm) were collected and the 9 samples pooled for the sample.

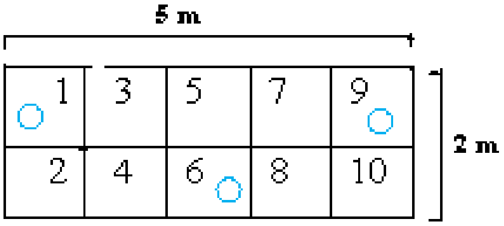


Figure 5—6 Shows the sampling sites in the 2 m by 5 m area. Sampling Annual Crops, (inner and outer circles)

The other seasonal crops (forage, barley and legumes) planted in the inner areas were sampled using the same procedure as for alfalfa. Table 5.8 shows the sampling method for the outer circle area planted with seasonal crops (barley and forage) on the same principle used for inner circle samples. Tracks 13, 12 and 10, were sampled on radii A B and C respectively.

Table 5-8 Sampling sites in the outer area.

Track	Radius	Counter-clock distance from radius (m)	Distance out from wheel track reach (m)
13	A	100	30
12	B	0	10
10	C	0	10

5.3.2.2 Private Farms

The private farms are spread over three main areas, which are known as Al-Jawf, Al Zwariq and Hawari, the average size of the farm is 3 hectares and they are planted with crops of cereal, alfalfa, vegetables and fruits .Usually crops are cultivated in areas of 0.5-1 hectares in fields of rectangular shape 50 x 100 meters or square shape 100 x 100 m^2.

The samples were collected from 10 farms (in the ratio 4, 3 and 3 for the three areas). Double this numbers of potential sites were chosen randomly from a list of farmers' names

(8, 6 and 6 farms) from the respective areas. The farms were visited in order, if the crops were present samples were collected or if crops were not present sampling moved to next farm on list until the quota for region was achieved.

Table 5.9 Shows the locations of private farms from which the soil samples were collected, as well as the crops grown.

Table 5-9 Soil sampling sites of private farms.

Farm No.	Region	Farm age	Crop growing
5	1	26	Alfalfa
6	1	28	Alfalfa
7	3	15	Alfalfa
8	3	15	Alfalfa
9	3	28	Alfalfa
10	1	24	Alfalfa
11	1	19	Alfalfa
12	2	27	Alfalfa
13	2	28	Alfalfa
14	2	39	Alfalfa
5	1	26	Potatoes
6	1	28	Potatoes
7	3	15	Potatoes
8	3	15	Potatoes
15	3	8	Potatoes
16	1	12	Potatoes
17	1	22	Potatoes
18	2	25	Potatoes
19	2	30	Potatoes
20	2	10	Potatoes

The areas used for the cultivation of alfalfa were both rectangular (50 m x 100 m) and square (100 m x 100 m), while the areas with potatoes were only rectangular (50 m x 100 m).

The Sampling points of these areas were along a diagonal as in figures 5.7 and 5.8.

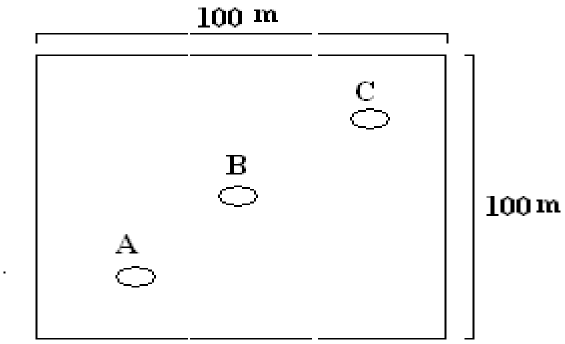


Figure 5—7 Shows the locations of the sampling area of 100 m by 100 m.

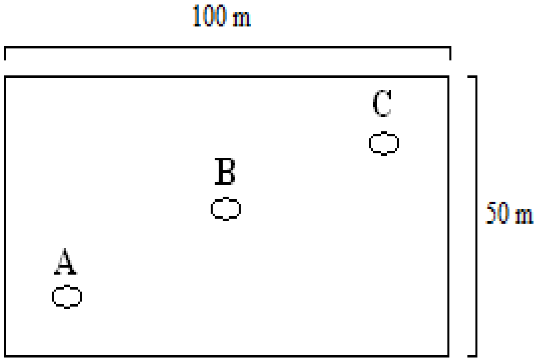


Figure 5—8 Shows the locations of the sampling area of 50 m by 100 m.

The annual crops were sampled from a 5 m x 0.6 m area rather than the 5 m x 2 m area used for alfalfa. The 5 m x 0.6 m (3 m^2) sample areas were marked out and divided into 3 equal parts (figure 5.9), Three auger samples (0 -25 cm) were taken from each area and the 9 samples pooled for the sample.

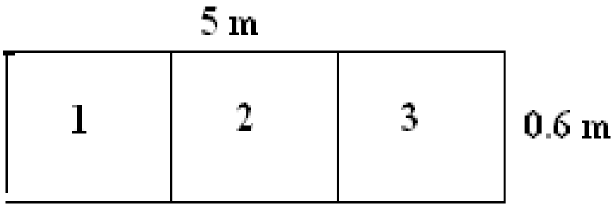


Figure 5—9 Shows the sampling sites in the 1m by 3 m area.

5.4 Results and Discussion

5.4.1 Initial soil survey

5.4.1.1 Mechanical analysis

The tables 5.10 and 5.11 show the data from state and private farms, regarding the mechanical analysis according to the Sieve Analysis method in section 2.2.14.

Table 5-10 Particle- size distribution for different locations under study in the state farms by the USDA classification system (values are the mean of three profiles).

Farm No.	Soil Type	Depth (cm)	Gravel (%)	Very coarse sand (%)	Coarse sand (%)	Medium Sand (%)	Fine Sand (%)	Very fine sand (%)	Silt+ Clay (%)
68	Virgin Soil	0 -25	0.58	1.44	24.48	22.19	31.10	12.54	6.15
		26 -50	0.07	0.44	29.28	20.20	27.49	13.93	7.99
		51- 75	1.13	2.21	26.88	17.56	27.46	15.13	9.33
		75-100	0.76	1.35	29.89	17.28	23.24	19.54	8.21
	Irrigated soil	0 -25	0.32	0.61	33.87	15.27	26.65	16.46	6.76
		26 -50	0.18	0.46	35.32	22.17	25.63	13.14	5.57
		51- 75	0.16	0.44	33.20	20.51	26.92	13.09	5.67
		75-100	0.14	0.54	28.79	22.11	29.13	13.29	5.99
78	Virgin Soil	0 -25	0.9	2.3	32.33	15.50	28.87	11.96	5.56
		26 -50	0.85	1.97	33.37	15.29	28.82	13.17	5.25
		51- 75	0.18	0.66	29.62	14.68	21.54	26.73	6.15
		75-100	1.54	3.08	33.62	16.35	21.12	18.95	4.51
	Irrigated soil	0 -25	1.6	1.73	29.59	13.81	30.84	16.41	5.95
		26 -50	0.44	0.82	34.01	14.87	27.66	16.06	6.12
		51- 75	0.15	0.39	34.3	15.46	27.31	16.52	6.34
		75-100	0.13	0.55	33.81	16.22	27.58	15.55	6.11
107	Virgin Soil	0 -25	1.03	2.75	33.43	13.95	30.67	10.13	5.32
		26 -50	0.78	1.48	34.34	16.07	25.99	14.77	5.13
		51- 75	1.18	0.83	36.56	12.47	21.79	20.53	5.70
		75-100	0.12	0.59	33.24	14.88	18.53	26.74	5.55
	Irrigated soil	0 -25	0.06	0.34	38.44	18.73	15.16	27.61	6.30
		26 -50	0.03	0.12	33.02	21.28	15.29	24.68	5.57
		51- 75	0.04	0.24	32.22	22.68	16.45	23.01	5.34
		75-100	0.03	0.17	30.18	22.36	18.84	22.75	5.76
115	Virgin Soil	0 -25	0.11	0.81	32.78	15.71	21.41	22.77	5.53
		26 -50	0.10	0.70	34.59	12.04	17.58	28.67	5.77
		51- 75	0.10	0.31	29.03	14.85	6.86	41.61	5.73
		75-100	0.24	0.55	30.84	13.02	11.44	37.55	6.16
	Irrigated soil	0 -25	0.25	0.67	31.25	12.34	13.31	35.55	6.54
		26 -50	0.21	0.30	29.98	14.00	11.21	37.14	6.89
		51- 75	0.18	0.28	30.20	14.91	14.14	33.14	7.12
		75-100	0.26	0.31	31.89	14.85	7.42	38.23	7.01

Table 5-11 Particle- size distribution for different location under study of the private farms by the USDA classification system (values are the mean of three profiles).

Farm No.	Soil Type	Depth (cm)	Gravel (%)	Very coarse Sand (%)	Coarse sand (%)	Medium sand (%)	Fine sand (%)	Very fine sand (%)	Silt+ Clay (%)
1	Virgin Soil	0 -25	6.46	0.98	17.68	28.65	28.85	9.05	5.64
		26 -50	2.64	1.63	19.81	31.48	30.22	8.57	4.64
		51- 75	0.65	0.95	21.15	27.73	33.03	10.92	5.11
		75-100	0.25	0.98	32.72	22.10	27.77	11.13	4.68
	Irrigated Soil	0 -25	0.88	1.29	37.18	19.31	24.99	11.86	4.37
		26 -50	0.27	0.67	37.30	2064	25.80	10.85	4.26
		51- 75	1.51	0.80	21.89	30.2	31.14	9.98	7.54
		75-100	17.74	2.21	14.64	17.84	24.21	8.12	12.75
2	Virgin Soil	0 -25	0.42	1.46	26.45	19.64	31.28	12.6	6.60
		26 -50	0.69	0.66	14.61	34.02	35.61	7.71	5.98
		51- 75	0.63	2.00	26.92	17.68	22.41	19.66	10.26
		75-100	0.11	0.71	28.97	20.44	30.29	12.04	7.32
	Irrigated Soil	0 -25	1.56	2.01	19.97	23.56	31.85	11.00	9.54
		26 -50	1.05	1.78	18.78	21.46	35.26	10.24	10.3
		51- 75	0.53	1.17	16.31	23.25	36.15	9.89	11.52
		75- 85	1.62	4.96	10.35	26.75	35.47	4.92	12.17
3	Virgin Soil	0 -25	6.50	1.54	20.58	20.04	30.48	12.43	6.07
		26 -50	0.29	0.85	25.56	23.46	41.01	9.76	6.72
		51- 75	0.27	0.91	35.45	21.81	24.61	9.57	6.32
		75-100	0.08	1.38	29.76	18.47	24.75	18.69	6.11
	Irrigated Soil	0 -25	2.91	1.57	29.86	18.58	24.34	12.49	10.04
		26 -50	19.05	1.48	22.09	15.24	21.34	10.80	9.75
		51- 75	13.77	1.44	22.36	17.78	23.79	10.49	10.19
		75-100	5.69	1.10	19.89	23.86	29.74	9.94	10.59
4	Virgin Soil	0 -25	0.04	0.69	34.01	12.75	30.61	13.13	6.95
		26 -50	1.49	2.74	33.51	18.26	26.71	10.22	5.55
		51- 75	0.58	0.90	35.34	20.58	24.84	10.61	6.42
		75-100	0.32	0.90	26.92	21.91	27.82	15.86	5.73
	Irrigated soil	0 -25	0.06	0.33	35.7	18.24	27.79	13.03	6.73
		26 -50	0.08	0.22	32.38	19.69	34.31	13.37	6.84
		51- 75	0.09	0.13	19.48	22.17	33.43	8.98	5.99
		75-100	0.07	0.78	25.29	22.19	30.77	14.31	6.67

The results of the study illustrated in Tables (5.10 & 5.11) show that most soil samples from Kufra region present either a sandy texture. Therefore the texture of soils of this area is mainly classified as sandy soils.

5.4.1.2 Chemical analysis

Tables 5.12 and 5.13 contain the percentage of saturation, the pH and electrical conductivity, as well as the percentage of calcium carbonate in virgin and irrigated soils of the state and private farms with a depth from 0 to 100 cm.

Table 5-12 Chemical analysis for the state farms of the virgin and irrigated soil of four depths.

Farm No.	Soil Type	Depth (cm)	SW (%)	pH	EC (dSm^{-1})	Ca CO$_3$ (%)
68	**Virgin soil**	0 -25	20	8.3	47.6	0.20
		26 -50	20	8.3	17.8	0.18
		51- 75	20	8.2	3.9	0.27
		75-100	20	8.1	3.3	0.33
	Irrigated soil	0 -25	29	7.6	1.8	0.07
		26 -50	16	7.9	1.3	0.10
		51- 75	17	7.7	2.3	0.07
		75-100	15	8.0	2.3	0.11
78	**Virgin soil**	0 -25	16	7.9	56.4	0.33
		26 -50	16	7.9	26.4	0.22
		51- 75	16	8.0	11.2	0.20
		75-100	17	7.9	5.3	0.54
	Irrigated soil	0 -25	29	7.7	1.8	0.46
		26 -50	23	7.9	1.6	0.45
		51- 75	23	8.3	2.7	0.25
		75-100	21	8.5	2.6	0.33
107	**Virgin soil**	0 -25	20	8.0	67.8	0.46
		26 -50	20	7.9	33.4	0.11
		51- 75	20	7.8	16.5	0.22
		75-100	20	8	6.9	0.17
	Irrigated soil	0 -25	28	7.6	1.4	0.34
		26 -50	20	7.7	2.1	0.16
		51- 75	20	7.7	3.1	0.16
		75-100	20	7.8	2.4	0.31
115	**Virgin soil**	0 -25	20	7.8	19.4	0.29
		26 -50	20	8.0	13.8	0.38
		51- 75	20	8.0	5.0	0.32
		75-100	20	8.1	3.2	0.29
	Irrigated soil	0 -25	26	7.4	1.2	0.20
		26 -50	19	7.3	2.3	0.19
		51- 75	20	7.6	2.0	0.24
		75-100	20	8.1	1.7	0.35

S. W = saturation water content

Table 5-13 Chemical analysis for the private farms of the virgin and irrigated soil of four depths.

Farm No.	Soil type	Depth (cm)	SW (%)	pH	EC (dSm^{-1})	Ca CO$_3$ (%)
1	Virgin soil	0 -25	17	9.2	65.8	0.50
		26 -50	18	8.8	32.7	0.42
		51- 75	18	8.3	10.1	0.04
		75-100	19	8.5	7.9	0.10
	Irrigated soil	0 -25	20	9.2	3.8	0.14
		26 -50	20	8.9	4.5	0.12
		51- 75	20	9.1	4.5	0.05
		75-100	20	8.9	4.9	0.53
2	Virgin soil	0 -25	17	8.7	56.7	0.53
		26 -50	19	8.8	23.2	0.38
		51- 75	18	9.0	8.8	0.27
		75-100	18	8.8	4.8	0.10
	Irrigated soil	0 -25	20	9.1	10.8	2.21
		26 -50	20	8.9	14.5	1.01
		51- 75	20	9.2	19.5	1.02
		75-100	23	9.1	16.4	4.03
3	Virgin soil	0 -25	16	9.1	76.9	0.34
		26 -50	17	8.2	30.4	0.11
		51- 75	17	7.9	15.0	0.25
		75-100	19	8.4	8.5	0.15
	Irrigated soil	0 -25	10	9.1	3.2	0.86
		26 -50	10	9.0	5.2	0.36
		51- 75	20	9.0	3.9	0.73
		75-100	10	9.3	3.3	0.31
4	Virgin soil	0 -25	16	9.2	105.9	0.15
		26 -50	20	8.7	37.7	0.16
		51- 75	20	8.4	20.4	0.27
		75-100	20	8.4	11.7	0.14
	Irrigated soil	0 -25	20	8.3	3.4	0.05
		26 -50	20	8.3	5.3	0.05
		51- 75	20	8.5	4.5	0.08
		75-100	20	8.6	4.1	0.07

pH saturation paste**, EC** saturation extract**, SW** saturation water content %

Tables 5.12 and 5.13 showed very little difference in the percentage of saturation water content %, pH, and the percentage of calcium carbonate between the types of soils, as well as between the depths of soils in the various profiles. The main difference appears in the values of electrical conductivity, which decreased with the increase of the virgin soil depth. In the irrigated soils the data is completely different, since the values of the conductivity show no clear trend with increase of depth. The differences in values of EC in the irrigated soil of private farms (irrigated with saline water) and the Kufra agricultural project farms (state farms, irrigated with high quality water) using a pooled t test. There were highly significant in relation to farm type (DF= 3, $p<0.001$). These results are consistent with the findings of Patel et al., (2001), where the soil between private farms ranged from medium to high electrical conductivity. This trend could be attributed to variability in quality of irrigation water and rates of leaching or applying fertiliser.

In the present study, values for soil pH were high, ranging between (7.3 to 9.3) could be due to the high levels of sodium carbonate in the soils. Ardahanlioglu et al., (2003). Khresat and Taimeh (1998) suggest that variations in soil pH may be related to high sodium levels in soil. Cardoso et al., (2013) suggest that the most essential parameters for overall changes in soil chemical properties were pH.

The tables (5.14 and 5.15) show the data from state and private farms regarding the soluble cations, and the dissolved anions measured in ($\text{cmol}_c\ \text{kg}^{-1}$).

Table 5-14 Concentrations of the soluble ions in saturation extract of the state farms of virgin and irrigated soils from four depths.

Farm no.	**Soil type**	**Depth (cm)**	**Soluble cations ($cmol_c$ kg^{-1})**				**Soluble anions ($cmol_c$ kg^{-1})**			**Ionic balance ($cmol_c$ kg^{-1})**	
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3	Cl^{-}	SO_4^{2}	Cations	Anions
68	Virgin Soil	0-25	3.14	1.50	4.32	0.44	0.02	7.08	3.04	9.40	10.14
		26-50	1.28	0.44	1.72	0.05	0.03	2.12	1.52	3.49	3.67
		51-75	0.60	0.03	0.64	0.04	0.05	0.86	0.44	1.31	1.35
		76-100	0.10	0.03	0.60	0.03	0.04	0.38	0.36	0.76	0.78
	Irrigated soil	0-25	0.03	0.03	0.08	0.01	0.05	0.08	0.05	0.15	0.18
		26-50	0.01	0.01	0.03	0.01	0.01	0.02	0.02	0.06	0.05
		51-75	0.02	0.01	0.02	0.01	0.01	0.03	0.01	0.06	0.05
		76-100	0.01	0.01	0.02	0.01	0.01	0.03	0.02	0.06	0.06
78	Virgin Soil	0-25	3.90	1.20	5.62	0.64	0.03	8.44	2.30	11.36	10.77
		26-50	2.50	0.54	2.68	0.22	0.03	3.20	2.14	5.94	5.37
		51-75	0.66	0.30	1.36	0.08	0.03	1.36	1.06	2.40	2.45
		76-100	0.36	0.24	0.50	0.02	0.04	0.46	0.62	1.12	1.12
	Irrigated soil	0-25	0.04	0.10	0.17	0.02	0.03	0.07	0.06	0.33	0.16
		26-50	0.03	0.02	0.04	0.01	0.04	0.05	0.03	0.10	0.12
		51-75	0.04	0.02	0.03	0.01	0.03	0.08	0.02	0.10	0.13
		76-100	0.04	0.01	0.03	0.01	0.03	0.07	0.02	0.09	0.12
107	Virgin Soil	0-25	2.74	0.78	8.68	0.86	0.04	11.4	2.70	13.06	14.12
		26-50	2.84	0.64	3.10	0.36	0.04	4.58	0.88	6.94	5.50
		51-75	1.58	0.54	1.18	0.10	0.03	1.66	0.70	3.40	2.39
		76-100	0.50	0.28	0.74	0.04	0.02	0.52	0.56	1.56	1.10
	Irrigated soil	0-25	0.07	0.05	0.11	0.01	0.02	0.04	0.02	0.24	0.08
		26-50	0.04	0.02	0.04	0.01	0.03	0.05	0.02	0.11	0.10
		51-75	0.04	0.02	0.04	0.01	0.03	0.04	0.03	0.11	0.10
		76-100	0.02	0.01	0.04	0.01	0.02	0.04	0.03	0.08	0.09
115	Virgin Soil	0-25	1.30	0.90	1.78	0.08	0.03	3.46	1.82	4.06	5.31
		26-50	0.84	0.42	1.30	0.08	0.03	1.48	1.36	2.64	2.87
		51-75	0.24	0.19	0.48	0.02	0.04	0.34	0.72	0.93	1.10
		76-100	0.15	0.12	0.34	0.02	0.04	0.20	0.46	0.63	0.70
	Irrigated soil	0-25	0.03	0.04	0.06	0.01	0.03	0.10	0.05	0.14	0.18
		26-50	0.04	0.04	0.07	0.01	0.03	0.12	0.03	0.16	0.18
		51-75	0.04	0.04	0.05	0.01	0.04	0.08	0.03	0.14	0.15
		76-100	0.04	0.03	0.04	0.01	0.04	0.06	0.02	0.12	0.12

Table 5-15 Concentrations of the soluble ions in saturation extract from the private farms of virgin and irrigated soils from four depths.

Farm no.	Soil type	Depth (cm)	Soluble cations ($cmol_c\,kg^{-1}$)				Soluble anions ($cmol_c\,kg^{-1}$)			Ionic balance ($cmol_c\,kg^{-1}$)	
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	Cations	Anions
1	**Virgin soil**	0-25	1.58	0.55	9.44	0.23	0.04	11.17	0.68	11.80	11.89
		26-50	1.28	0.23	4.55	0.11	0.03	4.82	1.33	6.17	6.18
		51-75	0.67	0.07	1.35	0.05	0.03	1.10	1.01	2.14	2.14
		76-100	0.46	0.08	1.03	0.03	0.02	0.74	0.84	1.60	1.60
	Irrigated soil	0-25	0.23	0.06	0.46	0.01	0.01	0.36	0.25	0.75	0.62
		26-50	0.34	0.08	0.48	0.01	0.02	0.34	0.29	0.91	0.65
		51-75	0.40	0.08	0.46	0.01	0.01	0.33	0.26	0.95	0.60
		76-100	0.38	0.11	0.55	0.01	0.02	0.39	0.28	1.05	0.69
2	**Virgin soil**	0-25	2.34	0.58	7.98	0.21	0.03	8.86	0.68	11.11	9.57
		26-50	0.92	0.25	3.21	0.10	0.03	3.34	0.60	4.48	3.97
		51-75	0.11	0.08	1.52	0.05	0.04	1.52	0.23	1.76	1.79
		76-100	0.10	0.06	0.72	0.02	0.03	0.55	0.25	0.90	0.83
	Irrigated soil	0-25	0.74	0.18	1.58	0.03	0.03	1.46	0.44	2.53	1.93
		26-50	0.78	0.18	2.10	0.03	0.03	1.55	0.50	3.09	2.08
		51-75	1.01	0.30	2.68	0.05	0.03	2.62	0.56	4.04	3.21
		76-100	0.99	0.30	1.96	0.06	0.02	2.70	0.50	3.31	3.22
3	**Virgin soil**	0-25	2.11	0.30	12.10	0.26	0.04	13.26	1.43	14.77	14.73
		26-50	2.16	0.86	1.85	0.07	0.02	4.00	1.84	4.94	5.86
		51-75	0.56	0.11	1.97	0.11	0.04	1.63	1.07	2.75	2.74
		76-100	0.46	0.24	1.0	0.04	0.83	1.01	1.74	1.74	3.58
	Irrigated soil	0-25	0.06	0.04	0.30	0.01	0.01	0.20	0.09	0.41	0.30
		26-50	0.10	0.05	0.36	0.01	0.01	0.27	0.12	0.52	0.40
		51-75	0.13	0.08	0.63	0.02	0.03	0.49	0.22	0.86	0.74
		76-100	0.04	0.02	0.22	0.00	0.01	0.20	0.10	0.28	0.31
4	**Virgin soil**	0-25	4.44	1.04	15.80	0.61	0.03	16.17	6.15	21.89	22.35
		26-50	1.35	0.31	4.90	0.35	0.03	6.12	1.18	6.91	7.33
		51-75	0.82	0.38	2.52	0.07	0.02	2.80	1.68	3.79	4.50
		76-100	0.74	0.28	1.48	0.05	0.02	1.38	1.28	2.55	2.68
	Irrigated soil	0-25	0.04	0.02	0.44	<0.01	0.02	0.44	0.05	0.50	0.51
		26-50	0.06	0.03	0.72	<0.01	0.02	0.58	0.08	0.81	0.68
		51-75	0.08	0.05	0.66	<0.01	0.02	0.60	0.12	0.79	0.74
		76-100	0.06	0.06	0.60	<0.01	0.01	0.58	0.11	0.72	0.70

Tables 5.14 and 5.15 show the data from private and state farms regarding the cations with the dissolved anions of soil, as well as ionic balance in irrigated and virgin soils from four different depths (0-100 cm). The results in the tables indicate that sodium was the dominant soluble cation, in both virgin and irrigated soil profiles, and ranged from (0.02 to

9.34 cmol$_c$ kg^{-1}) Ardahanlioglu et al., (2003); Flowers and Flowers (2005) suggested that soils in arid and semi-arid regions are often characterised by high salt with high sodium contents.

Tables (5.16 and 5.17) show the low cations exchange capacity of the soil in all soils under study, and at all depths.

Table 5-16 Cation Exchange Capacity and Exchangeable Cations in the state farms.

Farm No.	Soil Type	Depth (cm)	CEC (cmol$_c$ kg^{-1})	Exchangeable Cations (cmol$_c$ kg^{-1})				ESP (%)	P (mg/kg)
				Ca^{2+}	Mg	Na$^+$	K$^+$		
68	Virgin Soil	0 -25	2.75	1.63	0.49	0.42	0.21	14.40	Trace
		26 -50	3.16	1.82	0.83	0.37	0.14	11.20	Trace
		51- 75	3.64	2.46	0.54	0.54	0.09	14.00	Trace
		75-100	3.75	2.54	0.38	0.76	0.06	20.80	Trace
	Irrigated Soil	0 -25	2.40	1.41	0.67	0.29	0.05	12.20	30
		26 -50	2.29	1.53	0.42	0.26	0.03	11.50	14.0
		51- 75	2.68	1.88	0.67	0.26	0.04	10.70	8.0
		75-100	2.06	1.40	0.42	0.21	0.04	8.80	Trace
78	Virgin soil	0 -25	2.93	1.80	0.29	0.61	0.23	21.20	Trace
		26 -50	3.04	1.92	0.39	0.58	0.15	18.80	Trace
		51- 75	3.15	1.93	0.50	0.56	0.15	18.40	Trace
		75-100	2.99	1.84	0.32	0.66	0.18	22.70	Trace
	Irrigated soil	0 -25	2.62	1.81	0.47	0.30	0.04	11.20	28.0
		26 -50	2.80	1.73	0.58	0.44	0.05	15.40	16.0
		51- 75	2.04	1.32	0.43	0.36	0.04	18.00	10.0
		75-100	2.45	1.46	0.50	0.44	0.05	18.80	5.0
107	Virgin soil	0 -25	3.09	2.07	0.62	0.31	0.10	10.00	Trace
		26 -50	2.80	1.91	0.47	0.32	0.10	11.30	Trace
		51- 75	2.42	1.47	0.53	0.33	0.10	13.50	Trace
		75-100	2.15	1.51	0.43	0.16	0.06	7.30	Trace
	Irrigated soil	0 -25	3.02	2.19	0.57	0.31	0.05	10.30	30.0
		26 -50	1.80	1.22	0.34	0.19	0.06	10.30	10.0
		51- 75	2.05	1.34	0.46	0.19	0.07	9.40	Trace
		75-100	2.00	1.30	0.38	0.19	0.13	9.00	Trace
115	Virgin soil	0 -25	2.48	1.69	0.38	0.34	0.09	13.50	Trace
		26 -50	2.60	1.60	0.40	0.52	0.08	20.20	Trace
		51- 75	2.57	1.63	0.39	0.48	0.07	18.30	Trace
		75-100	1.94	1.15	0.31	0.41	0.08	20.90	Trace
	Irrigated soil	0 -25	2.29	1.45	0.61	0.18	0.06	7.80	35.0
		26 -50	1.71	1.07	0.40	0.15	0.06	8.60	14.0
		51- 75	2.08	1.42	0.46	0.15	0.06	7.40	6.0
		75-100	2.24	1.55	0.46	0.30	0.05	8.40	Trace

Table 5-17 Cation Exchange Capacity and Exchangeable Cations in the private farms.

Farm no.	Soil type	Depth (cm)	CEC ($\text{cmol}_c\ \text{kg}^{-1}$)	Exchangeable Cations ($\text{cmol}_c\ \text{kg}^{-1}$)				ESP	P
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	(%)	(mg/kg)
1	Virgin soil	0 -25	2.95	1.58	0.58	0.65	0.13	23.20	0.4
		26 -50	3.20	1.80	0.58	0.71	0.11	23.43	0.4
		51- 75	2.88	1.94	0.33	0.51	0.10	17.73	Trace
		75-100	2.76	1.92	0.25	0.51	0.09	18.48	3.0
	Irrigated soil	0 -25	2.32	1.40	0.47	0.40	0.05	16.96	9.0
		26 -50	2.11	1.28	0.42	0.36	0.05	16.94	8.0
		51- 75	2.65	1.61	0.52	0.48	0.04	18.26	2.0
		75-100	3.65	2.25	0.68	0.68	0.05	18.72	Trace
2	Virgin soil	0 -25	2.67	1.32	0.68	0.60	0.07	22.89	Trace
		26 -50	2.35	1.22	0.58	0.17	0.04	22.57	Trace
		51- 75	2.50	1.44	0.39	0.61	0.06	25.41	Trace
		75-100	1.97	1.01	0.37	0.55	0.05	27.73	Trace
	Irrigated soil	0 -25	4.77	2.75	0.83	1.01	0.18	21.00	7.0
		26 -50	4.31	2.67	0.75	0.83	0.07	18.72	Trace
		51- 75	4.18	2.52	0.67	0.94	0.05	23.96	Trace
		75-100	4.47	2.73	0.75	0.96	0.03	22.49	Trace
3	Virgin soil	0 -25	4.99	2.85	1.04	0.59	0.51	11.83	0.4
		26 -50	4.75	3.00	0.53	0.83	0.39	17.38	Trace
		51- 75	4.80	2.96	0.54	0.89	0.40	18.62	Trace
		75-100	4.72	2.87	0.61	0.88	0.36	18.67	Trace
	Irrigated soil	0 -25	3.88	2.47	0.50	0.84	0.07	21.64	12.0
		26 -50	4.16	2.61	0.72	0.71	0.09	17.57	5.0
		51- 75	4.21	2.48	0.83	0.81	0.09	19.57	0.4
		75-100	3.96	2.18	0.89	0.83	0.06	21.16	Trace
4	Virgin soil	0 -25	3.11	1.82	0.56	0.58	0.15	18.88	Trace
		26 -50	3.04	1.78	0.52	0.55	0.18	17.61	Trace
		51- 75	3.13	1.76	0.63	0.61	0.13	19.58	Trace
		75-100	3.65	2.22	0.57	0.67	0.24	18.75	Trace
	Irrigated soil	0 -25	2.71	1.71	0.46	0.52	0.06	19.51	13.0
		26 -50	2.06	1.09	0.37	0.52	0.08	26.05	2.0
		51- 75	1.76	0.84	0.29	0.52	0.11	29.96	Trace
		75-100	2.03	1.08	0.29	0.52	0.06	26.29	Trace

Tables 5.16 and 5.17 show the small cation exchange capacity of the soil in all soils under study and at all depths. The cation exchange capacity was small in the study soil compared with California soil. Malcolm and Kennedy (1970) reported that the CEC of the sand and gravel ranged from 7 to 16 $\text{cmol}_c\text{kg}^{-1}$, and additionally mentioned that the values of positive exchange ions capacity depend on the soil texture, and its contents of organic matter.

The results in the tables also indicate that calcium was the dominant exchangeable cation in both virgin and irrigated soil profiles while potassium was the lowest. These results are similar to Barber, (1995); Robbins and Carter, (1983) who pointed out that calcium is the dominant exchangeable cation in many soils in arid and semi-arid, while potassium is less easily exchanged from other exchangeable cations.

5.4.1.3 Soil classification

Table 5.18 Indicates that virgin soils in the farms under study were classified according to the criteria of USDA classification (Richards, 1954) as saline-alkali soils, but for one of the state farms the ESP was less than 15%, and it was consequently classified as a saline soil.

Table 5-18 Classification of virgin soils under study, data averaged over depth of 0 -100 cm.

Location	EC (dS m^{-1})	ESP (%)	pH	Remarks
Farm 68	18.19	15.00	8.22	Saline alkali soil
Farm 78	24.83	20.25	7.95	Saline alkali soil
Farm 107	31.15	10.50	7.94	Saline soil
Farm 115	10.36	18.22	7.95	Saline alkali soil
Farm 1	29.17	20.70	8.70	Saline alkali soil
Farm 2	23.37	24.58	8.82	Saline alkali soil
Farm 3	32.71	16.63	8.40	Saline alkali soil
Farm 4	43.93	18.67	8.65	Saline alkali soil

Table 5.19 Indicates the classification of the irrigated soils under study, all of the soils of state farms were normal soils, while the soils of private farms were classified as saline-alkali soils.

Table 5-19 Classification of irrigated soils under study, data averaged over depth of 0 - 100 cm.

Location	EC (dS m^{-1})	ESP (%)	pH	Remarks
Farm 68	0.97	10.89	7.81	Normal soil
Farm 78	1.63	12.91	8.08	Normal soil
Farm 107	1.47	9.75	7.69	Normal soil
Farm 115	1.40	8.06	7.63	Normal soil
Farm 1	4.43	17.71	9.02	Saline alkali soil
Farm 2	15.27	21.54	9.07	Saline alkali soil
Farm 3	3.90	19.98	9.09	Saline alkali soil
Farm 4	4.32	25.45	8.45	Saline alkali soil

The results in table 5.19 indicate that the classification of soil irrigated of state farms were normal soil, while the irrigated soils of private farms as a virgin soil classified (no change happened), may be due to quality of irrigation water and irrigation method used.

5.4.1.4 Effect of Irrigation

Figures. 5.10 – 5.13 show the effect of depth on pH and EC and soluble cations and anions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-} and SO_4^{2-}), and $CaCO_3$% of virgin and irrigated soil of the study area,

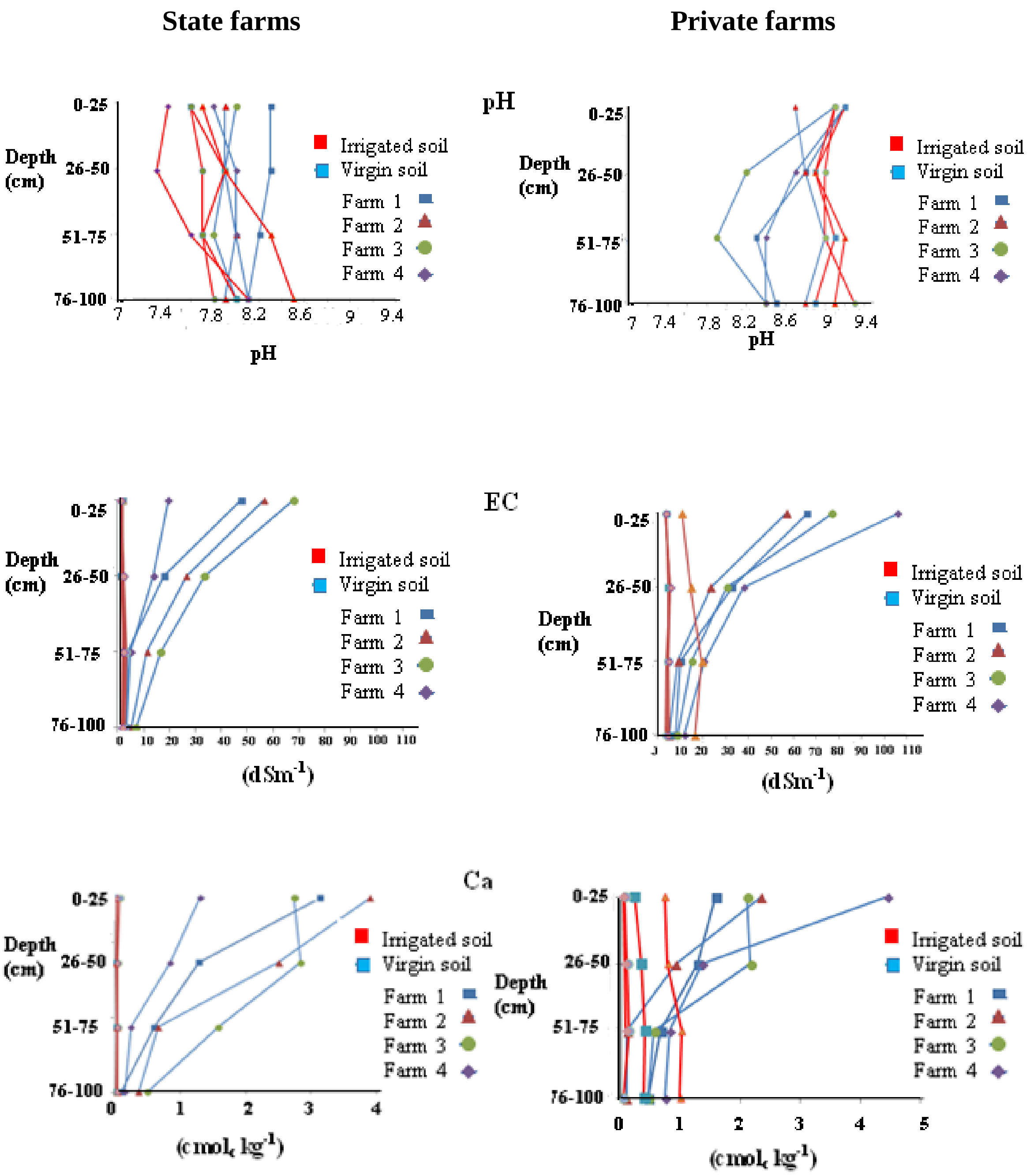


Figure 5—10 The effects of soil depth on the pH, EC and Ca^{2+} of virgin and irrigated soil from the state and private farms. (Average of 3 samples at each depth).

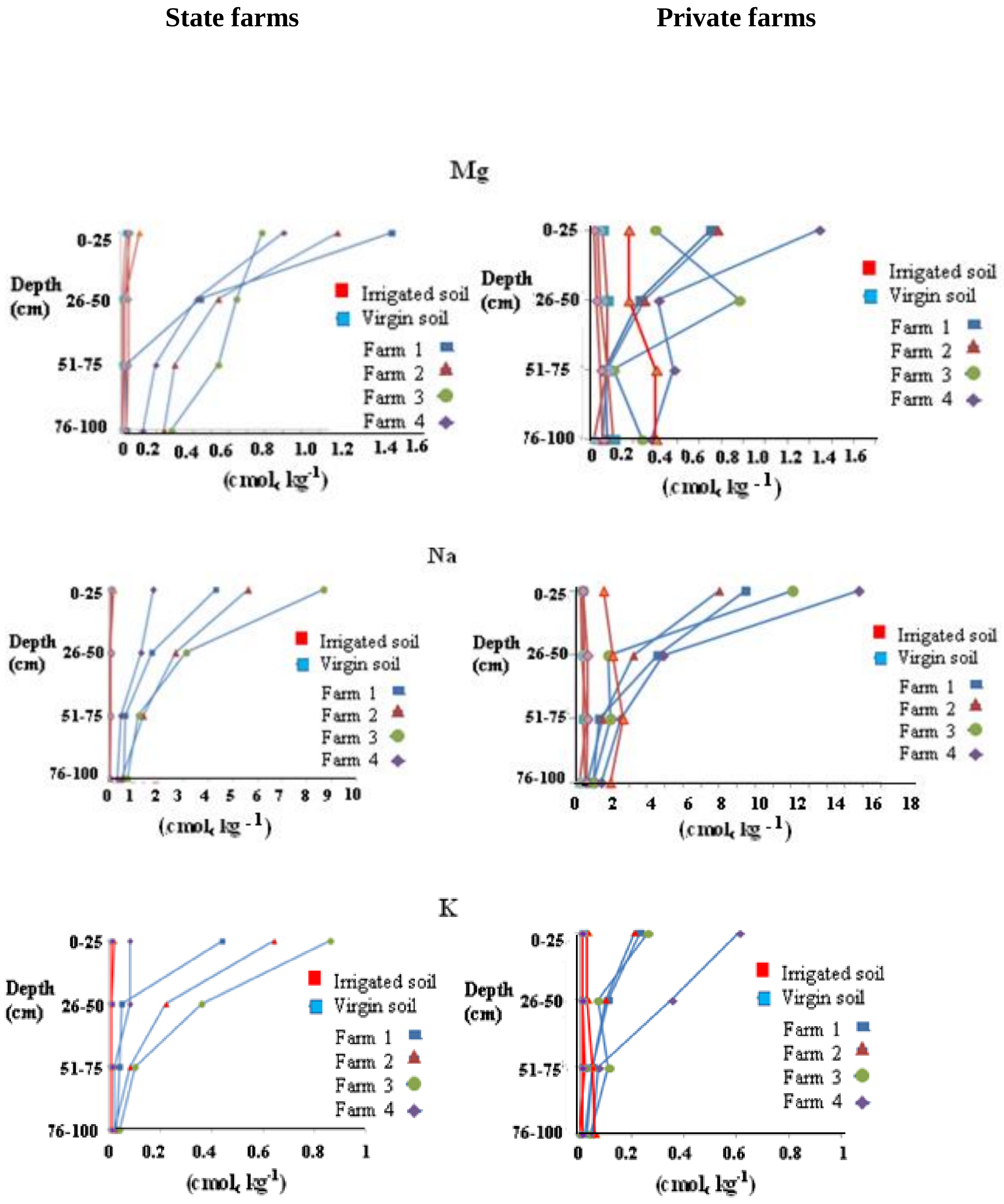
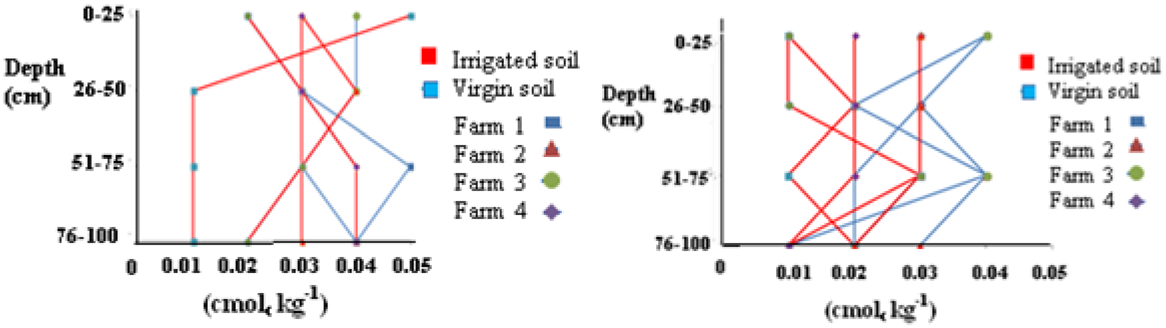


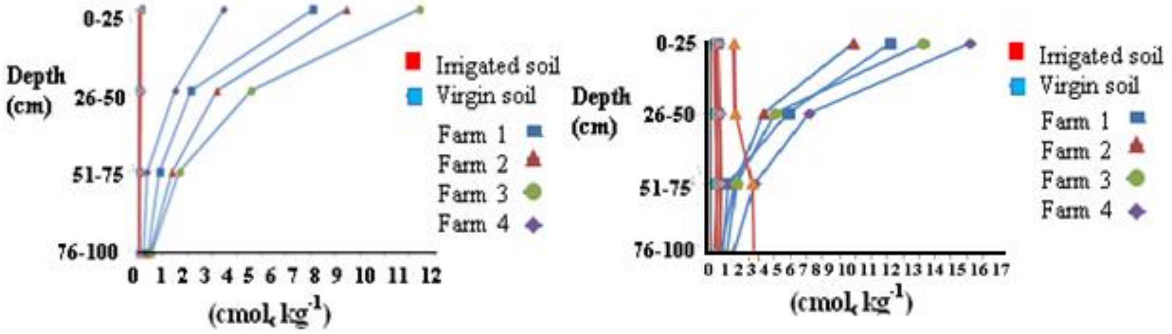
Figure 5—11 The effects of soil depth on the Mg^{2+}, Na^{+} and K^{+} of virgin and irrigated soil from the state and private farms. Average of three profiles.

State farms **Private farms**

HCO$_3$



Cl



SO$_4$

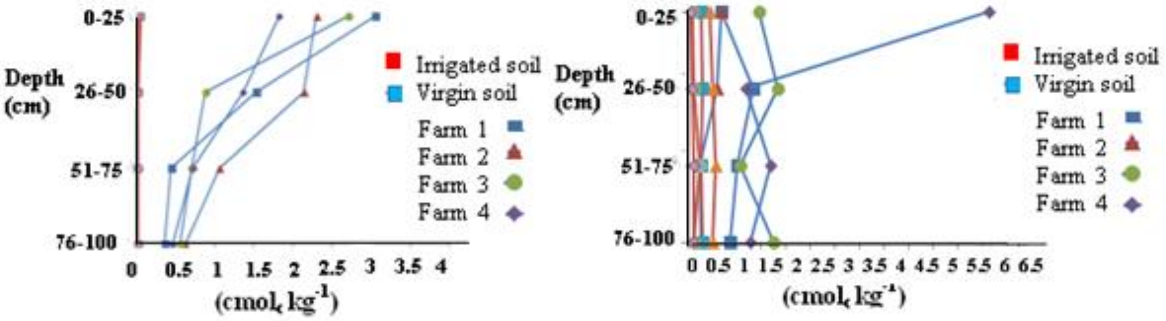


Figure 5—12 The effects of soil depth on the HCO$_3$, Cl$^-$ and SO$_4$ of virgin and irrigated soil from the state and private farms. Average of three profiles.

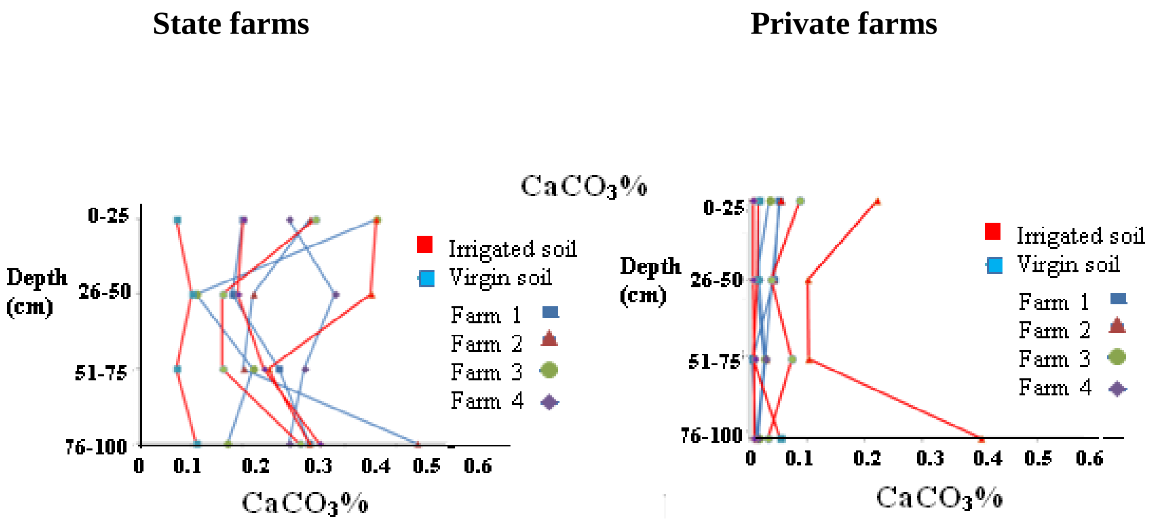


Figure 5—13 The effects of soil depth on the $CaCO_3$% of virgin and irrigated soil from the state and private farms. Average of three profiles.

Figures 5.10, 5.11 and 5.12 show a clear distinction between the virgin and irrigated soils in the state and private farms for the EC (dSm^{-1}) and soluble ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^- and SO_4^{2-} ($cmol_c\ kg^{-1}$) in the state farm soil profiles. In the virgin soil profiles these parameters showed a clear decrease with depth while in the irrigated soil profiles they were much lower in concentration and more uniform with depth. Figures 5.10, 5.12 and 5.13 show no distinction between irrigated and virgin soil profiles for pH, HCO_3^- and $CaCO_3$ for both the state and private farms.

Figures. 5.14 and 5.15 shows the effect of depth on Exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+, K^+ and ESP) of virgin and irrigated soil of the study area.

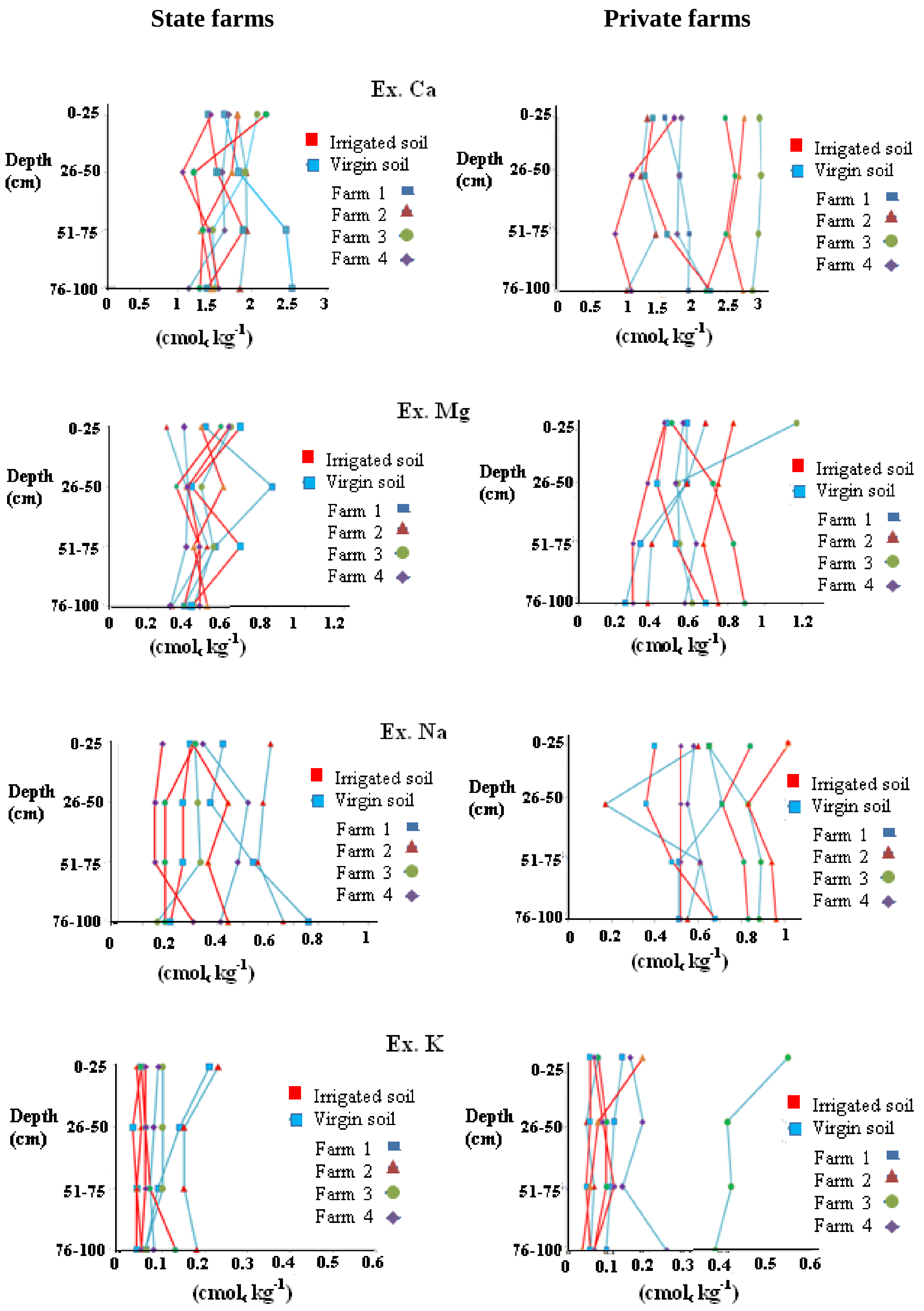


Figure 5—14 The effects of soil depth on the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) of virgin and irrigated soil from the state and private farms. Average of three profiles.

State farms **Private farms**

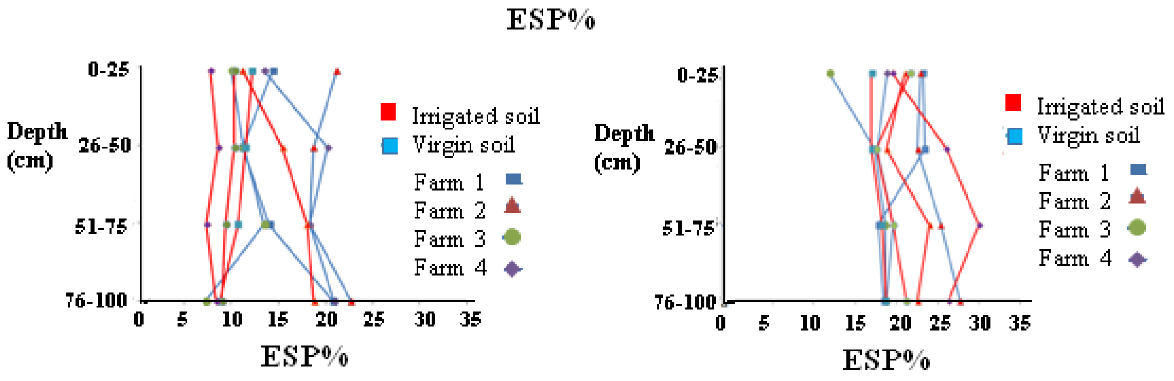


Figure 5—15 The effects of soil depth on the Exchangeable Sodium Percentage (ESP %) of virgin and irrigated soil from the state and private farms. Average of three profiles.

Calcium was the dominant exchangeable cation, in both virgin and irrigated soil profiles while potassium was the lowest.

There is no trend with depth values uniform down profile, also there was no clear difference between the virgin and irrigated soils in the profiles of any of the exchangeable cations (Na^+, K^+, Mg^{2+}, and Ca^{2+} ($cmol_c\ kg^{-1}$)) in the state or private farms. Figure 5.15 show no distinction between irrigated and virgin soil profiles exchangeable sodium percentage for both the state and private farms.

5.4.1.5 Statistical analysis

Table 5-20 Comparison of the means of all measured variables for soil profiles (averaged 0 - 100 cm) of virgin soils from state and private farms.

Parameters	**State farms Means**	**Private farms means**	***p*-value**
pH	8.01	8.6	* *
EC	21.1	32.3	NS
$CaCO_3$ %	0.28	0.24	NS
ESP%	16.03	20.2	**
Cations and Anions(cmol$_c$ kg^{-1})			
Ca^{2+}	1.42	1.26	NS
Mg^{2+}	0.51	0.34	NS
Na^+	2.19	4.35	NS
K^+	0.19	0.15	NS
HCO_3^-	0.03	0.03	NS
Cl^-	2.97	4.91	NS
SO_4^{2-}	1.22	1.38	NS
Exchangeable cations (cmol$_c$ kg^{-1})			
Ca^{2+}	1.81	1.96	**
Mg^{2+}	0.45	0.55	NS
Na^+	0.45	0.61	**
K^+	0.11	0.19	**

*** = $p \leq 0.05$;**= $p \leq 0.01$; ***= $p \leq 0.001$; NS = $p > 0.05$ pooled t -test**

Table 5-20 shows the profile (0-100 cm) mean values for the measured variables comparing the virgin soils from the state and private farms using a pooled t test. Most tests show no difference between the type of farm but there were significant differences for pH, ESP% and exchangeable cations (Ca^{2+}, Na^+, and K^+,). The mean values for these parameters were higher in private farms. The virgin soil of the study area is high in salinity and sodic (alkali).

Table 5-21 Comparison of the means of all measured variables for Top soil (0 – 25 cm) of virgin soils from state and private farms.

Parameters	State arms Means	Private farms means	*P*-value
pH	8.00	9.00	**
EC	47.8	76.3	NS
$CaCO_3$%	0.32	0.38	NS
ESP%	14.78	19.20	NS
Cations and Anions(cmol$_c$ kg^{-1})			
Ca^{2+}	2.77	1.56	NS
Mg^{2+}	1.1	0.5	*
Na^+	5.1	6.7	NS
K^+	0.51	0.22	NS
HCO_3^-	0.03	0.02	NS
Cl^-	7.6	7.4	NS
SO_4^{2-}	2.46	1.43	NS
Exchangeable cations (cmol$_c$ kg^{-1})			
Ca^{2+}	1.80	1.90	NS
Mg^{2+}	0.45	0.71	NS
Na^+	0.42	0.60	*
K^+	0.16	0.21	NS

*** = $p \leq 0.05$;**= $p \leq 0.01$; ***= $p \leq 0.001$; NS = $p > 0.05$ pooled t -test**

The results in Table 5-21 shows the same pattern when a comparison is made between the topsoils (0-25 cm), except that (ESP%, and exchangeable calcium and potassium) are not significantly different. However, there was significant difference for soluble magnesium.

Table 5-22 Comparison of the means of all measured variables for soil profiles (averaged 0 - 100 cm) of irrigated soils from state and private farms.

Parameters	**State farms Means**	**Private farms means**	***p-value***
pH	7.80	8.85	* *
EC	0.043	4.220	***
$CaCO_3$%	0.230	0.283	NS
ESP%	11.11	21.06	*
Cations and Anions(cmol$_c$ kg^{-1})			
Ca^{2+}	0.040	0.163	NS
Mg^{2+}	0.033	0.060	NS
Na^+	0.085	0.493	* *
K^+	0.018	0.0166	NS
HCO_3^-	0.038	0.027	*
Cl^-	0.063	0.400	* *
SO_4^{2-}	0.035	0.167	*
Exchangeable cations (cmol$_c$ kg^{-1})			
Ca^{2+}	1.51	1.75	NS
Mg^{2+}	0.495	0.54	NS
Na^+	0.268	0.60	*
K^+	0.058	0.070	NS

*** = $p \leq 0.05$;**= $p \leq 0.01$; ***= $p \leq 0.001$; NS = $p > 0.05$ pooled t -test**

Table 5-22 shows the profile (0-100 cm) mean values for the measured variables comparing the irrigated soils from the state and private farms using a pooled t test. Farm 2 was omitted from this test because its salinity and soluble ions were much higher than the other farms Overall, there were significant differences between the type of farm for pH, EC, ESP%, soluble ions (Na^+, HCO_3^-, Cl^-, and SO_4^{2-}), and exchangeable sodium. The mean values for these parameters were higher in private farms except for bicarbonate which was higher in state farms. The virgin soil of the study area is high in salinity and sodic (alkali).

There are different degrees of removal of salinity and alkalinity by the leaching of soil profile depending on the quality of the irrigation water. The soils of state farms were turned to normal (non-saline non-alkali) soils, due to irrigation with good quality water but leaching with the poor quality water available on the private farms was not sufficient to fully desalinise of the soils of private farms, which resulted in lack of uniformity in salts in the profile between the private farm soils. Mostazadeh-Fard et al., (2007) suggested that the leaching of the salts of soils depends on the quality and quantity of irrigation water.

Table 5-23 Comparison of the means of all measured variables for Top soil (0 – 25 cm) of irrigated soils from state and private farms.

Parameters	**State arms Means**	**Private farms means**	***p-value***
pH	7.58	8.88	**
EC	1.56	3.47	***
$CaCO_3$%	0.27	0.35	NS
ESP%	10.38	19.37	**
Cations and Anions($cmol_c\ kg^{-1}$)			
Ca^{2+}	0.043	0.11	NS
Mg^{2+}	0.055	0.04	NS
Na^{+}	0.105	0.40	**
K^{+}	0.013	0.017	NS
HCO_3^{-}	0.033	0.013	NS
Cl^{-}	0.073	0.33	**
SO_4^{2-}	0.045	0.13	NS
Exchangeable cations ($cmol_c\ kg^{-1}$)			
Ca^{2+}	1.72	1.86	NS
Mg^{2+}	0.58	0.48	NS
Na^{+}	0.27	0.59	*
K^{+}	0.051	0.06	NS

*** = $p \leq 0.05$;**= $p \leq 0.01$; ***= $p \leq 0.001$; NS = $p > 0.05$ pooled t -test**

The results in Table 5-23 show the same pattern when a comparison is made between the topsoils (0-25 cm), except that bicarbonate and sulphate are not significantly different.

5.4.2 Main soil survey

Table 5-24 Shows the chemical analysis of the topsoil (0 to 25 cm) samples from the state farms the first part of the table shows the data for the soils planted with alfalfa, while those planted with a variety of crops are in the second part of the table, the soils of these farms were in the normal range for pH, EC and ESP%, according to the standards established by the American Lands Classification (Richards, 1954).

Table 5-24 Results of soil analysis for state farms.

Farm No.	pH	EC (dSm^{-1})	Exchangeable cations (cmol$_c$ kg^{-1})				ESP (%)	Remarks
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
85	7.70	0.64	2.04	0.52	0.25	0.01	8.89	Normal soil
96	7.39	0.54	2.02	0.57	0.27	0.02	9.44	
102	7.82	0.96	1.78	0.59	0.25	0.02	9.54	
105	7.42	0.75	2.29	0.43	0.30	0.01	9.96	
62	7.42	0.75	1.71	0.52	0.29	0.01	11.51	
81	7.65	0.68	2.20	0.63	0.28	0.01	9.00	
37	7.63	0.55	2.30	0.70	0.25	0.02	7.67	
69	7.51	0.94	1.51	0.60	0.19	0.01	8.26	
126	7.84	0.81	2.27	0.62	0.31	0.01	9.68	
34	7.38	0.59	1.77	0.44	0.30	0.01	11.95	
48	7.64	0.87	2.36	0.60	0.30	0.02	9.20	
75	7.61	0.66	2.14	0.67	0.29	0.01	9.35	Normal soil
53	7.73	0.96	1.46	0.43	0.19	0.01	8.44	
62	7.69	0.63	2.22	0.65	0.26	0.01	8.31	
82	7.78	0.91	2.08	0.56	0.24	0.02	8.33	
37	7.46	0.53	2.40	0.65	0.25	0.02	7.59	
43	8.32	1.04	2.06	0.61	0.27	0.02	9.12	
51	7.81	0.95	2.28	0.44	0.26	0.02	8.72	
69	7.75	0.75	1.91	0.55	0.29	0.02	10.62	
27	7.31	0.58	2.41	0.48	0.28	0.02	8.81	

The results shown in Table 5-25 indicate the topsoil (0 to 25 cm) analysis of private farms and cultivated with alfalfa (Farms 1 to 10) and potato crops (farms 11 to 20). Only 15% were classified as normal soils with 5% of private farms classified as non-saline – alkali soils, 10% as saline - non alkali soil, and 70% saline alkali soil.

Table 5-25 Results of soil analysis of private farms.

Farm No.	pH	EC (dSm^{-1})	Exchangeable cations ($cmol_c\ kg^{-1}$)				ESP (%)	Remarks
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
5	9.1	6.4	1.42	0.52	0.49	0.01	20	Saline alkali soil
6	8.9	4.4	2.11	0.54	0.58	0.01	17.6	Saline alkali soil
7	8.8	4.1	2.34	0.47	0.48	0.02	14.8	Saline non alkali soil
8	9.2	2.8	2.69	0.52	0.47	0.02	12.8	Normal soil
9	8.9	3.1	2.12	0.48	0.50	0.02	16.1	Non saline alkali soil
10	8.7	4.2	2.62	0.54	0.74	0.02	19.0	Saline alkali soil
11	8.8	4.5	1.58	0.32	0.27	0.02	12.4	Saline non alkali soil
12	9.3	5.3	2.82	0.70	0.71	0.02	16.8	Saline alkali soil
13.	9.1	3.9	2.82	0.47	0.54	0.01	14.1	Normal soil
14	8.9	4.3	1.98	0.55	0.60	0.01	19.1	Saline alkali soil
5.	9.2	4.4	1.93	0.59	0.52	0.01	17.3	Saline alkali soil
6	9.0	4.2	2.04	0.61	0.47	0.01	15.1	Saline alkali soil
7	8.9	4.4	1.68	0.51	0.51	0.02	19.1	Saline alkali soil
8	9.3	5.2	2.11	0.61	0.49	0.02	15.3	Saline alkali soil
15	8.9	6.3	1.46	0.51	0.50	0.02	20.2	Saline alkali soil
16	8.7	4.2	1.80	0.61	0.49	0.02	16.9	Saline alkali soil
17	8.8	4.3	1.72	0.52	0.51	0.02	18.5	Saline alkali soil
18	8.5	4.0	2.02	0.69	0.50	0.02	16.1	Saline alkali soil
19	8.7	4.1	4.56	0.69	0.50	0.01	12.6	Saline non alkali
20	9.2	3.6	2.69	0.47	0.46	0.01	12. 7	Normal soil

Table 5-26 Comparison of the means of measured variables in all topsoil (0 – 25cm) samples in state and private irrigated soils.

Parameters	State farms means	Private farms means	*p- value*
pH	7.64	8.95	<0.001
EC	0.75	4.39	<0.001
ESP%	9.22	16.33	<0.001
Exchangeable cations ($cmol_c\ kg^{-1}$)			
Ca^{2+}	2.06	2.23	NS
Mg^{2+}	0.56	0.55	NS
Na^{+}	0.27	0.52	<0.001
K^{+}	0.02	0.02	NS

*** = $p \leq 0.05$;**= $p \leq 0.01$; ***= $p \leq 0.001$; NS = $p > 0.05$ pooled t -test**

Table 5-26 shows the topsoil (0 – 25 cm) means for the measured variables comparing the irrigated soil from the state and private farms using a pooled t test. Overall, there were highly significant differences (*p*<0.001) between the type of farm for pH, EC, ESP%, and exchangeable sodium. The mean values for these variables were higher in private farms.

Table 5-27 Comparison of the means of measured variables in all top soil for alfalfa cropped soils(0 - 25 cm) of state and private irrigated soils.

Parameters	**State farms means**	**Private farms means**	***p-value***
pH	7.58	8.98	<0.001
EC	0.74	4.30	<0.001
ESP%	9.55	16.27	<0.001
Exchangeable cations ($cmol_c\ kg^{-1}$)			
Ca^{2+}	2.02	2.25	NS
Mg^{2+}	0.57	0.51	NS
Na^{+}	0.27	0.54	<0.001
K^{+}	0.01	0.02	NS

*** = $p\leq$ 0.05;**= $p\leq$ 0.01; ***= $p\leq$ 0.001; NS = p>0.05 pooled t -test**

Table 5-27 shows the means for the measured variables in topsoils cultivated with alfalfa (0 – 25 cm) comparing the irrigated soil from the state and private farms using a pooled t test. Overall, there were highly significant differences (*p*<0.001) between the type of farm for pH, EC, ESP%, and exchangeable sodium. The mean values for these variables were higher in private farms. Overall, there were highly significant differences (*p*<0.001) between the type of farm for pH, EC, ESP%, and exchangeable sodium. The mean values for these variables were higher in private farms.

Table 5-28 Comparison of the means of measured variables in top soil (0 - 25 cm) for alfalfa crop and annual crop of state farms.

Parameters	**Alfalfa soil means**	**Annual crop means**	***p-value***
pH	7.58	7.72	NS
EC	0.74	0.78	NS
ESP%	9.55	8.81	NS
Exchangeable cations ($cmol_c\ kg^{-1}$)			
Ca	2.02	2.11	NS
Mg	0.57	0.56	NS
Na	0.27	0.26	NS
K	0.01	0.02	NS

Table 5-28 shows the topsoil cultivated with alfalfa and annual season crop (0 – 25 cm) mean for the measured variables comparing the irrigated soil from the state farms using a pooled t test. Overall, there was no significant affect of crop type on soil properties.

Table 5-29 Comparison of the means of measured variables in top soil (0 - 25 cm) for alfalfa crop and potatoes crop of private farms.

Parameters	**Alfalfa soil means**	**Potatoes soil means**	***p-value***
pH	8.98	8.92	NS
EC	4.30	4.47	NS
ESP%	16.27	16.38	NS
Exchangeable cations (cmol$_c$ kg^{-1})			
Ca	2.25	2.20	NS
Mg	0.51	0.58	NS
Na	0.54	0.50	NS
K	0.02	0.02	NS

Table 5-29 shows the topsoil cultivated with alfalfa and potatoes crop (0 – 25 cm) mean for the measured variables comparing the irrigated soil from the private farms using a pooled t test. Overall, there was no significant effect of crop type on soil properties.

The results in tables 5-28 and 5-29 show that there was no effect of plant species on soil chemical properties in the topsoils (depth 0 - 25 cm) on state and private farms using a pooled t test. Bezemer et al., (2006) found no effect of plant species on soil parameters.

5.4.2.1 The relationship between the parameters in the irrigation water and soil.

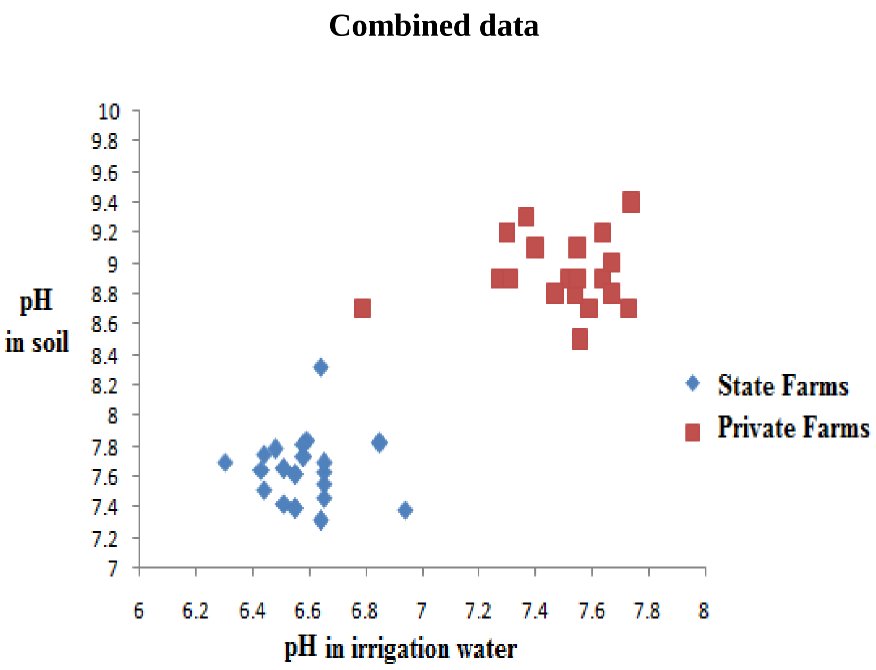


Figure 5—16 Relationship between irrigation water pH and soil pH with combined data of the state and private farms.

Figure 5-16 shows the relationship between irrigation water pH and soil pH in the state and private farms, two clusters point clear separately out state and private farms, however no trend. There is no correlation in the state or private farms.

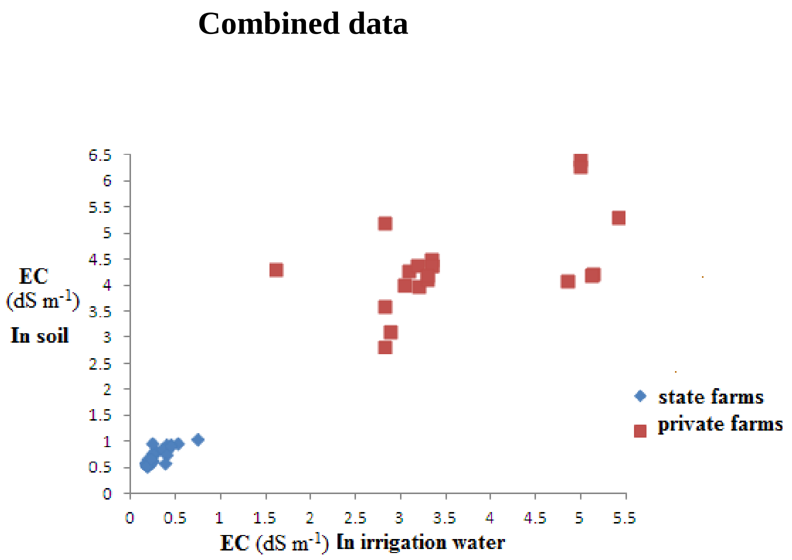


Figure 5—17 Relationship between EC dS m^{-1} in irrigation water and EC dS m^{-1} soil with combined data of the state and private farms.

Figure 5.17 shows the relationship between Electrical Conductivity (EC) in irrigation water, and EC in soil, in the state and private farms combined. There is a clear cluster of points for state farms, but the overall trend shows a significant correlation ($p<0.001$). Looking at the data of the private farms alone there is a significant positive correlation ($p<0.05$).

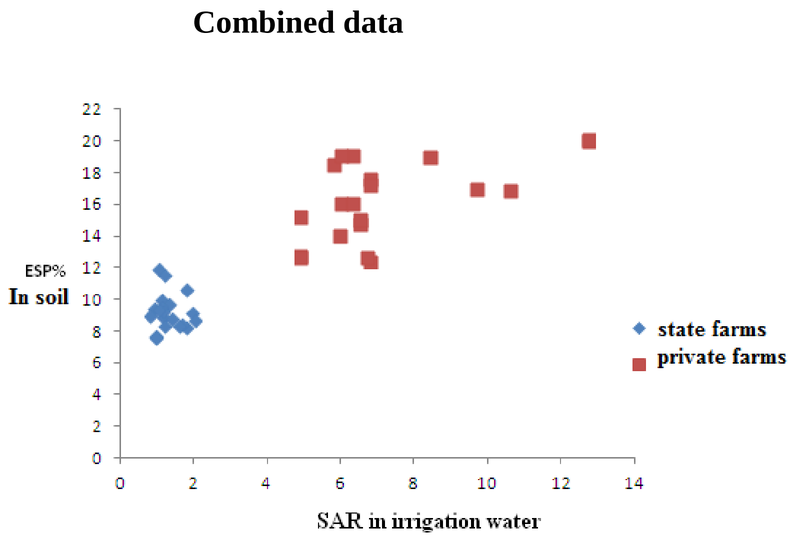


Figure 5—18 Relationship between SAR of irrigation water and ESP% of soil with combined data of the state and private farms.

Figure 5-18 show the relationship between Sodium Adsorption Ratio (SAR) in irrigation water, and Exchangeable Sodium Precentage (ESP%) in soil, in the state and private farms combined. There is a clear cluster of points for state farms, but the overall trend shows a significant correlation (p<0.001). Looking at the data of the private farms alone there is a significant positive correlation (p<0.05).

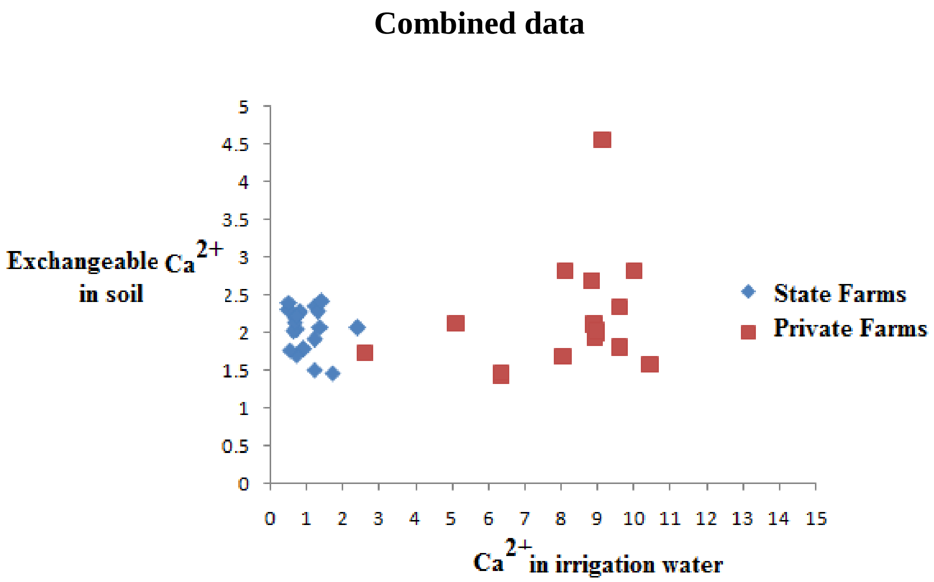


Figure 5—19 Relationship between soluble calcium in irrigation water and exchangeable calcium (Ca^{2+}) in soil with combined data of the state and private farms.

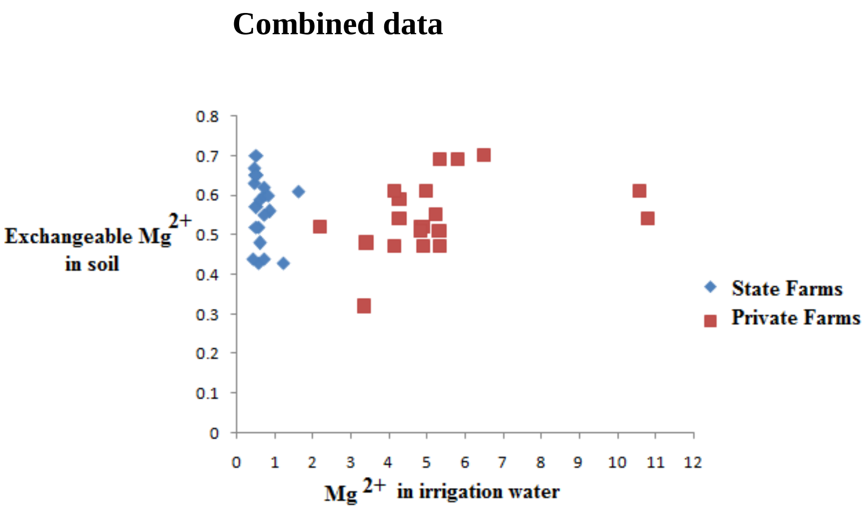


Figure 5—20 Relationship between soluble Magnesium in irrigation water and exchangeable Magnesium (Mg^{2+}) in soil with combined data of the state and private farms.

Figures 5.19 and 5.20 shows the relationship between soluble cations (Ca^{2+} and Mg^{2+}) in irrigation water and exchangeable cations (Ca^{2+}, and Mg^{2+}) in soil in the state and private farms. There was no significant correlation between the values in soil and water ($p > 0.05$)

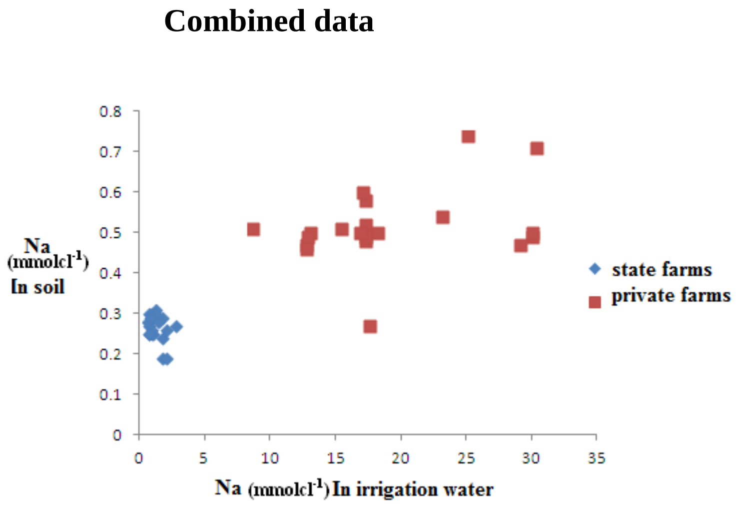


Figure 5—21 Relationship between soluble sodium in irrigation water and exchangeable sodium (Na^+) in soil with combined data of the state and private farms.

Figures 5.21 shows the relationship between soluble sodium (Na^+) in irrigation water, and exchangeable sodium in soil, in the state and private farms combined. There is a clear cluster of points for state farms, but the overall trend shows a significant correlation ($p < 0.001$). However, there is no significant correlation ($p > 0.05$) for the private farms.

The current study shows in Figures 5.16 to 5.21 a variation of the relationship between some parameters in soil and irrigation water, similar to the study by Endo et al., (2011) which confirmed that the correlation between the parameters in irrigation water and soil depend on the contents of anion concentrations in both soil and water. These results are in line with the findings in India by Paliwal and Gandhi (1976), who showed that the salinity and SAR of the irrigation water affects some parameters, and increases the percentage of sodium exchange in irrigated soils, because it contains a high percentage of sodium and other salts. It is also possible that inappropriate management of private farms plays a role, such as fertiliser type and irrigation methods.

In the present study, there was a high correlation between parameters in the irrigation water and the soil of state farms for electrical conductivity, while there was a low correlation in private farms. In contrast, there was no correlation for pH, A significant correlation between SAR and ESP in the irrigated soil of private farms may be due to the greater range of SAR values in the private well waters.

5.5 Conclusion

The results reported in this chapter show that the soil in the study area at a profile depth of 0-100 cm is a sandy soil. The virgin soils had high electrical conductivity (EC) and high Exchangeable Sodium Percentage (ESP %), so are classified as saline-alkali soils. The State farms which were irrigated with good quality irrigation water, had low EC < 2 dSm^{-1} and ESP% <15% so were classified as normal soils. However, the soils of private farms which were irrigated with poorer quality irrigation water, had lower EC although EC is still >4 dS m^{-1} and ESP> 15% so were classed as saline-alkali soils.

In the virgin soils EC, soluble ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, and SO_4^{2-}) but not pH, HCO_3^- and $CaCO_3$ show a clear trend of high values at the surface, falling with depth in the profile. In the irrigated soil profiles of the state farms all parameters were much lower in concentration and more uniform with depth, except for pH, HCO_3^- and $CaCO_3$ which were less uniform.   In the irrigated soil profiles of the private farms, all parameters were lower than the virgin soils but higher than state farm soils, and also uniform with a profile depth except for pH, HCO_3^- and $CaCO_3$ where there was no distinction with virgin soils and irrigated soils. Farm 2 had higher values of salinity and soluble salts but they were uniform with depth.

Calcium was the dominant exchangeable cation in both virgin and irrigated soil profiles, while potassium was the lowest. There was no trend with depth, values were uniform down profile. There was no clear difference between the virgin and irrigated soils in the profiles of any of the exchangeable cations (Na^{+}, K^{+}, Mg^{2+}, and Ca^{2+}) or exchangeable sodium percentage.

The soil profile (0-100 cm) mean values for the measured variables in the virgin soils from the state and private farms were comparing using a pooled t test. There were significant differences between the type of farm for pH and, ESP%, exchangeable cations (Ca^{2+}, Na^{+}, and K^+). The mean values for these parameters were higher in private farms. The same pattern is seen when a comparison is made between the topsoils (0-25 cm), except that (ESP%, and exchangeable calcium and potassium) are not significantly different. However, there was significant difference for soluble magnesium.

The soil profile (0-100 cm) mean values for the measured variables in the irrigated soils from the state and private farms were compared using a pooled t test. There were significant differences between the type of farm for pH, EC, ESP%, soluble ions (Na^+, HCO_3^-, Cl^-, and SO_4^{2-}), and exchangeable sodium. Values were higher in private farms except for bicarbonate which was higher in the state farms. The same pattern is seen when a comparison is made between the topsoils (0-25 cm), except that bicarbonate and sulphate are not significantly different. This difference between irrigated soils of private and state farms is probably related to irrigation water quality.

It was decided to extend the survey to see if these differences between state irrigated soils and private irrigated soil are found over the wider Kufra area.

As the topsoils of irrigated soils gave similar results to whole profile it was decided to limit soil sampling to top 25 cm. It was decided to samples soil and water from 10 private farms spread over 3 regions (Al-Jawf, Al-Zawraq and Hawari) and 10 state farms over all 5 agricultural units and to compare soils growing perennial and annual crops making 40 sites in total.

The soils of the 20 state farms were in the normal soil range for EC (<2) and ESP %(< 15), according to USDA classification. For the soils of the 20 private farms 15% were classified as normal soils, with 5% of private farms classified as non-saline – alkali soils, 10% as saline - non alkali soil, and 70% saline alkali soils.

The topsoil (0 – 25 cm) means for the measured variables of the irrigated soils from the state and private farms were compared using a pooled t test. Overall, there were highly significant differences, the private farms were significantly higher than the state farms ($p<0.001$) for pH, EC, ESP%, and exchangeable sodium, while the exchangeable cations (Ca^{2+}, Mg^{2+}, and K^+), were not significantly different.

There was no significant effect of crop type (perennial and annual crops) in the soils of state or private farms.

The relationship between Electrical Conductivity (EC) in irrigation water, and EC in soil, in both state and private farms showed a clear clusters of points for the state farms but , overall a positive trend with a highly significant correlation ($p<0.001$). Also, these two variables had a high positive correlation for the state farms ($p<0.001$), and low positive correlation relation ($p<0.05$) for the private farms when tested separately.

For the relationship between Sodium Adsorption Ratio (SAR) in irrigation water, and Exchangeable Sodium Percentage (ESP%) in soil, in state and private farms, there was also a cluster of points representing the state farms, but a general trend is a visible with highly significant correlation ($p<0.001$). These variables have no correlation within the state farms, and a low positive correlation ($p< 0.05$) within the private farms.

There was a relationship between soluble sodium (Na^+) in irrigation water, and exchangeable sodium in soil, in the state and private farms combined. There was a distinct cluster of points for the state farms but a trend was visible with highly significant correlation ($p <0.001$). However, these variables had no correlation between the values in soil and water ($p >0.05$) when examining the state and private farms sparely.

There was no correlation between soluble cations (Ca^{2+} and Mg^{2+}) in irrigation water, and exchangeable cations (Ca^{2+} and Mg^{2+}) in soil, in the state and private farms. ($p>0.05$).

Chapter 6 Crop Yield

6.1 Summary

This study was conducted to evaluate the effects of irrigation water and soil quality on the plant production of two types of crops; alfalfa (*Medicago sativa L.* Tajureia), as one of the main crops grown in the Kufra area, and the potato crop *(Solanum tuberosum L.* Spunta), and to compare yields between the state and private farms.

For the alfalfa crop in the state farms, 17 fields cultivated with alfalfa were identified and 10 of these were selected at random from the list, see chapter 5 section 5.3.2.1. The samples from 10 private farms (chosen randomly from the list of farmers' names from the Ministry of Agriculture were collected in the ratio 4, 3 and 3 for the three regions of the study area (Al-Jawf, Al-Zawriq and Hawari). The area from which the sample was taken covered 10 m^2 (2 x 5 m) see chapter 5 section 5.3.2.2. The dry matter yield of alfalfa was evaluated and the average harvested was respectively 6.3 t/ha for the state farms and 3.1 t/ha for the private farms. The comparison between private and state farms was made using a pooled t-test, and there was a highly significant difference (DF=18, T= 8.8, $p<0.001$) for alfalfa crop yield.

The alfalfa crop age had a highly significant positive effect on yield in the state farms using linear regression (DF=1, F= 32.89, $p<0.001$) and a highly significant negative effect (DF=1, F= -119.82, $p<0.001$) in the private farms. The coefficient of determination (R^2) shows that 80% - 94% of yield variability was explained by crop age. Alfalfa yields were not correlated with any measure of soil or water chemistry in either state or private farms.

No potatoes were grown on the state farms in the winter season 2013 when the samples were collected, so historical data has been used. The long term average yield of potatoes is 40.04 t/ha in the state farms. For the potato crop 10 private farms were selected randomly from the list of farmers' names of three main agricultural regions see chapter 5 section 5.3.2.2. The area per site was a 5 m length of a single row representing an area of 5 x 0.6 m (3 m^2). All tubers were collected and weighed to calculate the total fresh yield. The total crop yield t/ha was assessed showing an average of 23 t/ha. The comparison between private and state farms was made using a t-test based on pre-existing yield data (average 40 t/ha) for the state farms. There was a highly significant (DF=9, T=8.7, $p<0.001$) greater yield in the state farms. The relationship between the yield crop with the soil and water quality parameters in the private farms was not significant. No similar comparison was possible for state farms.

While yields of both crops differ greatly between private and state farms and between the private farms this cannot be explained by soil or water chemistry. Other farming practices such as fertiliser use may be more important at present and as a result the apparently poor standard of irrigation water quality in private farms does not appear to be the factor limiting production. The alfalfa yields in the private farms were strongly correlated to age. The highest yields were observed in the third year (4.47 t/ha) followed by a steady decline (1.95 t/ha) by year 7. Therefore the Ministry of Agriculture should set up a more extensive survey of alfalfa yields in the private farms examining a greater range of crop ages. If the findings of the current study are shown to be correct private farmers should be advised to replant or rotate alfalfa more frequently to get better crop production.

6.2 Introduction

In some parts of the world, and for more than 300 years, salinity has represented a real threat to agriculture. In recent times the threat has increased, with the steady growth of the world's population. Therefore, it is fundamental to increase the area of cultivated land, and increase crop production under conditions of high salinity (Flowers, 2006).

The current study assesses two crops in the state and private farms, in the state farms of the Kufra Agricultural Project (KAP) soils are irrigated with good quality water and under adequate supervision in terms of such agricultural operations as fertilisation, tillage, control of weeds and of harmful insects, and have recorded excellent crop yields (Zaid, 2005). On the other hand, in the private farms, where most people rely predominantly on agriculture as their primary economic activity, cultivation is based on grain (cereals), alfalfa, forages (cereals and legumes mixed), palm trees, and some fruits and vegetables (potatoes, tomatoes, onions, and garlic). In the Kufra region there are 2124 private farms distributed in three areas (Ebrik, 1981). These farms are irrigated using water from shallow wells. The shallow water wells have the highest salinity (chapter 4). Both the poorer water (chapter 4), according to the FAO classification 98% considered unsatisfactory for irrigation purposes under ordinary condition. The bad soil (chapter 5) according to USDA classification were 100% saline alkaline. These water and soils are classed as potentially posing a salinity/alkalinity risk.

These circumstances may affect productivity in general, and crops that are not salt-tolerant in particular. This study investigates if salinity in irrigation water or soil affects yields in the Kufra region and compares yields on the private farms with state farms yields where irrigation is with good quality water and the soils classed as normal.

Good management practices are needed to improve farmers' traditional methods and water use. Various studies have reported significant increases in crop yields following good management, including studies under saline conditions (Batra, 1990; Ayars et al., 1991; Parabhakar et al., 1991; Minhas, 1996; Bustan et al., 2004; Zhang et al., 2004; Malash et al., 2005; Jalota et al., 2006; Ali et al., 2007; Nagaz et al., 2007a and Nagaz et al., 2007b).

Alfalfa (*Medicago sativa L.*) is not only an indispensable crop for cattle foodstuff in particular (especially dairy cattle) but it is equally vital to feed other types of animals (camels and horses). The harvest potential of alfalfa is very high in comparison with other forage crops (Michaud et al., 1988). It represents a fundamental element of numerous crop rotations due to its capacity of fixing nitrogen, its role in the improvement of the structure of soils and tilth, and in the control weeds in succeeding crops (El-Bassam, 2013). Furthermore, alfalfa is the most widespread and important fodder crop grown worldwide (Michaud et al., 1988).

Under favourable conditions alfalfa, as a perennial crop, is able to produce dry matter during the whole year. Throughout the best growth period (i.e. from spring to autumn), alfalfa response to water application shows an increase of production with increasing quantity of irrigation water (Bauder et al., 1978; Sammis 1981).

Researchers such as Teixeira et al., (2007) observed that it is both the climatic conditions coupled with an appropriate management which determine how many times a year alfalfa can be harvested. The environmental diversity and the types of soil where alfalfa grows means reported yields range from below 1 t/ha per time dry matter in rain fed systems, to over 28 t/ha per year in well-watered deep silt loam soils in New Zealand (Brown et al., 2005). A comparable maximum harvest has been observed on the African continent, with yields of 10 to 20 t/h dry matter per year. In Europe, China and North America under irrigated conditions, yields of 5 to 17 t/h dry matter have been reported. Both the management and the location affect the productivity and persistence of alfalfa with a decline in plant population expected 4 to 5 years after planting (FAO, 2012).

As for the potato (*Solanum tuberosum L.*) crop world production is 329 million tonne on 18.6 million ha). It has been estimated that 44 % and 37 % of the world's production of the potato crops are respectively produced in Asia and in Europe. In the last two decades a fast increase of potato production has occurred in African and Asian developing countries, where production has more than doubled (FAO, 2011).

The potato crop requires in particular a cool climate. It is extensively cultivated in moderate, subtropical, arid and semi-arid environments (Haverkort and Verhagen, 2008). The crop season is short (90 -110 days). In terms of the management of potato production, either in Europe or in America, it is common to use intensive agricultural practices, such as fertilisation, the use of pesticides, or irrigation management (FAO, 2011).

6.2.1 Crops and salinity tolerance

Alfalfa plants, when subjected to salinity, are smaller and a darker bluish-green in colour than those grown under non-saline conditions. This becomes more evident with increasing salinity. Furthermore, alfalfa is extremely sensitive to salt concentration in the upper portion of the soil profile (Francois, 1981). Stone et al. (1979) and Lehman and Robinson (1979) mentioned that alfalfa is susceptible to salt damage during its cultivation. Assadian and Miyamoto (1987) reported that alfalfa germination is greatly reduced if the available irrigation water has a salt concentration > 4 dSm^{-1}. Carlson et al. (1983) found that with increasing salt concentration in soil, especially NaCl, the germination percentage of alfalfa seeds decreased. Hernandez (2013) observed that growth of alfalfa was affected more by the concentration of sodium in the soil than by any other single variable, when all independent variables were considered.

Potatoes are amongst the world's main food crops and demand is increasing at a greater rate than many other food crops (Lyons et al., 1995). The potential use of saline water from local wells on salty soil for potato production is of great importance due to the acute shortage of fresh water in many regions of the world and may have significant practical consequences to farmers (Shainberg and Singer, 1990).

Saline water is often used in potato crop production in districts where only saline water and salty soil are available. Several of these areas are located in semi-arid and arid zones, such as the Mediterranean region (Ondarza, 1982), Australia, China and Japan (Walker, 1982 and Somers 1982), the deserts of South America (Cordoba and Costa, 1982), and many parts of Asia such as Pakistan, India and Bangladesh (Chapman, 1982). The use of saline water for crop yield is often inevitable. This, in turn, requires the screening of crop plants and varieties for their tolerance to salinity. Potatoes are classified as moderately salt-sensitive (Ahmad and Abdullah, 1979; Maas and Hoffman, 1977) and as very sensitive to water stress (Harris, 1978).

Table 6.1 gives the expected yield reduction (in terms of percentage) of some crops for various levels of soil salinity as measured by soil EC under normal growing conditions, and Table 6.2 gives the potential yield reduction due to irrigation water salinity levels. Generally forage crops are the most resistant to salinity, followed by field crops, and fruit crops, which are generally the most sensitive.

Table 6-1 Soil salinity tolerance levels for a variety of crops.

(Adapted from Ayers and Westcot, 1976)

Crop	**Yield potential EC (dSm^{-1}) soil root zone**				**Maximum EC(dSm^{-1})**
	100%	90%	75%	50%	
Field crops					
Barley	8.0	10.0	13.0	18.0	28
Wheat	6.0	7.4	9.5	13.0	20
Vegetable crops					
Bean	1.0	1.5	2.3	3.6	7
Carrot	1.0	1.7	2.8	4.6	8
Cucumber	2.5	3.3	4.4	6.3	10
Onion	1.2	1.8	2.8	4.3	8
Pepper	1.5	2.2	3.3	5.1	9
Potato	1.7	2.5	3.8	5.9	10
Radish	1.2	2.0	3.1	5.0	9
Sweet potato	1.5	2.4	3.8	6.0	11
Tomato	2.5	3.5	5.0	7.6	13
Forage crops					
Alfalfa	2.0	3.4	5.4	8.8	16
Barely hay	6.0	7.4	9.5	13.0	20
Wheat grass	7.5	9.0	11.0	15.0	22

Table 6-2 Irrigation water salinity tolerance for various crops.

(Adapted from Ayers and westcot, 1976)

Crop	**Yield potential EC (dSm^{-1}) of irrigation water**			
	100%	90%	75%	50%
Field crops				
Barley	5.0	6.7	8.7	12.0
Wheat	4.0	4.9	6.4	8.7
Vegetable crops				
Bean	0.7	1.0	1.5	2.4

6.2.2 Aims for this chapter

The specific objectives of the study are to:
1- Evaluate the yield of alfalfa and potatoes in the state and private farms.

2- Evaluate the relationship between crop yield, and parameters for irrigation water and soil quality.

6.3 Methodology

The plant yield samples were taken from the same area as the soil specimens see section 5.3.2.1-2 of the soil chapter, the method for the selection of sites is based on the type of crop. In this instance, samples were collected in December (from the 2th to the 31st of December 2013, which is the winter season in Libya). The winter crops grown within the study area are alfalfa, potatoes, cereals, forage (cereals and legumes mixed) and vegetables. The plan was to collect 10 samples from alfalfa crops and 10 samples from potato crops from both state farms and private farms. No potatoes were grown on the state farms in winter season 2013, so past seasons data have been used.

6.3.1 Plant samples

Alfalfa (*Medicago sativa L.*)

Alfalfa variety Tajuria was typically sown in 15 cm rows at a depth of 2 cm and at a seed rate of 25-27 kg ha^{-1}. Harvesting was carried out when the plants reached 10% flowering stage. At each farm, three sites were chosen from the alfalfa-cultivated area as described in section 5.3.2.1 of chapter 5. The area harvested represented 2 m x 5 m (10 m^2) for each site for all private and state farms.

The total material harvested was weighed on the farm and a small subsample (approximately 100g) of fresh material was taken then weighed then dried for 24 hours at 105^{0}C, and was re-weighed dry, and the dry matter percentage calculated.

$$\text{dry matter } \% = \frac{100\,(B - C)}{(A - C)}$$

Where
A = is the mass of the container with sample before drying.
B = is the mass of the container with sample after drying.
C = is the mass of the empty container.

Potatoes (*Solanum tuberasum L.*)

These are planted in state farms in 60 cm rows, at seeding rate of 3 t/ha of spunta variety and the same method is followed on the private farms. Maturation of the crop (i.e. the leaves start yellowing), usually occurs around 100 days from planting, depending on the conditions of the study area in both state and private farms, because the same source for seeds is used. At maturation, three sites were randomly selected from the planted area to represent the whole area as described in section 5.3.2.2 of chapter 5. The area per site was a 5 m length of a single row representing an area of 5 m x 0.6 m (3 m^2). All tubers were collected and weighed to calculate the total fresh yield.

6.4 Results and Discussion

6.4.1 Alfalfa

Table 6-3 Harvest results of Alfalfa from state farms.

Farms No	Agricultural. Units	Moisture (%)	Fresh yield (t/ha)	Dry yield (t/ha)
69	B	79.36	22.87	4.72
105	A	73.99	24.43	6.35
85	A	79.64	27.61	5.62
34	E	75.79	29.13	7.05
126	D	73.54	25.86	6.84
96	A	68.99	23.36	7.24
62	B	76.66	28.12	6.56
102	B	72.59	26.77	7.35
81	C	75.02	25.69	6.42
37	C	81.42	26.94	5.01

Table 6-4 Harvest results of Alfalfa from private farms.

Farms No	Area	Moisture (%)	Fresh yield (t/ha)	Dry yield (t/ha)
5	1	73.33	13.06	3.48
6	1	74.91	13.00	3.26
7	3	81.04	15.11	2.86
8	3	78.23	20.12	4.47
9	3	80.41	16.21	3.17
10	1	71.88	11.61	2.93
11	1	75.39	14.36	3.53
12	2	79.94	9.72	1.95
13	2	77.55	12.80	2.87
14	2	77.45	9.25	2.08

Tables 6.3 and 6.4 show the productivity of the alfalfa crop (dry matter t/ha) in the state and private farms. In the state farms yields ranged between 4.72 and 7.35 t/ha, while in the private farms they ranged between 1.95 and 4.47 t/ha. There is variability on both state and private farms despite the uniform management in the state farms, though not in the private farms. Possibly this is an effect of age or declining plant cover / population. Patchiness was seen in some crops of private farms when sampling.

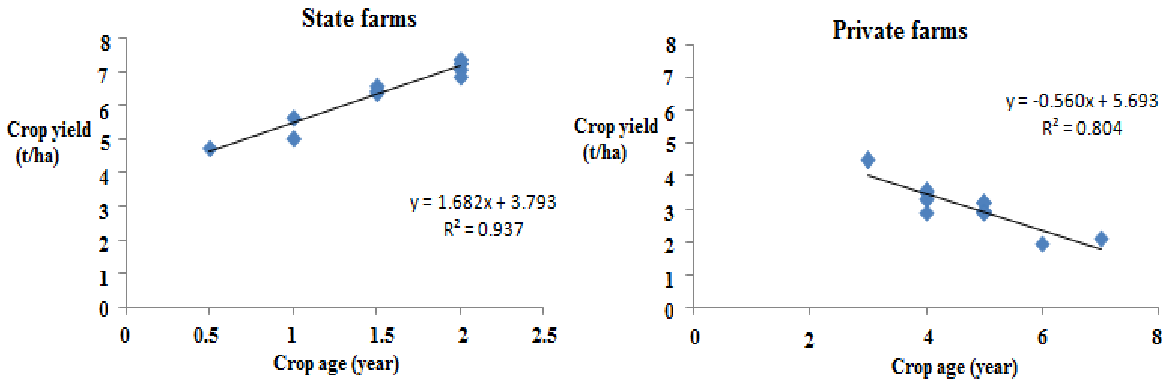


Figure 6—1 Relationship between crop age in land and dry matter yield in the state and private farms.

Figure 6.1 shows that crop age had a highly positive effect on yield in the state farms using linear regression (DF=1, F= 32.89, $p<0.001$) and a highly negative effect (DF=1, F= -119.82, $p<0.001$) in the private farms. The coefficient of determination (R^2) shows that 80% - 94% of yield variability was explained by crop age.

Jefferson and Cutforth, (1997) Using a historical database of yields from 1951 to 1994 showed that yields were highest in the first two years and in later years there was a slightly lower yield but no downwards trend was visible within the variability.

Li and Huang, (2008) compared a single continuous crop with short rotations. The yield in years 1-8 were variable from year to year but there was no trend in yield, while in years 8-16 there was a drop in yield and poorer yields were obtained compared to the short rotation. This was attributed to water stress in a rainfed system due to soil compaction.

In contrast Undersander et al., (2011) from the Department of Agronomy, University of Wisconsin report that the yield of alfalfa is highest in years 2-3 followed by a steady decline to 40-50% by year 7.

For alfalfa cultivation in Egypt and Saudi Arabia, average production is estimated at 10 t/ha of green (fresh matter) alfalfa per cut in Egypt (Osman and Ibrahim, 1990), while was it 16.3 and 16.6 t/ha in two years in Saudi Arabia (Al-Suhaibani, 2010). These values are much lower than the yields recorded in state farms of Kufra (there would be 8 cuts per year in Kufra).

Table 6.5 shows the mean values measured for dry yield of Alfalfa from state and private farms compared using a pooled t-test. There is a highly significantly greater yield in the state farms but this could be due to the difference in crop age.

Table 6-5 Comparison of the means of measured variable for state and private farms.

Variable	**State farm**	**Private farm**	**t- value**	***p-value***
Dry yield	6.32	3.06	8.82	<0.001

Linear regression shows that 80%-94% of the variability in the yield is due to age therefore, it is unlikely for there to be much an effect of water or soil quality parameters, and Figures 6.2 and 6.3 shows the relationship between alfalfa yield and parameters of water and soil quality.

Table 6-6 Relationship between Alfalfa yield and water and soil parameters in private farms

Correlation water parameters with alfalfa yield (t/h)	**Pearson correlation r**	**P- value**
pH	0.287	0.422
EC	0.289	0.418
SAR	0.348	0.324
Correlation soil parameters with alfalfa yield (t/h)		
pH	0.176	0.628
EC	0.508	0.134
ESP	-0.045	0.902

Table **6 – 6** shows the relationship between alfalfa yield and parameters (pH, EC, and SAR in irrigation water and pH, EC,and ESP in soil) in the private farms. There are no significant correlations with yield for all parameters.

Relationship between Alfalfa yield and water and soils parameters in state and private farms

Irrigation water

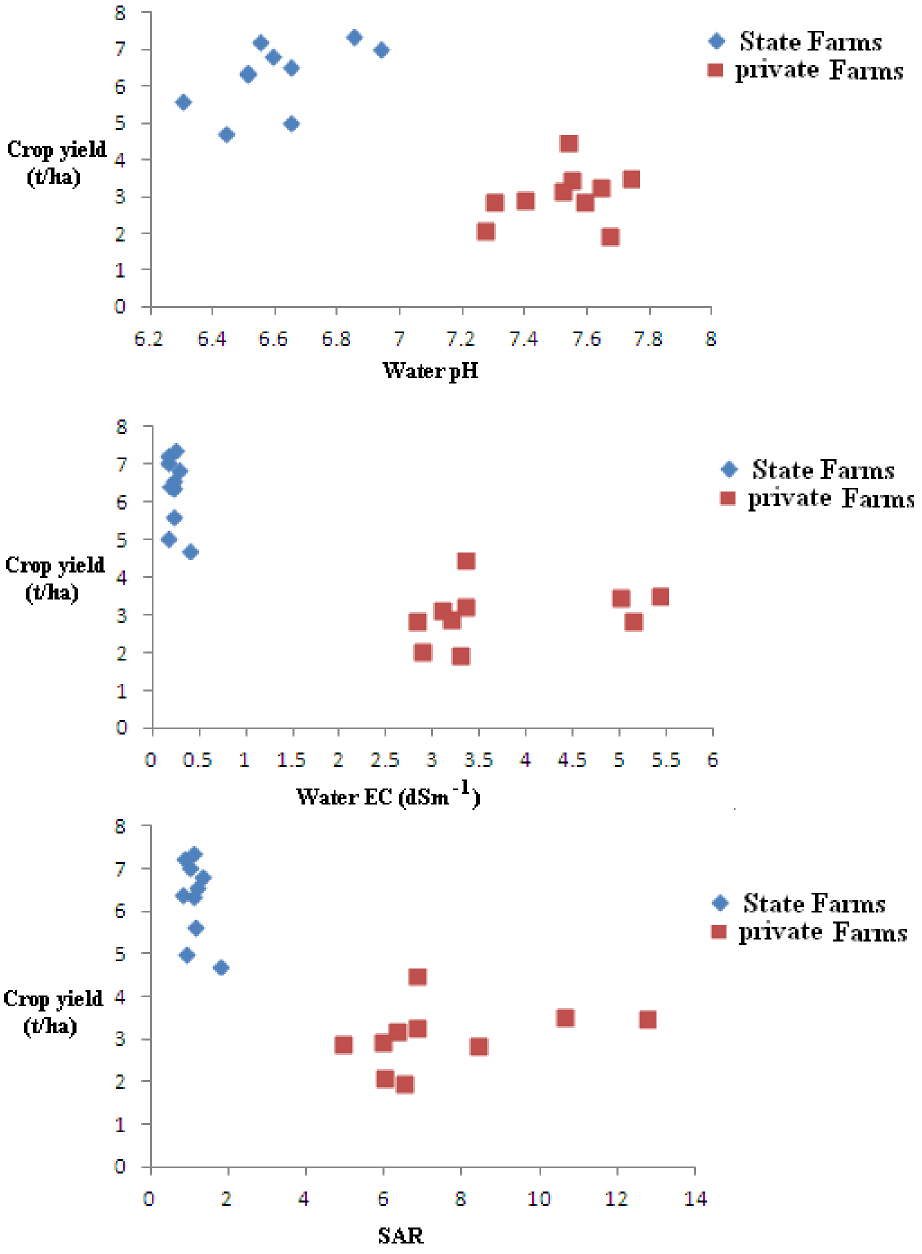


Figure 6—2 Relationship between Alfalfa yield (t/ha) and parameters of water with combined data of the state and private farms.

Soil parameters

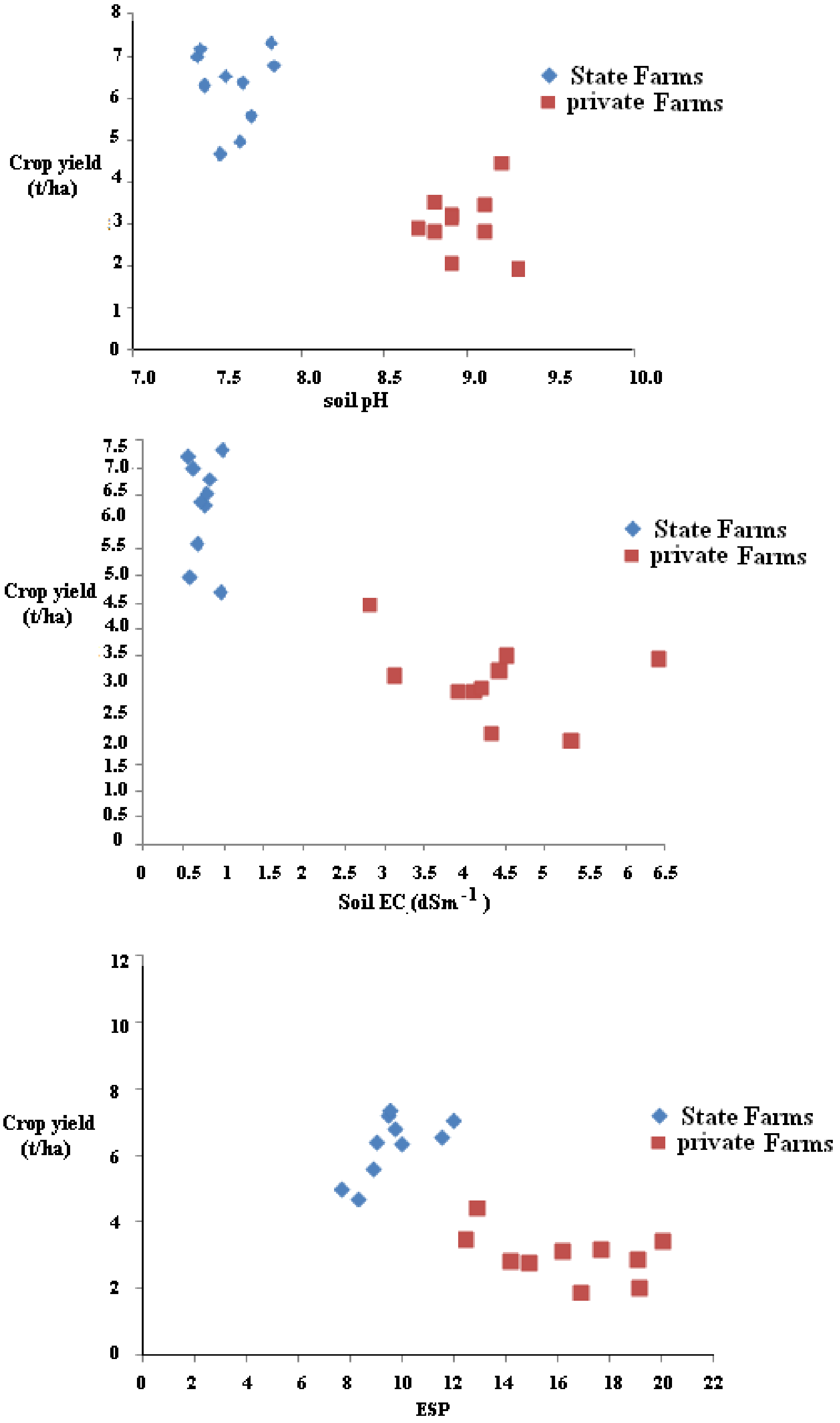


Figure 6—3 Relationship between Alfalfa yield (t/ha) and parameters of soil with combined data of the state and private farms.

Figures 6.2 and 6.3 show two clusters of point clearly separated out between the state and private farms. There are low yields at high values of water and soil parameters (private farms) and high yields at low values of water and soil parameters (state farms). There are no trends within the data for the private farms alone (see table 6 – 6). Surprisingly, there was no statistically significant correlation between yield and any of the quality parameters including salinity for soil or water, but this would be difficult to detect due to the variation in yield caused by crop age. Differences in yield between state and private farms may also be due to differences in crop age.

The situation in Kufra appears to be different to the situation described in previous research on the effect of salinity on alfalfa yield by Soussi et al., (1998) and Anand et al., (2000) who suggested production of alfalfa is considerably reduced due to salinity effects.

6.4.2 Potatoes

Tables 6.7 and 6.8 show the potato crop production (t/ha) on state and private farms.

Table 6-7 Results of Potatoes harvested from state farms. (Recorded from previous seasons)

Farm No.	Agricultural Unit	Year	Yield (t/ha)
53	B	2010	39.20
43	C	2008	42.00
62	B	2005	37.60
48	C	2004	38.50
51	C	2001	41.60
69	B	1999	38.70
82	B	1995	39.50
27	D	1994	40.10
37	C	1992	41.00
75	A	1990	42.20

Table 6-8 Results of Potatoes harvest from private farms

Farm No.	Region	Year	Yield (t/ha)
5	1	2013	20.7
6	1	2013	19.3
7	3	2013	24.3
8	3	2013	29.0
15	3	2013	28.3
16	1	2013	33.0
17	1	2013	25.0
18	2	2013	15.7
19	2	2013	21.6
20	2	2013	14.7

No potatoes were grown on the state farms in winter season 2013, so historical data has been used. Table 6.7 shows the year to year yield variation is low for the state farms, which is likely to be a result of the uniform management. The long term average yield of potatoes is 40.04 t/ha in the state farms.

The total yields of potatoes in northern Europe and North America average more than 40-50 tonne of fresh tubers per ha (FAO, 2011). These values are similar to yields recorded in Kufra. In Saudi Arabia and Egypt averages were 24.8 t/ha and 27 t/ha respectively (Arab organization for agricultural development, 2013). These values are much lower than the yields recorded in state farms of Kufra, but similar to those recorded on the private farms.

Yield comparison between state and private farms is based on the long term average of 40 t/ha for the state farms. Table 6.9 shows the mean values measured for yield of potatoes from state and private farms compared using a t-test. There is a highly significant ($p<0.001$) greater yield in the state farms.

Table:6-9 Comparison of the means of measured variable for state and private farms.

Variable	**State farm**	**Private farm**	**t-test**	***p-value***
Yield	40.04	23.16	8.74	< 0.001

This difference could be due to water or soil, so figure 6.4 shows correlations of yield and water / soil parameters for private farms only.

Relationship between Potatoes yield and water and soil Parameters in private farms

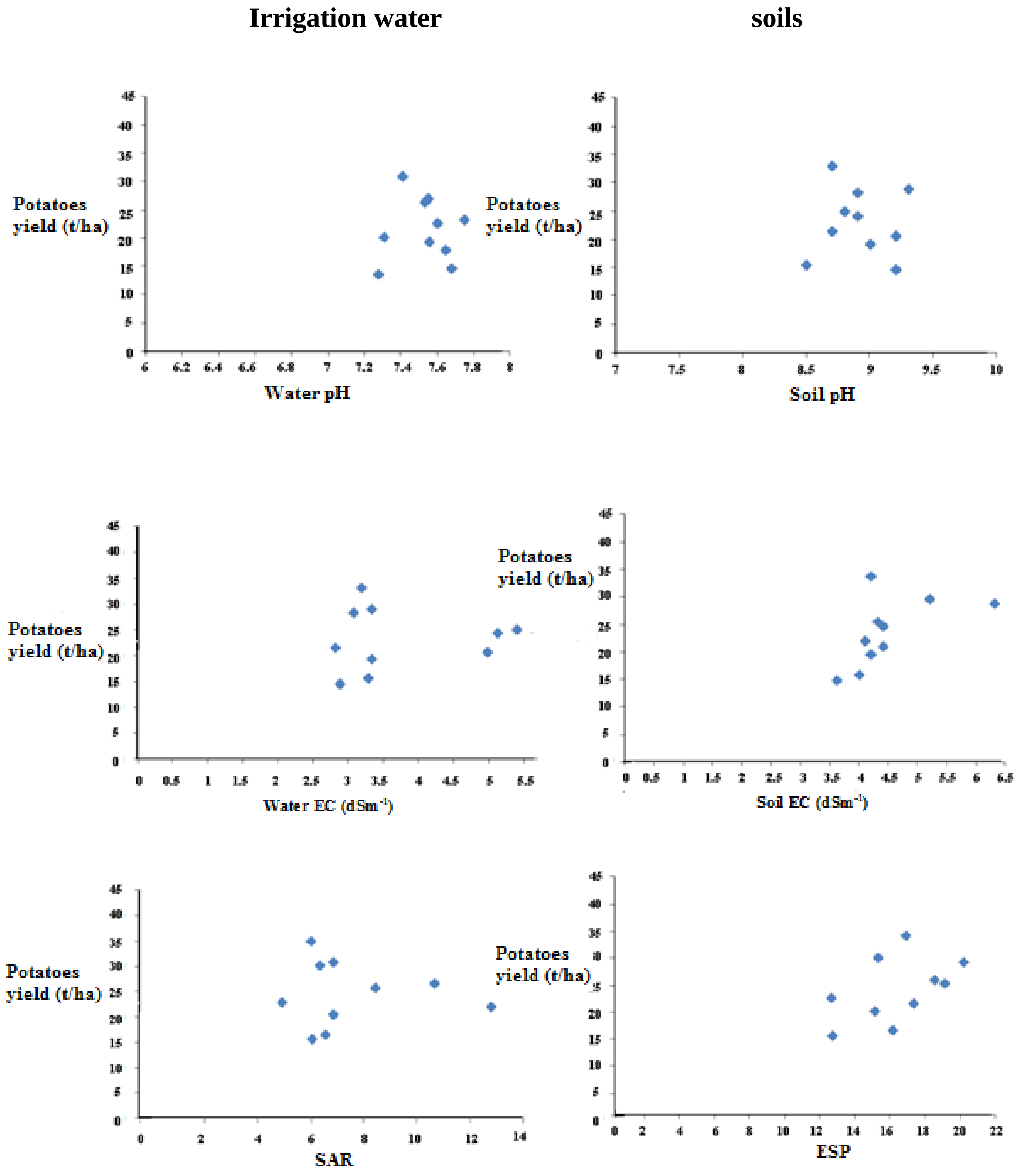


Figure 6—4 Relationship between potatoes yield (t/ha) and parameters of water and soils in the private farms.

Figure 6.4 shows the relationship between potatoes yield and parameters (pH, EC, and SAR in irrigation water and pH, EC,and ESP in soil) in the private farms. There are no significant correlations with yield for all parameters.

Table 6-10 Relationship between potatoes yield and water and soil parameters in private farms.

Correlation water parameters with potatoes yield (t/h)	Pearson correlation r	P- value
pH	0.004	0.992
EC	0.167	0.654
SAR	0.071	0.846
Correlation soil parameters with potatoes yield (t/h)		
pH	0.783	0.007
EC	0.196	0.588
ESP	0.285	0.425

Table **6 – 10** shows the relationship between potatoes yield and parameters (pH, EC, and SAR in irrigation water and pH, EC,and ESP in soil) in the private farms. There are no significant correlations with yield for all parameters including salinity.

6.5 Conclusion

The Ministry of Agriculture should set up a more extensive survey of alfalfa yields in the private farms examining a greater range of crop ages. If the findings of the current study are shown to be correct private farmers should be advised to replant or rotate alfalfa more frequently to obtain better yields.

Despite the large differences in soil and irrigation water chemistry between state and private farms there was no evidence that poor irrigation water quality or soil salinity currently limits production.

The differences observed in state versus private farms may be due to management effects (technology management, supply of fertilizer, irrigation methods, and plant protection). These aspects will be examined in the next chapter.

Chapter 7 Questionnaire survey

7.1 Summary

In order to complement the study on the effect of the relationship between water and soils on agricultural production in the region, it was essential to conduct a survey covering all aspects required by the study, which can be revealed through the farmers' answers to a questionnaire. The data gathered represents important information that might help to better understand and explain some of the results obtained in the previous chapters of this study

The study targeted farmers from the private sector, as the total number of farms by the Agriculture Office in the study area reached 2124, spread over three regions Al-Jawf, Al-Zawriq and Hawari (Naji, 2005). Based on this information, a questionnaire was distributed to 10 percent of the total number of farms (in January 2014). Farmers were chosen randomly through random number tables.

The questionnaire consisted of 21 questions relative to the farmers' knowledge of the nature of their work and their daily practices in terms of cultivation, irrigation, and fertilisation, as well as the extent of their cultural knowledge on agriculture, when dealing with the quality of seeds and fertilisers, as well as the proper and vital methods of working the agricultural soils.

The results show that 81% of the respondents did not consider farming a professional activity they could rely on, but rather an activity to fill their free or leisure time. The study also examined other aspects such as the farmers' education level, the farms' age, irrigation and the impact of water salinity, the types of fertilisers and their sources, and the farmers' degrees of familiarity with manures.

The present study concluded that traditional agricultural systems in this region are not built on a scientific basis, such as the needs of irrigation and fertilisation, or an adequate knowledge of economic feasibility. Consequently, the production rates of agricultural crops through the use of this type of agriculture are very low, in addition to the problems of salinity of the irrigation waters and soils, also affecting the area of study.

7.2 Introduction

Agriculture activity is one of the world's most important economic activities with almost the entire world's population dependent on the resulting food. But at the present time this field is often unprofitable and beset with problems (Singh et al., 2013). Issues include supply of skilled and willing labour through to natural hazards such as salinity.

The food requirements of humans increase at a faster than before, due both to the incease in human population and a widespread increase in affluence. This requires an increase in agricultural production to meet the demand Satterthwaite et al., (2010). Despite these measures vegetable farming systems are unable to cope with the demand for several and different reasons, one of which is a problem of salinity in irrigation water and soil, requiring intensive management of agricultural operations to control it Bouwer (2000).

The use of saline waters for the irrigation of already saline soil is a recurrent practice in private farms in the Kufra region (see chapter 4 & 5). However, beside its few positive effects in terms of getting some harvests of some crops, especially those who are salt-tolerant, there are potential negative effects on the environment and on the general life of farmers, such as the increase of salinity levels in irrigation waters and the salts accumulation in the soil and thus the abandonment of these farms.

This questionnaire considers mostly the factors most likely to be affecting agricultural productivity and livelihoods. Depending on the question they can be answered in different ways (yes, No, do not know), with some answers requiring a short statement (what crops grown) or a numerical answer (number of years farmed for instance). As well as asking about the current state of farms and farming the farmers were asked to speculate on the causes of problems and possible solutions.

The population study was composed by farmers who live in the study area and who are distributed in three major agricultural areas (Al-Jawf, Al-Zawriq and Hawari). The questionnaire included a group which accounted for 10 per cent of the farmers in the study area (from the private farms). The questionnaire prepared consists of 21 questions encompassing all circumstances related to the agricultural activities in the area.

7.2.1 Aims for this chapter

The aims of this study are:

1- To record farming practices and farm characteristics in the study area.
2- To record the major problems facing small farmers and the measures they have taken to overcome them.
3- To relate the experience of the farmers to the data collected from studies of agricultural productivity and the salinity of soil and water from the previous chapters.

7.3 Materials and research Methods

The study targeted farmers working in the private farms. The questions were reviewed at the University of Glasgow in English and then translated into Arabic prior to distribution to the farmers. As the number of private farms recorded in the Agriculture Office at the time of this study was 2124 farms spreading over three main areas (Al-Jawf, Al-Zawriq and Hawari), the questionnaire prepared was distributed to 10 percent according to the number of farms in each region, as is shown in the table 7.1. Farms numbers were selected using random number tables and the fieldwork was carried out from the 8th January 2014 to the 14th January 2014 (08/01/ 2014 to 14/01/2014).

Table 7-1 Distribution percent of questionnaires

Region name	**Farmers No.**	**Questionnaires (%)**
Al-Jawf	872	87
Al-Zawriq	592	59
Hawari	660	66

7.4 Results and Discussion

7.4.1 General farm practices

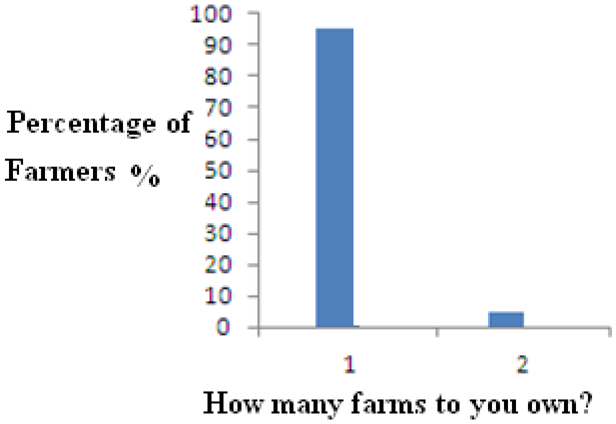


Figure 7—1 Shows relationship between percentage of farmer and own farm number.

The Figure 7.1 shows that 95% of the respondents have only one farm, while 5% possess more than one farm. This result might be explained by the difficulty of drilling due to the high costs of drilling. The other reason is that irrigation with saline water is not encouraging due to the little rewarding. These are small businesses, and might have limited access to the funds necessary for more sophisticated irrigation systems. A full financial analysis of these businesses would be a sensible follow up to the present study, allowing the priorities for development spending to be refined.

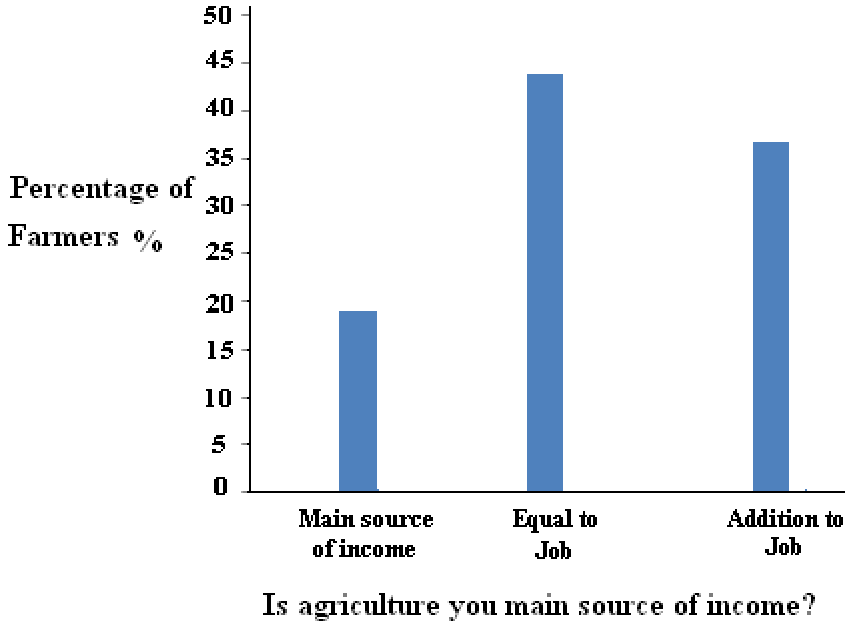


Figure 7—2 Shows relationship between percentages of farmer and if the agriculture is main source of income.

The figure show that 19% responded yes to the agriculture is main source of income, confirming that they do not have another work or alternative occupations (farming was the sole way of earning their livelihood). Accordingly, they were making huge efforts in order to get an adequate yield. The other important group, representing of 44% of the respondents, acknowledge that they have other occupations as state employees or other types of work, due to the fact that they are free after 14:00 pm (in Libya the work time is one period between 7 am to 2 pm in all state institutions). A 37% stated that farming was in addition to their normal work and careers. This last group consider working in farms as leisure to fill empty hours and enjoy planting crops, may be due to the land is cheap in the Kufra. These results means that the first categories A, B of farmers, make more efforts and dedicate more attention to farming since it will bring them the vital material return (livelihood) while the third category C is less preoccupied by what can result from this type of farming because it is not their main source of income and consequently it does not affect their livelihood. Again, this is useful information on which to develop development plans for the area. The priority should be professional farmers, though the potential role of part-time and recreational farmers in the economy should not be ignored as farming might still be an important factor in poverty alleviation even if the farm produce were for personal use only.

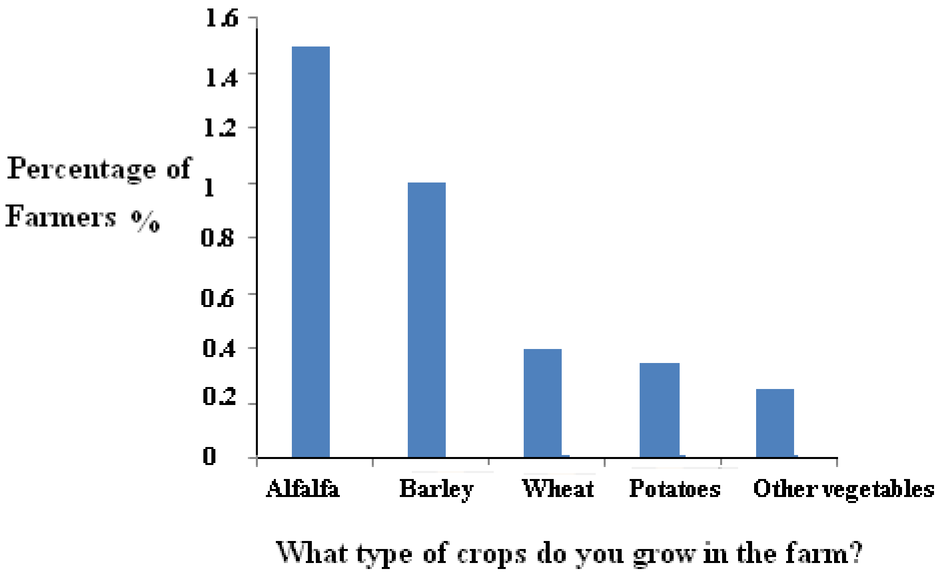


Figure 7—3 Shows relationship between percentages of farmer and type of crops grown in farm.

The figure shows that alfalfa crop had the highest rate (average 1.5 ha/farm) among all crops grown, for the reasons mentioned in the fifth figure, in addition to its resistance to salinity conditions (soil salinity and irrigation water), which confirmed its success under salinity levels (EC 6.4 dSm^{-1} in soil and 7.8 dSm^{-1} in water) (chapter 4 and 5).Next come barley and wheat (Average 1.0 and 0,4 ha/farm), the latter crop being vital since wheat grains are often being exploited for human consumption, and its tailings as fodder to animals or green feed. The wheat's tolerance to salinity is lesser than barley. Lacefield et al., (1997) reported that alfalfa in the United States has the highest yield potential of any perennial forage plants, and has spread and become popular because of its productivity and high feed value.

The potato crop comes immediately after barley and wheat (in fourth place, average 0.35 ha/farm), and is one of the favoured crops for farmers due to its commercial value and consumption, and its satisfactory productivity under saline conditions.

Meanwhile the other vegetables, such as onions, tomatoes, radishes, watercress etc came in fifth position, average 0.25 ha/farm, since they are cultivated for self-consumption, and most of the farmers cultivate at least one of these types of vegetable. Following his study on alfalfa Stichler (1997) observed that this crop, which is also nicknamed on purpose the "queen of forages" can produce, when it is adequately used, the highest protein and high-quality forage crop. Additionally, alfalfa is not only characterised by a rapid regeneration following each cutting, but it is also considered as an excellent rotating crop.

Mention results of alfalfa production study from previous chapter – yields lower in private farms, potential for increased productivity and improved livelihoods for farmers. Other results from that chapter.

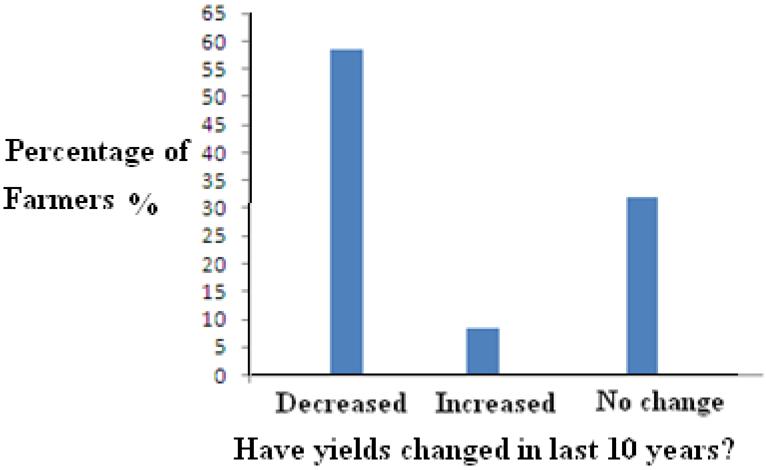


Figure 7—4 Shows relationship between percentages of farmer and yields changed in last 10 years.

The figure shows that the change in the productivities and if there was an increase or deficiency if it occurs during the last 10 years. As for the scarcity in terms of productivity (as a reason) it reached the highest score (59%) and it is a real and effective indicator of the farmers' lives. The other group (32%) of the farmers did not observe any change due probably to the fact that a large number of this category are not the real farmers (Figure 2) or because they only alfalfa crop. Finally, 8% of farmers noticed an increase in production, which is probably due to the good quality of water used, from wells over 30 m deep (chapter 4). The split in results can be compared to the results of the water quality chapter where some farm age. The shallow wells (<30 m) exhibit a significant ($p < 0.001$) increase in EC as well age decreases. The deeper well (30 m or more) exhibits no significant effect of well age ($p > 0.05$).

These results related to study by Tyagi, (2003) pointed out that the initial reaction of plants under the effect of water and soil salinities is reduced germination. Sound experiments confirm that the interchange of various parameters, such as the evaporative demand, salt content, soil type, rainfall, water-table conditions and type of crop and water-management practices, determines the accumulation of salts in the soil and crop performance resultant from the use of saline water for a long period.

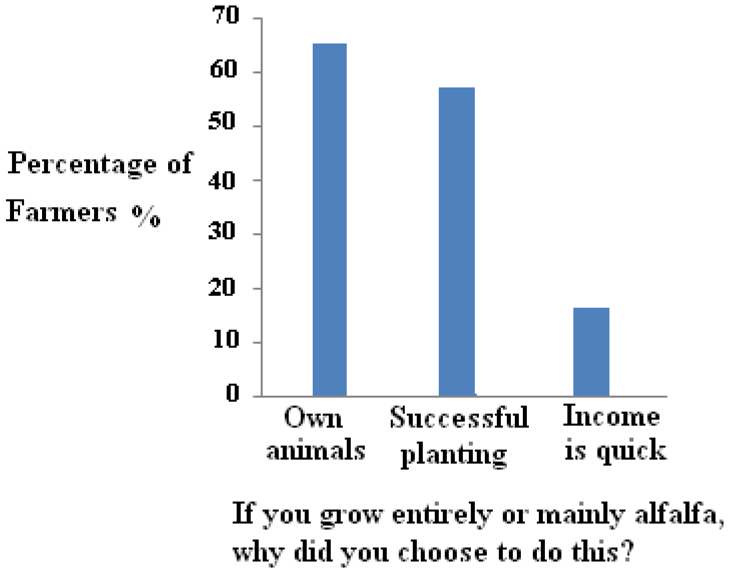


Figure 7—5 Shows relationship between percentages of farmer and reason choose of alfalfa crop.

The figure shows on the economic viability of the reasons for choosing to plant alfalfa, as animal feed (forage or fodder), or by considering it as more useful than other crops, these concerns got the higher ratios of 65% and 57% respectively, while the reason for obtaining a fast return reached 17%, which means that it is economically viable to cultivate alfalfa crop sought to breed animals and sell them directly. This is a valuable crop, efficient regardless of the changeable conditions, which grows rapidly as confirmed by the current study in chapter 6 (there were 8 alfalfa cuts per year in Kufra). also in reviewed no 3 and related with the study done by Stichler (1997) pointed that alfalfa crop grows rapidly and sprearted on worldwide.

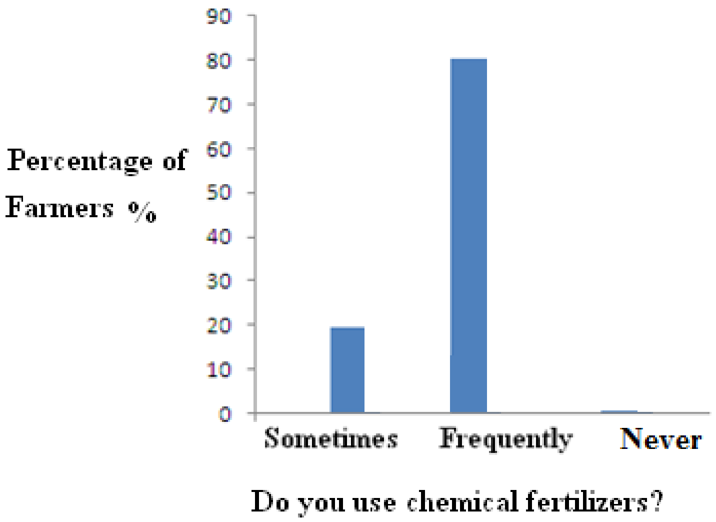


Figure 7—6 Shows relationship between percentages of farmer and chemical fertilizers used.

About the figure shows that the use of chemical fertilisers and accordingly three alternatives were given, sometimes - frequently - absolutely not used. The highest percentage (79%) of respondents recognised using frequently fertilizers, which means that they rely heavily on these fertilisers to increase the productivities because the sandy soils texture (chapter 5) are usually nutrient-poor (Noureen et al., 2008). This management practice might be linked with the increase of the productivities in the formative years of farming. The subsequent decrease in productivities might have been the result of inexperience in the use of certain fertilisers' type or irrigation method or to an inadequate acquaintance of farmers of the right type and appropriate quantity of fertilisers required for crops.

This should be a priority for future research. The differences in crop yields between state and private farms cannot easily be attributed to salinity because there appears to be no link between water salinity soil salinity for most parameters (Chapter 5). It is likely that other factors such as how water and fertiliser are used (type and concentration of fertiliser, rate and timing of water and fertiliser application). Improvements to farming technique might provide improvements in productivity with very limited costs, or even reductions in cost if fertiliser is being inefficiently used at present.

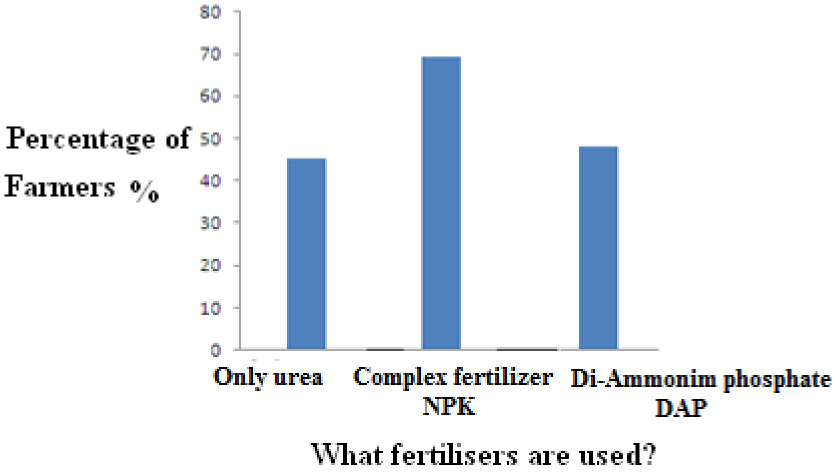


Figure 7—7 Shows relationship between percentages of farmer and type of fertilizers used.

Types of fertilisers used; The three options proposed represented the three types of fertilisers which are the most used in the study area, the urea fertiliser(the local production), the compound fertilizer Nitrogen- phosphorus- Potassium(NPK) and Di-ammonium phosphate (DAP) or any other type of fertilisers not mentioned. The ratios were very high for three kinds due to the fact that the farmers use more than one type of fertilisers, and the availability in the market of various types of fertilisers. It is believed by farmers that chemical fertilisers increase productivity without specifying the type and quantity needed by the plant or the impact they have on soils. As suggested above a programme of soil testing and agricultural training might be a very cost-effective means of improving the situation for these farmers.

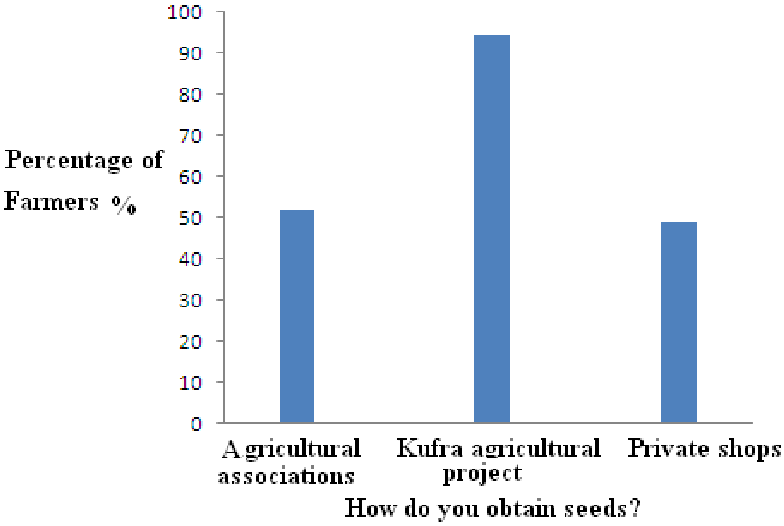


Figure 7—8 Shows relationship between percentages of farmer and obtain seeds.

The figure shows the sources of the seeds used by the farmers due to the importance of that element in determining its efficiency when comparing productivities.

The answers to this question show that 94% of the farmers get their alfalfa or potato seeds from the Kufra Agricultural Project. These seeds are provided to farmers when required. While 51% get their seeds from a regional agricultural association which provide this type of services. While 49% get their seeds from other locations such as the appropriate private commercial shops, which proves that the existing seeds are in majority from the same type. The dominant position of the agricultural project as a supplier provides great opportunities to improve farming practice through advice and training. A cost-effective mechanism could be free seeds or suitable fertilisers in return for participation in an improvement programme.

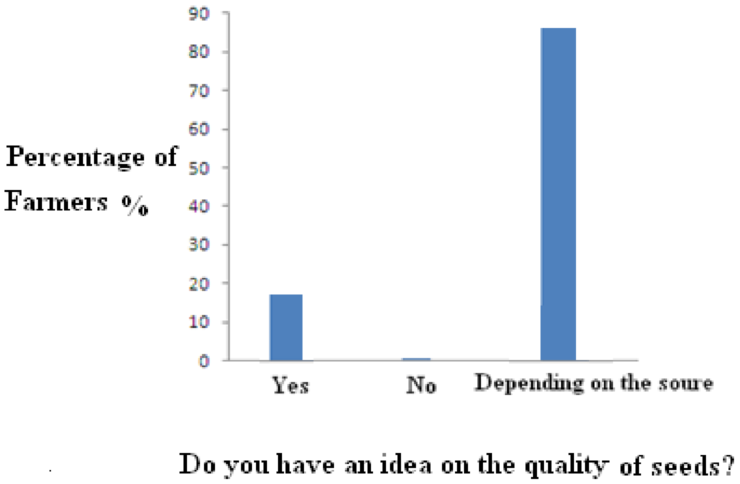


Figure 7—9 Shows relationship between percentages of farmer and quality of seeds.

The figure shows that the highest percentage of respondents (84 %) rely on the source (provider) when choosing their seeds in particular when the provider is the Kufra Agricultural Project, and the agricultural associations due to the fact that they are managed by specialists and as well some commercial shops related to the agriculture field. Consequently, the farmers are not really concerned by such aspect or these issues.15% of the respondents have an adequate knowledge about the seeds quality through their sons and relatives who are qualified or worked in the agricultural field.

7.4.2 Irrigation practices and water quality

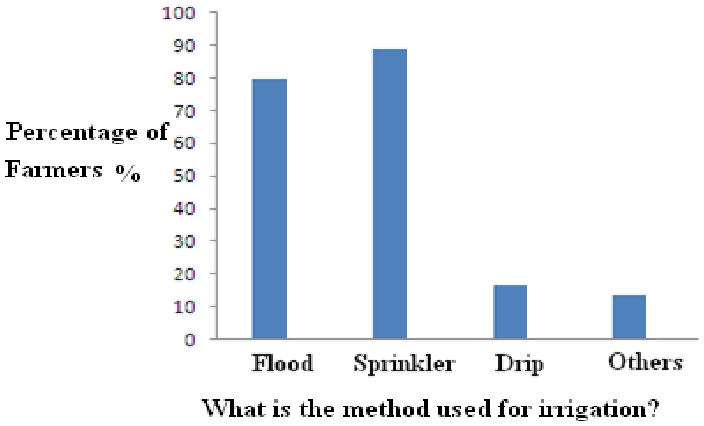


Figure 7—10 Shows relationship between percentages of farmer and irrigation method used.

The figure shows that the answers show that farmers use more than one method of irrigation. For instance, 89% of the respondents use the sprinkler irrigation system, then 80% use flood or surface irrigation and it is clear that most farmers use both irrigation methods in the same farm.

The flood irrigation is a traditional method through the use of agricultural basins and it is this particular technique which causes problems to the soil especially when using saline irrigation waters. Drip irrigation was ranked third, with 17% only of respondents acknowledging the use of this method.

The other methods of irrigation such as the sub-irrigation and the gullies are used by 14% of the farmers which means that farms' soils encounter problems due to the methods of irrigation used, with the saline waters, in particular the flood irrigation and the irrigation for a long period of time, and this was confirmed by the statistical analyses done in the previous chapter (water chapter) regarding the differences in the soils irrigated with saline waters in private and state farms. The inadequate methods and farming practices, such as the traditional flood irrigation method occurring in India are still used according to Rajaram and Qadri, (2014), provoke the evaporation of more than of 90% of water.

A progressive programme of modification of irrigation methods could be carried out here with the aim of reducing the use of flood irrigation over time.

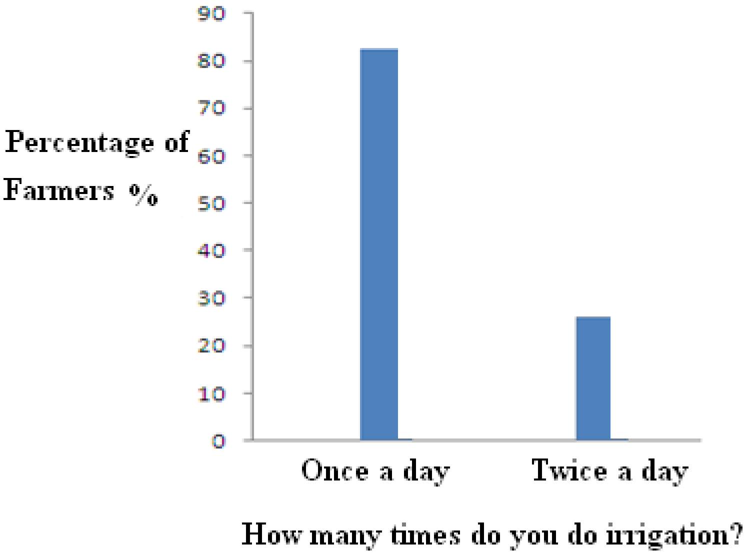


Figure 7—11 Shows relationship between percentages of farmer and irrigation times.

The figure shows that most used method and the traditional one in the private farms without any scientific consideration is the irrigation once a day since 83% affirmed doing that, while 26% conduct the operation of irrigation twice a day and especially when the temperature is high and when they plant tuber crops, as the results show that the farmers used a large quantity of water for irrigation in the presence of salts varying between a farm and another and the damage caused to the soils to those farms. The results in soil chapter (chapter 5) refer that the irrigated soil profiles of the private farms, all parameters were lower than the virgin soils but higher than state farm soils.

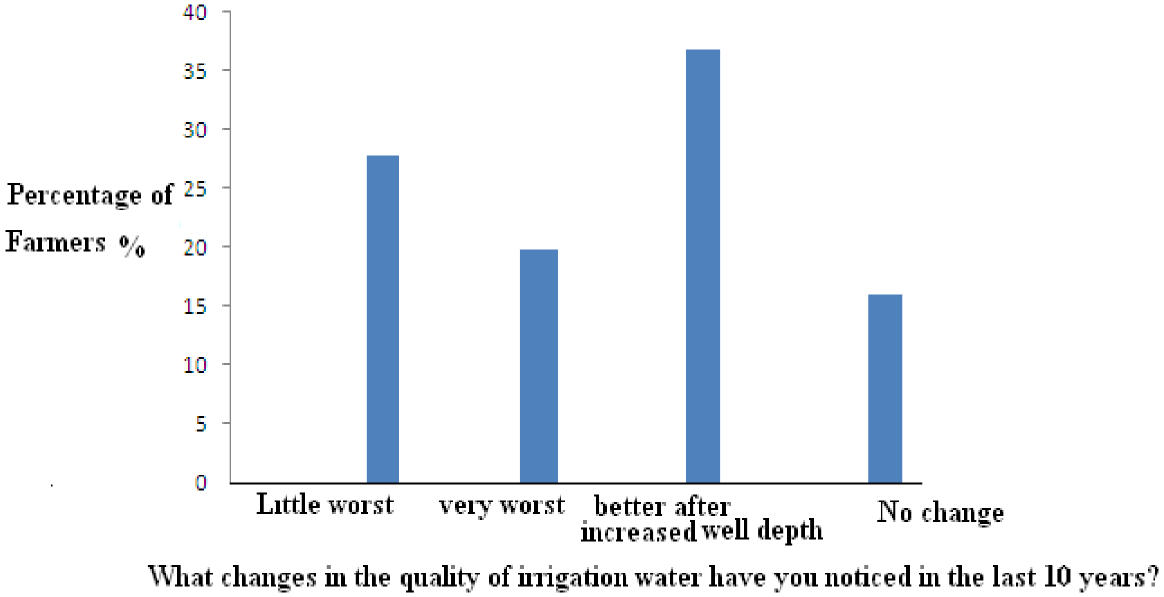


Figure 7—12 Shows relationship between percentages of farmer and changes in the quality of irrigation water in the last 10 years.

The figure shows to what the farmers observed during the last decade as regards to the irrigation waters. 48% indicated observing effects between low or severely negative, while 37% observed an improvement in the quality of waters, following deeper digging of the wells. This observation confirms that the depth of wells is significant factor when assessing the quality of water, and this is in conformity with the results found in the chapter 4 of this study. It has been observed that the salinity of wells under 30 m depth is significantly high, while the wells deeper than 30 m are less saline.

A total of 16% did not observe any changes, which might be due to the fact that they are not permanently on the fields (either they are part-time farmers or considering farming only a leisure activity as the data in figure 2).

Based on these results and those of the previous chapters, investment in digging wells to depths of >30 m would reduce irrigation water salinity and probably the decline in water quality over time. Given the complexity of the relationship between water and soil quality in this area it is likely that other factors such as irrigation method and timing are having an important effect on how water salinity effects are manifested.

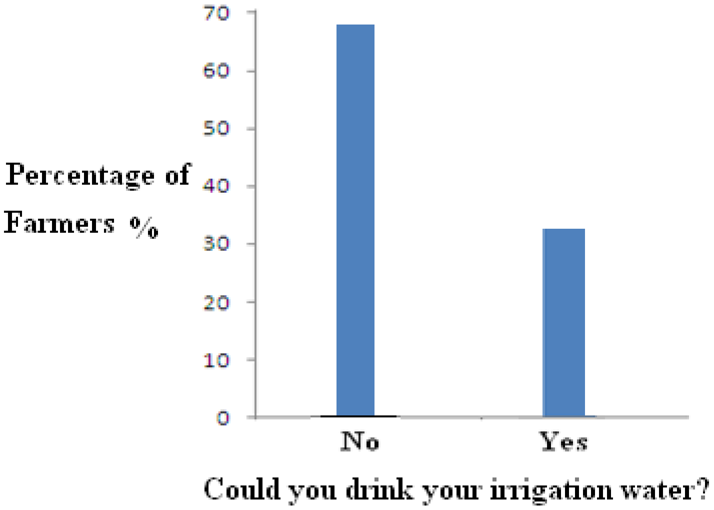


Figure 7—13 Shows relationship between percentages of farmer and acceptance of irrigation water for drink.

The answers in figure show that 67% affirm that they will not use it for drinking purposes and this is a real indication that the waters of these farms are of inferior quality. The EC values in chapter 4 of irrigation water of private farms ranged between 1.6 dS m^{-1} to 7.8 dS m^{-1}. While 33% say they will use it but only if it is really necessary and this is another indication for stating that the problem is not due to biological pollution but a problem of flavour or taste of saline waters and this type of waters is known in the region as the heavy waters.

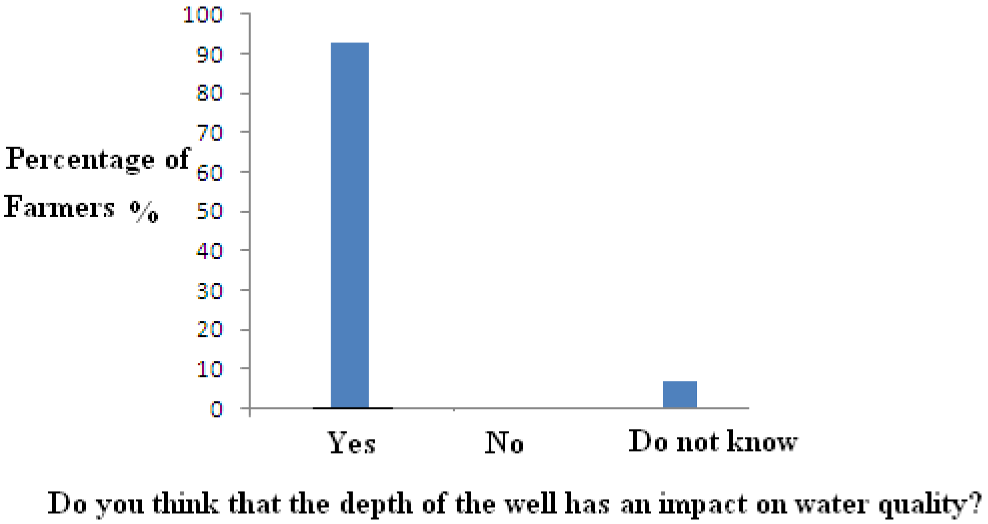


Figure 7—14 Shows relationship between percentages of farmer and impact of well depth on water quality.

The figure shows that the yes category for 93% of the respondents who acknowledged the connection between depth of wells and the salinity of the water, while 7% do not believe that the depth has an effect on irrigation water salinity, the rest (less than 1%) do not know the answer. These answers were confirmed on the ground since farmers increased the depths of the old wells years after the first digging and as well when digging new wells they go to the most adequate depth, and this was confirmed by the statistical analyses conducted in the fourth section which show that the waters of wells under 30 m depth are more saline than the wells who are deeper. The study shows (in chapter 4) that the classification of irrigation water according to the FAO and USDA system, from wells deeper than 220 metre in the state farms can be used for irrigation purposes without problems, due to the fact that the values for Electrical Conductivity are lower than 0.7 dS m-1, and the SAR values are lower than 2.

While the effect of very deep drilling has been clear for some time, such well were apparently beyond the reach of most farmers for financial reasons. The results presented here indicate that only relatively modest increases in well depth could have significant effects however and a programme of limited well improvement might be worthwhile.

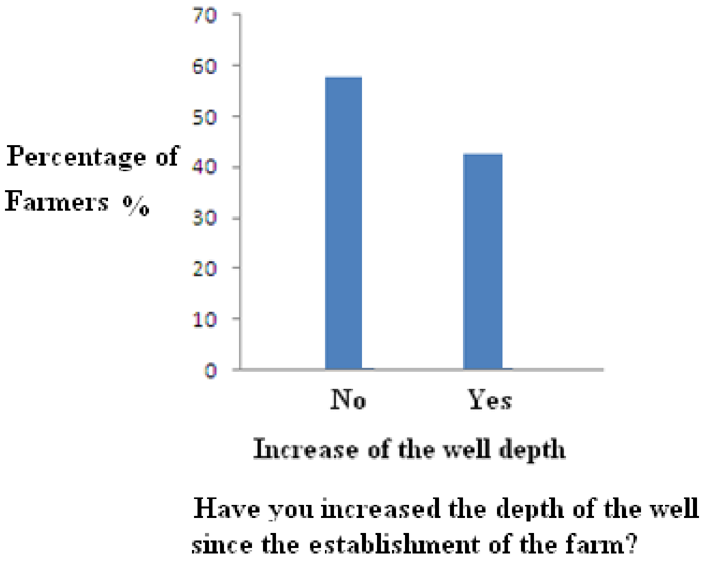


Figure 7—15 Shows relationship between percentages of farmer and increase of the well depth.

Figure 7.15 shows that 58% of the farmers dug wells with more than 30 m depth, while 42% did not increase the well depths because their wells were already more than 30 m depth or because the costs to increase depth were too high. Farmers may well have believed that wells needed to be very deep and therefore expensive in order to gain any benefit, something which does not appear to be correct. To be worthwhile however, it is likely that alteration to fertiliser and irrigation practices would also be necessary in many cases.

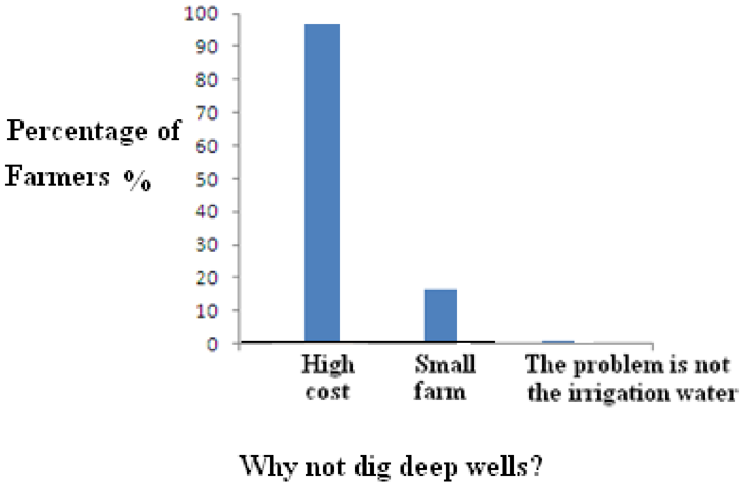


Figure 7—16 Shows relationship between percentages of farmer and reason for not dig deep wells.

The figure shows that the reasons why farmers did not dig deeper well since the beginning (i.e. when the farms were established). They were several options for answering to this question; such as high costs for digging, or the area to irrigate was relatively small and did not need too much water, another option was that the problem was not linked with the irrigation waters, and finally any other reasons different from the ones cited above. 97% of the respondents choose the first option, invoking the high costs for digging and the conditions and limited material capacities of farmers limited, while 17% of the farmers recognised that it was a combination of two factors, the high dig costs and the farm small. These conditions were reflected on the quality of irrigation water in private farms (see chapter 4). The current study agrees with Namara et al., (2011) who noted that well depths was related with the financial means of the farmers due to the relatively high cost. Effectively, in a study of upper east region of Ghana it has been stated that the main factor in the development of shallow wells was the financial cost of increasing the well depth.

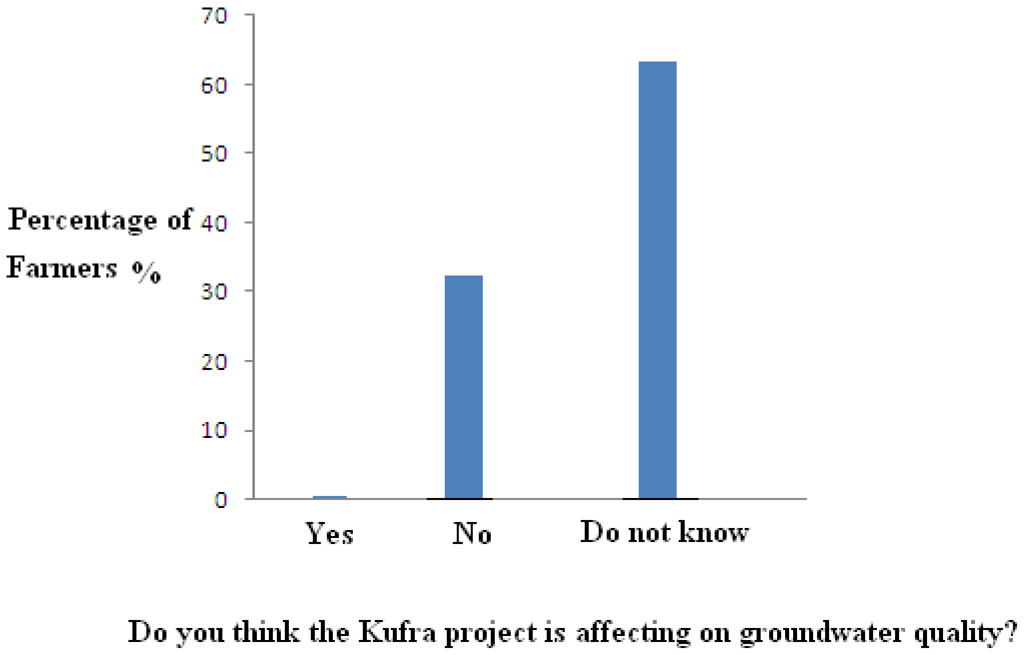


Figure 7—17 Shows relationship between percentages of farmer and effect of the Kufra project on groundwater quality.

The figure shows if the Kufra Agricultural Project has a relation with the quality of water in the private farms in view of the volume of water pumped from the wells of that project and the use of pumps of 200 horsepower pumping 76 liters per second. A 64% answered by ‘I do not know’, while 31% of the farmers answered negatively (no), and less than 1% answered positively (yes). According to the answers given by the farmers the Kufra

Agricultural Project did not have any perceived influence on the quality of water. Whereas highest category was I do not know due to the limited and insufficient knowledge of farmers in the groundwater field.

7.4.3 Consequences

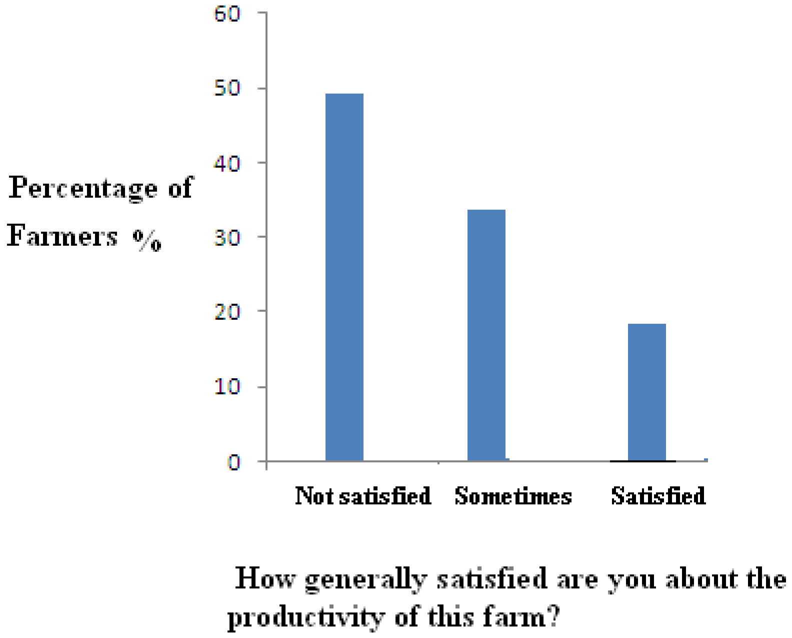


Figure 7—18 Shows relationship between percentages of farmer and satisfied about productivity farm.

The figure shows that 49% of farmers expressed their dissatisfaction due to several reasons, 32% say that they were sometimes satisfied, depending on the productivity, the yield and on the price competition, while only 19% of the respondents acknowledge their satisfaction. The results in the chapter on the yield crop (chapter 6) it appears that there is variability on crop yield of private farms. The productivity of the alfalfa crop in the private farms ranged between 1.95 and 4.47 t/ha and the yield of potatoes ranged between 14.7 and 33.0 t/ha. While it is disappointing to hear that farmers are currently unhappy, this does provide an incentive for them to participate in an improvement programme.

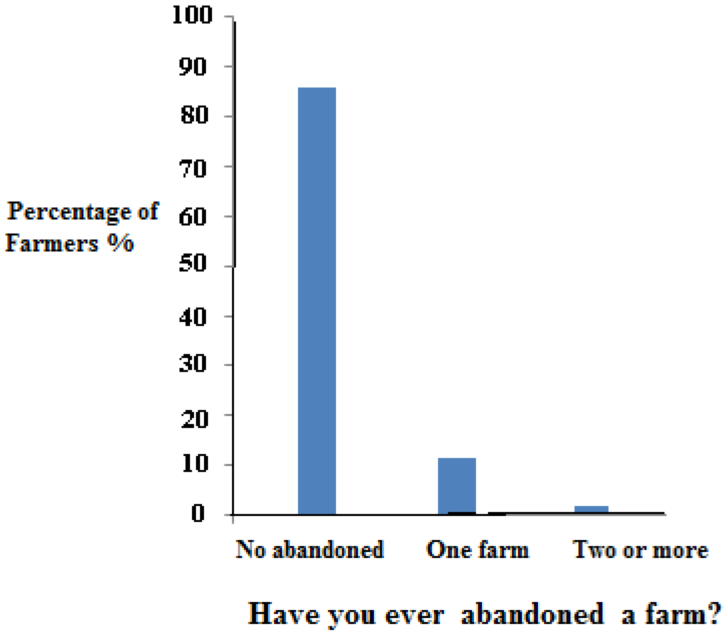


Figure 7—19 Shows relationship between percentages of farmer and abandoned a farm.

The results in figure show that 86% did not abandon their farms, despite all the difficulties and the challenges encountered such as soil and/or the irrigation water salinity. On the other hand, 12% stated that the change of farm occurred once, while 1% acknowledges having to change farm twice or more due the accumulation of problems. These results relate to the answers in figure 7.2, where was recorded that the lowest percentage of farmers stated that the agriculture was their main source of income. For all the challenges, farmers are clearly invested in the land they own and would prefer to continue farming it rather than moving to a new site. As soil salinity falls from virgin levels once irrigation begins, starting a new farm is likely to be harder than improving an existing one from which much of the salinity has been removed.

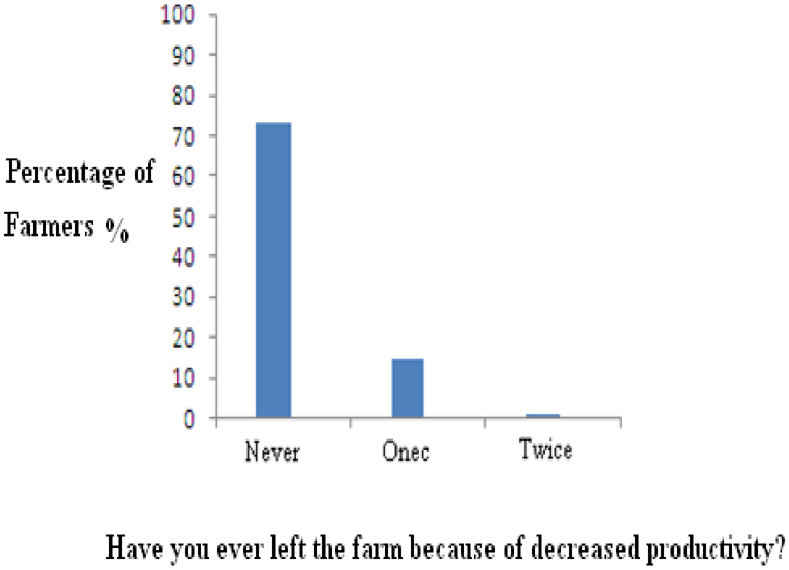


Figure 7—20 Shows relationship between percentages of farmer and left the farm because of decreased productivity.

The results in figure shows that 73% of the respondents answered by no while 15% of the farmers acknowledge that they did leave a farm once. The rest of the participants (1%) said they left twice, which means the abandon of farms is not necessarily linked to a low productivity. These results may be related to the answers which appear in figures 7.2 and 7.20 for first category(never), and related with soil salinity and saline water irrigation in chapter 4, 5 respectively, for once and twice categories.

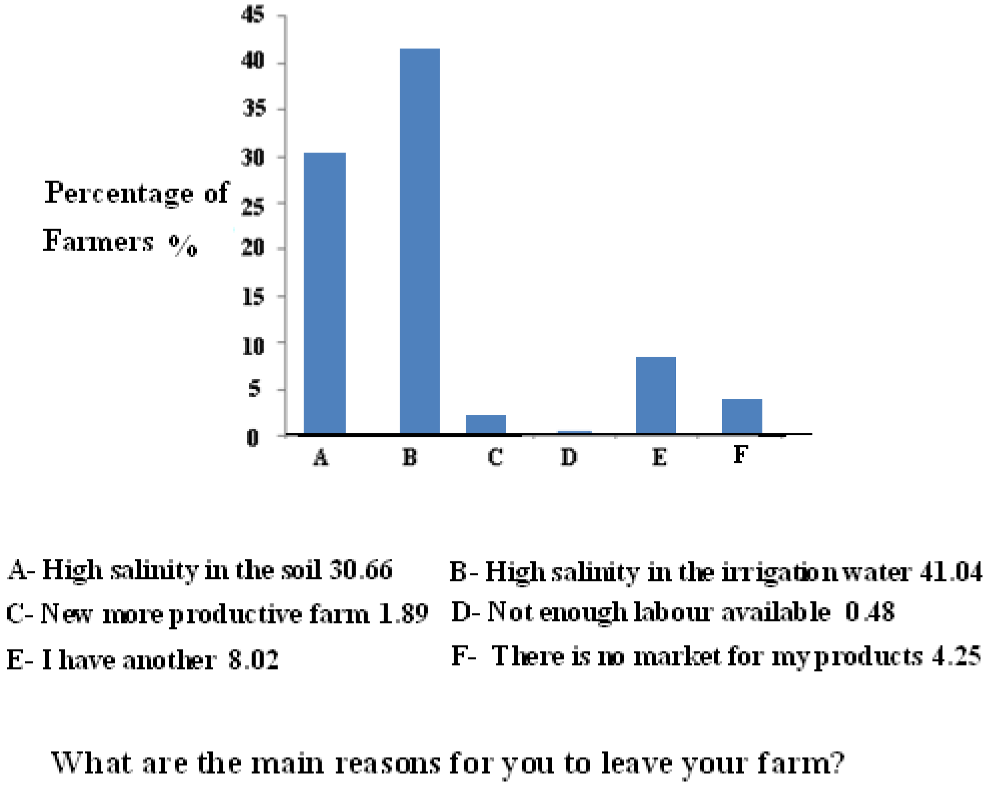


Figure 7—21 Shows relationship between percentages of farmer and main reason to leave the farm.

The results in figure shows that, 41% of the respondents agreeing on that reason, especially in the farms where the wells were less than 30 m depth. The second main reason for leaving the farms was unsurprisingly was due to soil salinity (31%) (to the nature of the soil itself), and which require huge efforts to better the soil characteristics through the use of a good quality of irrigation waters (and overcome these problems) in the light of limited possibilities for farmers. The third reason represented by 8% was due to the fact that farmers owning more than a farm do not focus enough on the needs of a single farm. Other reasons were invoked by 4% such as inheritance and/or social problems. Finally, 2% abandon their old farms due to the high productivity of new farms.

The farmers consider that the salinity in irrigation water in chapter 4 or soil in chapter 5, affects yields in the Kufra region and compares yields on the private farms with state farms yields where irrigation is with good quality water and the soils classed as normal. Despite the large differences in soil and irrigation water chemistry between state and private farms and the expectation of the farmers, this study found no evidence that poor irrigation water quality or soil salinity currently limits production.

7.5 Conclusion

Most of the results of the polls in the questionnaires are linked with the results of the study in chapters 4, 5 and 6 as following;-

We can summarize in three important paragraphs.

1. 93% of respondents believed that the depth of the well has an impact on the quality of the water, while 37% noticed improved quality of irrigation water following the increasing of wells' depth, which confirms the conclusion in chapter four, to assess the effect of the depth of water wells on the quality of water in private farms.

   While 42% of respondents indicated that they had increased the depths of their wells, 97% had wanted to increase the depth but were not able to do so, due to the high costs of the digging, which represents a real obstacle for a number of the respondents when asked about the reason for not increasing the depth of wells (figure 7.16).

   The increase in digging was on average 19.5 m in depth, which means that all the increases were for wells less than 30 m in depth. This increase led to improved of irrigation water, which has been confirmed in chapter four, where it was observed that the quality of the irrigation water in the private farms was generally salty, but that salinity increases in depths of less than 30 m. The percentage of wells that are less than 30 meters is 48%, and they are the most salty than other wells as in the fourth chapter.

2. The most commonly used methods for irrigation in the private farms are spray and immersion/flooding, estimated at 89% and 80% respectively. For irrigation on a daily basis, the percentage reached was 83%, and for twice daily the figure was 26%. When comparing the type of fertilizers used, the percentages were: urea 45%, compound fertilizers 69%, and diammonium phosphate 48%. Fertilizers were used on a frequent basis by 79 % of farmers, while 20% indicated using them from time to time. These fertilizers do present special features, in particular urea, which is easily soluble under heavy conditions of irrigation in private farms and sandy soil texture, which leads to the loss of large amounts of fertilizer without benefiting the

crop. This is an example of bad practice by farmers, which leads to lowering of productivity.

Drip irrigation was used by 17% of respondents (this technique was new to the farmers in the region since it started to be used only since the last decade), which probably explains the increased yield of 8.49% in the past ten years (there was less loss of fertilizers), despite the density of irrigation.

It appears from the data that only 19% of respondents are dependent on agriculture as their main source of income, which means that this category are keener to use appropriate practices for planting, fertilizing and irrigation, which explains the differences in productivity between private farms and state farms.

The most planted crop is alfalfa which is one of the perennial crops, salt-tolerant, and does not require excessive work or numerous service operations. Alfalfa is also quick in terms of returns, and is considered as an excellent fodder for some animals, which suits 80% of the farmers surveyed.

3. The results of the survey indicate that the largest area of farms was 8 ha, and the smallest covered 1.5 ha; the average was 3.5 ha. By area, the crops planted were an average of 1.5 ha of alfalfa, 1 ha of barley, 0.4 ha of wheat, 0.35 ha of potatoes, and 0.25 hectares miscellaneous vegetables (such as onions, garlic, and radish). About 49% of respondents were unsatisfied with the productivity of their farms, which was observed through the low yields of alfalfa and potatoes in some private farms in chapter 6 (crop yield), while 73% did not leave their farms, despite the low productivity. In contrast, about 15% left their farms due to previous low productivity; this is because agriculture is their only source of income, representing 19% of respondents.

   There were various reasons for leaving their farms, the highest proportion being attributed to the salinity of soil and irrigation water, though that has not been established through the study of the effect of the quality of irrigation water and soil on the yields of alfalfa and potatoes in the crop yield chapter (6). There is no relationship between the quality of irrigation water or soil with low productivity in alfalfa and potatoes.

7.5.1 Overall summary

Although apparently beset with a major salinity problem most farmers stick with their farms for the long term. The trends in soil and water quality are complex, with the time under irrigation being a weaker predictor of salinity problems that expected. Shallow wells are a known source of poor water quality but surprisingly saline waters were not a strong predictor of highly saline soils. Productivity is certainly lower in private farms than in state farms but this is probably the result of many different factors including that many farms are not the farmers' main occupation and so get less investment in money and time than where farming is the priority.

While salinity is a problem the salinity of irrigation water can be improved significantly with only small increases in well depth. This information should be provided to farmers immediately. Over the medium term, perhaps over the next 10 years a progressive programme of education and small grants to improve irrigation and fertiliser use is likely to provide social and economic dividends. In particular a switch to drip irrigation and fertiliser combinations optimised to particular crops and soil types is a possible plan which might pay for itself. The dominant position of the Kufra Agricultural Project as a supplier and source of advice provides a key opportunity to help farmers improve livelihoods and potentially to expand the number of people supported in this key industry.

Soil salinity appears to be a real problem with not only its negative effect on productivity (clear reduction of agricultural productivity) but also by affecting deeply the livelihood of small farmers. The severity of the problem reaches such a dimension that it represents a real challenge for the farmers who are struggling to overcome this adversity. The various attempts made by the farmers to find a solution appeared to have negative effects on the long-term. Effectively, the measures taken will put more pressure on the small farmers (who are already in a bad situation) as well as damaging the soil and (in the long run) the entire agricultural set up. It is believed that only with joint efforts between three parties, the government, Non-Government Organization (NGO'S) and farmers a lasting solution could be found to deal quickly with the situation.

7.6 Recommendations

Given the findings of the study, regarding the salinity of irrigation water in the private farms and the fact that salinity decrease with the increasing depth of the well, the virgin soil in the area is saline and the salinity decreases with the sector depth, and the irrigated soil in the state farms is less saline than the soils of the irrigated private farms. It was also observed a low production of potato and alfalfa crop in private farms compared to the state farm.

Through the evaluation of the water irrigation and the state of the agricultural soils, and crop yield presented in this study, and the reviewed literature, several recommendations can be suggested, as follows:

- The exclusive use of deep-water wells for irrigation, with the necessity of the government to help small farmers who cannot afford the high cost of deep wells, coupled with the use of modern irrigation methods appropriate to the weather conditions of the desert region, and in the most suitable periods or times. It is essential to adopt drip irrigation and to eliminate flood irrigation practices. Watering during the day should be avoided because of the high temperatures increasing evaporation rates during daytime.

- The reliance on vertical agriculture rather than on horizontal agriculture in order to reduce the leaching of soil salts, and use of foliar fertilisation when necessary, and according to the recommendations of the scientific program.

- It will be fundamental to give the salinity issue more attention by studying it more exactly. Such a task should be conducted by competent and experienced scientists (due to their awareness of the seriousness of the phenomenon), in calculating the water budget to determine the amount of leaching of the groundwater, and tracking the changes in shallow water for irrigation in private farms and other sites. This will help researchers know how the parameters are altered through time, and when the changes occur, due to the importance of these changes for the development of appropriate strategies.

- It is advisable to obtain a series of data values from different depths of the known sites, and establish an index on the basis of the data in order to build an accurate model which will reflect the effects of the irrigation with different qualities of water on saline soils, It is also possible to test other parameters such as micronutrients and the dropout rate, to ascertain whether or not these parameters play a similar role, or are equally or more important than those considered by this study.

- Taking several measures to ensure the conservation of the water resources and to reduce further deterioration of the quality of irrigation water through: keeping accurate records of all irrigation wells, determining the location and the quality of their waters, and developing further research in irrigation and rationalisation when using irrigation water, as well as promoting use of the most modern irrigation techniques known for their high-efficiency. In addition, attention should be paid to issues involved in determining appropriate depths for drilling wells in proportion to the water quality of the aquifer.

- Follow the appropriate improvement in methods for soil management according to the requirements of each area, reflected by: the use of agricultural methods to preserve the variety of plant species adapted to soil and water quality, so that appropriate species and cultivars of varying salt-tolerance can be used, appropriate to the soil characteristics. It will also be relevant to encourage the further cultivation and development of salt-resistant crop plants, and to establish specific programs which will allow the forecasting of soil salinity, together with a database showing soil deterioration in the Kufra area.

- Additional studies are needed to identify optimum irrigation practices, especially irrigation scheduling and leaching fraction management.

- Conducting specific studies on non-crop plant species growing in the area, which are able to resist drought, salinity and other desert climatic conditions, in order to assess the feasibility of using available natural vegetation in order to treat salt-affected soils. Their potential nutritional value for use as livestock feed could also be investigated.

- Use the agricultural cycle of the alfalfa in private farms and re-evaluation of the productivities

7.7 Future work

The main objectives of this study were to evaluate the effects that may have been caused by the irrigation with different quality of irrigation water on the physical and chemical properties of Kufra region soils and evaluate the yield of alfalfa and potatoes under two different agricultural management. Based on the present results of this study and literature reviewed, several lines of further research or work can be suggested:

1. Track changes in the Kufra agricultural regions to see how the parameters change over time in well waters. For example, it would be desirable to know how change these parameters with well depths.
2. The study of the causes for the increase of salinity irrigation water with low depth of the well.
3. Test other parameters, such as soil micronutrients and infiltration rate, to see if they are equally or more important parameters than those studied here.
4. Study the depths of more than 1 m to determine the impact of irrigation on soil
5. Extensive study to compare a greater number of crop productions between state farms and private farms with the unification of the constants except for the quality of irrigation water.
6. Comparison of the production of potato crop in state and private farms in the same year with the unification of the constants as class and planting date, fertilization and irrigation methods.

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9 Appendix

Appendix 9 - 1 Water analysis of the deeper wells from the state farms (Kufra Agricultural Project.

Well No.	Depth (m)	pH	EC (dSm^{-1})	Ca ($mmol_c l^{-1}$)	Mg ($mmol_c l^{-1}$)	Na ($mmol_c l^{-1}$)	SAR
1	285	6.30	0.219	0.70	0.55	0.91	1.15
2	352	6.55	0.170	0.60	0.50	0.65	0.88
3	241	6.51	0.220	0.80	0.55	0.91	1.11
4	270	6.57	0.212	0.70	0.50	0.74	0.96
5	265	6.55	0.242	0.65	0.45	0.74	1.00
6	270	6.58	0.12	0.68	0.50	0.67	0.90
7	255	7.56	0.29	0.90	0.59	1.35	1.57
8	245	6.26	0.28	0.95	0.60	1.25	1.40
9	220	6.37	0.35	1.10	0.70	1.39	1.40
10	261	6.80	0.183	0.70	0.55	0.87	1.10
11	260	6.65	0.217	0.70	0.50	0.91	1.18
12	255	6.85	0.229	0.90	0.60	0.96	1.10
13	260	6.51	0.173	0.65	0.45	0.61	0.82
14	250	6.58	0.514	1.70	1.20	2.00	1.66
15	235	6.48	0.428	1.35	0.85	1.65	1.57
16	282	6.42	0.169	0.55	0.45	0.65	0.92
17	267	6.60	0.163	0.60	0.40	0.65	0.91
18	240	6.43	0.336	1.20	0.80	1.15	1.15

Appendix 9 - 2 Water analyses of the deeper wells from the state farms (Kufra Agricultural Project)

Well No.	Depth (m)	pH	EC (dSm^{-1})	Ca ($mmol_cl^{-1}$)	Mg ($mmol_cl^{-1}$)	Na ($mmol_cl^{-1}$)	SAR
19	242	6.65	0.159	0.50	0.50	0.65	0.92
20	242	6.66	0.185	0.70	0.50	0.74	0.96
21	230	6.44	0.385	1.20	0.70	1.74	1.79
22	255	6.58	0.435	1.30	0.70	2.00	2.00
23	230	6.64	0.721	2.40	1.60	2.74	1.94
24	292	6.84	0.189	0.60	0.50	0.87	1.17
25	281	6.67	0.184	0.60	0.40	0.91	0.91
26	262	6.45	0.228	0.60	0.55	0.96	1.28
27	250	6.70	0.224	0.70	0.40	1.00	1.35
28	242	6.59	0.271	0.80	0.70	1.13	1.31
29	258	6.37	0.274	0.80	0.50	1.22	1.52
30	245	6.54	0.364	1.40	0.60	1.39	1.39
31	252	7.15	0.173	0.50	0.50	0.78	1.11
32	248	6.77	0.159	0.50	0.40	0.69	1.03
33	232	6.38	0.166	0.50	0.40	0.83	1.23
34	280	6.74	0.184	0.50	0.40	0.96	1.43
35	255	6.53	0.207	0.50	0.50	0.96	1.37
36	231	6.94	0.152	0.51	0.41	0.69	1.01

Appendix 9 -3 Water analyses of the shallow wells from the private farms.

Well No.	Depth (m)	pH	EC (dSm^{-1})	Ca ($mmol_cl^{-1}$)	Mg ($mmol_cl^{-1}$)	Na ($mmol_cl^{-1}$)	SAR
1	55	7.47	1.592	2.6	2.2	8.7	5.8
2	47	7.49	2.867	5.1	3.4	13.04	6.3
3	30	7.63	3.982	7.0	4.6	14.48	6.6
4	25	7.55	4.983	6.35	4.83	30.06	12.7
5	36	7.66	3.331	8.92	4.27	17.29	6.7
6	24	7.60	5.031	13.59	9.10	30.13	8.9
7	45	7.38	2.807	8.99	5.04	12.97	4.9
8	23	7.56	6.321	13.87	9.51	34.37	10.0
9	26	7.73	5.449	9.93	5.75	30.23	10.8
10	18	7.80	6.886	14.64	12.33	41.43	11.3
11	20	7.71	6.661	13.04	11.88	38.14	10.8
12	35	7.56	3.021	8.96	5.33	16.87	6.32
13	25	7.59	5.12	13.62	10.82	25.10	7.2
14	25	7.56	5.26	13.58	11.02	29.57	8.4
15	19	7.77	6.76	15.59	12.68	41.53	10.9
16	33	7.54	3.32	10.44	3.35	17.64	6.8
17	38	7.6	3.1	8.3	3.8	15.26	6.2
18	43	7.4	2.78	8.7	4.79	12.25	4.7
19	40	7.8	2.12	5.3	3.70	8.52	3.9
20	30	7.6	4.14	6.96	4.76	14.85	6.1
21	27	7.74	5.417	10.0	6.5	30.43	10.6
22	19	7.55	7.806	15.20	12.8	41.3	11.0
23	30	7.73	4.831	9.14	5.8	18.24	6.7

Appendix 9 -4 Water analyses of the shallow wells from the private farms.

Well No.	Depth (m)	pH	EC (dSm^{-1})	Ca (mmol$_c$l^{-1})	Mg (mmol$_c$l^{-1})	Na (mmol$_c$l^{-1})	SAR
24	25	7.65	5.101	13.54	10.59	29.14	8.4
25	42	7.40	3.180	8.10	5.33	23.21	8.9
26	21	7.67	6.451	12.34	5.68	34.91	11.6
27	32	7.81	3.561	10.66	3.52	17.95	6.7
28	25	7.75	5.062	11.3	7.74	29.98	9.7
29	42	7.31	3.17	8.05	5.32	15.47	6.0
30	23	7.59	6.50	14.01	9.27	34.40	10.1
31	35	7.52	3.07	8.98	5.23	17.05	6.3
32	29	7.66	4.01	8.33	4.88	16.45	6.3
33	27	7.77	4.25	7.90	4.70	30.43	12
34	31	7.67	3.274	9.6	4.14	17.28	6.6
35	27	7.77	5.31	10.02	6.56	29.25	10.1
36	22	7.70	6.56	12.76	7.87	34.65	10.8
37	31	7.65	3.25	9.61	4.19	17.27	6.6
38	44	7.37	2.81	8.88	4.98	12.91	4.9
39	43	7.30	2.80	8.85	4.91	12.76	4.9
40	50	7.20	2.06	4.03	2.79	10.75	5.8
41	48	7.20	2.21	4.24	2.99	11.00	5.8
42	20	7.73	6.64	13.08	11.93	38.22	10.8
43	28	7.46	5.05	9.81	6.15	29.82	10.7
44	42	7.27	2.87	7.86	5.50	15.67	6.0
45	30	7.64	3.92	6.93	4.59	14.86	6.2
46	22	7.66	6.39	12.57	5.79	35.17	11.6

Regions Al-Jwaf - Al- Zawriq – Hawari