Impact of Irrigation Frequency and Farm Yard Manure on a Salt-Affected Soil and Wheat Production in Dongola

By

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DEDICATION

To my father and Mother

To those whom I love ..

And admire particularly, My brothers and Sisters

El Moiez Lidin Allah

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ABSTRACT

A field experiment was conducted in January 2001 and December 2002, at Dongola University Farm to investigate the effects of irrigation frequency and farm yard manure on salt leaching and on wheat (*Triticum aestivum* L.) growth on a saline – sodic sandy loam soil classified as fine loam, mixed, hyperthermic, Sodic Haplocalcids. Each experiment consisted of three irrigation frequencies: 7, 14, and 21 days, and three levels of farm yard manure (F.Y.M): 0, 4.8 and 9.7 ton/fed. The quantity of water applied was proportional to the irrigation frequency and estimated from knowledge of reference evapotranspiration as predicted by Jensen and Haise equation, a crop factor and an irrigation efficiency value. Each treatment was replicated thrice in a split-plot design.

Irrigation treatments accommodated main plots (7 × 18m) and organic amendment sub-plots (7 × 6m). Results showed that all irrigation treatments caused salt leaching, which decreased with increase of soil depth. Furthermore, irrigating every 7 or 14 days caused more leaching than irrigating every 21 days. Application of F.Y.M. increased the effectiveness of salt leaching, however, 9.7 ton/fed was disadvantageous in salt leaching, because it required more water.

The effect of irrigation frequency on yield components was greater than the effect of organic amendment. Irrigation every 7 or 14 days increased leaf area index (L.A.I.). Addition of F.Y.M. increased plant height at 7 and 14 days, other yield components including head length, number of heads/m^2, number of grains /head and 1000 grain weight increased significantly in the following order: 7 > 14 > 21, days in the first season.

The effects of treatments on biomass had the same trend in the first season, but the trend was different in the second season. However, the effects on grain yield had the same trend in both seasons.

Decrease in irrigation frequency and addition of organic amendments increased crop water use efficiency (W.U.E.) in both seasons.

خلاصة الأطروحة

، بمزرعة جامعة دنقلا 2002 وديسمبر 2001أجريت تجربتين حقليتين في يناير
بغرض دراسة تأثيرات الري والسماد البلدي علي غسيل الأملاح ونمو القمح في الأراضي
يوم وثلاثة 21، 14، 7الملحية الصودية. كل تجربة أحتوت علي ثلاثة مناوبات ري:
طن/ فدان. 9.7، 4.8، 0مستويات من سماد الحظائر:
كمية الماء التي أضيفت تناسبت مع مناوبات الري وذلك لمعرفة مرجع البخر نتح
المحسوب بمعادلة جنسين وهييز، معامل المحصول وكفاءة الري. كل معاملة كررت ثلاثة
مرات باستخدام طريقة القطعة المنشقة.

م) 7x6م) لمعاملات الري والقطع الصغيرة (7x18خصصت القطعة الكبيرة (
للسماد البلدي.

أوضحت النتائج أن معاملات الري تسببت في غسيل الأملاح والذي ينخفض
بزيادة العمق.

يوم تسبب في غسيل الأملاح أكثر من الري 14 أو 7أوضحت النتائج أن الري كل
يوم. 21كل

إضافة السماد البلدي (روث البهائم) زاد من فعالية غسيل الأملاح، رغم أن
طن/فدان أعطى نتائج عكسية لحوجته لوفرة من الماء.9.7المستوى
مناوبات الري كانت أكثر تأثيراً علي مكونات الإنتاج من السماد البلدي، الري كل
يوم زاد من دليل مساحة الورقة، وارتفاع النبات عند إضافة السماد.14 أو 7
مكونات الإنتاج الأخرى متضمناً طول السنبلة، عدد السنابل في المتر المربع وعدد البذور
حبة والكتلة الحية زادت زيادة معنوية في الموسم الأول فقط.1000في السنبلة ووزن الـ
أثبتت التجارب أن نقص مناوبات الري وإضافة السماد البلدي زادوا من الإنتاج
وكفاءة استخدام الماء للمحصول في الموسمين.

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Chapter I

INTRODUCTION

The accumulation of excessive amount of salts in agricultural lands is a major soil constraint that spreads worldwide, particularly in the arid and semi-arid areas, (Nachtergaele, 1976; Mustafa, 1986).

Because salinization reduces the productive capacities of the land, it is considered as one of the determinative processes of desertification.

In North Sudan, more than 250 thousand hectares of land are affected to some degree by salinity and sodicity (Izzeldin, 1996).

Dongola area is severely affected by desertification and salinization processes. Furthermore, the land is much fractionated due to land tenure laws. The fertile and more productive first terrace soils are intensively used. This prompted horizontal expansion of agriculture into the upper terrace salt-affected soils (Izzeldin *et al*., 2000). Hence utilization of salt-affected soils has become an important aspect of agricultural development. The upper terrace soils are constrained by salinity and sodicity, which reduce crop productivity due to the osmotic and specific ion effects. The specific ion effect i.e. Na, may be toxic, nutritional imbalance or deterioration of soil physical properties.

Wheat (*Triticum aestivum* L.) is a strategic field crop in the Sudan. It is grown in northern and Central Sudan. But recently, there was a trend to restrict its production in the Northern State because of its favourable environment. Furthermore, wheat is the favourite cereal of a wide sector of northern people. The accessibility of good quality Nile water and ground water prompted horizontal agricultural expansion in the salt-affected upper terrace soils (Mustafa, 1973; Mustafa, 1984; Izzeldin, 1996).

Water resources in the Sudan are limited because of the large expansion of the cropped area particularly in arid and semi-arid region. The scarcity of rainfall led to increased demand for irrigation water. This situation emphasizes the need for using scientifically sound method for scheduling irrigation water.

Soil amendments proved to be efficient sources of nutrient and good soil physical conditioners, and their application to the soils offers another possibility of increasing the efficiency of salt leaching.

Previous research emphasized the combined favourable effects of fertilizers, irrigation management and organic amendment on the production of forage sorghum and Lucerne in salt-affected soils of Shambat and Soba Research Station (Mustafa and Abdel Magid, 1982; Gaber, 1984; Abdel Rahim, 1985; Ahmed, 1995).

Very limited research was conducted on wheat in the salt-affected soils of Dongola (Izzeldin, 1996).

The main objectives of this research is to investigate the effect of different irrigation regimes and different levels of farm yard manure (FYM) on soil properties and wheat growth in a salt-affected Aridisol in Dongola.

Chapter II
LITERATURE REVIEW

2.1 SALINITY: PROBLEM AND DISTRIBUTION IN SUDAN

2.1.1 Introduction

Salt-affected soils contain excessive concentration of soluble salts and/or exchangeable sodium percentage. For agricultural purposes such soils are regarded as problem soils that require special reclamation measures and appropriate soil and water management practices (Richards and Hayward, 1957).

Soil salinization arises due to the build up of soluble salts within the root zone by primary and secondary processes that alter the soil physicochemical properties and lead to direct and indirect soil degradation (Schofield *et al*., 2001). Knowledge of physicochemical characteristics of the different types of salt-affected soils is essential to serve as basis for their diagnosis, amelioration and management.

Sudan is a large country (2.5×10^6 km^2) dominated by arid and semi-arid tropical regions that favour the formation of salt-affected soils (Mustafa, 1986). It has 2138 hectares of saline area and 2736 hectares of sodic area (FAO/UNESCO, 1988).

In the Sudan, there are three soil orders. Affected by salts namely Vertisols, Aridisols and Entisols. The flood plains and the upper terraces are affected to various degrees by salinity and sodicity (Finck, 1961; Blockhius *et al*., 1964; DeVos and Virgo, 1969; Soil Survey Staff, 1976).

2.1.2 Distribution of salt-affected soils in the Sudan

Seven selected areas extending from Managil to Wadielkhawi, were surveyed by the Soil Survey Administration. Sodium was found to be the dominant cation in these soils (Nachtergaele, 1976).

The following four soil groups were distinguished with regard to anion dominance:

(1) Managil and North Gezira:

Sulphate or Sulphate plus carbonate is the dominant anion in the top soil, where as in the subsoil sulphate is dominant.

(2) Khartoum and Shandi:

Chloride and sulphates are dominant anions both in top and subsoil.

(3) Eldamer:

Similar to the second group above with the exception that chloride is dominant in the subsoil.

(4) Wadi Elkhawi:

Sulphate is dominant in the top soil, while chloride and sulphate are dominant in the subsoil.

Soils of the Northern State:

Northern State is characterized by an arid climate, where evapotranspiration exceeds precipitation throughout the year.

Natural vegetation is lacking except few scattered *salam* trees along valleys (Ahmed, 2001). Agricultural activity is confined to the stripes parallel to the River Nile banks and oases. The rest of the state is completely desert. Due to the high wind velocities in the north and north-east directions, desertification processes are in progress. Generally, the soils may be classified into three main groups according to distance from the Nile.

(1) First terrace (*Gureir*) soils:

These are recent alluvial deposits on islands and narrow river banks. They have a sandy to clay loam textures, very good soil physical and chemical properties (nonsaline, nonsodic) and have no limitation for plant growth and yield. The fact that these soils are subjected to annual flooding limit their suitability for perennial crops (Ahmed, 2001).

(2) Second terrace (*Karu*) soils:

It is an old alluvium which once formed the river bank (Joseph, 1924). Ahmed (2001) described this group, which occur directly after *gureir* soil. They are darker in color and have slightly more clay content compared to the *gureir*. Saline and/or sodic pockets are sometimes present. This group is not very extensive.

(3) Third (Upper) terrace soils:

This group lies after *karu* soil and occupies larger areas compared to the first two groups. The upper terrace soils are affected by some of the following limitations:

Climatic limitation, unfavorable topography, erosion hazards, salinity, sodicity, low chemical fertility (NPK), low organic carbon, surface gravel cover and stones, shallow soil depth.

The most common order in the state is Aridisols Entisols occurs but not common (Ahmed, 2001).

Entisols extend on the first terrace, and the Aridisols occur in the second and third terraces (Izzeldin, 1996). The third terrace soils dominate the west bank, where as the first and the second (basin) terrace soils dominate the east bank.

2.1.3 Composition of salt-affected soils

Most of the salt-affected soils of Sudan are characterized by low fertility status. In general, the soil profiles contain appreciable amounts of $CaCO_3$ and gypsum (Gupta, 1969). However, the Northern State soils were considered devoid of gypsum and even in few cases, when present, quantities are not sufficient for sodicity correction. The dominant clay minerals are montmorillonite, chlorite and traces of kaolinite (Bonifica, 1986).

2.2 EFFECT OF SALTS ON SOIL PROPERTIES

2.2.1 Effect of salts on physicochemical properties

The effect of salt on soil properties depends upon kind and concentrations of salts, nature of soils and climatic factors. These effects include chemical, physical and microbiological effects. The effect of salts on cation exchange reactions play an important role in alkali soils. Kelley and Cummins (1921) showed that the amounts of Ca^{++} and Mg^{++} replaced and Na^{+} adsorbed increased as the concentration of Na^{+} in solution increased. The replacing power of the common bases given by various research workers are in the following order: $Na^{+} < K^{+} < Mg^{++} < Ca^{++}$. The relative replacing powers of the common bases depend on at least three variables, namely, concentration of the solution, the kind of adsorbed cation, and the kind of exchangeable material in the soil. When salt of Ca^{++} or $Ca^{++} + Mg^{++}$ in addition to Na^{+} accumulate in a soil, cation exchange will be substantially different from that produced when a pure Na^{+} salt of equal concentration accumulates. The solubility of $CaCO_3$ in Na_2SO_4 exceeds that in NaCl considerably but is not high in either cases. Hissink (1907) leached a soil sample with 0.17 N of chloride solution followed by distilled water after few days. The result showed that the rate of leaching decreased with all samples. Williams (1968) performed one hundred and fifty seven permeability tests on varied soil horizons in the west-central Gezira. He found that the permeability decreased with decrease in solube salt content of soil with a high proportion of exchangeable sodium. Non-saline non-alkali soils were as permeable as saline non-alkali soils, and that most highly saline alkali soils are floccutated and relatively permeable. Highly alkali soils are impermeable whether saline or not, and soil of intermediate alkalinity (ESP = 30-45) show a slight increase in permeability as salt content increases. Permeability cannot be predicted solely from knowledge of soil texture, exchangeable sodium content and salinity, but factors such as soil depth, porosity, bulk density, micro and macro structure, land use, and root penetration are also important determinates of permeability.

Soil crust formation is a phenomenon, which results from the salt physical effect. It is formed either by mechanical action due to the direct impact of rain drops on the soil surface, or by chemical action such as hydration and dispersion (Levy *et al*., 1986). A soil crust consists of a thin dense surface layer with oriented clay particles caused by compaction or sorting. Crusts formed by this method are referred to as structural crusts, while crusts formed in depressions due to slow sedimentation of soil particles are referred to as depositional crusts (Shainberger and Singer, 1985). Crust thickness can vary from < 1mm for structural crust (McIntyre, 1958) to several centimeters for depositional crusts, which is much more compact, hard and brittle, when dry than the material immediately beneath. Crusting is one of the surface features of salt-affected soils (Richards, 1954; Brady, 1984; Mohammed and Mustafa, 2001).

Crusts form on alkali soils but their formation is by no means limited to these soils. Factors influencing development of hard surface crusts include exchangeable sodium, low organic matter, puddling and wetting the soil to zero tension. An important crust presents a serious barrier for emerging seedlings and, for some crops, crusting is often the main cause of a poor stand. A negative linear relationship between crust strength and seedling emergence was reported by several research workers (Richards, 1954; Black, 1957; Gupta and Yadav, 1978).

Alperovitch *et al*. (1981) found that in calcareous soils the exchangeable Mg does not affect hydraulic conductivity (HC) or clay dispersion; conversely in soils which do not contain $CaCO_3$, exchangeable Mg decrease HC and increase clay dispersion. Barrow

(1979) found that phosphate concentration in solution increased with increase in temperature. This effect was interpreted as an effect of temperature on the position of the equilibrium between solution phosphate and adsorbed phosphate. Bolan *et al*. (1986) suggested that, depending upon pH, phosphate is adsorbed when the potential in the plane of adsorption is either positive or negative; where as sulphate is absorbed only when the potential is positive. El Mahi and Mustafa (1980) studied the effect of both electrolyte concentration (C) and sodium adsorption ratio (SAR) on phosphorus retention by three surface soil samples from arid zone, equilibrated to different (SAR) values. The result showed that phosphorus retention increased as the total salt concentration increased and SAR decreased. Also Verma and Kachroo (1984) observed that $CaCO_3$ decreased available P and Zn in soils. Malik *et al*. (1992) studied the effect of mixed Na/Ca solution on swelling, dispersion and transient water flow in unsaturated montmorillonitic soil. Results showed that swelling and dispersion increased when SAR increased and/or electrolyte concentration decreased (Mohammed and Mustafa, 2000). Also penetrability and unsaturated hydraulic conductivity decreased with the increase in (SAR) and/or decrease in electrolyte concentration. Hamid and Mustafa (1975) showed that the hydraulic conductivity (K) was sensitive to (SAR) and salt concentration (C). For a solution of SAR = 0 and C = 800 meq/L, K was 63mm/hr, whereas for SAR = 25 and C = 3.1 meq/L, K was 6.3mm/hr. Saleh and Letey (1990) studied the effect of two synthetic polymers on the physical properties of a sodium treated soil. Their investigation showed that flocculation, aggregate, stability and the soil strength decreased with increase of SAR. The relatively high ESP of the Gezira soil decrease soil permeability, impede drainage, increase water retention capacity and have adverse effects on soil aeration (Green, 1928, 1935; Zein El Abdine *et al.*, 1969; Mustafa, 1986). The minimum electrolyte concentration required to maintain a relative hydraulic conductivity of 0.75 in a Gezira Vertisol of ESP = 25 is 400 meq/L^{-1} (Hamid and Mustafa, 1975). Chloride and sodium sulphate salts give higher electrical conductivity (EC) than $MgSO_4$, $CaSO_4$ and $NaHCO_3$ (Richard, 1954).

2.2.2 Effect of salt on soil micro-organism

Salt accumulation affects the activities of soil micro-organism. Lipman and Sharp (1912) found that the action of non-symbiotic bacteria was affected by NaCl below 0.5% concentration and by Na_2SO_4 concentration above 1.2%. Nitrogen fixation was markedly depressed by 0.5% $NaCO_3$. The results also showed that with salt concentrations slightly above these toxicity was marked specially with NaCl. Increase of salt concentration directly increases the degree of toxicity. Richardson (1938) and Russell (1950) showed that lack of calcium and phosphate limits the rate of nitrification produced by organism due to high pH. At high levels of sodicity, the rate of urea hydrolysis decreased when salinity level increased. This was attributed to high concentration of salt, which adversely affected the microbial growth, and hence, the microbial induced urease activity, which caused reduction in the rate of urea hydrolysis (Awad El Karim *et al.*, 1995).

Salinity significantly reduced nodulation, dry matter production, plant nitrogen content and nitrogen fixation (Forawi and Elsheikh, 1995; Ahmed and Elsheikh, 1998).

2.3 EFFECT OF SALINITY AND SODICITY ON PLANT GROWTH

2.3.1 Osmotic effect

There are two forms of osmotic potential, one is a partial component of matric potential, namely, osmotic potential due retained salts and the other is osmotic potential due to free salts. The magnitude of latter depends on the total salt concentration. As the salt concentration increases, the osmotic potential (ψ_o) decreases according to the following empirical relationship:

$$\psi_o = -0.36 \text{ ECe}$$

Where

ψ_o ≡ osmotic potential

ECe ≡ electrical conductivity of paste extraction

– 0.36= constant

The decrease in the osmotic potential limits the uptake of water by plant root (Eaton, 1941; Buckman and Brady, 1952; Richards, 1954; Hanks and Saken, 1977).

Buckman and Brady (1952) stated that high soluble salt concentration brought into contact with a plant cell will cause shrinkage of the protoplasmic lining. This action is called plasmolysis and it is due to the osmotic movement of water from the cell towards the more concentrated soil solution causing the cell to collapse. Uhvits (1946) found that the percentage of germination of alfalfa seeds decreased with increase of osmotic pressures of NaCl. Hegan (1973) stated that the growth of plant is depressed at an osmotic potential ranging from –3 to –4 bar, the plants are killed when osmotic potential ranges between –5 to –6 bar. Hayward and Spurr (1944) grew corn plants in nutrient solutions and transferred them to other solutions in which the kind and concentration of solute were varied, they found that the rate of water-intake decreased with increasing concentration of each solute. The study of osmotic effect was carried further by Wadleigh and Ayers, (1945) who grew bean plants in cultures of soil that were treated with different quantities of sodium chloride. They found that the growth of the plants decreased with increasing water tension and increasing salt content. Black (1957) reported that plant growing in saline soils are relatively small in size and dark bluish-green in color due to low content of chlorophyll and a usually thick coating of wax. Rains (1972) noted that if a plant cannot regulate cellular ionic contents, its survival is reduced. Richards (1954) stated that the primary deleterious effect of excessive salinity is the increase of the concentration of the soil solution; in consequence, the flow of water into the plant by osmosis is reduced or reversed and the plant is starved of water even though the soil is moist. Hank and Saken (1977) reported that main effect of salinity is making soil water relatively less available to the plant uptake. The presence of large amount of soluble salt in the root zone may limit water uptake by plants and may cause physiological and metabolic disorder.

2.3.2 Nutritional imbalance and toxic effect

This problem occurs when certain constituents in the soil solution are taken up by the crop and accumulated in amounts that causes nutritional imbalances or plant toxicity and consequently reduce crop yield. Certain ions exert specific effects that depress growth and yield independent of osmotic effects. A toxic effect is considered due to the presence of an ion in the solution, which cause direct damage to the plant. Injury is usually associated with the accumulation of harmful concentration of the toxic ion in the plant tissue. Brown *et al.* (1953) grew various stone fruit trees in sand cultures and added calcium or sodium chloride, the growth was much poorer in the cultures salinized with calcium chloride than in those salinized with sodium chloride.

Gauch and Wadleigh (1944) found that the yield of bean plants was impaired by magnesium. Hayward and Wadleigh (1949) showed that high concentrations of sulphate generally, decreased the uptake of calcium, but promoted the uptake of sodium. Rao *et al.* (1969) studied the effect of salinity on the germination of paddy rice varieties and found that potassium sulphate was least harmful, while calcium chloride most harmful, sodium chloride was next to calcium chloride in suppressing germination. Patil and Bhambota (1980) indicated that higher soil salinity levels decreased K^+ and Ca^{++} in leaves of all root stocks of different citrus trees. Jumberi *et al*. (2002) studied the effect of salinity and sodicity on the growth and absorption of metal elements by asparagus, tomato and bean. They found that shoot dry weight of the three species decreased with increase in ESP, growth of asparagus and tomato was suppressed by salinity and strongly suppressed by salinity and sodicity. However, beans couldnot survive under saline and sodic condition. The sodium concentration in shoot increased with increase in ESP. Asparagus and tomato showed a lower ability to absorb low-available microelements in sodic than in saline soils. Page and Talibudeen (1982) noted that the yield reductions of wheat, maize, peas, beans and sugar beet caused by higher potassium potentials, were caused by inhibition of the uptake of other cations rather than by toxic levels of potassium in the plant tissue. Larson and Pierre (1953) reported that the addition of either Na^+ or K^+, depresses the uptake of Ca^{++} and Mg^{++} but the addition of one may have little effect if Ca^{++} and Mg^{++} have already been depressed by the other. Heikal (1977) studied the effect of salinity stresses on water content and mineral composition. He found that the leaf water content of wheat was not affected by salinity whereas the water content of leaves of safflower, sunflower and radish, were significantly decreased at high salinity level (6000 ppm) only. Total nitrogen content of safflower and sunflower leaves were significantly increased, whereas those of wheat and radish were, significantly, decreased. Salinity and phosphorus content significant effect on all test plants, but it significantly reduced Na^+ and Ca^{++} content. Mg^{++} content of salf flower and sunflower was, significantly decreased by salinity but the effect was non significant in case of wheat and radish. Parra and Cruze Romero (1980) showed that transpiration rate and leaf extension rate per plant unit of leaf area were decreased by increasing soil salinity and by decreasing soil moisture. Meiri *et al*. (1981) reported that increased salinity reduced fruit size in musk melon (*Cucumis melo*). However, ripening was accelerated by salinity. Shalhevet *et al*. (1969) reported a reduction of seed size in groundnuts beginning at soil salinity level ECe of 3 dS/m, however, there is an increase in seed oil content with increasing salinity up to a point.

2.3.3 Soil physical deterioration

Sodium causes dispersion of the soil colloidal particles in non saline alkali soils. The dispersed colloidal soil particles clog the large pores and there by reduces soil permeability (Fireman and Reeve, 1949; Marwan and Rowell, 1995). Puttaswamygowda *et al*. (1973) reported that exchangeable sodium is known of its adversed effect on physical properties of the soil. It reduces water movement, limits salt leaching, restricts aeration and causes nutrition imbalance. Abrol *et al*. (1975) stated that excess sodium, impart causes poor physical properties to soils, raises soil pH and the latter effect brings about nutritional imbalance in the soil that reduces crop growth and yield. Hamid and Mustafa (1975) using equilibrated Vertisol soil samples found that the relative hydraulic conductivity (RHC) decreased and dispersion index (DI) increased as ESP increased and C decreased. DI was found to account for over 80% of the variability of RHC. Malik *et al*. (1992) found that swelling and dispersion increased when SAR increased and/or salt concentration decreased. Penetrability and unsaturated hydraulic conductivity decreased with increase in SAR and/or decrease in C. Mohamed and Mustafa (2001), using equilibrated soil samples from an Aridisol and Vertisol observed significant polynomial increase in soil strength with increase in SAR and decrease in salt concentration (C).

2.4 RECLAMATION

2.4.1 General

The reclamation of salt-affected soil is the process and practice of removal of the excessive salinity and sodicity from the root zone. The different methods used for reclamation and improvement of slat-affected soils are reported in the forthcoming sections. The reclamation of a specific soil may involve the use of one or more of these methods.

2.4.2 Chemical methods

Reclamation of saline soils involves the leaching and removal of excessive salt from the root zone, whereas reclamation of sodic soil is based upon the removal of sodium ions from the base-exchange complex by replacement with calcium ions. The replaced sodium must then, be removed from the soil through leaching.

There are three sources of calcium ions:

(1) Calcium compounds of low solubility such as calcium carbonate and gypsum.

(2) Soluble calcium salts, e.g. calcium chloride.

(3) Acidifying materials, e.g. sulfuric acid, sulphur and ion sulphate.

The type and amount of chemical used for amelioration depend upon the soil characteristic, required rate of replacement and economic consideration (Yadav, 1993; Izzeldin, 1996).

The effectiveness of an amendment under different soil conditions is governed by different factors, the principal ones being the alkaline-earth carbonate content and pH value (Richards, 1954). Davidson and Quirk (1961); Bajwa *et al*. (1993), showed that treatment with gypsum leads to a more friable soil surface, increased yield per plant due to increased infiltration rate. Mahgoub (1979) found that the addition of gypsum reduced ESP in the first 15cm layer. In the subsoil (30 – 60cm) gypsum application improved infiltration rate and salt leaching but increased the salt concentration in the upper 30cm. Apparently, most of the calcium emanating from the solution of the gypsum addition was adsorbed by the exchange complex of the upper three strata. Elamin (1980) showed that application rate of gypsum (11.9 tone/ha) significantly increased the germination percentage, however, the benefits from gypsum application were low (5% at the 7 day irrigation interval). Yagodim (1982) stated that the effectiveness of gypsum application is significantly enhanced when it is combined with deep tillage or if gypsum is present in the subsoil. Niazi *et al*. (2001) studied the effects of gypsum, H_2SO_4, farmyard manure and sand on the performance of wheat and rice on a salt-affected soil. The combination of gypsum and F.Y.M. reduced the ECe more than the rest. A significant reduction in SAR was recorded with the application of gypsum and H_2SO_4 and sand with gypsum application significantly enhanced grain yield of both crops.

2.4.3 Mechanical methods

Several physical methods have been used to improve salt-affected soils. These methods include deep ploughing, subsoiling, sanding and profile inversion. They improve soil permeability by mixing fine–and coarse–textured layers, by breaking up impermeable layers and by incorporating sand into a fine-textured soil and thereby increasing salt leaching efficiency. Deep ploughing of a soil containing appreciable amounts of gypsum in the subsoil enhances the reclamation of sodic soils by incorporation of the natural gypsum through the profile. Deep ploughing enhances mixing of subsoil with gypsum throughout the profile and, hence, promotes the replacement of exchangeable sodium by calcium (Rasmussen and McNeal, 1973). Sanding was found to be effective in promoting salt leaching in heavy clay soils (Hamdi *et al*., 1963; Izzeldin, 1983; Bonifica, 1986).

2.4.4 Biological methods

Living organisms and organic matter have the following three principal beneficial effects on reclamation of salt-affected soils:

(a) Improvement of soil permeability.

(b) Release of carbon dioxide during respiration and decomposition of organic matter. Mixing of carbon dioxide with water causes the formation of carbonic acid, which reacts with calcium carbonate to release calcium.

(c) The shading of plants reduces evaporation and the build up of surface salt by capillary movement of water. Shading the surface helps to prevent the rise of ground water (Leeper, 1964).

2.4.5 Hydro-technical methods

Hydro-technical methods include irrigation, leaching and drainage. They are essential for successful reclamation of saline and/or alkali soils. These methods are employed to complement other method i.e. biological. Drainage is essential for complete reclamation of salt-affected soils.

2.5 MANAGEMENT

When complete reclamation is not feasible such as in heavy clay soils, salt-affected soils are managed to give acceptable levels of production. The technical management package includes the use of salt tolerant crops, application of fertilizers, proper irrigation water management and addition of soil amendments (Mustafa and Abdelmagid, 1982; Rengasamy and Olsson, 1993).

2.5.1 Crop selection

Plants vary widely in their tolerance to salinity depending upon soil, climate, farm management practices and other local factors (Israelsen and Hansen, 1962). Tables of crop salt tolerance are available in various textbooks (Richards, 1954).

Crop tolerance is the ability of a crop to produce acceptable yield under saline soil conditions. The relative yield of the crop on the saline soil, as compared with its yield on a non-saline soil under similar growing conditions reviewed for crops (Maas and Hoffiman, 1977; Marcer *et al*., 1995; Slavich *et al*., 1999). Bernal *et al*. (1974) showed that wheat is relatively tolerant and germinates freely in the presence of -16 to -20 atm osmotic potential. Gauch and Wadleigh (1944) explained some plants become salt tolerant by accumulating salt in there root systems and restricts its transport upward into the leaves e.g. sugar beet. Jumberi *et al*. (2002), noted that tolerance of vegetable crops as in the case of grain crops conclude ionic balance with shoot and the ability to absorb low available micronutrient.

2.5.2 Soil management for better crop establish

Fine textured salt-affected soils are managed to improve salt leaching by physical, chemical and biological methods. These methods include tillage, deep ploughing, addition of gypsum, organic amendment etc.

2.5.3 Water and irrigation management

The salinity of the soil among other factors, depends on the quality and method for scheduling irrigation, amount and interval.

2.5.3.1 Water quality

Irrigation water contains dissolved salt in varying amounts. The quality of irrigation water is determined and classified by total salt concentration, SAR, residual sodium carbonate and the presence of certain toxic substances (Richards, 1954; Shainberger and Oster, 1978).

2.5.3.2 Irrigation management

In general, quantity of irrigation water is applied to an agricultural field to satisfy the water requirement of the crop and to control soil salinity within the root zone of a salt-affected soil. For optimum plant growth, water is applied to the field at a soil water potential between ⁻ ⅓ and – 15 bar, depending upon the soil, crop, stage of crop development and the evaporative demand of the atmosphere i.e. at a moisture content between wilting point and field capacity. Iljin and Maximove (1927) postulated that as the water content decreases, the cell content and protoplasm shrink away from the cell wall and water uptake by the plant is restricted. However, a drought tolerant crop e.g. sunflower has an elastic cell wall, which permits the cell wall to follow the contracting protoplasm. Turgor pressure was the main factor responsible for plastic extension of the cell wall and tissue. Thus, increasing irrigation interval will prolong the reduction in plant turgor pressure and cause reduction in cell elongation and consequently in LAI and plant height (Heyn, 1940). Abrol and Bhumbla (1973) studied the effect of continuous and intermittent ponding of water with or without the application of gypsum on salt leaching in highly saline sodic texture soil. After 42 days of water application, the results showed that gypsum greatly enhanced leaching of salts and that intermittent ponding had no particular advantage over continuous ponding, and this was ascribed to the low permeability of the studied soil. Amemiya *et al*. (1956) noted that there was a relationship between the amount of water used for leaching and the decrease of the amount of soluble salt and exchangeable sodium. They found that 4 to 6 feet of water were required to reclaim such a soil to depth of 50 inches. Russell (1950) stated that both adequate good quality water supply and appropriate crop rotation were an excellent insurance against alkali problem, since crops can build up the structure of a soil and improve its stability. El Nadi (1969) studied responses of a wheat to water stress during different stages of its growth. Flowering, grain filling and maturation (reproductive stage) were more sensitive to drought than the vegetative stage. Yield of wheat was not reduced when it suffered water stress during the vegetative period, if the crop received favourable water regimes, thereafter. Kirda *et al*. (1974) stated that continuous ponding produce shallower penetration of salt and water in comparison to intermittent ponding of water or continuous water application with low intensity sprinklers. Ahmed (1995) found that plant height, LAI and dry matter yield increased with decrease in irrigation interval. This finding was in agreement with Mustafa and Abdel Magid, 1982; Ahmed and Elhag, 1999, who attributed that to the fact that frequent irrigation reduced both osmotic and water stresses. This effect was thought to increase water uptake by plant roots, which enhanced cell elongation, nutrient uptake and subsequently lead to extensive growth. In a saline-sodic site in North-eastern Gezira, irrigation with Blue Nile water and cropping with alfalfa, caused a net downward movement of salts. Forty months of watering reduced the exchangeable sodium percentage from above 50 to below 10 in the top 30cm. Izzeldin *et al*. (2000) found that irrigation method significantly affected wheat performance, whereas ploughing depth and its interaction with irrigation method failed to do so. The 7-meter furrow basin, gave significantly the highest growth and yield. Baraka *et al*. (2000) concluded that all irrigation treatments caused salt leaching, which decreased with increase of soil depth. The ECe and SAR redistribution profile did not depict a marked salt accumulation zone. Abdel Rahim (1985) studied the effects of irrigation regimes and some soil amendments on salt redistribution and production of forage sorghum. The results showed that irrigation every 7 days improved salt removal and dealkalinization of the soil and increased yield, LAI, plant height and leaf nutrient uptake. Mahgoub (1979); Zhu and Lu (1993) concluded that lighter and frequent irrigation supply significantly increased wheat yield for all treatments.

2.5.4 Organic amendment

The use of domestic animal manure has long been recommended because of its value as an efficient source of nutrients for plants and as an amendment for soil physical conditions. The effectiveness of manure depends upon its composition which varies with kind and age of animal, feed consumed bedding used and waste management. The superiority of the manure as a source of nutrients was attributed to the slow release of nutrients from it. The surface application of organic matter to the soil or its incorporation with the surface soil was found to improve the soil structure and increase the water infiltration rate (Pillsbury, 1947; Pillsbury and Richards, 1954). Williams and Cooke (1961); Bhatnagar *et al*. (1992) found that the addition of farmyard manure to the soil improved and maintained soil structure. Leeper (1964) stated that organic matter has the reputation of improving the physical properties of both sandy and clayey soils, the main effect on sandy soils is to increase their ability to hold water, and its effect on clay soils is to improve soil structure. Puttaswamy Gowda *et al*. (1973) found that soil pH, ECe, SAR of the soil saturation extract and ESP were reduced by organic amendment. Crop growth also hastened the reclamation process. Dahiya and Singh (1980) showed that the farmyard manure application removed the harmful effect of $CaCO_3$ to some extend and increased the dry matter of oats. Organic manures are prized in horticultural husbandry for their favorable effects on soil physical conditions. Haworth (1959) found large increases in vegetable yield due to the application of F.Y.M., whereas the application of fertilizer had a little effect. Warren and Johnston (1960) suggested that F.Y.M. plowed into a cultivated soil layer is distributed through the whole soil top layer and so it is more effective than chemical fertilizer applied by hand to the soil surface. The effectiveness of gypsum as a soil amendment increased by the application of manure, nitrogen and phosphorus fertilizers (Russell, 1950; Ygodim, 1982). Prasad and Singh (1980) found that the continuous application of F.Y.M., N, P and K fertilizers and lime over a period of 20 years, improved hydraulic conductivity, aggregate stability, water holding capacity and porosity. These findings agree with those of reported by Darwish *et al*. (1995). These treatments also reduced soil pH and increased organic carbon, N, P and micronutrients. Singh *et al.* (1980), found that the continuous application of F.Y.M. to a sierozem semiarid region of Haryana resulted in a decreased in soil pH and an increase in organic carbon content, cation exchange capacity and exchangeable cations. Bandyopadhya *et al*. (1969) found that the application of compost increased organic carbon, total nitrogen, cation exchange capacity and decreased the exchangeable bases. Gabir (1984) reported that plant height and dry matter yield of Lucerne increased significantly due to the application of organic amendment, which improve salt leaching, N, P and K uptake and lowered soil sodicity. Salter and Haworth (1961) reported that the annual application of F.Y.M. to a sandy loam soil for six successive years, increased available water of the top 18cm by 33 percent. Tester (1990) observed that the addition of sewage-sludge compost, significantly reduced soil strength. Compost significantly reduced bulk density, but increased soil water content, pH and the specific surface area of the soil. Ammal *et al*. (2001) recorded maximum rice yield due to the application of compost plus 50% gypsum. This treatment reduced soil pH, ECe and ESP significantly due to the application of composted 100% gypsum requirement. Gomes *et al*. (2000) reported that F.Y.M. and gypsum, caused appreciable decrease in ESP, ECe, pH, however, the effect of the treatments on rice yield was not significant. Chicken manure was very effective in counteracting the salinity effect, which was reflected in the proportionate promotion of growth and yield in response to the applied amount (Eltilib *et al*., 1993; Elsheikh, 1998). Ahmed (1987) evaluated the effect of two soil amendments on wheat yield grown on a nonsaline sodic soil in Eldamer area. He concluded that gypsum had no effect on yield, while the application of organic manure resulted in a significant increase in yield of wheat crop.

2.5.5 Tolerance of wheat in salt-affected soil

Wheat is one of the most important cereal crops in Sudan. It is moderately tolerant to salinity (Richards, 1954). Harter (1905) Showed that half of the seedlings of wheat died by the following salt solutions:

0.05 N NaCl, 0.04 Na_2SO_4 , 0.026 $NaHCO_3$, 0.01 Na_2CO_3 , 0.009 $MgCl_2$, 0.007 $MgSO_4$. This range corresponds to 0.8–0.2 atm. However, the yield of rice was not reduced by ESP up to 55 and the decrease was 20% at an ESP of 75. However, the wheat yield was reduced by 40 percentage at an ESP of 45 and the crop will not grow when the ESP exceeds 55 (Hira *et al*, 1980). Similarly, Pearson and Bernstein (1958) observed that wheat crop can not grow beyond ESP of 51.

2.5.6 Response of wheat to fertilizers

Walia *et al* (1980) reviewed dry land wheat as influenced by nitrogen fertilization and reported that nitrogen application increased the dry matter up to 100 kg N/ha at all growth stages. Nirtogen content and its uptake at various growth stages, showed consistent positive relationship with grain yield. The dry matter yield produced at the dough and maturity stage was found to be related with grain yield. Nitrogen uptake was increased by application of F.Y.M. only. Dhargawe *et al.* (1992) observed that the application of 10–20 tons of F.Y.M /ha significantly increased phosphorus availability in soil, resulting in increased wheat dry matter production.

Chapter III

MATERIAL AND METHOD

3.1 THE STUDY AREA

A field experiment was conducted in two successive seasons (Dec. 2000 – April 2001, Dec. 2001 – April 2002) in Dongola University Farm at Elseleim village on the eastern bank of the Nile, opposite to Dongola town (10º 19'N, 29º 30'E).

3.1.1 Climate

The study was conducted in Dongola area, which is a true desert with extremely high temperatures and solar radiation in summer, low temperatures in winter, scarce rainfall, and high wind speed. The diurnal range of temperature is wide all the year round. The mean maximum and minimum temperatures are 36.8 and 19.5ºC, respectively. Temperatures as high as 49ºC are not uncommon in the period extending from April to June. In winter, temperatures as low as 1.0ºC have been recorded. The climate is hyper arid with a vapour pressure of only 10.8 mb and a relative humidity of less than 20%. The mean bright sunshine duration is 10.5 hours (at 87% of the possible hours). Clouds are generally rare. Solar radiation is as high as 27.1 in June, as low as 14.4 MJM in December. Rainfall is scarce with a mean annual amount of 12.3 mm, wind prevails from the north with a mean speed of 15.7 km/hr (Izzeldin, 1996).

3.1.2 Physiography

In Dongola area, a basement complex of Precambrian metamorphic rocks is over lain by the Nubian sandstone, which is known for its abundant ground water (Izzeldin, 1983). Andrew (1947) observed out crops of basement complex just north of Kerma town.

Alluvial deposits dominate the flood plains along the Nile bank. Away from this bank, sand dunes rest upon smooth ground sloping gently towards the Nile. The land is flat due to wind erosion and the nature of the underlying rocks (Andrew, 1947).

The geomorphology of the area is characterized by sand dunes and wind hammocks.

The soils of the study area are divided into two main groups, namely, soils of the recent flood plain and soils of the high terrace (Karouri, 1978).

3.2 MATERIALS

3.2.1 Soil of the experimental site

A profile was dug in the experimental site and described according to the standard soil survey procedure, (Soil Taxonomy, 1996). The physical and chemical properties of this profile are reported in Table 3.1.

Profile description

(a) Parent material: Nile alluvial deposit.

(b) Drainage: Well drained.

(c) Soil moisture condition: Dry.

(d) Depth of ground water Table: 8 meters.

(e) Presence of surface stones: Nil.

(f) Evidence of erosion: Wind erosion.

(g) Presence of salt or alkali: Common $CaCO_3$ white concretions.

(h) Human influence: Wheat fields nearby.

A_1: 0 – 10 cm: Brown to dark brown (10 *YR* 4/3) moist and dry; loam to sandy loam; weak fine and very fine granular; slightly sticky and slightly plastic wet; friable moist; soft dry; few very fine tubular pores; calcareous matrix; abrupt smooth boundary; pH 7.4.

Table 3.1: The physical and chemical properties of a typical soil profile from the experimental site.

Depth (cm)	pH paste	ECe dS/m	Soluble cations, meq/L					Soluble anions, meq/L				SAR	CEC %	ESP %
			Na^{+}	Ca^{++}	Mg^{++}	K^{+}		CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}			
0 – 10	7.4	16.1	152.2	10.5	1.5	0.0001		0.0	12.0	42.5	106.5	62.1	34.0	21.9
10 – 30	7.2	29.3	260.9	28.5	7.5	0.001		0.0	6.0	183.1	103.9	61.5	57.0	42.9
30 – 55	7.5	19.6	173.9	18.0	7.5	0.001		0.0	7.5	122.5	66.0	48.7	71.0	55.8
55 – 75	7.3	23.4	212.0	17.0	5.0	0.001		0.0	6.5	78.8	148.7	63.9	56.0	54.3
75 – 120	7.5	16.0	152.2	4.0	0.5	0.0001		0.0	8.0	86.3	65.7	101.5	29.0	34.9
120 – 135	7.1	18.1	173.9	3.5	4.0	0.0001		0.0	7.5	101.3	72.2	89.6	18.0	23.0
135 –	7.3	6.8	60.9	1.5	2.0	–		0.0	6.0	27.5	34.5	46.1	7.0	–

Table 3.1: (Contd).

Depth (cm)	S.P %	Particle-size distribution (%)				B.d g/cm^3	$CaCO_3$ (%)
		Coarse sand	***Fine sand***	***Silt***	***Clay***		
0 – 10	33.90	41.30	33.70	9.00	16.00	1.60	6.20
10 – 30	33.02	26.70	37.30	14.00	22.00	1.50	3.20
30 – 55	50.31	21.30	27.70	24.00	27.00	1.70	11.20
55 – 75	41.15	12.10	37.90	31.00	19.00	1.70	30.00
75 – 120	45.41	1.40	37.60	14.00	11.00	1.60	2.60
120 – 135	44.34	2.40	77.60	10.00	10.00	1.60	1.40
135 –	33.19	24.60	75.40	–	–	1.40	0.00

ECe: Electrical conductivity, SAR: Sodium adsorption ratio, CEC: Cation exchange capacity

SP: Saturation percentage, Bd.: Bulk density.

Bw_1: 10 – 30 cm: Brown to dark brown (10 *YR* 4/3) moist and dry; sandy clay loam; moderate, medium and fine sub-angular blocky; sticky and plastic wet; friable moist; hard dry; few fine tubular pores; few to common $CaCO_3$; gray modules; calcareous matrix clear smooth boundary; pH 7.2.

Bw_2: 30 – 55 cm: Grayish brown (10 *YR* 5/2) dry; brown to dark brown (10 *YR* 4/3) moist; sandy clay loam; moderate, medium and fine sub-angular blocky; sticky; plastic wet; firm moist; very hard dry; few fine tubular pores; few single sand grains; common gray $CaCO_3$ modules and $CaCO_3$ streaks, calcareous matrix; gradual smooth boundary; pH 7.5.

Bk: 55 – 75 cm: Grayish brown (10 *YR* 5/2) moist; loam; weak, coarse, medium and fine sub-angular blocky; slightly sticky; slightly plastic; firm moist, hard dry; few tubular pores; many $CaCO_3$ modules and concretions, very strong calcareous matrix; gradual smooth boundary; pH 7.3.

$2C_{11}$: 75 – 120 cm: Light yellowish brown (10 *YR* 6/4) dry; dark brown to brown (10 *YR* 4/3) moist; friable; sandy loam; massive; slightly sticky, slightly plastic; wet friable moist, hard dry; few $CaCO_3$ white concretion; slightly calcareous matrix, clear smooth boundary; pH 7.5.

$2C_{12}$: 120 – 135 cm: Light yellowish brown (10 *YR* 6/4) dry; yellowish brown (10 *YR* 5/6) moist; loamy sand; single grain; none sticky and non plastic wet; friable moist; soft dry; non calcareous matrix; abrupt to smooth boundary; pH 7.1.

$2C_2$: +135 cm: Yellow (10 *YR* 7/6) dry; yellowish brown (10 *YR* 5/6) moist; sand; single grain, non-sticky and non-plastic, loose moist, loose dry; non-calcareous matrix; pH 7.3.

3.2.2 Soil amendments

The following three levels of farm yard manure (compost), were used in the research work: O, 4.8 and 9.7 ton/feddan. The characteristic are presented in Table 3.2.

3.2.3 Irrigation water system

Parshal Flume, 5cm width, was used for delivering a specific quantity of water to the plots. The source of water is River Nile, which is of good quality (Mustafa, 1973).

3.3 METHODS

3.3.1 Design of experiment

The experiments were undertaken to investigate the effect of irrigation frequency (F) and farmyard manure (M) on the productivity of wheat (*Tritichum aestivum*) on a salt-affected soil in Elseleim.

The treatments consisted of three irrigation frequencies: 7, 14 and 21 days, and three levels of farmyard manure: zero (M_o) 4.8 (M_1) and 9.7 (M_2) ton/feddan. Each treatment was replicated three times. One quantity of irrigation water was used.

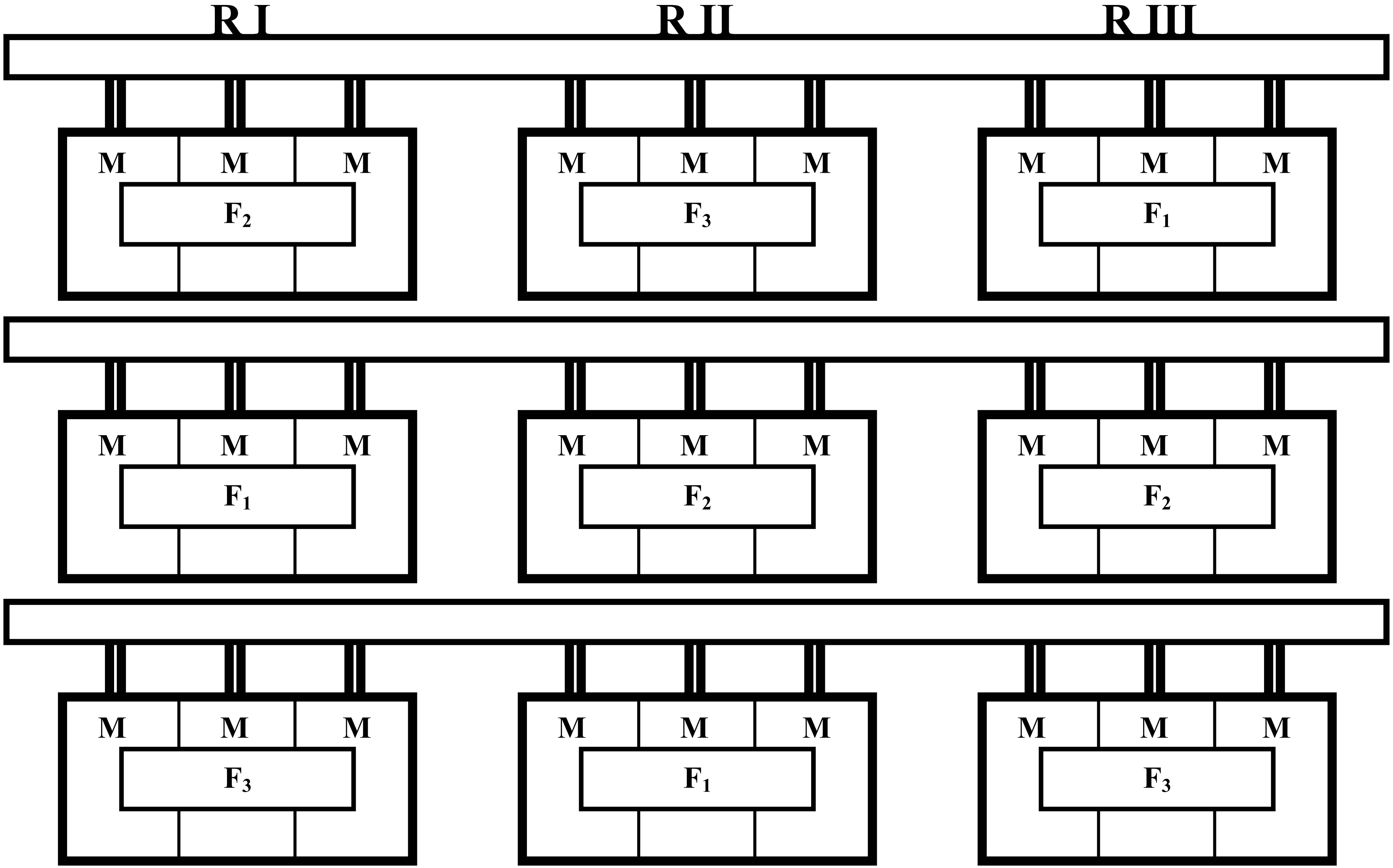
The experiment was arranged in a split-plot design, where irrigation intervals (frequency) were assigned main plots (7 × 18m), each of which was divided into three sub-plots (7 × 6m) to accommodate the three levels of farmyard manure (Fig. 3.1). The main plots were a meter apart to prevent lateral water movement.

Table 3.2: Characteristics of the Farmyard Manure.

Organic amendment F.Y.M.	pH	ECe dS/m	SAR	Soluble cations meq/L				N %	P %	O.C %	Organic mater %
				Na^+	K^+	Mg^{++}	Ca^{++}				
2000	7.73	19.0	0.63	0.75	1.75	0.93	1.80	0.54	0.226	35.10	60.40
2001	8.11	22.5	0.58	0.70	1.31	1.10	1.90	0.70	0.338	39.00	67.10

Abbreviations as explained on table 3.1

Fig. 3.1: The layout of the two field experiments in Dongola University Farm



Legend:
F= Main plots
F_1= 7 days
F_2= 14 days
F_3= 21 days
F.Y.N = Sub-plots
M_0= 0
M_1= 4.8 ton/fed
M_2= 9.7 ton/fed

3.3.2 Land preparation

In the first season, the land of the experimental site was disc-ploughed to a depth of 20cm. It was then leveled using along-span blade leveler. The land was then divided into plots and sub-plots using earth embankments. In the second season, the experiment was repeated on the same plots, which were harrowed before planting.

3.3.3 Crop sowing and fertilizer application

Sowing was made on the first of January, 2001, for the first season, and on the 27th of December 2001 for the second season. Seeds were hand dibbled in rows 20cm apart in every sub-plot. The seed rate was 60 kg/feddan.

In all treatments P fertilizer (Triple super phosphate) was applied before sowing in the order of 80 kg/feddan. After 21 and 63 days from sowing urea at the rate of 20 kg N/feddan was applied to all treatments. Fertilizers were applied at the same rate and crop stage in both seasons.

3.3.4 Application of farmyard manure

At the third irrigation, 21 days after sowing, farmyard manure was applied to the plots at the three predetermined rates.

3.3.5 Irrigation treatments

A predetermined quantity of irrigation water (Qi) was delivered to the sub-plots using Parshal flume in both seasons.

This quantity was estimated by the following relationships:

$$Qi\ (mm) = \frac{Kc\ ETp \times F \times 100}{Ei}$$

Where:

Kc	≡	crop coefficient
ETp	≡	potential evapotranspiration (mm/day)
F	≡	irrigation frequency (days)
Ei	≡	irrigation application efficiency assumed

$$as = 70\%$$

ETp was estimated by the following Jensen and Haise (1963) equation:

$$ETp = C_T (T - T_x) R_s$$

ETp has the same units as R_s.

Where:

$$C_T = \frac{1}{C_1 + 7.6 \times C_H}$$

$$C_H = \frac{50\ mb}{e_2 - e_1}$$

$T \equiv$ mean air temperature, C°.

e_2 is the saturation vapor pressure of water in mb at the mean monthly maximum air temperature of the warmest month in the year (long-term climatic data), and e_1 is the saturation of vapor pressure of water in mb at the mean monthly minimum air temperature of the warmest month in the year.

$$C_1 = 38 - \frac{2E}{305}$$

Where:

$E \equiv$ the site elevation in m.

$$T_x = -2.5 - 0.14\,(e_2 - e_1) - \frac{E}{550}$$

$R_s \equiv$ short wave incoming solar radiation.

The potential evapotranspiration was estimated from previous mean monthly long-term climatic data (1961 – 1993) Appendix (1). The crop coefficient varies with the crop, stage of development and prevailing climatic conditions. According to FAO (1984) estimates, it was considered to be equal to 0.7, 1.2, 1.2 and 0.7 for the months of January, February, March and April, respectively in the first season, and

0.6, 0.7, 1.1 and 1.1 for the months of December, January, February and March, respectively in the second season.

The data used for estimating irrigation water requirements for wheat in the two seasons are reported in Table 3.3. The comprehensive irrigation data for the two seasons are reported in Tables 3.4 and 3.5.

3.3.6 Weeding

No weeding was required in the first season because the soil was initially virgin. In the second season, manual weeding was done when needed.

3.3.7 Soil sampling

Soil samples (2 kg) were collected at the following 5 soil depths: 0 – 20, 20 – 40, 40 – 60, 60 – 80, 80 – 100cm, in each subplot, before sowing and at harvest for both seasons.

A total of 540 soil samples were collected for analysis. The soil samples were air-dried, ground, passed through 2.mm sieve and kept in labeled plastic bags. Five replicate clods were taken at an increment of 0.2 m from the surface to one meter depth, for measuring the soil bulk density at different depths.

3.3.8 Soil analysis

The particle-size distribution was determined by the pipette method and bulk density by the clod method (Black, 1962).

The chemical properties of the soils including electrical conductivity of the saturation extract (ECe), cation exchange capacity (CEC), soluble Ca^{++}, Mg^{++} and Na^{+}, exchangeable sodium (NaX), $CaCO_3$ and pH, were determined according to the standard procedures of the U.S. Salinity Laboratory Staff (Richards, 1954).

Exchangeable sodium percentage [ESP = 100 (NaX/CEC)] and sodium adsorption ratio [$SAR = Na/\sqrt{\frac{Ca + Mg}{2}}$] were then calculated.

Table 3.3: Estimated Irrigation Water Requirements for wheat in Dongola area for the two seasons

Month	ETp (mm/day)	Kc	ET_{crop} (mm/day)	IR (mm/day)
First Season				
January	3.50	0.70	2.45	3.50
February	4.48	1.20	5.38	7.70
March	6.70	1.20	8.04	11.4
April	8.69	0.70	6.08	8.70
Second Season				
December	3.64	0.60	2.18	3.10
January	3.50	0.70	2.45	3.50
February	4.48	1.10	4.93	7.00
March	6.70	1.10	7.37	10.5

Table 3.4: Irrigation Data for wheat (*Tritichum aestivum*) growth during the first season (Jan. – April 2001).

Data	Irrigation frequency (days)		
	7	14	21
Sowing date	1 Jan. 2001	1 Jan. 2001	1 Jan. 2001
<u>Crop establishment period:</u>			
i. No. of irrigations	3	3	3
ii. Irrigation frequencies (days).	7	7	7
iii. Depth of irrigation (mm).	209.0	209.0	209.0
<u>After crop establishment:</u>			
a. During January:			
i. No. of irrigations.	2	1	–
ii. Depth of irrigation (mm)	52.5	52.5	–
b. During February:			
i. No. of irrigations	4	2	2
ii. Depth of irrigation (mm)	215.6	215.6	268.1
c. During March:			
i. No. of irrigations	4	2	1
ii. Depth of irrigation (mm)	319.2	319.2	239.4
d. During April:			
i. No. of irrigations	1	1	1
ii. Depth of irrigation (mm)	60.3	60.3	140.1
Total number of irrigations	14	9	7
Total water added (mm)	856.6	856.6	856.6
Date of harvest	15/4/2001	15/4/2001	15/4/2001
Growing period (days)	104	104	104

Table 3.5: Irrigation Data for wheat (*Tritichum aestivum*) growth during the second season (Dec. 2001 – March 2002).

Data	Irrigation frequency (days)		
	7	14	21
Sowing date	29 Dec. 2001	29 Dec. 2001	29 Dec. 2001
Crop establishment period:			
i. No. of irrigations	3	3	3
ii. Irrigation frequencies (days).	7	7	7
iii. Depth of irrigation (mm).	190.2	190.2	190.2
After crop establishment:			
a. During January:			
i. No. of irrigations.	2	1	–
ii. Depth of irrigation (mm)	49.0	49.0	–
b. During February:			
i. No. of irrigations	4	2	2
ii. Depth of irrigation (mm)	182.0	182.0	231.0
c. During March:			
i. No. of irrigations	5	3	2
ii. Depth of irrigation (mm)	353.5	353.5	353.5
Total number of irrigations	14	9	7
Total water added (mm)	774.7	774.7	774.7
Date of harvest	10/4/2002	10/4/2002	10/4/2002
Growing period (days)	93	93	93

3.3.9 Crop measurements

3.3.9.1 Leaf area index

Ten plants were identified at random from each treatment, the number of leaves in each plant were counted and the top leaf of the plant was marked to measure its length and width of the mean number of leaves per plant and the mean length and width of the top leaves were calculated. The plant population per square meter was determined and the leaf area index (LAI) was calculated by the following relationship:

$$LAI = N_L \times N_P \times L \times W \times 0.75 \times 10^{-4}$$

Where:

N_L ≡ number of leaves per plant

N_P ≡ number of plants per m^2

L ≡ length of leaf (cm)

W ≡ width of leaf (cm)

3.3.9.2 Plant height

The heights of 10 plants, taken at random from each treatment, were measured and the mean plant height was calculated.

3.3.9.3 Head length

The length of 10 heads, taken at random from each treatment, were measured and the mean head length was calculated.

3.3.9.4 Heads per meter square

At harvest, one meter square was randomly taken in each subplot and the number of heads were counted.

3.3.9.5 Seeds per head

At harvest, ten heads were taken at random from each subplot and they were threshed collectively. The number of seeds per head was counted.

3.3.9.6 Thousand grain weight

After harvest and threshing, thousands grains were taken randomly from each treatment and weighed using a sensitive analytical balance.

3.3.9.7 Total biomass (Fresh Weight)

The total biomass enclosed in an area of 5×6 m^2 in each subplot was cut at the ground surface, and the weight which was expressed in ton/fed was determined.

3.3.9.8 Grain yield

The total harvested biomass, as described in the previous section (3.3.9.7), was left for 7 days to dry, then it was threshed manually. The collected grains were weighed and expressed in ton/fed.

3.3.10 Determination of crop water use

Crop water use (CWU, mm) was calculated by the following water balance equations:

$$\text{CWU, mm} = I + P + \sum_{i=1}^{n} \frac{(mbi - mai)}{100} \times Bdi \times Di$$

Where:

I	≡	irrigation water depth, mm;
P	≡	precipitation depth, mm;
Mbi, Mai	≡	percentage gravimetric water content in ith layer at the beginning and end of the season, respectively;
Bdi	≡	bulk density of the i^{th} layer, gm/cm^3;
Di	≡	soil depth of the i^{th} layer, cm; and
n	≡	number of layers

Soil moisture content was determined by the standard gravimetric method for one location, in each subplot, taken randomly in each subplot.

Soil samples were collected by an auger from each location at an increment of 0.2 m from the surface to a depth of one metre. Soil sampling was made before sowing and at harvest for the first and the second seasons.

3.3.11 Crop water use efficiency (CWUE)

This is calculated as amount of grain yield per unit of water used by the crop:

$$\text{CWUE} = \frac{\text{grain yield}}{\text{Crop water requirement}}$$

Chapter IV

RESULTS AND DISCUSSION

4.1 THE EFFECTS OF TREATMENTS ON SOIL CHEMICAL PROPERTIES

4.1.1 Redistribution of electrical conductivity (ECe)

Table 4.1 shows the effects of treatments on the ECe redistribution in the soil profile by the end of the first season. In general, the results indicate that irrigation with or without farmyard manure reduced ECe prior to irrigation (hence forth referred to as initial ECe) in the 0 – to 60–cm soil depth. It is also evident that, in this soil depth, the initial ECe decreased to a lesser extent with each successive increase in irrigation interval.

Statistical analysis showed that salt leaching was not significantly affected by the irrigation frequency, farmyard manure application or their interaction. Hence, the data were averaged over the three levels of farmyard manure and over the three irrigation frequencies and plotted in Figs. 4.1a, b to depict the main irrigation and farmyard manure effects, respectively. The main data show that the initial salinity of the 0–to 20 cm layer {ECe (0 – 20)} was reduced by 89, 90, or 79% when irrigated every 7, 14, or 21 days, respectively.

ECe (0 – 20) was reduced by 85, 84, or 88% due to the application of M_0, M_1, or M_2, respectively. The explanation is that, irrigation with good Nile water (Mustafa, 1973) would cause desalinization of the top layers of this highly saline sodic soils. It is also evident that the combined treatment F_1M_0 reduced the initial ECe by 94%. The data also show that F_1, F_2 and F_3, lowered ECe (20 – 40) by 56, 50 and 59%, respectively.

Table 4.1: Mean electrical conductivity (dS/m) profile as affected by irrigation frequency (F) and farmyard manure (M) at the end of the first season (Dec. 2000 / April 2001).

Soil depth (cm)	Initial ECe (dS/m)	Irrigation frequency (days)	Farmyard manure			
			M_0	M_1	M_2	*Mean*
00 – 20	29.5	F_1	1.7	2.7	5.4	3.3
		F_2	3.3	3.6	2.0	3.0
		F_3	7.9	7.9	2.7	6.2
		Mean	4.3	4.7	3.4	
20 – 40	32.5	F_1	13.4	13.4	15.9	14.2
		F_2	20.6	12.0	16.6	16.4
		F_3	11.6	15.3	12.9	13.3
		Mean	15.2	13.6	15.1	
40 – 60	27.1	F_1	20.6	18.5	24.6	21.2
		F_2	17.5	18.3	16.1	17.3
		F_3	20.5	23.1	22.3	22.0
		Mean	19.5	20.0	21.0	
60 – 80	22.5	F_1	27.1	21.5	41.8	30.1
		F_2	18.6	13.6	32.7	21.6
		F_3	54.4	52.7	23.5	43.5
		Mean	33.4	29.3	32.7	
80 – 100	17.0	F_1	28.7	34.5	48.5	37.2
		F_2	18.7	22.2	16.8	19.2
		F_3	32.6	41.1	28.4	34.0
		Mean	26.7	32.6	31.2	

F_1, F_2, and F_3 denote irrigation frequency of 7, 14 and 21 days, respectively.

M_0, M_1, and M_2 represent 0, 4.8 and 9.7 ton/fed farmyard manure, respectively.

The effects of treatments at each depth were not significant at the 5% level.

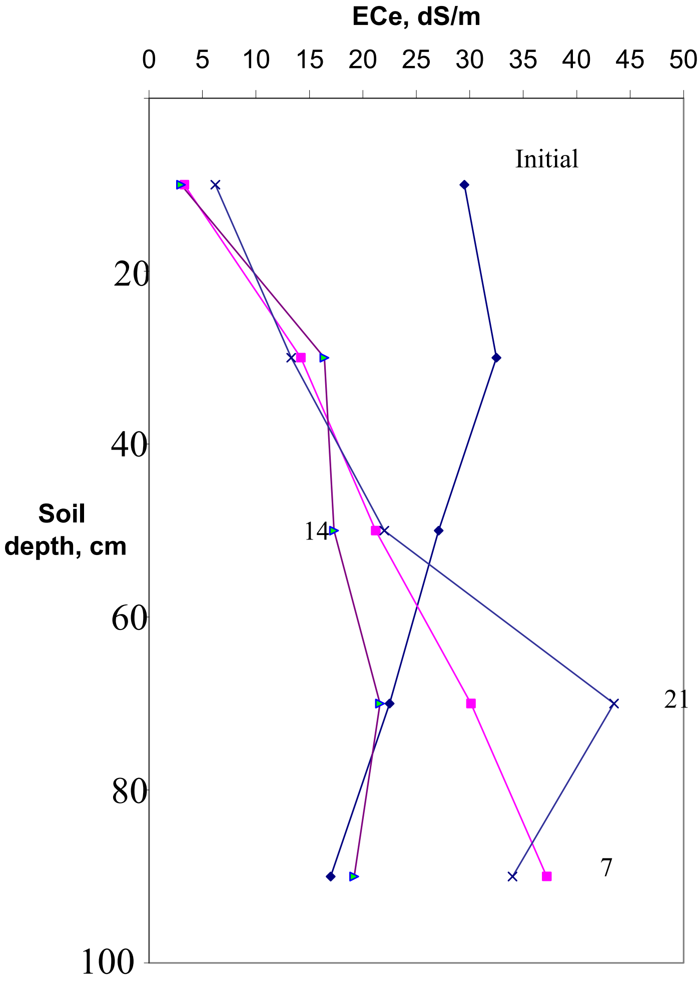


Fig. (4.1a) Mean electrical conductivity (dS/m) profile as affected by irrigation frequency (days) at the end of the first season (Dec. 2000- April 2001)

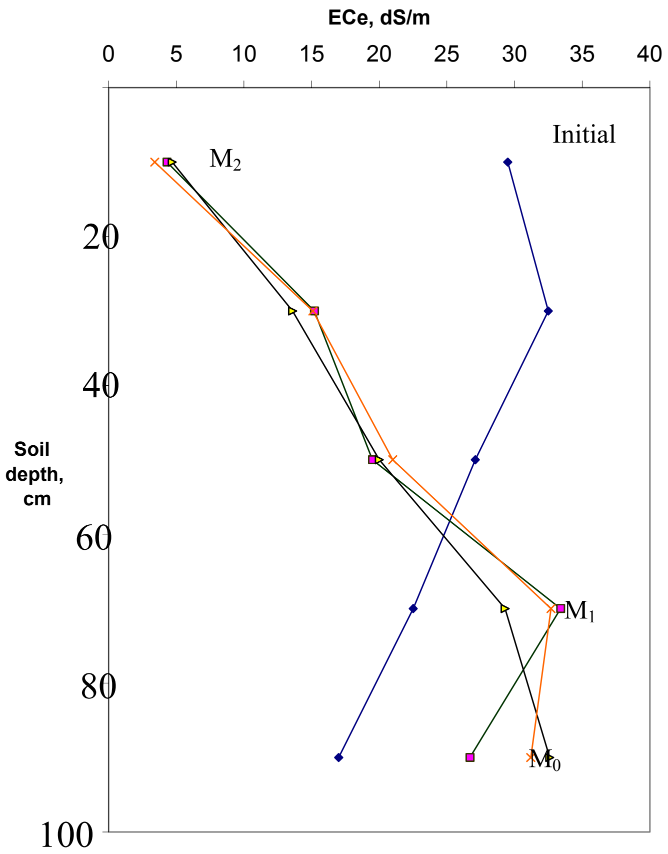


Fig. (4.1b) Mean electrical conductivity (dS/m) profile as affected by farm yard manure (ton) at the end of the first season (Dec. 2000- April 2001)

Whereas M_0, M_1 and M_2 reduced ECe at the same depth by 53, 58 and 54%, respectively. In contrast to the first layer, the combined treatment F_1M_0 reduced the initial ECe in this layer (20 to 40 cm) by 58% only. It is clear that the impact of treatments on this layer was not as marked as that on the top layer. This maybe attributed to the reduced water movement in this layer.

At 40 – 60 cm, F_1, F_2 and F_3 reduced ECe by 22, 36, or 19%, respectively. Whereas M_0, M_1 and M_2 reduced ECe (40 – 60 cm) by 28, 26, or 23%, respectively.

In general, the results indicate that the effects of treatments on the initial ECe of the 60 – 100 cm soil depth were the reverse of their effects of the initial ECe of the overlying depth. The ECe of the 60 – 80 cm layer, was increased by 34, – 4 and 93% by treatments F_1, F_2 and F_3, respectively. Treatments M_0, M_1 and M_2, increased ECe (60 – 80) by 48, 30 and 45%, respectively. Treatments F_1, F_2 and F_3, increased the ECe of the last depth (80 – 100) by 119, 13 and 100%, respectively. Whereas treatments M_0, M_1 and M_2 increased ECe of this soil depth by 57, 92, and 84%, respectively. The effectiveness of leaching decreased with increasing soil depth or salt leaching efficiency decreased with depth. This maybe attributed to water flow in the soil profile.

In general, F_2 was relatively, more efficient in salt leaching than F_1 and F_3 and it desalinized the top 0 – 70 cm depth, whereas the other treatments desalinized the top 60 cm. Fig. 4.1a This finding agrees with that of Mustafa and A/Magid (1981). Application of FYM promoted water movement, enhanced root development and ramification and increase salt leaching, but the effect was not significant Fig. 4.1b.

In general, the second season data indicated that irrigation with or without F.Y.M. reduced ECe. The initial ECe decreased throughout the profile (0 – 100 cm), Table 4.2, Fig. 4.1c, Fig. 4.1d. Treatments F_1, F_2 and

F_3 reduced the initial ECe (0 – 20 cm) by 59, 80, or 84%, respectively. Whereas M_0, M_1 and M_2 lowered ECe (0 – 20) by 59, 81 and 84%, respectively. In this layer, the result indicated that the decrease percentage (salt leaching) was greater in the first season. This is because salts were higher in the virgin soil than at the beginning of the second season (Izzeldin *et al*., 2000).

The initial ECe (20 – 40) was lowered by 40, 52, or 31%, due to treatments F_1, F_2, or F_3, respectively. Treatments M_0, M_1 and M_2 decreased the initial ECe at the same soil depth by 27, 56 or 38%, respectively. The initial ECe of the 40 – to 60 cm layer was lowered by 35, 38, or 18% by treatments F_1, F_2 or F_3, respectively, while M_0, M_1 and M_2 decreased it by 25, 33 and 32, respectively. The salinity of the 60 – to 80 cm layer was lowered by 22, 36, or 19% by treatments F_1, F_2 or F_3, respectively; and it was lowered by 23, 33, or 22 by treatments M_0, M_1 or M_2, respectively. The initial ECe of the 80 – to 100 cm layer, was lowered by 23, 2, or 12% by treatments F_1, F_2 or F_3, respectively. Treatments M_0, M_1 decreased the salinity at this depth by 34 and 30%, respectively. However, M_2 increased the salinity in this depth by 27%.

In this season, the main effects of irrigation and F.Y.M. were lower than those in the first season because the initial ECe in different soil layers were lower than those of the first season. However, the trends were nearly the same.

Table 4.2: Mean electrical conductivity (dS/m) profile as affected by irrigation frequency (F) and farmyard manure (M) at the end of the second season (Dec. 2001 / April 2002).

Soil depth (cm)	Initial ECe (dS/m)	Irrigation frequency (days)	Farmyard manure			
			M_0	***M_1***	***M_2***	***Mean***
00 – 20	8.6	*F_1*	7.9	1.2	1.3	3.5
		F_2	1.3	2.2	1.5	1.7
		F_3	1.2	1.5	1.4	1.4
		Mean	3.5	1.6	1.4	
20 – 40	13.1	*F_1*	12.2	3.2	8.4	7.9
		F_2	7.9	5.7	5.2	6.3
		F_3	8.3	8.2	10.6	9.0
		Mean	9.5	5.7	8.1	
40 – 60	20.0	*F_1*	16.2	11.2	11.7	13.0
		F_2	13.2	11.9	12.5	12.5
		F_3	15.6	17.4	16.6	16.5
		Mean	15.0	13.5	13.6	
60 – 80	25.0	*F_1*	19.1	15.9	23.1	19.4
		F_2	21.3	13.0	13.8	16.0
		F_3	17.5	21.2	22.0	20.2
		Mean	19.3	16.7	19.6	
80 – 100	26.8	*F_1*	13.2	13.4	35.2	20.6
		F_2	25.4	11.0	42.4	26.3
		F_3	14.6	31.8	24.4	23.6
		Mean	17.7	18.7	34.0	

Abbreviation as explained in Table 4.1.

The effect of treatments at each depth were not significant at the 5% level.

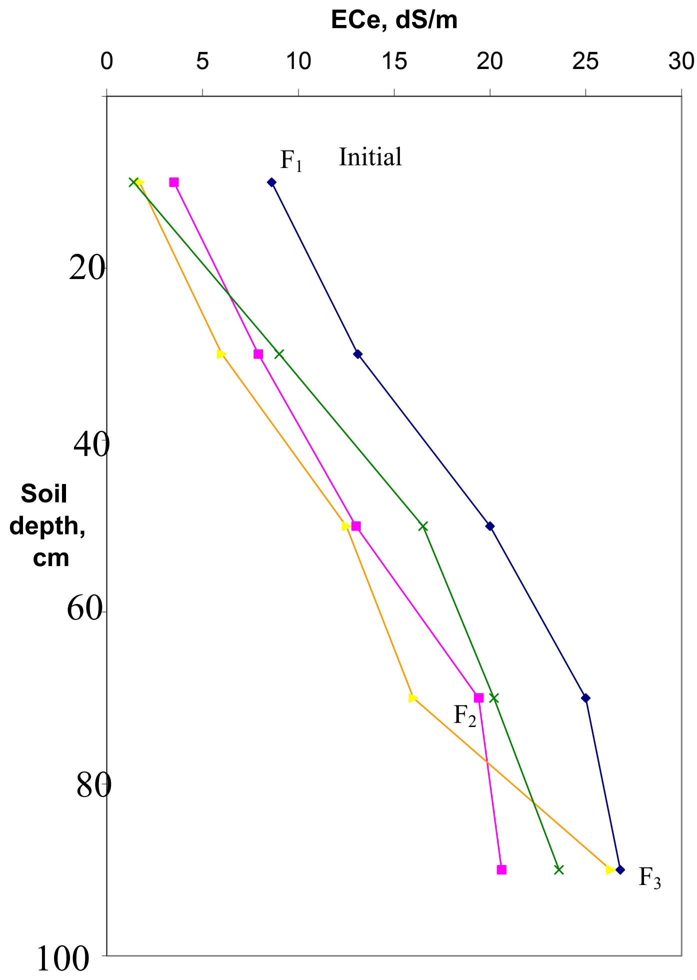


Fig. (4.1c) Mean electrical conductivity (dS/m) profile as affected by irrigation frequency (days) at the end of the second season (Dec. 2001- April 2002)

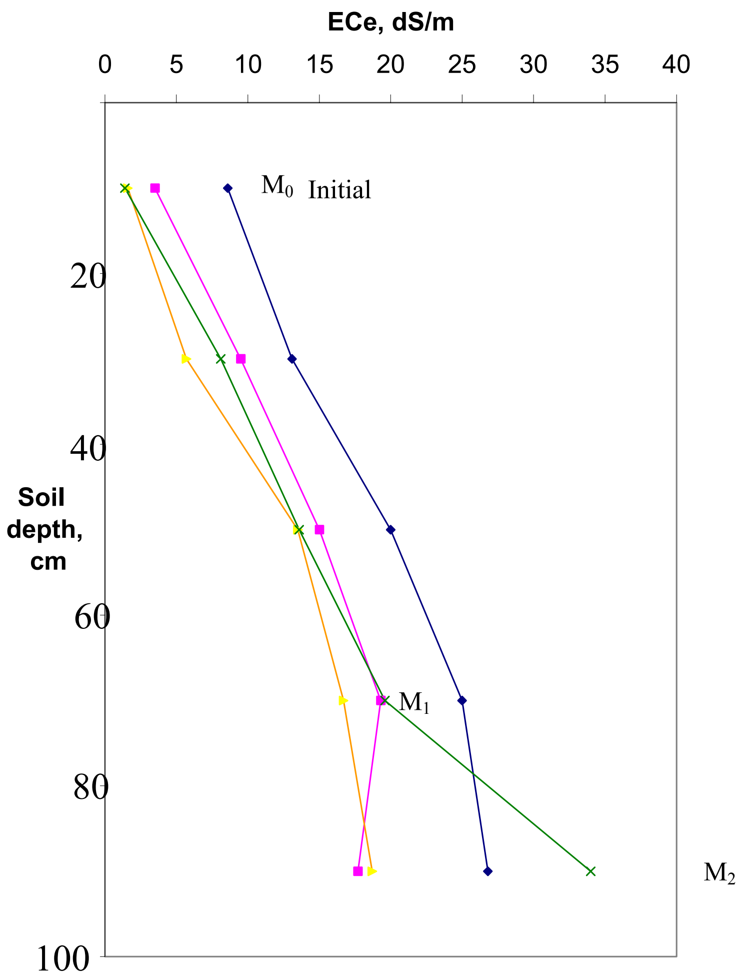


Fig. (4.1d) Mean electrical conductivity (dS/m) profile as affected by farm yard manure (ton) at the end of the second season (Dec. 2001- April 2002)

4.1.2 Redistribution of sodium adsorption ratio

The data of SAR redistribution by the end of the first and second seasons are presented in Tables 4.3 and 4.4, respectively.

Statistical analysis of SAR data indicated that the influence of irrigation frequency, F.Y.M. and their interaction were not significant.

In general, the results indicate that irrigation, irrespective of its frequency or F.Y.M. application reduced the initial SAR in the 0 to 40 cm soil depth. Fig. 4.2a depicts the main effects of the irrigation frequency on SAR redistribution by the end of the first season. The plots show that the initial SAR of the 0 to 20 cm layer was reduced by 72, 80 and 64% by F_1, F_2 and F_3, respectively.

The reductions caused by the same irrigation frequencies in sequence in the second layer, were 35, 27 and 39%. The SAR values of the third layer were decreased by 6, 7 and increased by 12 by the same treatments in sequence. For 60 – 80 cm layer, the initial SAR values were increased by 3 and 47% by F_1, and F_3, respectively and decreased by 17% by F_2. Treatments F_1 and F_2 decreased the initial SAR at 80 – 100 cm layer by 4 and 2%, respectively, but F_3 increased the initial SAR by 19%. Treatment F_2 was more effective in salt leaching but the difference between irrigation treatments were not significant.

Table 4.3: Mean sodium adsorption ratio (SAR) profile as affected by irrigation frequency (F) and farmyard manure (M) at the end of the first season (Dec. 2000 / April 2001).

Soil depth (cm)	Initial SAR	Irrigation frequency (days)	Farmyard manure			
			M_0	***M_1***	***M_2***	***Mean***
00 – 20	65.3	*F_1*	14.4	17.8	22.4	18.2
		F_2	14.3	13.1	11.0	12.8
		F_3	21.9	26.3	21.3	23.2
		Mean	16.9	19.1	18.2	
20 – 40	55.3	*F_1*	37.0	34.1	37.5	36.2
		F_2	50.6	29.5	41.0	40.4
		F_3	31.2	40.2	30.6	34.0
		Mean	39.6	34.6	36.4	
40 – 60	48.3	*F_1*	50.5	44.6	41.5	45.5
		F_2	41.9	52.0	41.3	45.1
		F_3	50.8	59.6	52.0	54.1
		Mean	47.7	52.1	44.9	
60 – 80	44.7	*F_1*	52.6	45.6	40.1	46.1
		F_2	32.3	33.3	46.0	37.2
		F_3	74.7	79.0	43.0	65.6
		Mean	53.2	52.6	43.0	
80 – 100	45.8	*F_1*	51.7	40.6	40.0	44.1
		F_2	52.2	45.7	36.9	44.9
		F_3	64.9	56.2	42.0	54.4
		Mean	56.3	47.5	39.6	

Abbreviation as explained in Table 4.1.

The effect of treatments at each depth were not significant at the 5% level.

Table 4.4: Mean sodium adsorption ratio (SAR) profile as affected by irrigation frequency (F) and farmyard manure (M) at the end of the second season (Dec. 2001 / April 2002).

Soil depth *(cm)*	**Initial SAR**	**Irrigation frequency *(days)***	**Farmyard manure**			
			M_0	***M_1***	***M_2***	***Mean***
00 – 20	29.2	*F_1*	19.5	6.50	6.20	10.70
		F_2	7.40	5.30	9.60	7.40
		F_3	6.80	8.20	7.30	7.40
		Mean	11.2	6.70	7.70	
20 – 40	35.6	*F_1*	29.2	13.6	23.1	22.0
		F_2	19.8	17.2	15.3	17.4
		F_3	21.9	20.8	24.1	22.3
		Mean	23.6	17.2	20.8	
40 – 60	50.3	*F_1*	39.2	29.5	27.3	32.0
		F_2	38.2	32.9	30.4	33.8
		F_3	37.3	44.8	39.7	40.6
		Mean	38.2	35.7	32.5	
60 – 80	51.0	*F_1*	46.4	37.8	34.3	39.5
		F_2	47.2	30.3	41.2	39.6
		F_3	41.3	49.6	45.8	45.6
		Mean	45.0	39.2	40.4	
80 – 100	49.4	*F_1*	46.0	39.6	29.1	38.2
		F_2	44.5	27.7	45.1	39.1
		F_3	42.1	56.2	39.8	46.0
		Mean	44.2	41.2	38.0	

Abbreviation as explained in Table 4.1.

The effect of treatments at each depth were not significant at the 5% level.

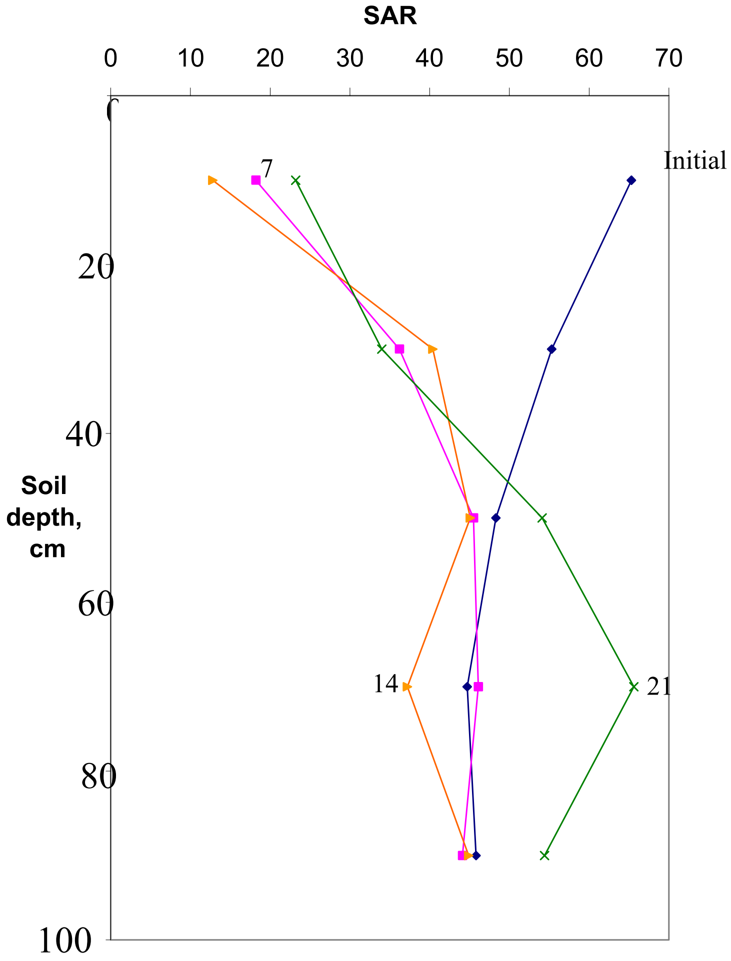


Fig. (4.2a) Mean sodium adsorption ratio (SAR) profile as affected by irrigation frequency (days) at the end of the first season (Dec. 2000- April 2001)

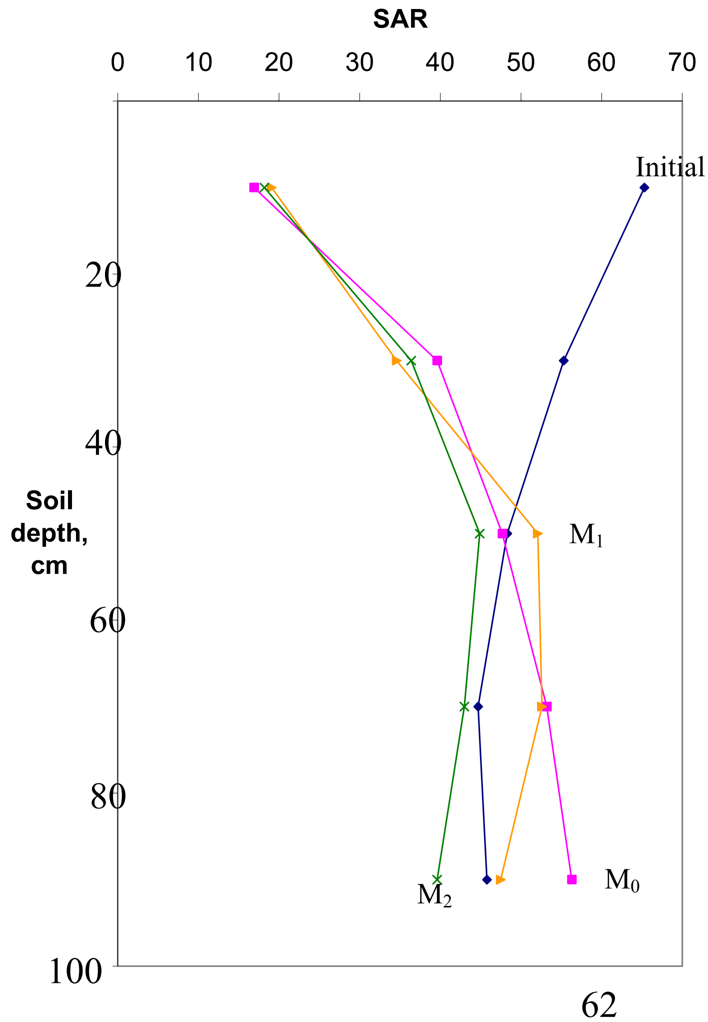


Fig. (4.2b) Mean sodium adsorption ratio (SAR) profile as affected by farm yard manure (ton) at the end of the first season (Dec. 2000- April 2001)

In general, the sodicity decreased due to dissolution of Ca – bearing compounds, replacement of Na^+ by Ca^{++} ions on the exchange complex, and leaching of the more mobile Na^+ ions (Mustafa and A/Magid, 1981). The initial SAR of the upper layer (0 – 20 cm) was rapidly and markedly reduced merely by leaching with water; this maybe attributed to:

(1) Decrease in soil solution SAR values during leaching because of dilution and faster leaching of sodium compared with calcium and magnesium.

(2) Low SAR of irrigation water. Similar results were also obtained for bare field of such soils in India. Leffellaar and Sharma (1977); Dahiya *et al*. (1981, 1982), obtained similar results for the experimental soil in cropped plots.

Fig. 4.2b depicts the main effect of F.Y.M. application on SAR redistribution by the end of the first season. The initial SAR (0 – 20 cm) values, were reduced by 74, 71 and 72% due to M_0, M_1 and M_2, respectively. The reduction in the second layer caused by the same treatments in sequences, are 28, 37 and 34%. In the third layer, treatment M_0 and M_2 reduced the initial SAR by 1 and 7%, respectively, whereas treatment M_1 increased it by 8%. Below 60 cm depth, treatments M_0, and M_1 caused slight increase, while treatment M_2 caused slight decrease in the initial SAR value.

In general, treatment M_2 was more effective in salt leaching. However, the differences between the F.Y.M. treatment were not significant.

The main irrigation effects for the second season are depicted in Fig. 4.2c. The initial SAR values of the 0 – 20 cm layer were reduced by 63, 75 and 75% by F_1, F_2 and F_3 irrigation frequencies, respectively. For the same irrigation frequencies in sequence, the reduction in the 20 – 40 layer, were 38, 51, and 37%. For the 40 – 60 cm layer, F_1, F_2 and F_3 reduced the initial SAR values by 36, 33 and 19%, respectively. At the 60 – 80 cm layer, the F_1, F_2 and F_3 frequency decreased the initial SAR values by 23, 22, and 11%, respectively. At the last layer, the F_1, F_2 and F_3 frequency reduced the initial SAR values by 23, 21 and 7%, respectively. Fig. 4.2d depicts the main effects of F.Y.M. on SAR redistribution by the end of the second season. The SAR values averaged over the three irrigation frequency; show that the initial SAR of the 0 – 20 cm layer was reduced by 62, 77, and 74% due to treatments M_0, M_1 and M_2 respectively. The reductions caused by the same treatments in sequence, were 34, 52, and 42 for the second layer; 24, 29, and 35% for the third layer; 12, 23, 21% for the fourth layer; and 11, 17 and 23% for the fifth cm layer.

4.2 THE PROFILE DISTRIBUTION OF SALTS

In general, the results show that the soil profile is initially dominated by NaCl and Na_2SO_4 Table 4.5. The NaCl ranged between 44.3 to 55.9 with a mean of 51% and SD of 4.6% (CV = 9.0%), whereas, Na_2SO_4 ranged from 27.1 to 45.1 with a mean of 33.0% and SD of 7.2% (CV = 21.8%). The (Ca + Mg) SO_4 ranged from 8.7 to 16.5 with a mean of 13.5% and SD of 3.0% (CV = 22.2%) and (Ca + Mg) $(HCO_3)_2$ ranged from 0.9 to 1.9 with a mean of 1.5% and SD of 0.4% (CV = 26.6%).

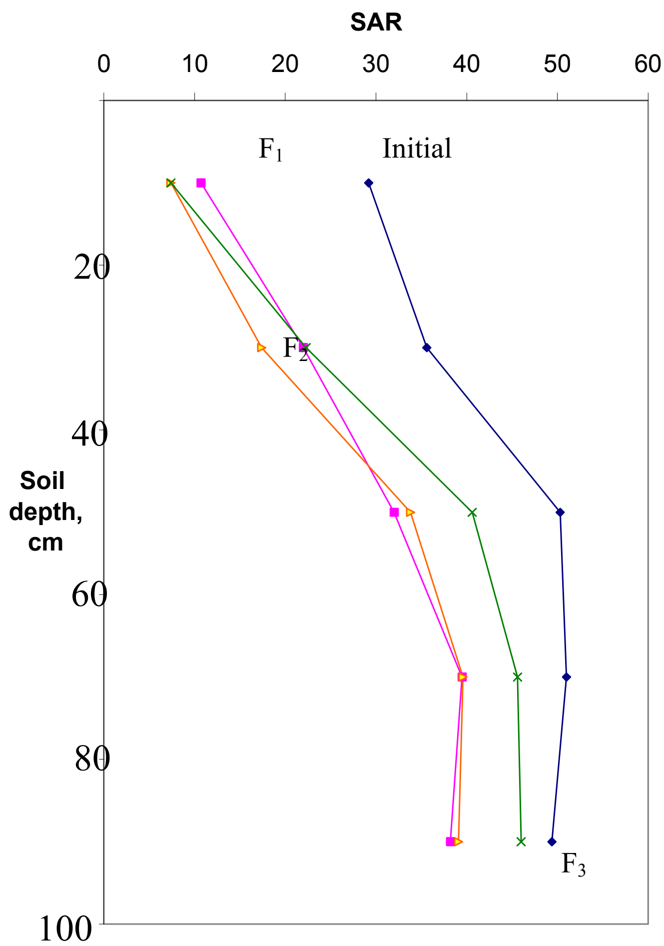


Fig. (4.2c) Mean sodium adsorption ratio (SAR) profile as affected by irrigation frequency (days) at the end of the second season (Dec. 2001-April 2002)

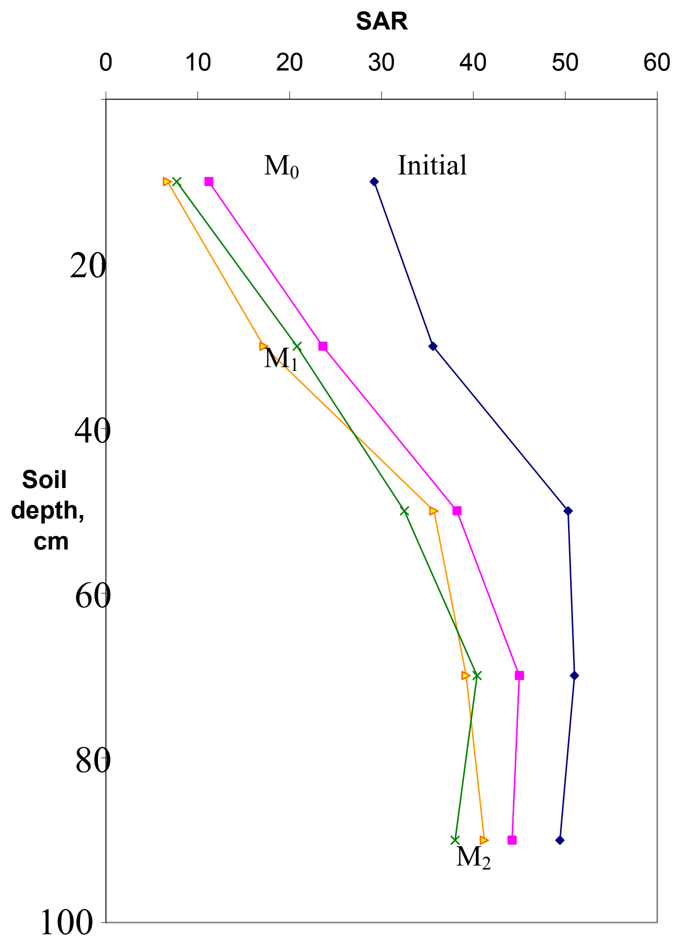


Fig. (4.2d) Mean sodium adsorption ratio (SAR) profile as affected by farm yard manure (ton) at the end of the second season (Dec. 2001-April 2002)

Table 4.5: Salt formation before and after sowing by the first season 2000/2001

Depth	Initial	Meq/L	%	At harvest	Meq/L	%
0 – 20	$(Ca+Mg)(HCO_3)_2$	5.6	1.9	$(Ca+Mg)(HCO_3)_2$	4.5	11.0
	$(Ca+Mg)SO_4$	25.8	8.7	$(Ca+Mg)SO_4$	3.7	9.0
	Na_2SO_4	133.3	45.1	Na_2SO_4	15.8	38.5
	NaCl	130.7	44.3	NaCl	17.0	41.5
20 – 40	$(Ca+Mg)(HCO_3)_2$	2.9	0.89	$(Ca+Mg)(HCO_3)_2$	3.2	2.2
	$(Ca+Mg)SO_4$	47.7	14.7	$(Ca+Mg)SO_4$	18.9	12.9
	Na_2SO_4	88.2	27.1	Na_2SO_4	97.2	66.6
	NaCl	181.8	55.9	NaCl	27.8	18.6
40 – 60	$(Ca+Mg)(HCO_3)_2$	3.2	1.9	$(Ca+Mg)(HCO_3)_2$	2.9	1.4
	$(Ca+Mg)SO_4$	44.6	16.5	$(Ca+Mg)SO_4$	23.5	11.6
	Na_2SO_4	75.5	27.9	Na_2SO_4	129.9	64.3
	NaCl	147.8	54.5	NaCl	45.1	22.3
60 – 80	$(Ca+Mg)(HCO_3)_2$	3.0	1.3	$(Ca+Mg)(HCO_3)_2$	2.4	0.8
	$(Ca+Mg)SO_4$	34.0	15.1	$(Ca+Mg)SO_4$	62.5	19.7
	Na_2SO_4	72.0	32.0	Na_2SO_4	75.0	23.6
	NaCl	111.1	49.4	NaCl	177.9	55.9
80 – 100	$(Ca+Mg)(HCO_3)_2$	2.9	1.7	$(Ca+Mg)(HCO_3)_2$	2.2	0.7
	$(Ca+Mg)SO_4$	21.5	12.6	$(Ca+Mg)SO_4$	65.8	22.3
	Na_2SO_4	58.6	34.5	Na_2SO_4	37.9	12.8
	NaCl	86.5	50.9	NaCl	180.1	61.0

Fig. 4.3a shows that at a depth greater than 10 cm, the salt concentration was in the following order: NaCl > Na_2SO_4 > (Ca + Mg)SO_4 > (Ca + Mg) $(HCO_3)_2$.

By the end of the first season, NaCl ranged from 18.6 to 61.0 with a mean of 39.9% and SD of 19.2% (CV = 48.1%), whereas $NaSO_4$ ranged from 12.8 to 66.6 with a mean of 41.2 and SD of 24.0% (CV = 58.2%). (Ca + Mg) SO_4 ranged from 9 to 22.3 with a mean of 15.1% and SD of 5.6% (CV = 37.1%). (Ca + Mg) $(HCO_3)_2$ ranged from 0.7 to 11.0 with a mean of 3.2% and SD of 4.3% (CV = 134.3%).

Irrigation of the first season caused salt leaching and modified the salt distribution pattern. It reduced the concentration of salts in the desalinized zone, and at depths less than 60 cm, the salt concentration was in the following order:

Na_2SO_4 >> NaCl > (Ca + Mg) SO_4 > (Ca + Mg) $(HCO_3)_2$. The Na_2SO_4 depicts salt accumulation zone Fig. 4.3b. The solubility and transport of NaCl was much greater than that of Na_2SO_4 (Fig. 4.3b). It seems that irrigation mobilized NaCl more than Na_2SO_4. In the second season, the salt was further reduced by more salt leaching. NaCl ranged from 23.1 to 73.2 with a mean of 45.3% and SD of 18.8% (CV = 41.5%). Na_2SO_4 ranged from 1.8 to 56.3 with a mean of 33.0% and SD of 22.0% (CV = 66.6%). (Ca + Mg) SO_4 ranged from 11.1 to 19.5 with a mean of 14.8% and SD of 3.3% (CV = 22.2%). (Ca + Mg) $(HCO_3)_2$ ranged from 2.6 to 6.0 with a mean of 3.9% and SD of 1.4% (CV = 35.8%).

The irrigation of the second season caused more leaching and reduction of the salt concentration Table 4.6. The salt distribution pattern qualitatively was similar to that of the first season. The Na_2SO_4 accumulation zone moved further down Fig. 4.3c.

In all cases, NaCl and Na_2SO_4 dominated the soil profile constituting about 84, 81 and 78%, initially, after the first and second season, respectively, the rest was (Ca + Mg) SO_4 and $(HCO_3)_2$. This agrees with the findings of Nachtergaele (1976). The salt distribution can be explained on the basis of ionic mobility salt solubility, and water movement through the soil profile.

The relationship between the total salt concentration and ECe

Fig. 4.4 shows that there's a highly significant linear regression relationship between the total salt concentration expressed in me/L or mg/L (ppm) and ECe in dS/m. The following two relationship were obtained:

C (mg/L) = 629 ECe (dS/m), ($r^2 = 0.990$) ______ (1)

C (me/L) = 9.856 ECe (dS/m), ($r^2 = 0.996$) ______ (2)

These equations maybe used as possible checks on ECe or C determinations in the laboratory.

Richards (1954), using data of large number of samples, reported average constant of 640 and 10 for equations (1) and (2) respectively. Using pure salts, Richards (1954) reported constants of 500 for NaCl, 640 for Na_2SO_4 and 800 for $CaSO_4$. The constant for Dongola soil samples, are between that reported by Richards for Na_2SO_4 and that for NaCl, because the soil samples are dominated by these two salts.

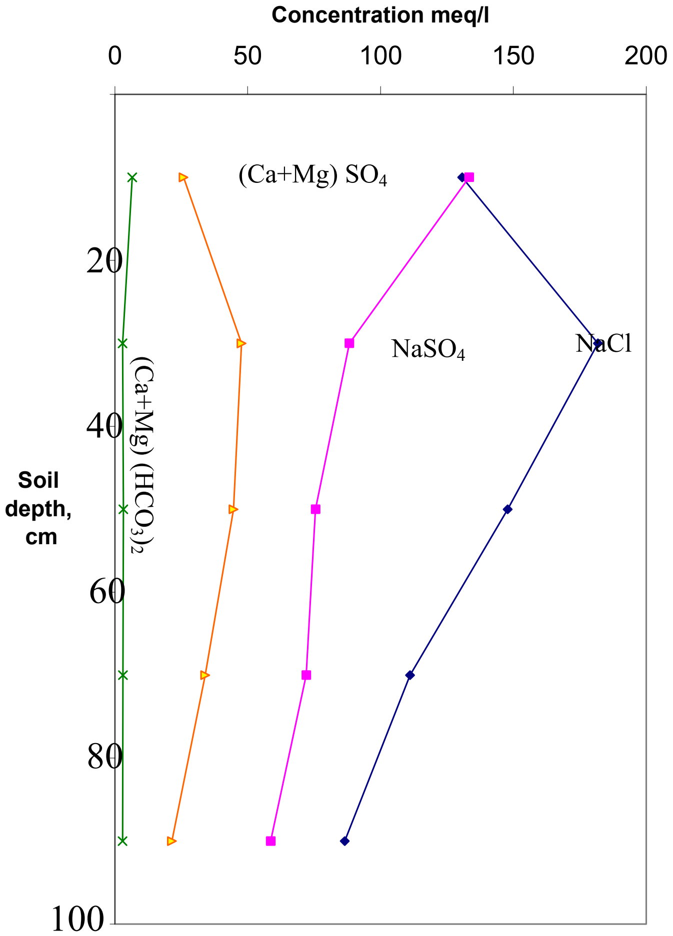


Fig. (4.3a) Initial salt distribution in the soil profile

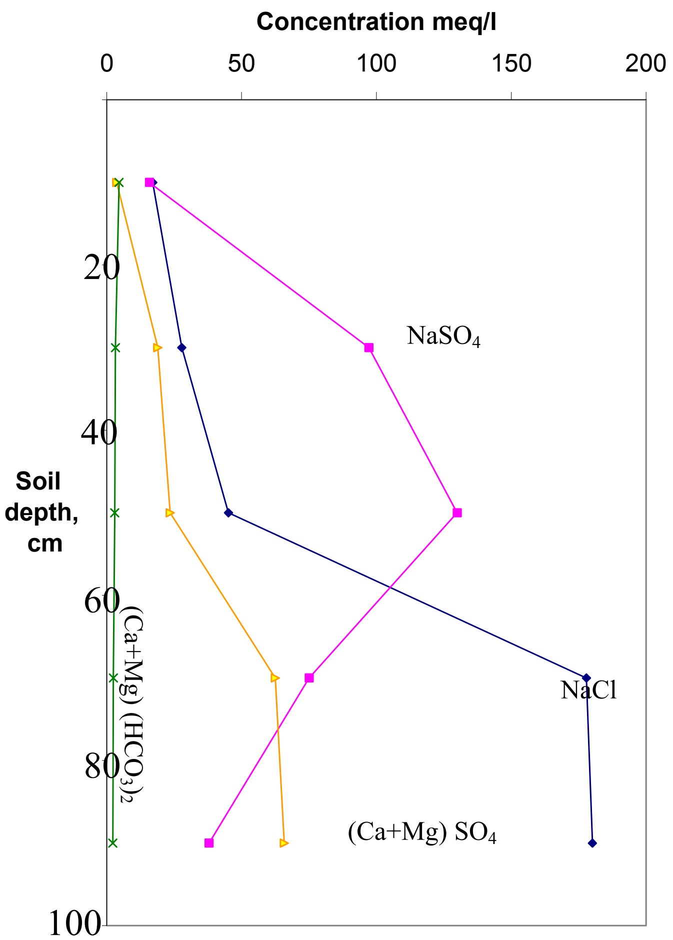


Fig. (4.3b) Profile salt distribution in the first season

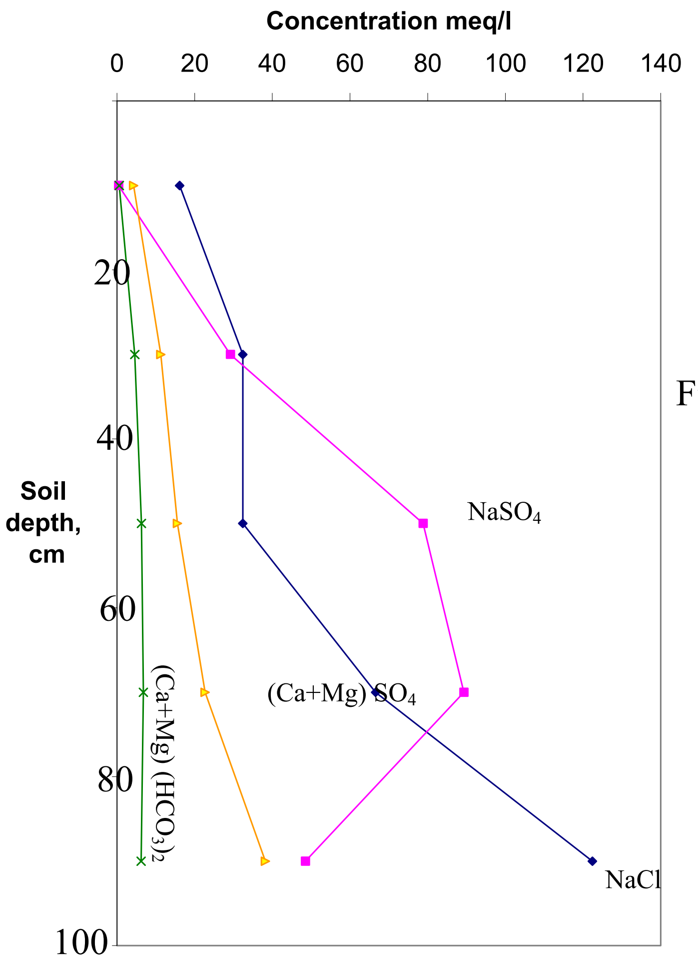


Fig. (4.3c) Profile salt distribution in the second season

Table 4.6: Salt formation after the second season, 2001/2002

Depth	At harvest	Meq/L	%
0 – 20	$(Ca+Mg)(HCO_3)_2$	0.6	2.7
	$(Ca+Mg)SO_4$	4.3	19.5
	Na_2SO_4	0.4	1.8
	NaCl	16.1	73.2
20 – 40	$(Ca+Mg)(HCO_3)_2$	4.6	6.0
	$(Ca+Mg)SO_4$	11.3	14.7
	Na_2SO_4	29.2	37.9
	NaCl	32.4	42.1
40 – 60	$(Ca+Mg)(HCO_3)_2$	6.3	4.5
	$(Ca+Mg)SO_4$	15.6	11.1
	Na_2SO_4	78.8	56.3
	NaCl	32.4	23.1
60 – 80	$(Ca+Mg)(HCO_3)_2$	6.8	3.7
	$(Ca+Mg)SO_4$	22.7	12.3
	Na_2SO_4	89.3	48.3
	NaCl	66.6	36.0
80 – 100	$(Ca+Mg)(HCO_3)_2$	6.2	2.6
	$(Ca+Mg)SO_4$	38.2	16.3
	Na_2SO_4	48.5	20.6
	NaCl	122.4	52.1

4.3 YIELD COMPONENTS AND TOTAL YIELD OF WHEAT AS AFFECTED BY TREATMENTS

4.3.1 Leaf area index

Table 4.7 presents the leaf area index for the two seasons. The main irrigation frequency and farmyard manure effects are shown in Fig. 4.5A and B. The irrigation frequency significantly, affected the LAI in the first ($P = 0.01$) and second season ($P = 0.05$), respectively. Whereas farmyard manure effect and its interaction with irrigation frequency were not significant. In the first season, F_1 gave a significantly higher LAI than F_2 and F_3 whereas, in the second season F_1 gave higher LAI than F_2 and F_3, but the difference was only significant between F_1 and F_3.

4.3.2 Plant height

The plant height data as affected by treatments in the first and the second season are presented in Table 4.8 and Fig. 4.6 A and B show the main effects of treatments.

The first season data show that plant height significantly increased with decrease in irrigation frequency and increase in F.Y.M., the difference between M_2 and M_1 was not significant. The interaction effect was not significant.

In the second season, the impact of irrigation frequency, F.Y.M. and their interaction on plant height, were not significant.

4.3.3 Head length

The head length data as affected by treatments in the first and the second season are presented in Table 4.9 and Fig. 4.7 A and B show the main effects of treatments. In general, the head length increased with decrease in irrigation frequency and increase of F.Y.M.

Statistical analysis of the head length data of the first season indicated that the influence of irrigation frequency and farmyard manure were highly significant, but their interaction was not significant.

Table 4.7: Mean leaf area index (%)as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	**Farmyard manure**			**Mean**
	M_0	**M_1**	**M_2**	
	First season (2000 / 2001)			
7	1.4	1.5	1.8	1.6 a
14	1.0	1.3	1.4	1.2 b
21	0.9	1.1	0.9	1.0 b
Mean	1.1	1.3	1.4	

Main frequency effect (F) $LSD_{0.0108}$ = 0.30

Main farmyard manure effect (M) = NS

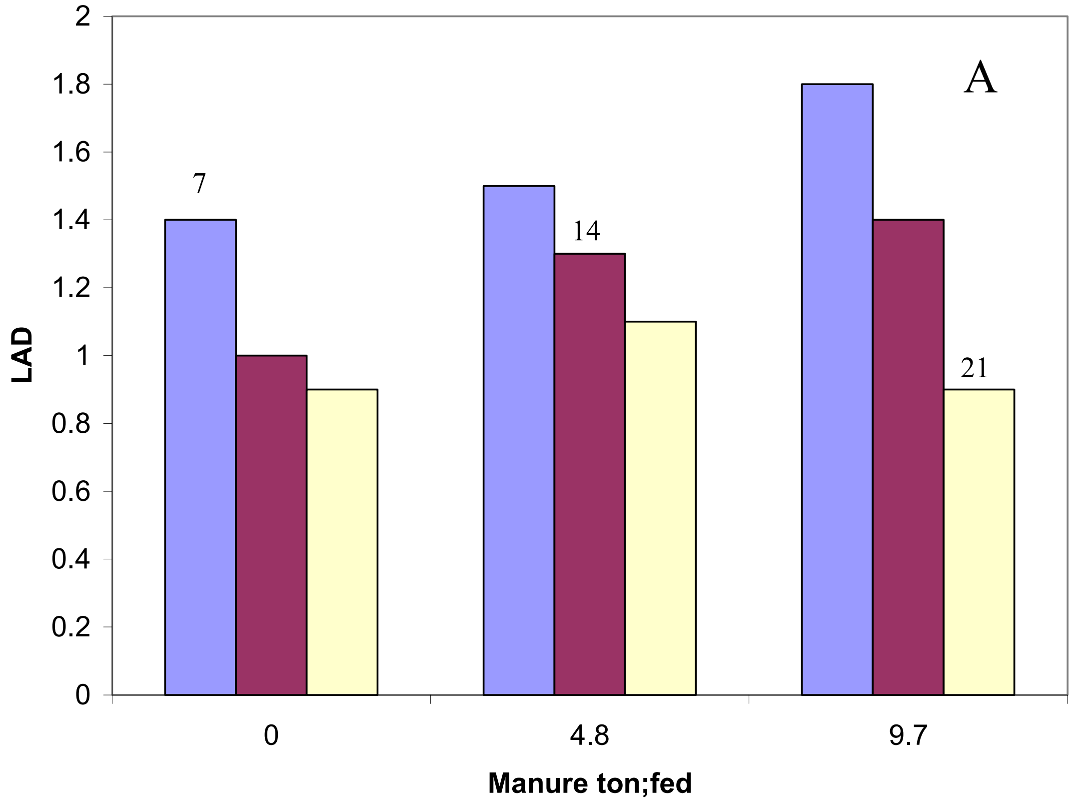
F × M effect = NS

	Second season (2001 / 2002)			
7	1.5	1.6	1.5	1.5 a
14	1.1	1.5	1.6	1.4 ab
21	0.9	1.1	1.4	1.1 b
Mean	1.2	1.4	1.5	

Main frequency effect (F) $LSD_{0.041}$ = 0.29

Main farmyard manure effect (M) = NS

F × M effect = NS



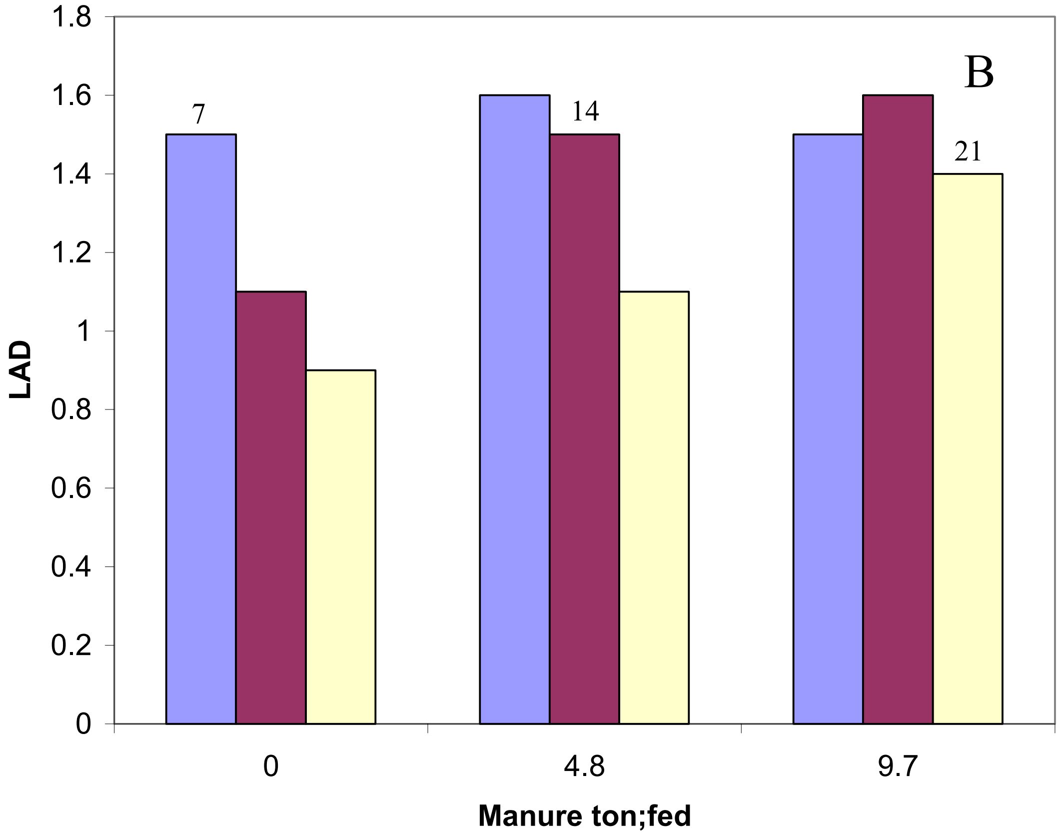


Fig. (4.5) Mean leaf area index (LAD) as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

Table 4.8: Mean plant height (cm) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	60.8	67.0	69.4	65.7 a
14	48.9	59.1	60.2	56.1 b
21	46.7	49.7	52.2	49.5 c
Mean	52.1	58.6	60.6	
	b	a	a	

Main frequency effect (F) $LSD_{0.0022}$ = 5.06

Main farmyard manure effect (M) $LSD_{0.0001}$ = 2.82

F × M effect = NS

	Second season (2001 / 2002)			
7	60.3	61.9	62.8	61.7
14	53.6	61.0	61.7	58.8
21	55.0	56.2	57.9	56.4
Mean	56.3	59.7	60.8	

Main frequency effect (F) = NS

Main farmyard manure effect (M) = NS

F × M effect = NS

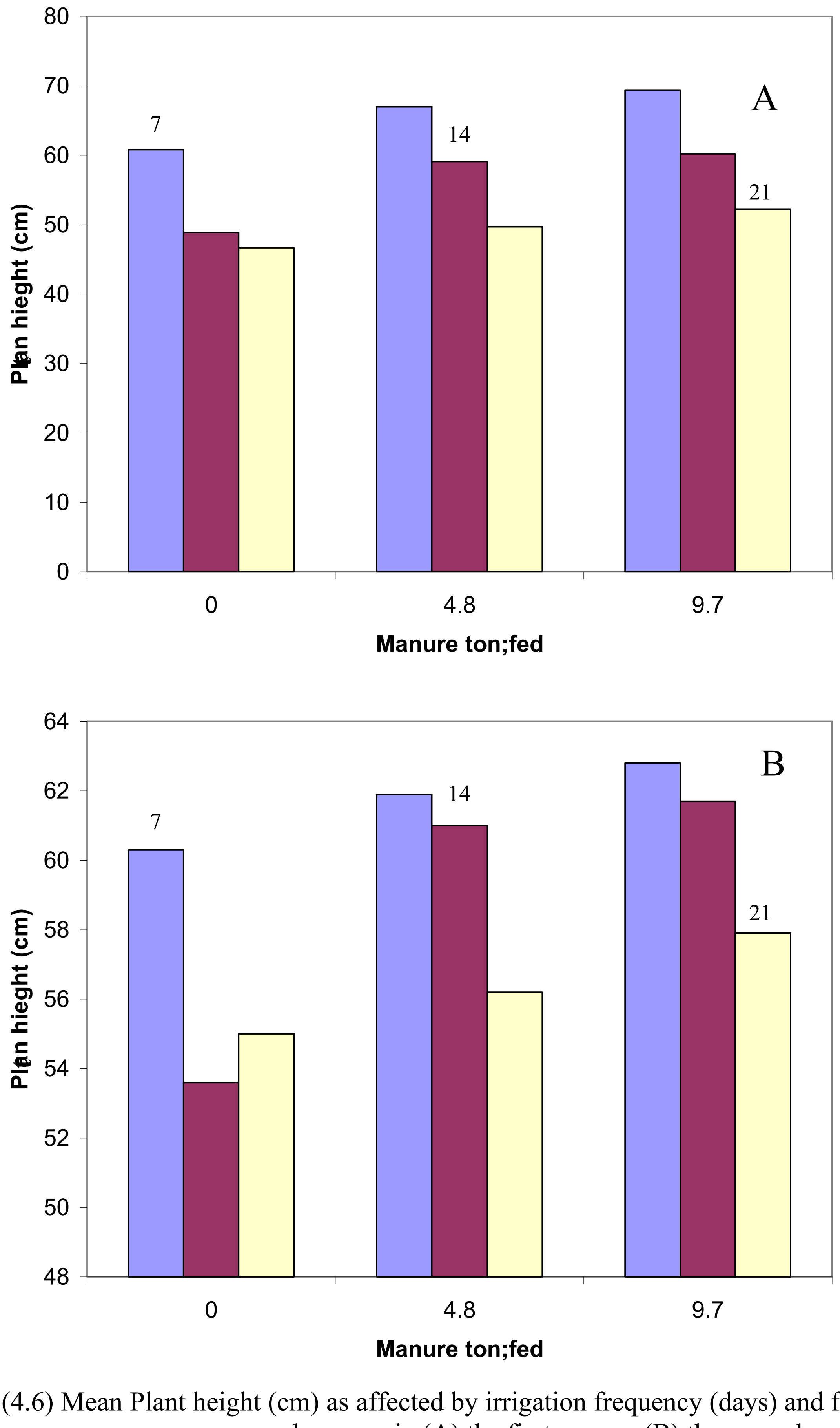


Fig. (4.6) Mean Plant height (cm) as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

Table 4.9: Mean head length (cm) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	6.60	7.00	6.90	6.80 a
14	5.90	6.30	6.50	6.20 b
21	5.60	6.00	6.30	6.00 b
Mean	6.00	6.40	6.60	
	b	a	a	

Main frequency effect (F) $LSD_{0.0092}$ = 0.41

Main farmyard manure effect (M) $LSD_{0.0053}$ = 0.30

F × M effect = NS

	Second season (2001 / 2002)			
7	6.10	6.40	6.40	6.30
14	5.20	6.30	6.40	6.00
21	5.40	5.60	6.20	5.70
Mean	5.60	6.10	6.30	
	b	a	a	

Main frequency effect (F) = NS

Main farmyard manure effect (M) $LSD_{0.0005}$ = 0.32

F × M effect = NS

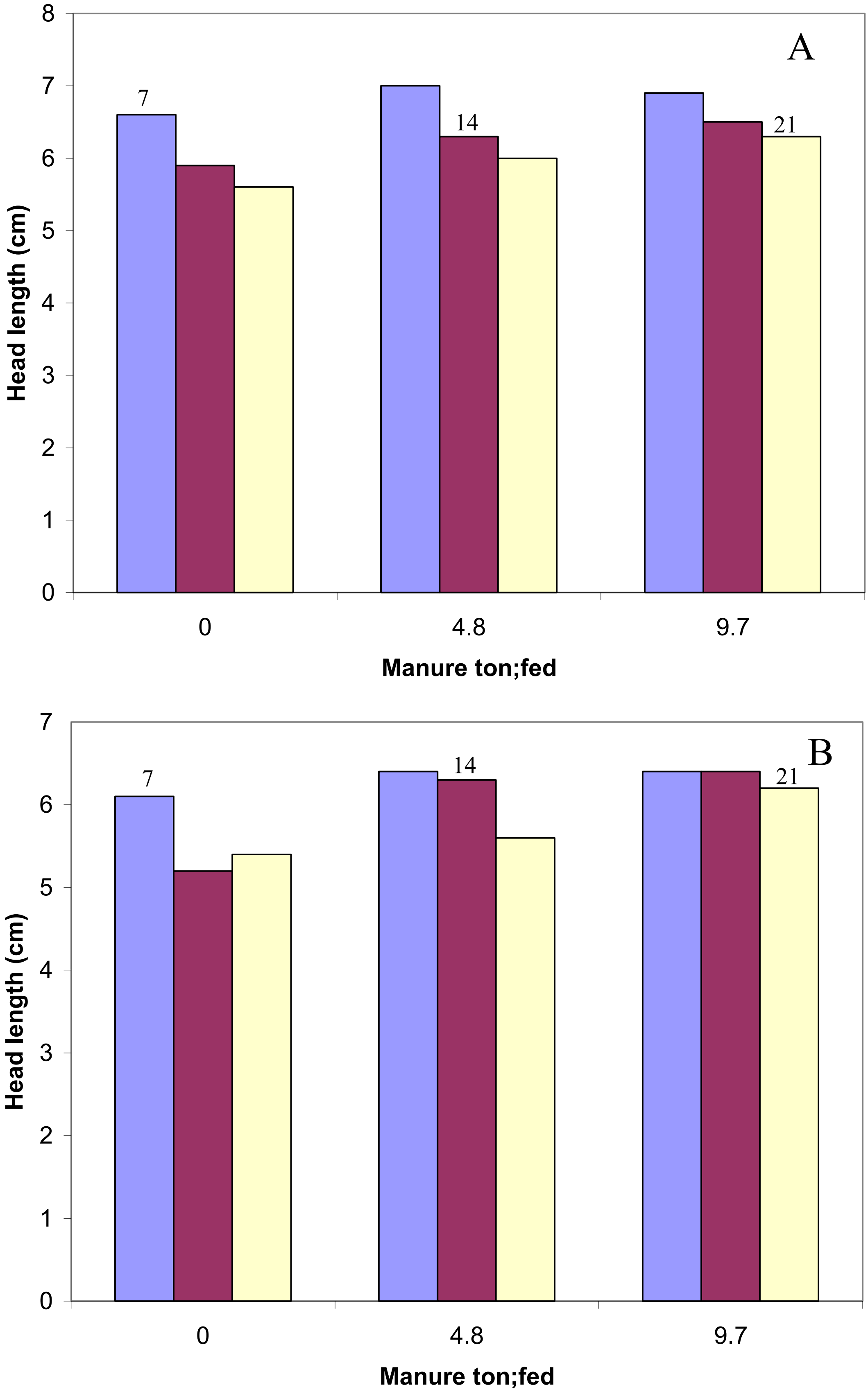


Fig. (4.7) Mean head length (cm) as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

Treatment F_1 gave a highly significant ($P = 0.01$) head length than F_2 and F_3, which weren't significantly different. Furthermore, M_2 and M_1 gave significantly ($P = 0.05$) higher head length than M_0, but there was no significant difference between M_2 and M_1.

In the second season, the head length increased with increase of F.Y.M. level and decrease of irrigation frequency. However, the effect was only significant ($P = 0.0005$) in the case of F.Y.M. Treatment, M_2 and M_1 gave significantly higher head length than M_0, but the difference between M_1 and M_2 was not significant.

4.3.4 Number of head per metre square

Table 4.10 presents the number of heads per metre square (NHM) data for the two seasons. The main effects of treatment are plotted in Fig. 4.8 A and B.

In general, the NHM increased with decrease in irrigation frequency and increase in F.Y.M in both seasons. But the effects were only significant for the F.Y.M treatment in the first season. In this season, M_1 gave significantly ($P = 0.03$) higher NHM value than M_0, and there was no significant difference between M_1 and M_2 and M_2 and M_0.

4.3.5 Number of grains per head (NGH)

The NGH data are presented in Table 4.11 and the main treatment effects are shown in Fig. 4.9 A and B. In general, NGH increased with decrease in irrigation frequency and increase in F.Y.M. in both seasons. The effects of both treatments were highly significant, but their interaction is not significant in both seasons.

Table 4.10: Mean number of heads per metre-square as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	**M_1**	**M_2**	
	First season (2000 / 2001)			
7	342.0	370.0	423.7	378.6
14	298.3	378.7	342.0	339.7
21	280.3	361.0	280.0	307.1
Mean	306.9	369.9	348.6	
	b	a	ab	

Main frequency effect (F) = NS

Main farmyard manure effect (M) $LSD_{0.0325}$ = 45.93

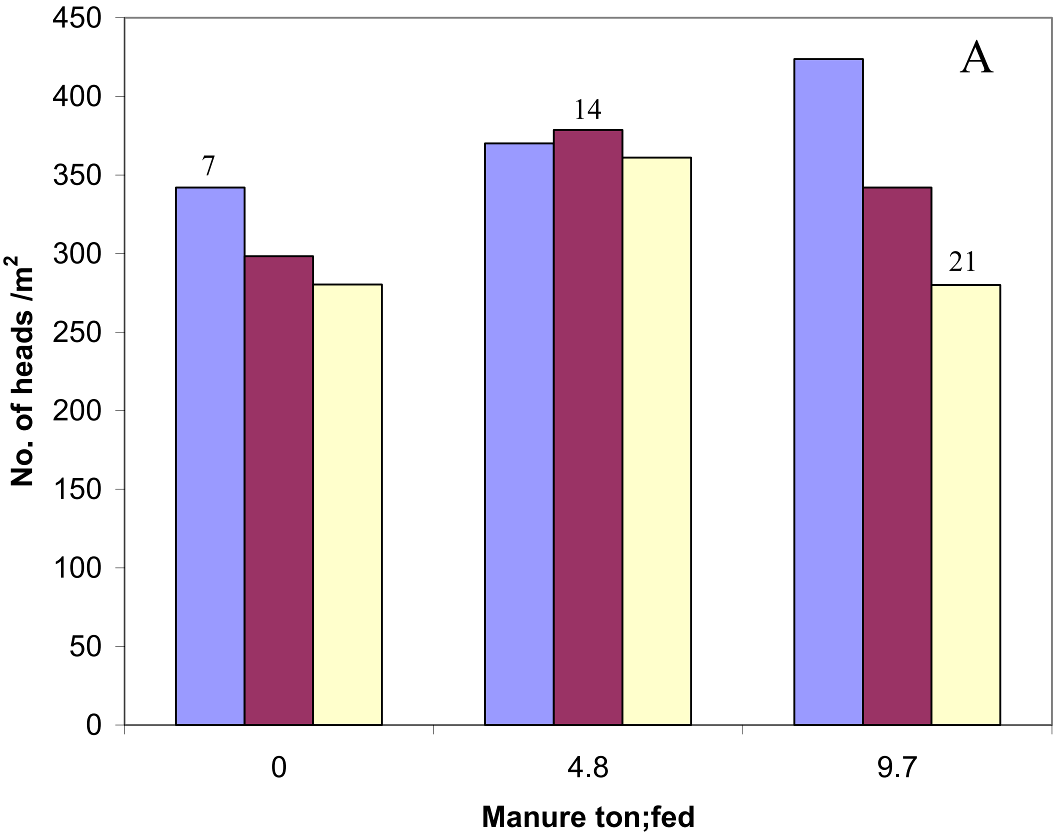
F × M effect = NS

	Second season (2001 / 2002)			
7	422.0	420.3	426.3	422.9
14	468.7	408.7	417.0	398.1
21	347.7	378.0	449.0	391.6
Mean	379.5	402.3	430.8	

Main frequency effect (F) = NS

Main farmyard manure effect (M) = NS

F × M effect = NS



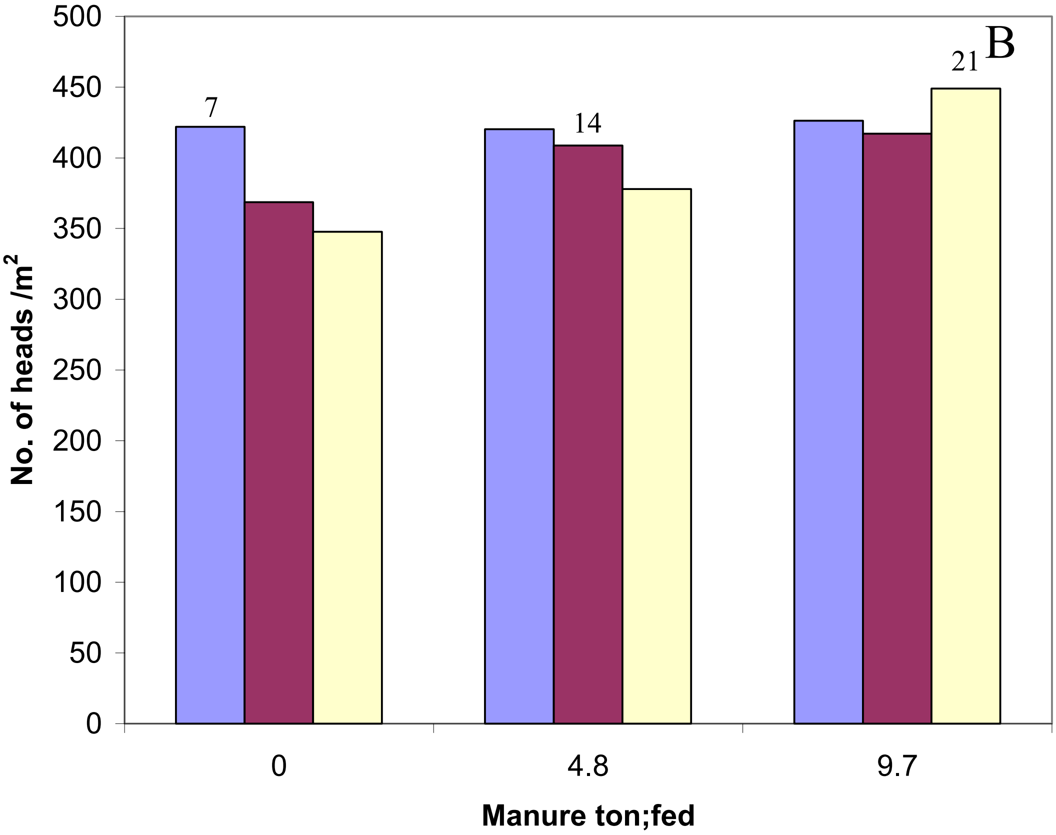


Fig. (4.8) Mean number of heads/m^2 as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

Table 4.11: Mean number of grains per head as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	30.7	30.3	30.7	30.6 a
14	21.0	27.0	28.7	25.6 ab
21	16.0	18.7	26.3	20.3 b
Mean	22.6	25.3	28.6	
	b	ab	a	

Main frequency effect (F) $LSD_{0.0185}$ = 5.63

Main farmyard manure effect (M) $LSD_{0.0102}$ = 3.53

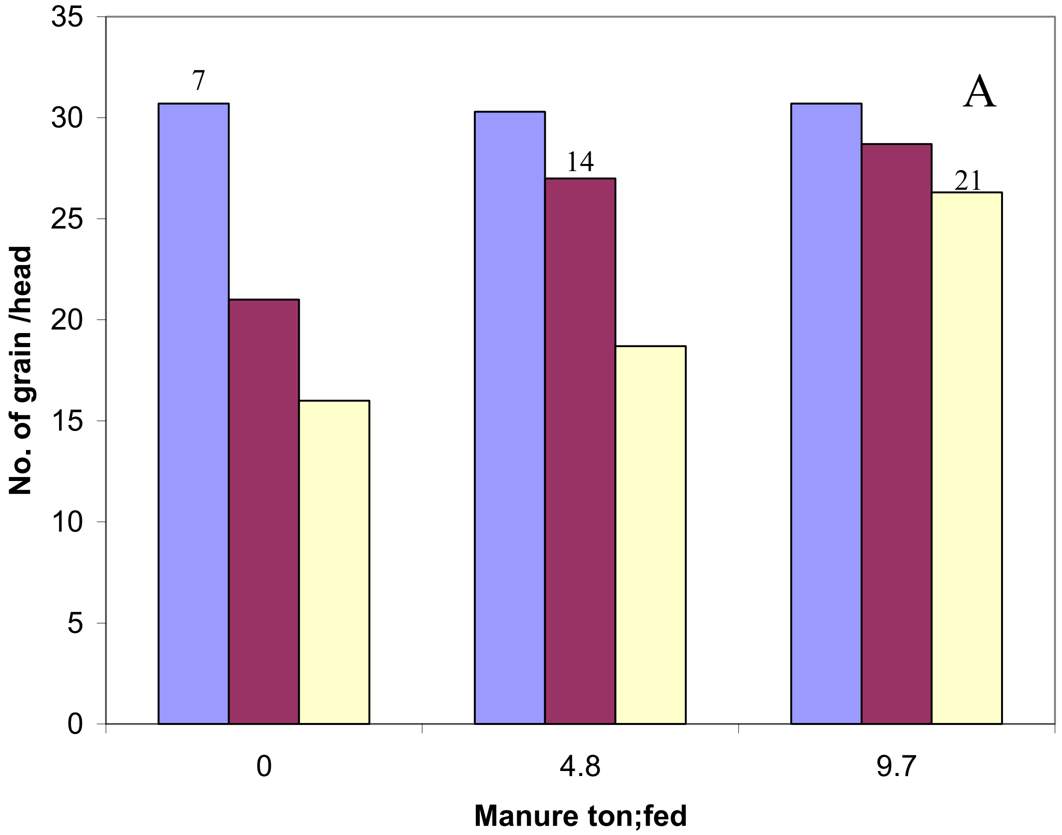
F × M effect = NS

	Second season (2001 / 2002)			
7	27.3	30.3	36.3	31.3 a
14	21.0	28.0	29.0	26.0 b
21	22.3	22.3	27.7	24.1 b
Mean	23.5	26.9	31.0	
	b	ab	a	

Main frequency effect (F) $LSD_{0.0076}$ = 3.20

Main farmyard manure effect (M) $LSD_{0.0180}$ = 4.80

F × M effect = NS



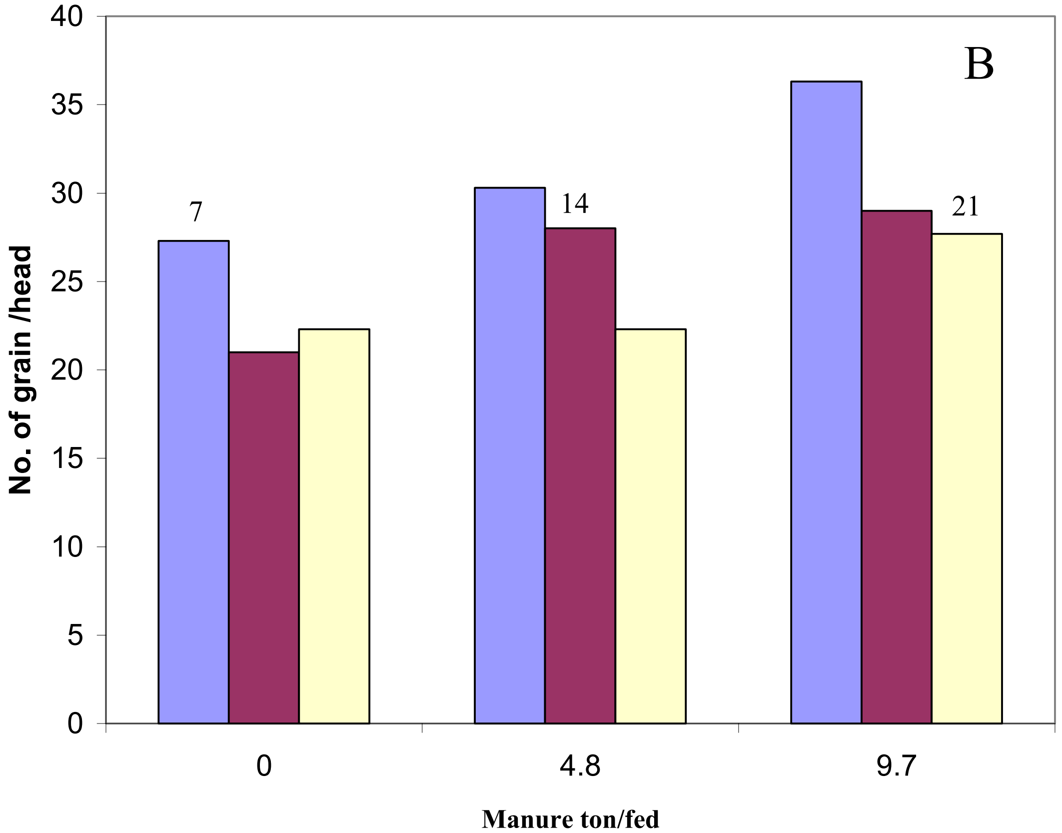


Fig. (4.9) Mean number of grain /head as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

In both seasons, treatment F_1 gave significantly, greater NGH values than F_2 and F_3, but the difference between F_1 and F_2 was not significant in the first season. Furthermore, M_2 gave a significantly greater NGH value than M_0 and M_1, but the difference between M_1 and M_2 and M_1 and M_0 were not significant in both seasons.

4.3.6 1000-grains weight (seed index)

Table 4.12 shows the effects of treatments on 1000-grain weight, and Fig. 4.10 A and B show the main effects of treatments on the 1000-grain weight.

In general, 1000-grain weight increased with decrease of irrigation frequency and increase of farmyard manure in both seasons. However, the effect of irrigation frequency was highly significant in the first season, but not significant in the second season; the reverse was true in case of farmyard manure effect. The interaction between the two treatments was significant in the first season.

Generally, more frequent irrigations increased the yield components as compared with less frequent irrigations. This maybe due to the fact that frequent irrigation reduced both osmotic and water stresses and increased soil water potential (Hillel, 1982). Less frequent irrigation aggravates salinity effects on growth, on the other hand, more frequent irrigations by keeping the soil at higher soil moisture content dilutes the concentration of salt in the soil solution and tend to minimize the adverse effects of salts in the soil (Abrol *et al.*, 1988). Also it increased water uptake by plant roots, which enhanced cell elongation, nutrients uptake and subsequently lead to extensive growth and more yield.

Table 4.12: Mean 1000-grains weight (gm) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	31.8	33.9	34.3	33.3 a
14	28.8	31.7	31.7	30.7 b
21	31.1	29.2	28.8	29.7 c
Mean	30.6	31.6	31.6	

Main frequency effect (F) $LSD_{0.0002}$ = 0.64

Main farmyard manure effect (M) = NS

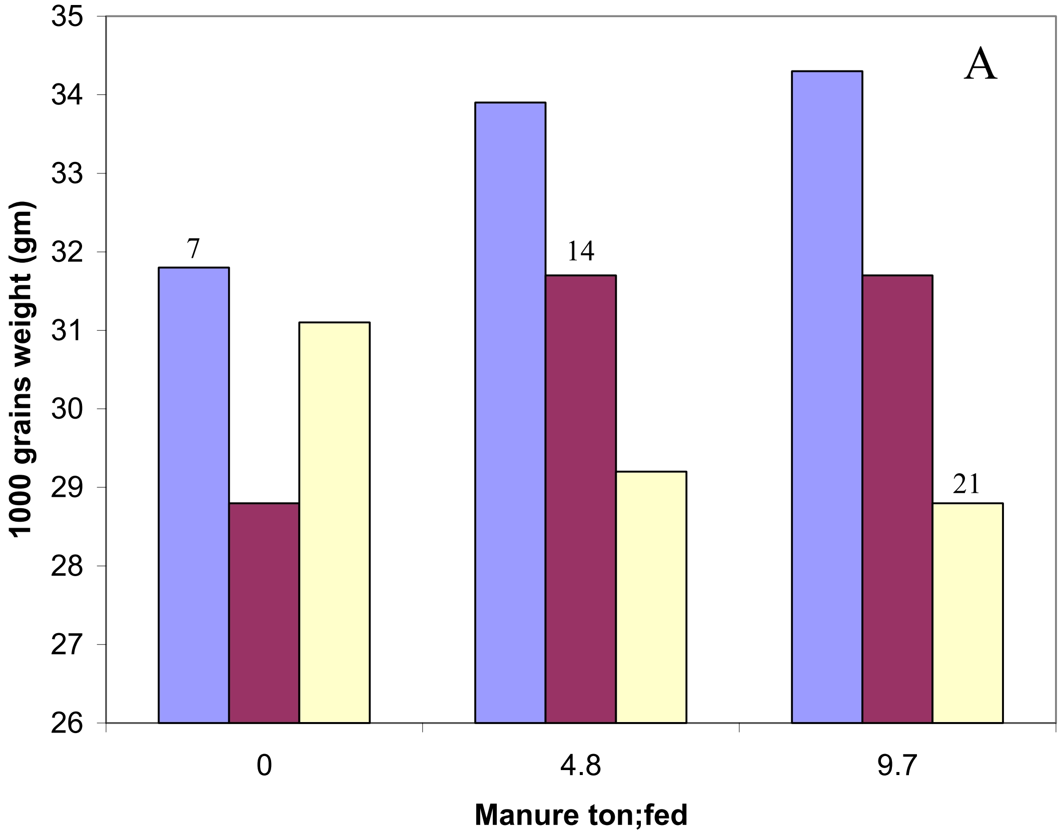
F × M effect $LSD_{0.0506}$ = 2.00

	Second season (2001 / 2002)			
7	32.6	34.2	35.3	34.0
14	31.2	32.6	35.5	33.1
21	31.4	31.8	32.4	31.9
Mean	31.7	32.9	34.4	
	b	ab	a	

Main frequency effect (F) = NS

Main farmyard manure effect (M) $LSD_{0.0402}$ = 2.01

F × M effect = NS



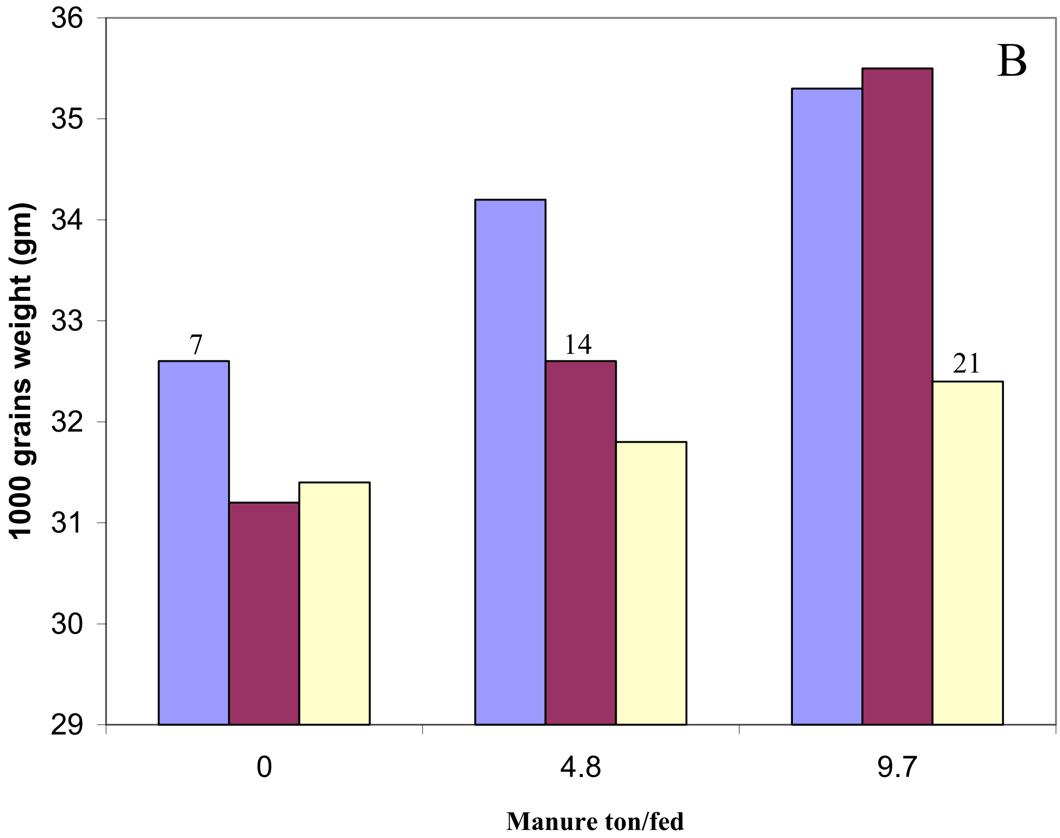


Fig. (4.10) Mean 1000 grains weight (gm) as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

In the second season, the effects of M_0 and M_1 on leaf area index and NHM were similar to those in the first season. However, these treatments had reversible effects on other yield components due to the residual micro organisms effect, which tied up the available nitrogen and thus gave dewarf and yellowing plants, which disappeared after adding another split of urea. Moreover, the soil texture Table 3.1 shows the high permeability to remove leached products into deep layer. Greene and Snow (1939), through planting *Atriplex spp*, found an efficient removed of sodium from the soil, but was effective also in depletion considerable amount of K and N from the soil. The treatment F_3 disadvantage was found in successive seasons; this maybe due to decrease of available nutrient, water and increase of high salt concentration in the root zone, which may have some effect on plant nutrient, uptake.

In general, organic amendment, exerted a favourable effect on LAI, plant height and NHM, which maybe due to more nutrient availability available beside water and increase root penetration.

4.3.7 Total biomass

The total biomass data in the two seasons are presented in (Table 4.13) The overall effect of treatment is shown in Fig.11 A and B.

Statistical analysis of the total biomass data indicated that the influence of irrigation frequency and F.Y.M. levels were significant in the first season, but not significant in the second season. However, the interaction between treatments was not significant in both seasons.

In the first season, F_1 gave significantly greater total biomass than F_3, and F_1 gave greater biomass than F_2 but the difference wasn't significant. Treatment M_2 gave significantly greater biomass than M_0 but not greater than M_1.

4.3.8 Total grain yield

The total grain yield data are presented in Table 4.14 and the main effects of treatments are shown in Fig. 4.12 A and B.

In the first season, the total grain yield significantly (P = 0.05) increased with decrease in irrigation frequency, with increase (P = 0.03) in the level of F.Y.M., but the interaction effect was not significant.

In the second season, the total grain yield also increased with decrease in irrigation frequency and increase in farmyard manure level. However, neither the effects of both treatments nor their interaction was significant.

In both seasons, treatment F_1M_2 was the superior treatment and treatment F_3M_0 was the inferior one since increasing irrigation interval would prolong the reduction in plant turgor pressure and cause reduction in cell elongation and thus reduce yield (Heyn, 1940). The total grain yield was increased by 170 and 46% due application of M_2 and weekly irrigation instead of every 21 days.

The beneficial effect of the superior treatments was reduced in the second season because the soil was relatively ameliorated by the first season irrigation.

Table 4.13: Mean biomass (ton/feddan) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	2.3847	3.0240	3.4090	2.9392 a
14	1.7874	2.4150	2.4127	2.2050 ab
21	1.4467	1.5470	1.6753	1.5563 b
Mean	1.8729	2.3287	2.4990	
	b	a	a	
	Second season (2001 / 2002)			
7	2.1863	2.4267	2.3147	2.3092
14	1.7733	2.2027	2.1887	2.0549
21	1.8527	1.8900	2.1957	1.9795
Mean	1.9374	2.1731	2.2330	

First season:

Main frequency effect (F) $LSD_{0.0225}$ = 0.8073

Main farmyard manure effect (M) $LSD_{0.0004}$ = 0.24822

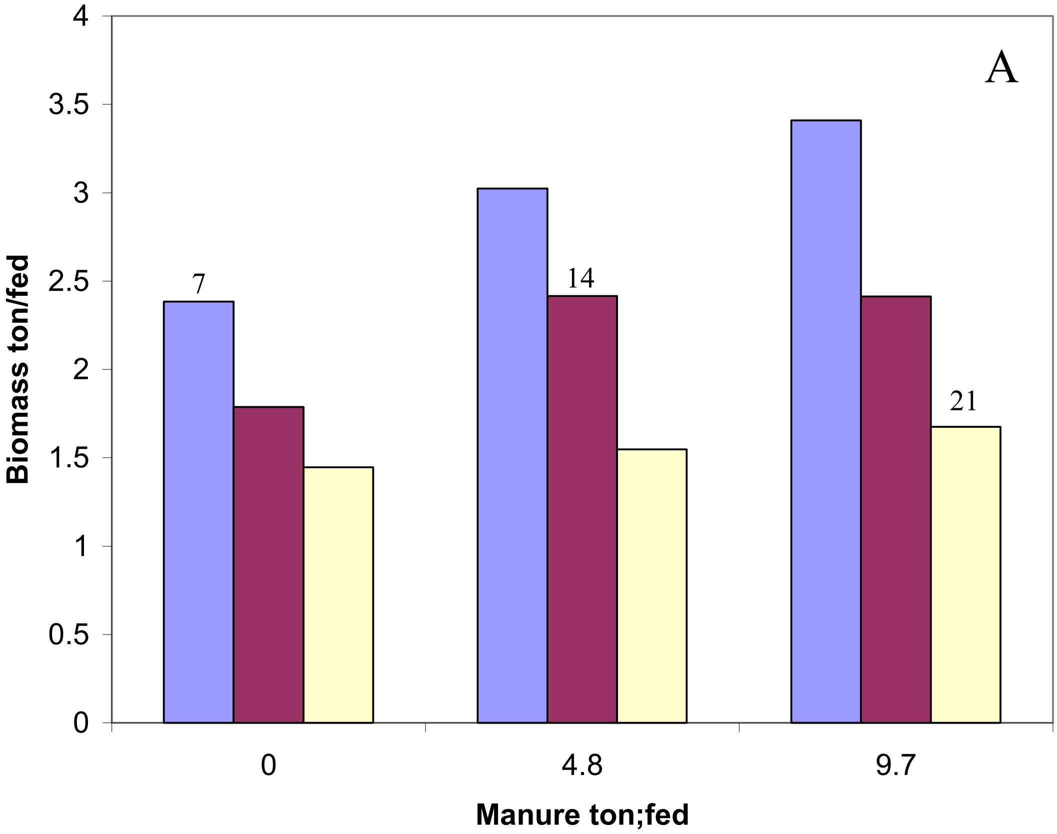
F × M effect = NS

Second season:

Main frequency effect (F) = NS

Main farmyard manure effect (M) = NS

F × M effect = NS



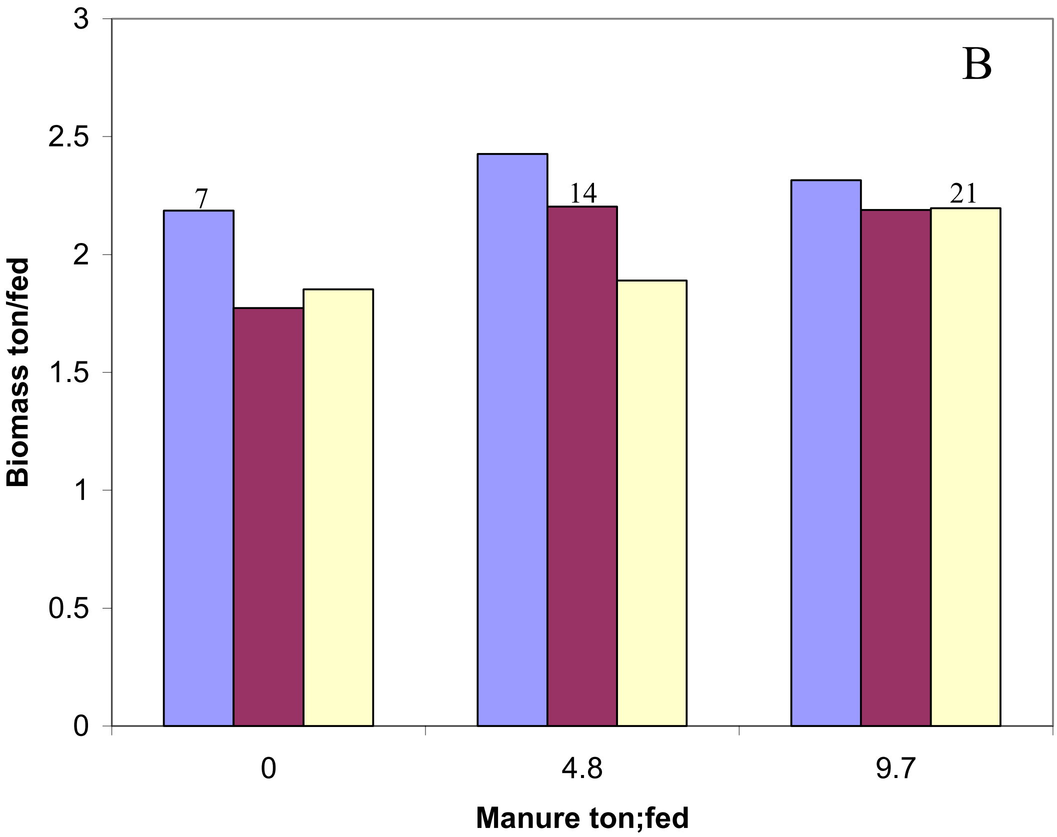


Fig. (4.11) Mean biomass ton/fed as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

Table 4.14: Mean yield of wheat (ton/feddan) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	M_1	M_2	
	First season (2000 / 2001)			
7	0.8275	1.1208	1.3018	1.0834 a
14	0.6221	0.9292	0.9148	0.8220 b
21	0.4818	0.5111	0.5731	0.5220 c
Mean	0.6438	0.8537	0.9299	
	b	a	a	

Main frequency effect (F) $LSD_{0.0045}$ = 0.20963

Main farmyard manure effect (M) $LSD_{0.0003}$ = 0.11100

F × M effect = NS

	Second season (2001 / 2002)			
7	0.8573	0.9817	0.9520	0.9303
14	0.6750	0.8507	0.8640	0.7966
21	0.6513	0.6603	0.8063	0.7060
Mean	0.7279	0.8309	0.8741	

Main frequency effect (F) = NS

Main farmyard manure effect (M) = NS

F × M effect = NS

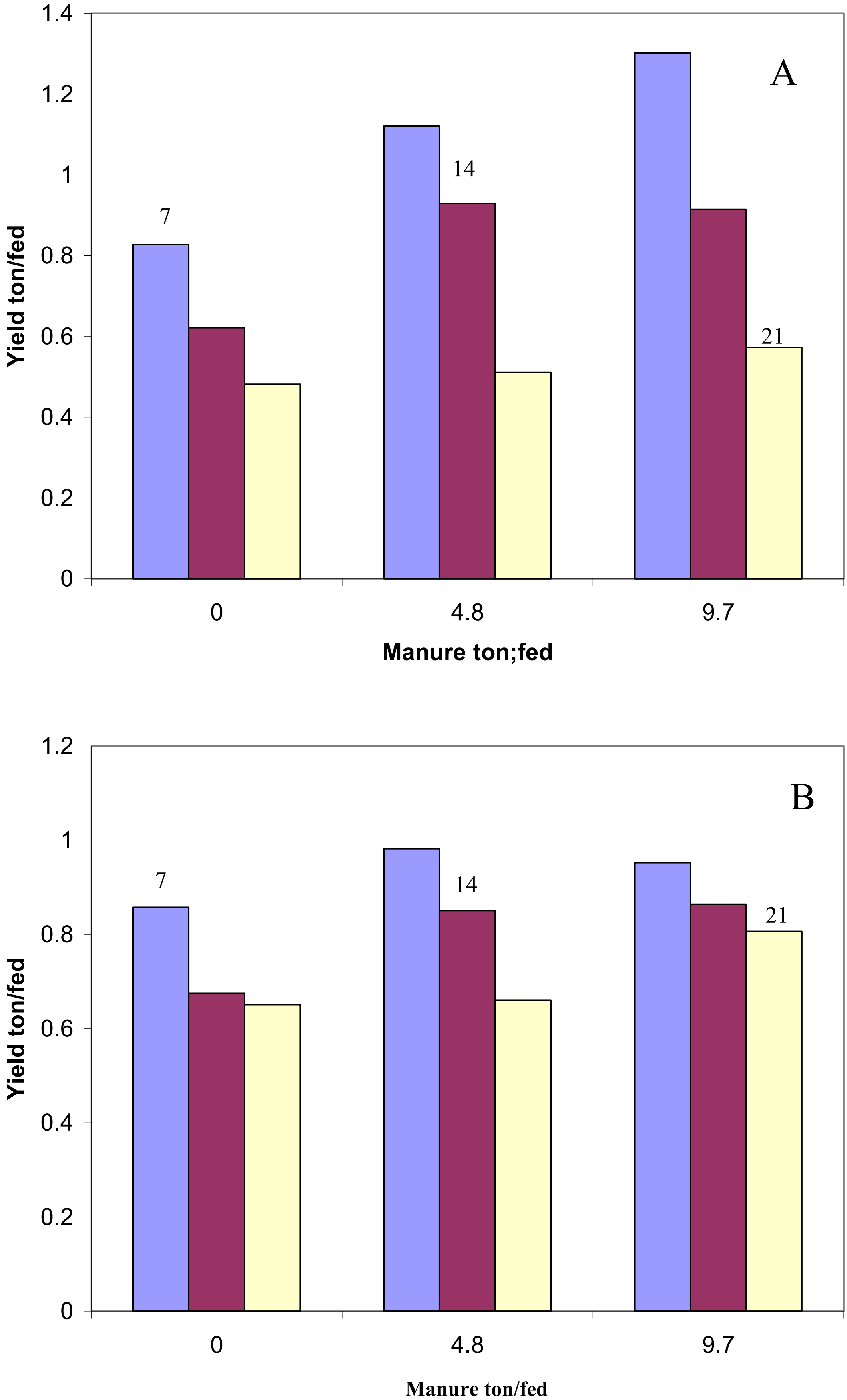


Fig. (4.12) Mean yield ton/fed as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

4.3.9 Water use efficiency (WUE)

The water use efficiency data as affected by treatments, are presented in Table 4.15 and the main effects of irrigation frequency and farmyard manure are shown in Fig. 4.13 A and B. It is interesting to note that the impact of treatments on water use efficiency results, were followed by the same trend of their impact on the total grain yield.

In general, WUE increased with decrease of irrigation frequency and increase of F.Y.M. in both seasons, However, the effects of treatments were significant in the first season but not in the second season. Furthermore, the interaction between treatments wasn't significant.

Table 4.15: Mean water use efficiency (kg/m^3) as affected by irrigation frequency (F) and farmyard manure (M).

Frequency (day)	Farmyard manure			Mean
	M_0	**M_1**	**M_2**	
	First season (2000 / 2001)			
7	0.230	0.311	0.361	0.301 a
14	0.172	0.258	0.254	0.228 b
21	0.134	0.141	0.159	0.145 c
Mean	0.179	0.237	0.258	
	b	a	a	

Main frequency effect (F) $LSD_{0.0046}$ = 0.06

Main farmyard manure effect (M) $LSD_{0.0003}$ = 0.03

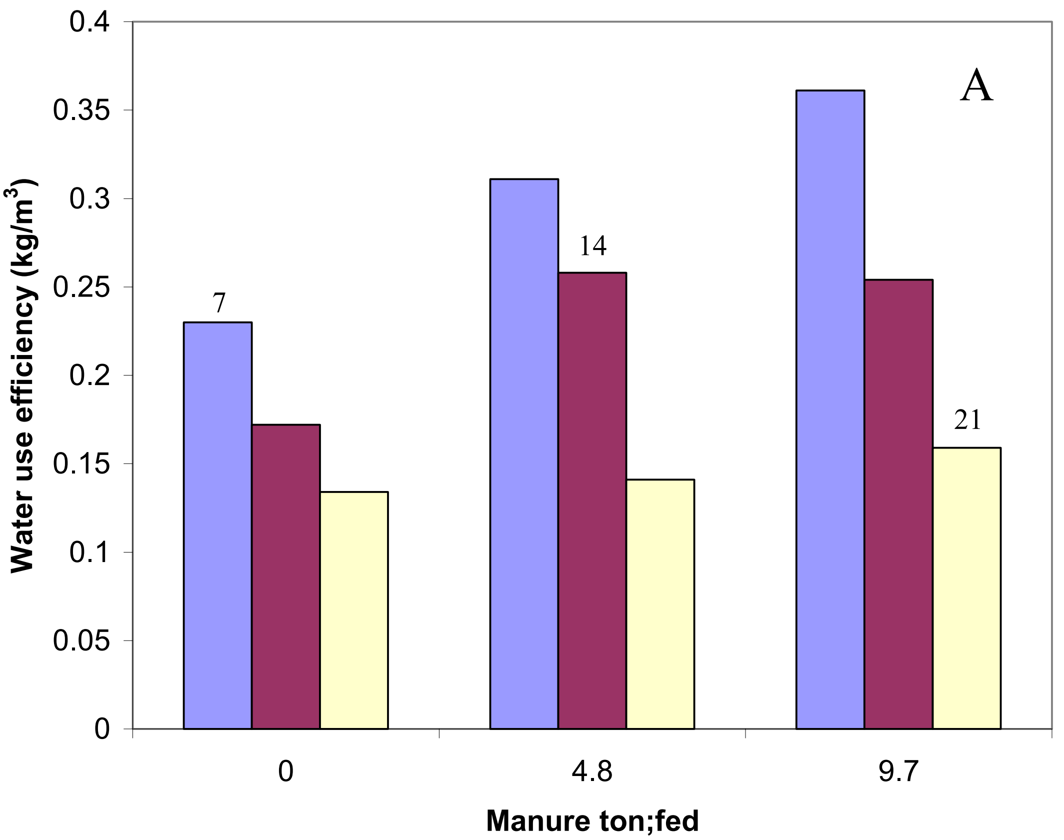
F × M effect = NS

	Second season (2001 / 2002)			
7	0.263	0.301	0.292	0.285
14	0.207	0.261	0.265	0.244
21	0.200	0.203	0.248	0.217
Mean	0.223	0.255	0.268	

Main frequency effect (F) = NS

Main farmyard manure effect (M) = NS

F × M effect = NS



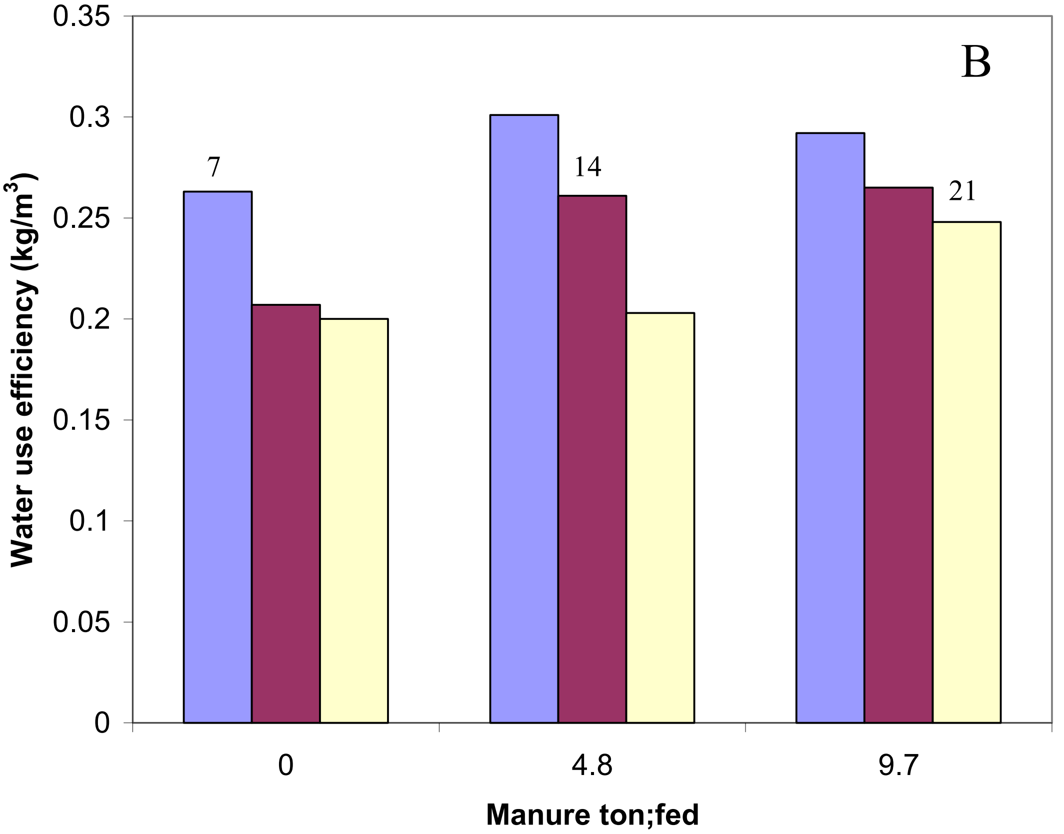


Fig. (4.13) Mean water use efficiency (kg)/m^3 as affected by irrigation frequency (days) and farm yard manure in (A) the first season, (B) the second season

CONCLUSIONS

This field experiment was designed investigate the effect of irrigation frequency and FYM on wheat growth in a slat – affected soil. The study indicated that employing proper soil and water management could increase the productivity of such problematic soils. The following main conclusion are drawn from this experiment:

1. The impact of irrigation interval on wheat growth and productivity was greater than the effect of organic amendment.
2. The 7-days irrigation interval results in better growth and yield of the crop due to efficient salt reaching and higher water potential between irrigations.
3. Application of FYM promoted water movement and increased salt leaching but the effect was not significant.
4. Irrigation promoted desalinization of top 0-60cm and dealkalization on top 0-40cm.

It is recommend that wheat in saline soils should be receive weekly irrigation at a rate equivalent to potential evapotranspiration.

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Appendix (1)

Potential Evapotranpiration According to Jensen and Haise (1963), Equation for Dongola (10-19N, 29-30E) 228m AMSL

Month / Parameter	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Max	26.6	29.3	33.8	38.7	41.9	43.4	42.2	41.8	39.5	38.5	32.1	28.2
Min	8.5	9.7	13.9	18.6	22.5	24.7	25.1	25.3	24.7	20.5	14.9	10.1
Mean	17.6	19.5	23.9	28.7	32.2	34.1	33.7	33.6	32.1	29.5	23.5	19.2
e_2	34.86	40.79	52.62	68.82	81.48	88.06	82.78	81.0	71.8	68.1	47.87	38.26
e_1	11.1	12.06	15.99	21.44	27.25	31.13	31.89	32.27	31.13	24.15	16.91	12.38
e_2-e_1	23.76	28.73	36.63	47.38	54.23	56.93	50.89	48.79	40.67	43.95	30.96	25.88
C_1	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5	36.5
C_2	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6
C_H	2.1	1.74	1.36	1.05	0.92	0.87	0.98	1.02	1.22	1.13	1.61	1.93
C_t	0.019	0.020	0.021	0.022	0.022	0.023	0.022	0.022	0.021	0.022	0.02	0.019
T_x	-6.24	-6.93	-8.04	-9.54	-10.5	-10.88	-10.03	-9.74	-8.6	-9.06	-7.24	-6.53
T- T_x	23.84	26.43	31.94	38.24	42.7	44.98	43.73	43.34	40.7	38.56	30.74	25.73
R_s	456.6	500.2	589.6	610.1	609.4	606.2	602.5	560.1	545.3	524.8	473.1	439.4
ET mm/day J-H	3.50	4.48	6.7	8.69	9.70	10.63	9.82	9.05	7.89	7.54	4.92	3.64

T max	Maximum Temperature
T min	Minimum Temperature
T mean	Mean Temperature
ET_r (J-H)	C_t (T-T_x) R_s
C_t	Heat coefficient
T	Mean Temperature ^oC
Tx	Heat Value in crossing to axil represented to heat
Rs	Incoming short waves radiation - cal/cm^{-2}/day^{-1}