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Published

2006

Journal Title

Agricultural Water Management

DOI

10.1016/j.agwat.2005.04.010

Potential Use of the Caspian Sea Water for Supplementary Irrigation in Northern Iran

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Abstract

Iran's groundwater resources have been over-exploited, often at the expense of deteriorating both water and land quality and there is limited room for expanding irrigation agriculture. Thus the possible use of Caspian Sea water, whose salinity is well below that of the open seas, for supplementary irrigation has some appeal. The impact of irrigation with diluted Caspian Sea water on the growth and yield of barley and on the characteristics of soil was investigated in field plots and in pot experiments during the 2001-2002 growing season. Three irrigation regimes of well water alone (I_0); Caspian Sea water diluted with well water and used at the time of plants' stem elongation (I_1), and the same diluted sea water used at the time of plants' ear formation (I_2). A rainfed treatment was also added to the field experiments. The results of both pot and field experiments show that a 1:1 mixture of Caspian Sea and well water can be used for irrigation without a significant reduction in the growth and yield of barley, provided that it is not applied earlier than the time of ear formation. This would amount to a significantly reduced demand on the limited ground water resources of the region for agricultural use. However, when this mixture was applied at the earlier time of stem elongation, significant yield reduction occurred. All other growth components of barley plants were also adversely affected by this early application of diluted sea water. Soil analysis after harvest showed that the EC of its saturation

extract had increased significantly in both seawater treatments. This may suggest that the mixing of sea and ground waters at rates used in these experiments may not be sustainable over a long period of time and soil salinization may occur unless soils are of light textured types and sufficient good quality fresh water or winter rain is available to lower the salinity of soil between successive crops. Further research for the determination of a suitable Leaching Ratio (LR) to stabilize soil salinity are in progress.

Keywords: Sea water, saline water, irrigation, salinity, groundwater, Caspian Sea

Introduction

Iran's winter-dominated rainfall pattern is such that rainfed agriculture is confine to the costal regions of the Caspian Sea in the north of the country. Irrigation agriculture is by far the most prevalent form of agricultural throughout the country. Using the landscape configuration and good engineering and hydrological skills, early settlers of Persian plateau invented the "Ghanat" system of irrigation through which free flowing groundwater provided them with an abundance of good quality water for irrigation which made Iran the largest irrigation agriculture country in the Middle East. Over-exploitation of ground-water in recent years, mostly though digging wells and pumping the water out, has lowered the ground-water levels rendering many thousands of Ghanats dry and in ruin. At the same time a rapid increase in the population of Iran during the past two decades has significantly increased the country’s need for water, food and fibre and has put its land and water resources under severe stress. Freshwater resources of the country, both surface and ground water, has been over-exploited, often at the expense of deteriorating water and land quality. With limited room for expanding irrigation agriculture due to the lack of extra capacity in the country's freshwater resources, the possible use of Caspian Sea water, whose salinity is well below that of the open seas and oceans, has some appeal (Dordipour 2000). As shown in Table 1, the Caspian Sea water is also lower in Cl^{-1} and Na^{+1} and higher in Ca^{+2} and

$SO4^{-2}$ contents than the water from open seas or oceans, which make it less harmful to soils' physical and chemical health.

Saline water was previously considered unusable for irrigation but new research during the past two decades has helped bringing into practice some large irrigation schemes which depend on saline water (Hamdy *et al.*1993; Beltran 1999; Qadir *et al*. 2001). However, with its potential hazard of increasing land and ground-water salinity as well as possible deterioration of soil physical, chemical and biological characteristics, the issue needs to be thoroughly researched. The sustainability of irrigated agriculture in arid and semi-arid regions depends on the maintenance of salt balance within the soil profile and disposal of shallow groundwater is often necessity. Saline drainage waters can be used for irrigation of certain crops and their use lessens drainage disposal requirements and water pollution (Rhoades *et al.*1980). Rhoades *et al.* (1989) further demonstrated a strategy for using saline and non-saline water in rotation, which caused no reduction in yield providing there was a good plant stands is already established.

Salinity generally affects the growth of plants by either ion excess or by water deficits in the expanded leaves (Greenway and Munns 1980). Water uptake is restricted by salinity due to the high osmotic potential in the soil and high concentrations of specific ions that may cause physiological disorders in the plant tissues (Feigin 1985) and reduce yields (Verma and Neue 1984). However, some crops such as wheat and barley can be tolerant of saline irrigation water, a property that can be enhanced by selection and breeding (Norlyn and Epstein 1982; Yazdani 1991). Research suggests that irrigation of barley with up to two-thirds seawater is feasible and may result in economically significant yields. This study examines growth and yield of barley in irrigated pot and field plot experiments using a mixture of Caspian Sea water and well water. The effect of the application of saline water on soil properties is also examined together with an assessment of overall water use and water use efficiencies in different irrigation regimes.

Materials and Methods

Pot experiments

Barley (*Hordeum vulgare* L. cv. 'LB') was grown in a silty loam soil of the Agh-ghala series in plastic pots, 20-25 cm diameter and 31 cm height under a plastic green house (Fig 1). The soil was passed through a 5mm sieve before being transferred into the pots. Irrigation water was provided from the Caspian Sea (carried by a tankers to the experimental site) and from a local well. The basic physio-chemical properties of the soil and water were determined with standard techniques (Richards 1954; Page *et al*. 1982; Sparks *et al.* 1996). Some chemical data for the irrigation waters and soils used in the trials are presented in Tables 2 and 3 respectively. The sea-water was considerably more saline than the well water and salt concentrations varied slightly with season.

Drainage holes were made at the bottom of the pots and the pots were filled with ~2 cm of gravel/sand to further improve drainage. Pots were packed with 16.95 kg air-dried soil in 5 x 5 cm uniformly compressed increments (Homaee 1999). The soil contained 12%, 64% and 24% sand, silt and clay respectively and was classed as a silty loam texture. The bulk density and organic carbon content were 1400 kg m^{-3} and 0.59% respectively. The soil surface was then covered by a 10 mm layer of gravel to reduce evaporation and to avoid disturbance when applying irrigation water. A completely randomized factorial design was used with three irrigation and nine fertilizer regimes and application times and three replications. The three irrigation regimes were: (I_0) well water alone (EC = 0.802 dS/m), (I_1) Caspian Sea water (EC = 21.5 dS/m), diluted with the well water at a 1:1 ratio and used at the stem elongation stage (Zadoks *et al.* 1974) and (I_2) same sea water/well water mixture as (I_1) but used at the ear formation (heading stage, Zadok's code 70), respectively. The surface of each pot was divided into concentric circles, in which 40 barley seeds were sown on January 22, 2001. They were thinned to 20 plants after germination and full establishment of seedlings (Hassan *et al.* 1970). Ten plants were used for measurement and sampling in the tillering and heading stages to determine the quantities of fresh and dry matter production and the 10 remaining plants used for yield and its components such as dry matter, nutrient contents, height, root length and so on. The pots were irrigated with well water for germination and establishment of seedlings. The irrigation then continued according to water requirement, until the respective irrigation treatments were applied. Three pots from each treatment were weighed before every irrigation and the required quantity of water was calculated from the difference between "pot capacity" (analogous to field capacity) and the actual weight minus plant weight, plus 30% leaching fraction. Pot capacity was determined by adding excess water to pots with soil. The pots were then covered by plastic sheet to prevent evaporation and weighed over a few days until an equilibrium weight was attained. The irrigation cycle was adjusted according to the depletion of 50% available water from the pot soil (Hassan *et al*. 1970; Bar-Tal *et al.* 1991; Marcelis and Van Hooijdonk 1999).

Fertilizer treatments consisted of all possible combinations of three levels of potassium and three levels of zinc whose results are reported elsewhere (Dordipour, 2004). Nitrogen was applied to all pots at the rate of 300 kg/ha of urea (one third before planting, one third at the tillering and one third at the heading stage). Each treatment also received 75 kg P_2O_5/ha as $NH_4H_2PO_4$. At harvest, the plants were divided into tops (head, leaf and shoot) and roots (in two depth intervals of 0-10 and 10-20 cm) and their fresh and oven-dry weights were determined. After harvest, the soil of all pots was divided into two horizontal layers from 0-10 and 10-25 cm depths and analysed. Statistical analysis and mean comparisons test of main effects and interactions on the yield and its components, fresh and dry matter, soil and other parameters of plant were analysed by the SAS-ANOVA and SAS-MEANS procedures (SAS 1992).

Field Experiments

Field experiments were carried out at Banavar Agricultural Research Station 15 km north-east of the city of Bandar Torkman and 5km from the Caspian Sea shore in the northern province of Golestan of Iran (latitude of 37°, 10′ N and the longitude of 54°, 13′ E). Average annual temperature of the region is 17°C and annual rainfall and evapo-transpiration are 420mm and 1636mm respectively. Most of the rainfall occurs during the winter months of December to March, thus there is a sever water shortage during the growing season of crops. The region has around 26000 hectares of agricultural land, 5500 hectares of which is irrigated and the rest is rainfed. There are two rivers in the region but groundwater is the main source of irrigation water. The alluvial soil upon which field experiments were carried out is of silt-loam texture. Some of the physical and chemical characteristics of the soil are given in Table 3. The soil was ploughed in fall using conventional mouldboard plough but also tilled twice more prior to broadcasting barley seeds using disk plough. Plot size was 1 x 2 m. A complete randomized block split plot factorial experiment with three replications was carried out during 2001-2002 growing season using four irrigation treatments (I_r = rainfed, no irrigation, $I_{0,}$ = irrigation with well water alone, I_1 irrigation with a 1:1 mixture of well and sea waters starting at the time of stem elongation and I_2 same as I_1 but irrigation began at the time of ear formation). Eight fertiliser treatments where also included as secondary factors in the experiments whose results are reported elsewhere. There were 96 experimental plots arranged in a completely randomized form as shown in Fig 2. Three hundred barley seeds were sown in each plot in 5 rows 20 cm apart. One square metre in the centre of each plot was harvested for the measurement of yield and its components and the rest was used for sampling soil and plant for various other measurements carried out during the growing season.

Measurements

The following measurements were carried out for both pot and field experiments:

1. Measurement on barley plants included: plant height, head length, length of awns, peduncle length, kernel yield, yield components such as weight of 1000 kernel, number of kernel per head and the number of heads per m^2, biomass (wet and dry), yield index, leaf area, water use efficiency, root weight.
2. Chemical analysis for the measurement of Zn, B, Mg, Ca, Na, and K in leaves, stems, kernel and the entire plant were also carried out.
3. Measurements on soil samples included pH, EC, ESP, K, B, Cl and soluble and exchangeable Na, Ca and Mg.
4. Measurements on water samples were: pH, EC, SAR, Na, Ca, Mg, K, B, and Cl.

Results and Discussions

Effect of irrigation with saline water on the growth and yield of barley

1. Pot experiments

As expected growth and yield of barley were highest in treatment I_0 where pure well water was used for irrigation (Table 4). Irrigation with seawater-well water mixture at stem elongation time (I_1) significantly reduced yield and most of the measured yield and growth components, but when applied at the later stage of ear formation (I_2) the yield and yield components’ reductions were not significant (Table 4 and Fig 3). In I_2 treatment yield, weight of 100 seeds and the number of heads per plant was slightly reduced compared to I_0, but the number of seeds per head and spikelets were actually increased by 6.6 and 2.6% respectively. These results are in agreement with the findings of Francois *et al*. (1994) and Grieve *et al*. (1992) that salinity stress reduced the grain weight but not the number. Francois *et al*. (1994) also demonstrated that the time or stage of salinity stress had a significant effect on grain-weight of wheat, which is the same as the results of this study on barley. Compared to I_0 the number of sterile shoots in barley plants was increased by 68% and 17% and the number of unfilled heads by 11% and 12% for I_1 and I_2 respectively. Prolonged exposure of plants to saline water in I_1 appears to have affected all aspects of plant growth and yield. The reduction in yield in treatment I_1 appears to be the result of across the board reduction in yield and growth components, but a large increase in sterile shoots appears to have a major role in yield decline. Irrigation with seawater in the last stages of plant growth (I_2) on the other hand did not significantly increase the number of unfilled heads or sterile shoots, thus insignificantly influencing barley yield.

Fig 4 shows the effect of irrigation regimes on the ratio of dry/fresh weights of leaf, head and shoot and areal biomass. This ratio for all four factors of leaf, head, shoot and areal biomass at harvest stage was higher than at the heading stage. With increasing soil salinity, induced by the extended use of seawater, this ratio for leaves and heads had a descending trend, but for the shoot and total areal biomass at harvest and for leaves, heads, shoots, and total areal biomass at heading stage showed a progressive trend, which indicates a water deficit in plant, resulting in less dry matter production and decline in yield. These results agree with those shown by Kwaon *et al*. (2000). The fact that total fresh weight was reduced more than total dry weight also suggests a water deficit at high salinity (Marcelis and Van Hooijdonk, 1999).

Visual observations of plant growth indicated that chlorosis, necrosis and margin/tip burns of leaves appeared at early stages of growth and developed as growth progressed. These injuries to plants increased as the salinity of water increased or as the period of plant exposure to saline water increased, with all the symptoms being more evident in I_1 than I_2. Similar salt-induced injuries to plants have also been reported for other cereal and non-cereal crops (Feigin, 1985; Feigin *et al*., 1991; Hu, 1996).

The results also show that irrigation regimes significantly ($P<0.01$) affected the length of plants and those of the heads, peduncles and clavus. Irrigation with seawater, at stem elongation stage (I_1), decreased the overall length of the plants by 32%, peduncle by 33%, heads by16% and clavus by 11%. However when seawater was used at heading stage (I_2), plant height was only reduced by 1% while the length of the heads, peduncles and clavus actually increased by 3%, 0.4% and 13% respectively. These results are in accordance with those shown by Verma and Neue (1984). It can therefore, be concluded that the effects of irrigation with seawater at the lather stage of growth of barley (I_2) on the length parameters is negligible and sometimes beneficial and positive whereas, the adverse effects on all these factors are severe when irrigation with saline water starts early (I_1).

Statistical analysis of the experimental data showed that the effect of irrigation regimes on the fresh and dry weights of the roots were significant in the 0-10 and 10-25 cm and for the sum of the two depth intervals (0-25 cm) at $P<0.01$ (Fig 5). Irrigation with seawater resulted in decline in the fresh and dry weights of roots for all depths at stem elongation and heading stages, but the decline was twice higher in I_1 than I_2. Such a high reduction in root production in I_1 could have severely reduced plants' ability to uptake water and nutrients resulting in low growth and reduced yield of barley, as reported above. Plant root system was more concentrated in the 0-10 cm depth, which is the depth in which root growth was severely retarded.

The use of seawater caused a decline in the ratio of total fresh weight of roots to fresh weight of shoot (or aerial biomass) and also a decline in the ratio of total dry weight of roots to dry weight of shoots by 30% and 40% for I_1 and I_2 treatments respectively. This indicates that the use of seawater limited root growth of barley plants more than its shoots or areal biomass. These results appear to contradict those given by Helal and Mengel (1979) and Marcelis and Van Hooijdonk (1999) who have reported that salinity limits the growth of areal parts of the plants more than roots. In spite of applying a LF factor of 30% in our pot experiments, soil salinity increased and resulted in salt accumulation in the root zone. This may have resulted in an undesirable drainage situation for plant roots thus adversely affecting their growth. However a large difference in root growth between I_1 and I_2 treatments does not support such argument.

2. Field Experiments

The results of field experiments closely followed those of pot experiments. Field results show that irrigation with diluted seawater at the time of stem elongation (I_1) and under rainfed conditions (I_r) caused significant reduction in the barley yield and all the major yield components including, biomass and straw, number of heads and SW5000 (Fig 6). Number of seeds per head was not significantly affected by irrigation treatment and the difference between all treatments and control (I_0) remained small (Fig 5). The decrease in kernel weight amounted to 33% and 59% respectively for I_1 and I_r treatments as compared with the control (I_0). On the other hand application of seawater at a later stage (I_2) did not cause significant differences with I_0 with respect to all these parameters. Longer use of diluted seawater in I_2 and also in rainfed treatment contributed to the reduction of the number of unfilled seeds per plant, which is mainly due to a significant reduction in the number of heads per plants in these two treatments. Similar results have been reported by Maas (1990), Bar-Tel (1991), O'Leary and El-Haddad (1994), Sharma (1996) and Tahir *et al.* (1997).

The results of field trial also clearly show that rainfed agriculture is not a viable option for the region. With the soil salinity already high and rainfall low, the plants suffer from both water stress and ion poisoning thus the lowest yield and yield components of I_r treatments as shown in Fig 6. The results of both pot and field experiments suggest that supplementary irrigation with the diluted seawater after head formation is a viable option for barley crop in the region. It makes a significant saving in the consumption of the limited freshwater resources of the region without significantly reducing the yield of barley.

Effect of irrigation on soil quality

1. Pot experiments

The results of chemical analyses carried out on soil samples before and after the pot experiments are presented in Table 5. These results show that the concentration of sodium, calcium, magnesium and potassium in the top 10 cm of the soil irrigated with diluted seawater increased by more than 400, 17, 200 and 100 folds respectively during the growing season of barley. Also shown in Table 5 is a 60 and 30 folds increase in EC and SAR of saturated extract of soils during the same period and due to the irrigation with diluted seawater. The concentrations of all above cations are significantly lower in the 10-25 cm soil depth than 0-10 cm. EC and SAR are also lower in 10-25 cm depth by a factor of 10 compared to I_0. These results indicate that the above reported reduction in yield and yield components of barley when irrigated with a diluted seawater early in the growing season (I_1) is largely due to the poisoning effect of high ion concentration in the soil solution in the root zone than water stress caused by osmotic potential of soil solution. Water stress appears to have a more immediate effect on the growth and yield of plants while ion poisoning needs a longer term exposure of the plant to such condition in order to have a significant impact on its growth and yield.

Mean comparison tests indicate that irrigation treatment I_1 significantly increased soil salinity levels (Fig 7), particularly in its top 10 cm. This indicated that the applied leaching fraction of

30% was not sufficient to prevent salt accumulation in the pots. Work on adequacy of LR is in progress.

2. Field experiments

Irrigation with 1:1 diluted seawater during the stem elongation period (I_1) and under rainfed condition (I_r) significantly increased soil salinity, concentration of Na, Mg and Cl ions and the SAR value of saturated extracts in the top 30 cm of soil profile (Fig 8). These changes were less pronounced deeper in the profile (30-60 cm). The increases in soil salinity and SAR in I2 treatment were insignificant. These field plot results confirm those obtained in pot experiments that irrigation with Caspian Sea could result in increased soil salinity if not used cautiously. It can only be used for supplementary irrigation of salt tolerant plants such as barley in light textured soils at the latter stages of plant growth.

Using the results of both pot and field plot experiments on soil salinity-plant yield interaction, the following equation was obtained relating barley yield (Y) to soil salinity.

$$Y = 100-6.8(ECe - 7.7)$$

This equation can be used to determine the EC level at which barley production becomes un-economical in the Gorgan region of Iran.

Conclusion

Irrigation with a 1:1 mixture of Caspian Sea water and well water at the stem elongation stage of barley (I_1 treatment) adversely affected the yield and most growth and yield components of barley including aerial biomass, root and shoot growth and seed number and weight. This treatment also significantly increased soil salinity. However, irrigation with the same mixture at the heading stage (I_2 treatment), had an insignificant effect on the growth and yield of barley. Use of Caspian Sea water for supplementary irrigation is therefore a viable option and has the potential of substantially reducing the pressure on the limited groundwater resources of the region without a significant loss in barley production. However, the application of seawater-well water mixture whether applied early (I_1) or late (I_2) will result in an increased soil salinity which may cause problems for next crop's germination and seedling growth as young plants are more susceptible to soil salinity. Long-term use of seawater for barley irrigation is only possible if the leaching of excessive salt from root zone is possible. Supplementary irrigation of barley with the Caspian Sea water-well water mixture can therefore be recommended light textured soils and only towards the last stages of barley growth, provided that low salinity fresh water or precipitation can be applied to lower soil salinity before the next crop is due to go in. The heading time of barley crop is precisely the time that fresh water resources of the region are very limited and the need for extra irrigation water is at its highest. With all its limitations and long-term adverse impacts on soils, irrigation with the Caspian Sea water can provide a much needed relief to farmers that their crops may otherwise fail.

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Table 1: Comparing chemical composition of Caspian Sea water with that of ocean water

Salt type	% in Caspian Sea water	% in Ocean water
NaCl	62.2	78.3
MgSO4	23.6	6.40
MgCl2 , MgBr2	4.54	9.44
CaCO3	1.24	0.21
KCl	1.21	1.69
CaSO4	6.92	3.93

Table 2. Chemical characteristics of well and sea waters used in the experiments

Property	Caspian Sea water		Well water
	Spring	Summer	
ECe (dS/m)	21.5	23.0	0.8
pH	7.3	7.0	7.5
Cl ($mmoles_{-}$/l)	180	165	2
HCO_3 ($mmoles_{-}$/l)	2.0	3.6	2.7
SO_4 ($mmoles_{-}$/l)	58.0	67.0	3.2
Sodium ($mmoles_{+}$/l)	160	150	2
Calcium ($mmoles_{+}$/l)	80	68	5
Magnesium ($mmoles_{+}$/l)	0	18	1

Table 3: Some physical and chemical characteristics of the soils used in pot and field experiments

Property	Soil used in pot experiment	Field soil
EC (dS/m)	16.1	10
pH	7.75	8.1
CEC (Cmol/kg)	10	13
SP (%)	38.5	43
Exchangeable Na^{+1} (cMol/kg)	2.8	3.1
Exchangeable Ca^{+2} (cMol/kg)	6	7.9
Exchangeable Mg^{+2} (cMol/kg)	1.1	2
Bulk density (kg/m^3)	1450	1540
Texture	Silt loam	Silt loam

Table 4: Growth and yield of barley at harvest as affected by irrigation treatment in pot experiments

Yield & yield components	Irrigation treatments		
	I_0	I_1	I_2
Yield (g/pot)	23.06 A*	8.71 B	22.26 A
Seed No (per head)	22.97 B	17.99 C	24.49 A
SW 100 (g)	3.85 A	2.62 B	3.83 A
Head No (per pot)	33.48 A	20.63 B	31.37 A
Sterile shoot No (per pot)	10.82 A	3.44 B	8.89 A
Spikelet No (per head)	10.18 A	8.26 B	10.45 A
Hallow heads (%)	24.89 AB	27.68 A	21.90 B
Dry head weight (g/pot)	27.22 A	10.95 B	26.54 A
Dry leaf weight (g/pot)	8.59 A	4.66 C	7.75 B
Dry shoot weight (g/pot)	17.72 A	6.59 C	16.45 B
Dry root weight (g/pot)	5.49 A	1.27 C	3.53 B

* Means within each row followed by the same letter are not significantly different at $P< 0.05$ (Duncan's multiple range test)

Table 5. Chemical characteristics of soil before and after pot experiments

Property	Soil before experiment	Soil after experiment (0-10 cm)	Soil after experiment (10 – 25 cm)
ECe (dS/m)	16.19	1024	143
Sodium Adsorption Ratio	19	689	59
Sodium (mmoles$_{+}$/l)	112	48503	4919
Calcium (mmoles$_{+}$/l)	39	676	315
Magnesium (mmoles$_{+}$/l)	29	5556	808
Potassium (mg/kg)	240	23109	1094

Figure captions

Fig 1: Pot experiments in the greenhouse

Fig 2: Plot experiments at Gorgan Experimental Station

Fig 3: Effect of irrigation regimes on the yield and yield components of barley in pot experiments

Fig 4: Effect of irrigation regimes on dry/fresh weight of leaf, head, shoots and areal biomass in pot experiments

Fig. 5: Variation of root parameters with irrigation regime and soil depth

Fig 6: Effect of irrigation regime on yield and yield components of barley in field plot experiments

Fig 7. Effect of irrigation regime on the electrical conductivity of soil in pot experiments

Fig 8: Effect of irrigation regime on soil salinity and the SAR of its saturation extract

Fig 1

Fig 2

Fig 3

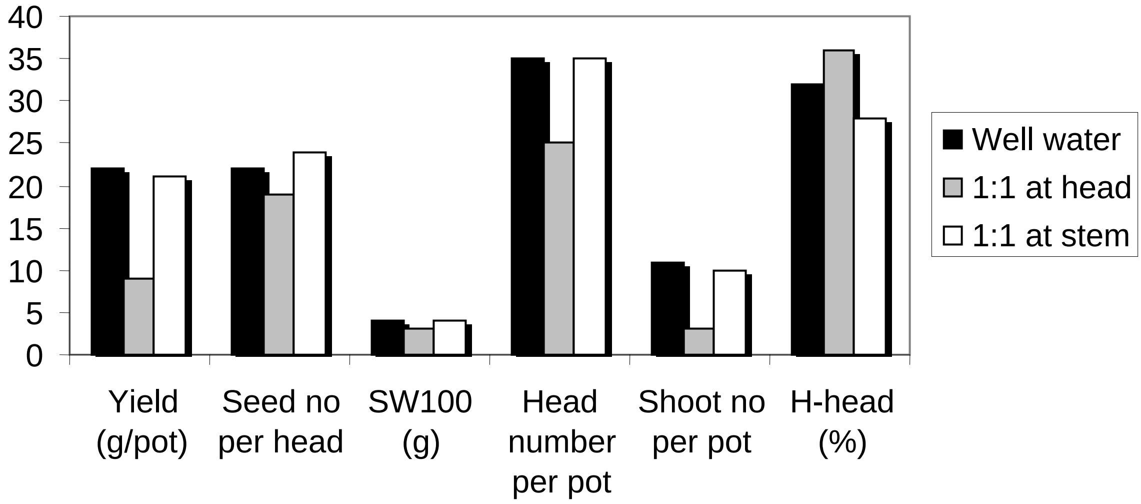

40
35
30
25
20
15
10
5
0
Yield (g/pot)
Seed no per head
SW100 (g)
Head number per pot
Shoot no per pot
H-head (%)
Well water
1:1 at head
1:1 at stem

Fig 4

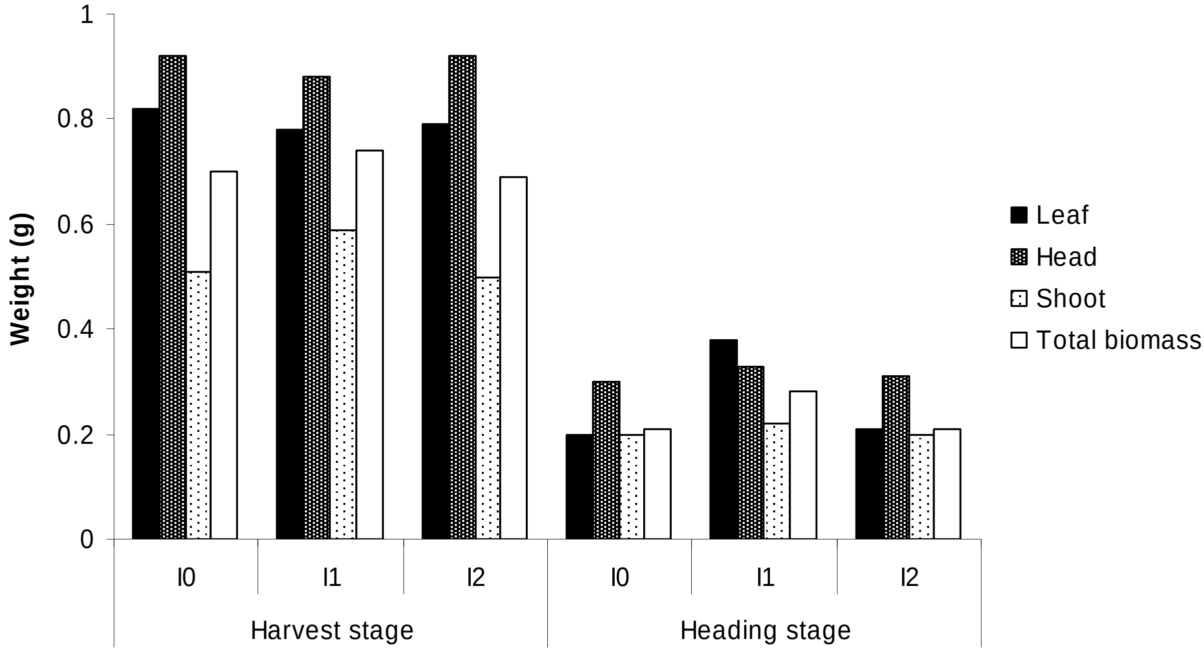
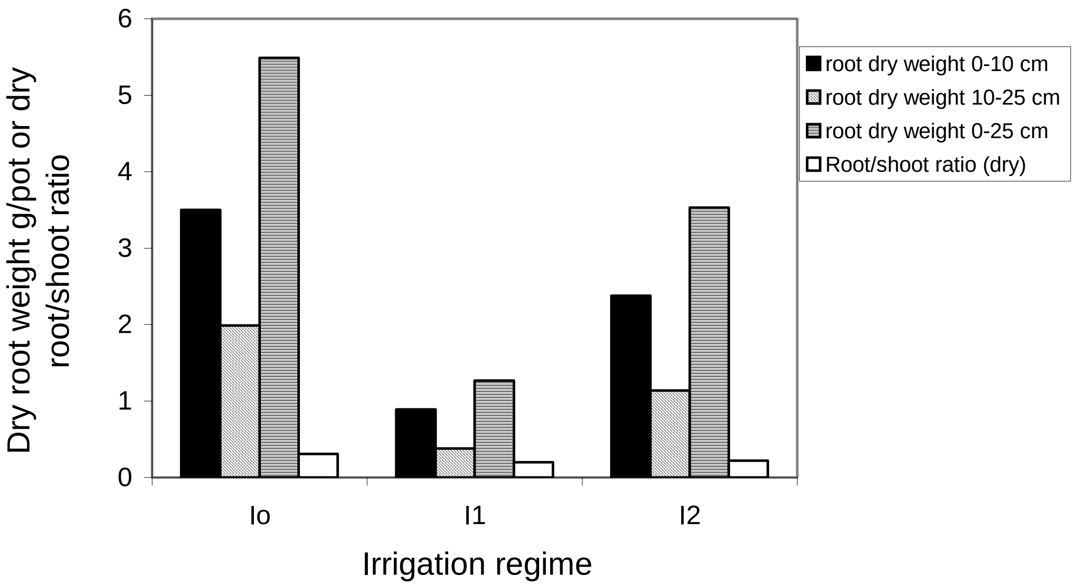

Weight (g)
1
0.8
0.6
0.4
0.2
0
I0
I1
I2
I0
I1
I2
Harvest stage
Heading stage
Leaf
Head
Shoot
Total biomass

Fig 5



Dry root weight g/pot or dry root/shoot ratio
6
5
4
3
2
1
0
Io
I1
I2
Irrigation regime
root dry weight 0-10 cm
root dry weight 10-25 cm
root dry weight 0-25 cm
Root/shoot ratio (dry)

Fig 6

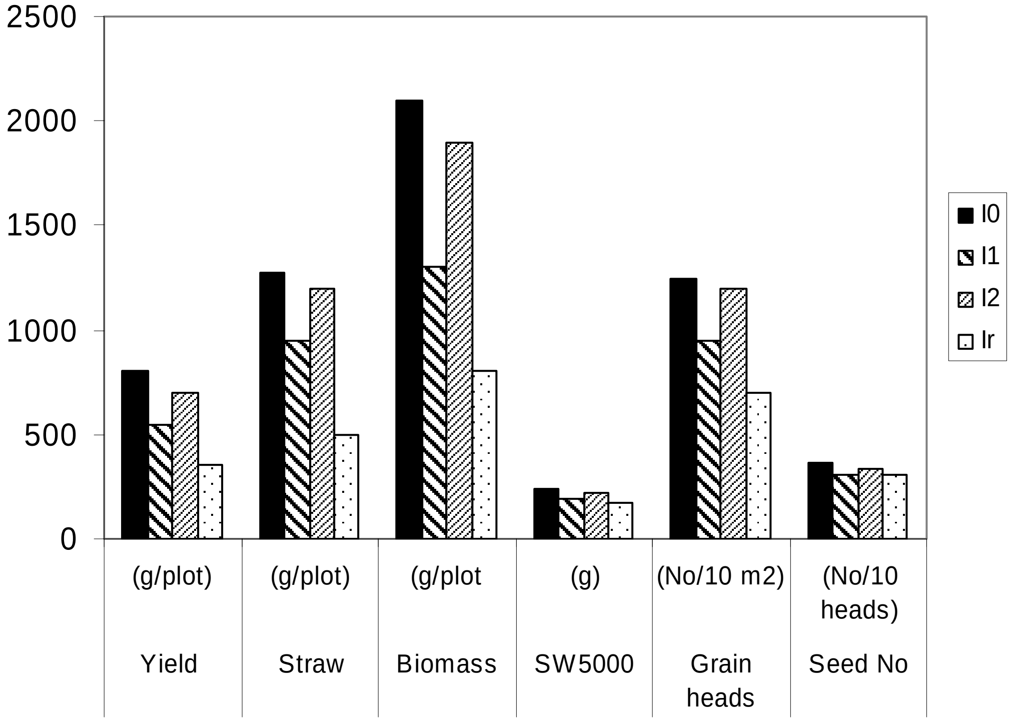

2500
2000
1500
1000
500
0
(g/plot)
Yield
(g/plot)
Straw
(g/plot
Biomass
(g)
SW5000
(No/10 m2)
Grain heads
(No/10 heads)
Seed No
I0
I1
I2
Ir

Fig 7

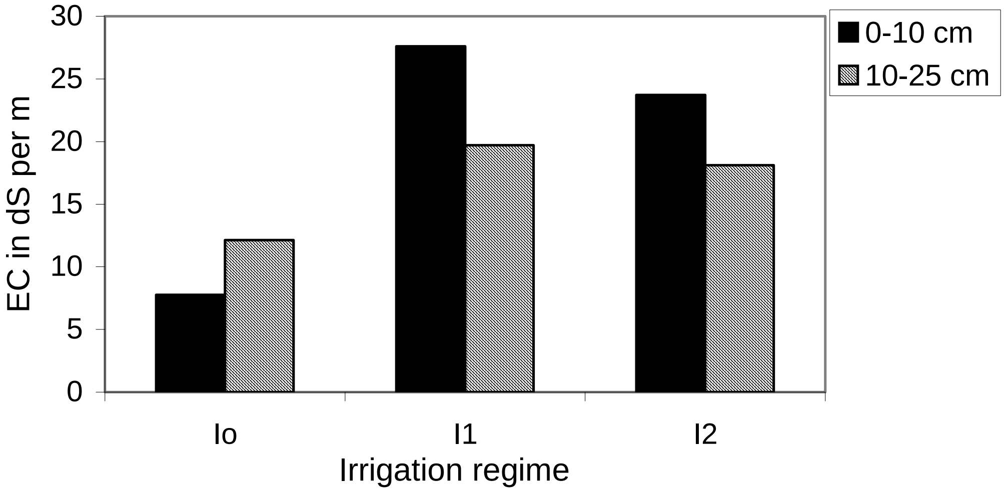
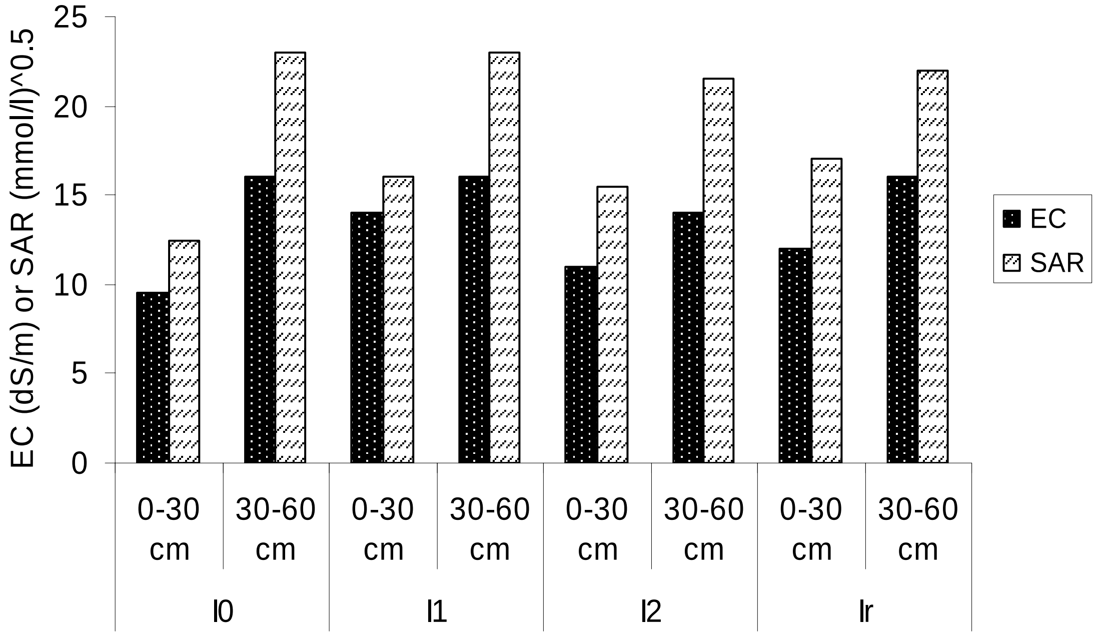

30
25
20
15
10
5
0
EC in dS per m
Io
I1
I2
Irrigation regime
0-10 cm
10-25 cm

Fig 8


EC (dS/m) or SAR (mmol/l)^0.5
25
20
15
10
5
0
0-30 cm
30-60 cm
0-30 cm
30-60 cm
0-30 cm
30-60 cm
0-30 cm
30-60 cm
I0
I1
I2
Ir
EC
SAR