Iraq Salinity Project **Technical Report 16**

Adaptation of Crop and Forage Genotypes to Soils Affected by Salinity

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The Iraq Salinity Project is an initiative of Government of Iraq, Ministries of Agriculture, Water Resources, Higher Education, Environment, and Science and Technology, and an international research team led by ICARDA – the International Center for Agricultural Research in the Dry Areas, in partnership with the University of Western Australia, the Commonwealth Scientific and Industrial Research organization (CSIRO) of Australia, the International Water Management Institute (IWMI), Sri Lanka, and the International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates.

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This technical report series captures and documents the work in progress of the Iraq Salinity Project, in its six research themes, working at the regional, farm and irrigation system scales. Technical reports feed into the *Iraq Salinity Assessment*, a synthesis and solutions to solving the problem: Situation Analysis (Report 1); Approaches and Solutions (Report 2) and Investment Options (Report 3).

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Key words: best adapted genotypes, salinity, EC level, grain yield, boron toxicity, barley cultivars, soil texture, productivity, plant testing in Iraq, Mirror trial in Syria.

http://icarda.org/iraq-salinity-project/teaser

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Summary

This report presents the research in progress for the Iraq Salinity Research project's research component on the adaptation of crop and forage genotypes to soils affected by salinity. It describes the outcome of three experiments: The testing of the effects of irrigation with high B water on the growth of barley cultivars and wheat); testing of the adaptation of sorghum and pearl millet); testing of the adaptation of annual forage species). Our focus was on soils that fell into two general ECe classes: 10-20, and 20-30[i].

This study tested the adaptation of a range of key crop and forage species for the tolerance to the saline conditions found in Iraq. In addition, the research team tested the effects of irrigation with water of elevated boron on the growth of wheat and barley in a mirror trial in Syria.

Initial conclusions, point to high production of guar, sesbania and sorghum at Dujailah soils, which have productive plant capacity of 6-8 dS/m and high levels of variations in salinity tolerant species.

The mirror trial in Der Azzor, in Syria, shows that irrigation with non-saline water raises good yields of boron-tolerant wheat. Repeating a similar experiment in Iraq noted that hot water extractable boron concentrations could be high. Other remarks speak of the relationship between salinity and boron on yield, forage growing on salt, and boron concentrations in tall wheatgrass leaves.

Background and Context

Approximately 5% of the world's land surface is cultivated salt-affected land, which includes 19.5% of irrigated agricultural land (Flowers and Yeo 1995; Ghassemi et al. 1995). The use of salt tolerant crop plants and halophytes provides an opportunity to obtain production from these lands.

Crop salt tolerance is widely reported in the agricultural literature as the productive capacity of that plant at different levels of soil salinity (EC_e) and the ratio of its productivity under non-saline conditions; this ratio is termed the relative yield and is abbreviated as Y_r. According to Steppuhn et al. (2005a), the relationship between Y_r and EC_e can be described in terms of a "compound-discount equation", in which Y_r is defined by two parameters: "C_{50}" (the EC_e in dS/m associated with a 50% decrease in relative yield) and "*p*" (a curve shape parameter). Relative yield (Y_r) is described by the following equation:

$$Y_r = 1/[1 + (C/C_{50})^p]$$

This equation describes a symmetrical concave-convex yield response with the inflection point at C_{50} (Figure 1).

At present C_{50} and *p* values are available for 108 possible agricultural plant combinations (Steppuhn et al. 2005b) from 3 agricultural plant groups: (a) bulk grain and fibre crops, (b) grasses and forages, and (c) vegetable, nut and fruit crops. Non-quantified salt tolerance assessments are available for a further 49 herbaceous crops, 14 vegetables and fruit crops and 37 woody crops (Maas and Grattan 1999).

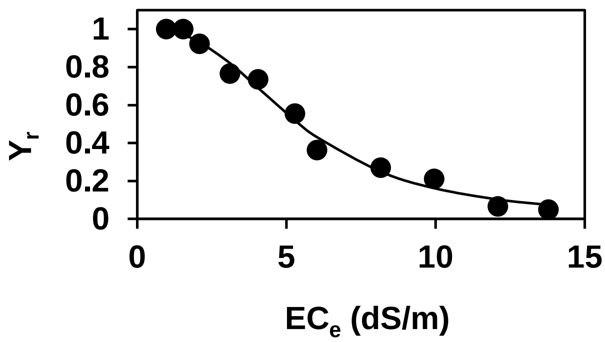

Figure 1. Typical response of an agriculturally important plant (wheat) to EC_e using the compound-discount equation (after Steppuhn et al. 2005a).

Central and Southern Iraq has a major salinity problem. At least part of this landscape has had a 5,000 year history of irrigated agriculture using the waters of the Tigris and Euphrates river system. The area is very flat and lies at the down-stream end of the river basin that includes Turkey and Syria. There are also regional groundwater aquifers that flow towards the coast under the Plain and discharge over most of the lower Plain. As a consequence, shallow water tables of varying salinities and depths underlie the area. It is estimated that every year Iraq is losing about 25,000 ha of agricultural cropping land as a result of salinity (ACIAR 2009).

RESEARCH STRATEGY

A desktop analysis using published C_{50} and *p* values suggested that 5 key species (cowpea, Sesbania, sorghum, guar and barley) would have Y_r> 0.7 at EC_e values around 5 dS/m, but as salinity increased to 10 dS/m only sorghum, guar and barley would have Y_r> 0.7, and at EC_e 15 dS/m only barley would have a Y_r> 0.7. We therefore conducted a range of field experiments using these and some additional species. This program is still on-going.

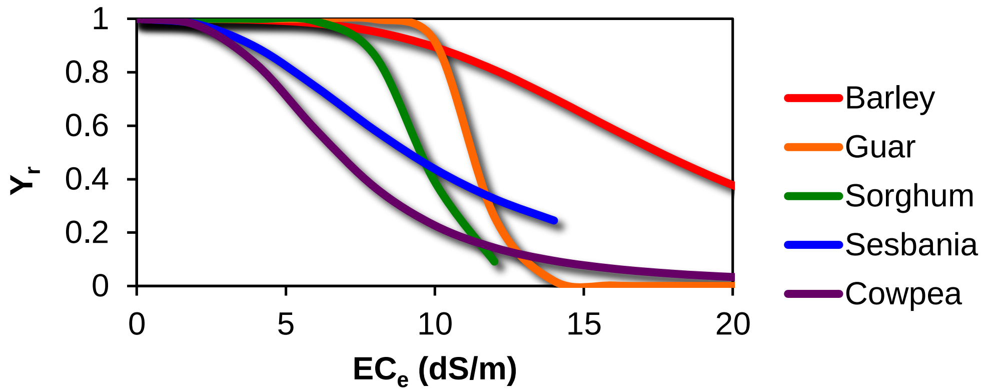

Figure 2. Estimates of the relative salt tolerance (Y_r) of different crops and forage species being trialled in Iraq. These curves have been drawn from the tolerance data (C_{50}, *p*-values) published by Steppuhn et al. (2005b).

a- Activity E1. Effects of irrigation with saline/high boron water on the relative productivity of barley cultivars and wheat

This trial aimed to determine the effects of irrigation with saline water of high B concentration on the growth of barley cultivars and wheat. The trial was established on the Syrian Government's Irrigation Research Station at Deir-Azzor. The trial tested the effects of irrigation water of three salinities (S1 – canal water, S2 – a mix of canal water and local groundwater, and S3 groundwater alone) on the growth of five cereal genotypes. S1 had an EC_w of 1.1 dS/m and a B concentration of 0.6 mg/L, S2 had an EC_w of 7.8 dS/m, and a B concentration of 8.0 mg/L, and S3 had an EC_w of 10.4 dS/m and a B concentration of 12.2 mg/L. Each irrigation treatment x cultivar combination was replicated three times, so the trial had a total of 45 plots. Plots were ~ 2 x 2 m and bounded by bunds ~0.2 m high.

The five cereal cultivars grown were supplied by ICARDA in Aleppo (DrStefaniaGrando – Barley Breeder) and consisted of four 6-row barleys (IPA7, California Mariott, Maknusa and Martin) and one local wheat cultivar (Kheder1). The plots were sown on 25 January 2011. The first irrigation with the saline water treatments occurred on 19 February, and these continued at frequencies consistent with normal district practice.

The soils were sampled at early tillering, anthesis and maturity, but the soil composition remained relatively stable, so we report the data from the first sampling (1 March). The crop was harvested (1 m^2 from each plot) on 5 June. Samples of grain and straw were analysed for Na, Cl and B.

Activities E1(B) and E2. Screening of sorghum, pearl millet and summer forages at Dujailah project (Wasit*)*

These two experiments aimed to identify best adapted sorghum and pearl millet lines and summer forages from ICBA. A screening trial was established in Wasit Governerate, Dujailah project on a field site with moderate soil salinity (EC_e 10-20 dS/m), and irrigation water from the Tigris River of EC_w 1.14 dS/m.

Genotypes with reputed salt tolerance and adaptation to Iraqi conditions were obtained from ICBA; these included accessions of pearl millet (6 lines), sorghum (3 lines), guar (2 lines), and single lines of sesbania& cowpea. These were compared with 2 local varieties of millet and one of sorghum.

The trial was established on 25 May 2011 using the layout in Figure 3. Groundwater and soil properties were measured at monthly intervals from 2 and 5 locations respectively. Irrigation was supplied at 3 to 8 day intervals, with more frequent application during periods of high temperature.

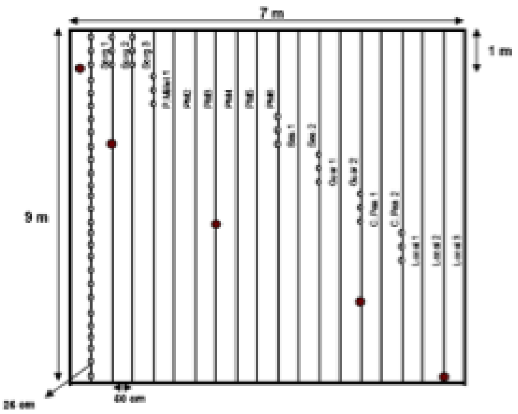

Figure 3. Layout of trial at Dujailah. The brown circles represent the sampling locations for soil salinity assessment.

MATERIALS and METHODS

Activity E1. Effects of irrigation with saline/high boron water on the relative productivity of barley cultivars and wheat

1-Soil texture, salinity and boron

The site was a clay loam at 0-10 and 10-25 cm depth, but was clayey at 25-50 cm depth. Average salinities (EC_e values) and B concentrations in the soils are given in Figure 4. The boron concentration and EC_e were both affected by the irrigation water treatment (P< 0.001) and depth in the soil profile (P< 0.001). Across all plots and depths between plots, the concentration of B in the soil was correlated with the EC_e (P< 0.001, r^2 = 0.805).

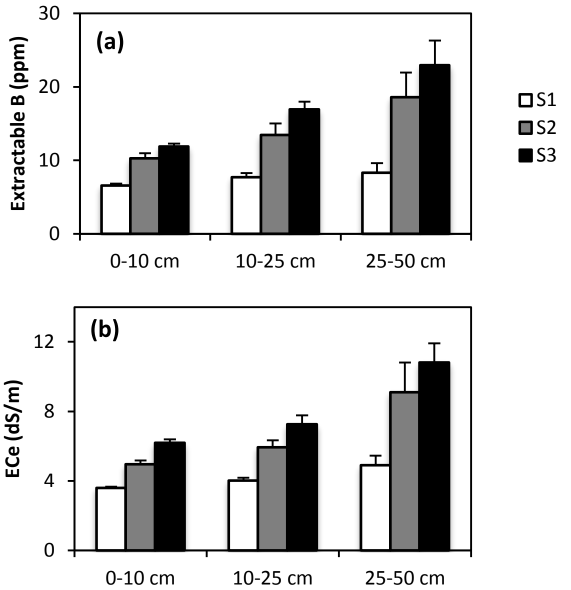

Figure 4. Effects of irrigation treatment on: (a) extractable soil boron, and (b) soil salinity. Soils were sampled on 1 March 2011 at 0-10 (15 replicates), 10-25 (15 replicates) and 25-50 cm (3-4 replicates) depth.

2-Concentrations of B in leaves

Leaves were sampled on 1 March and analysed for B concentration. Leaf B concentrations were affected by irrigation water treatment (*P*< 0.001), but there was no effect of cultivar on leaf B (Figure 5).

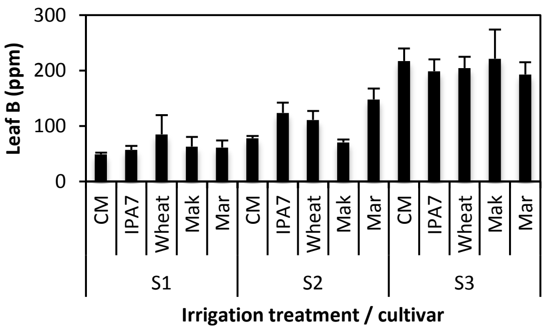

Figure 5. Concentrations of B in leaves of barley and wheat seedlings. Each value is mean of 3 replicates. Bars are SEM. Cultivars are: California Marriott (CM), IPA7, Maknusa (Mak), Martin (Mar) and Kheder1 (wheat).

3-Grain yield at harvest

Grain yield was affected by irrigation treatment (P < 0.001) and cultivar (P < 0.001). However there was no significant interaction (Figure 6). At each irrigation treatment, the highest grain yield was with the wheat (3.5 t/ha at S1; 3.2 t/ha at S3). Grain yields of barley were 7-36% lower than wheat at S1, 6-60% lower than wheat at S2 and 30-62% lower than wheat at S3. At S3, the yields of barley were highest for Maknusa (2.2 t/ha) and decreased in the order: Maknusa> California Mariott> IPA7 > Martin.

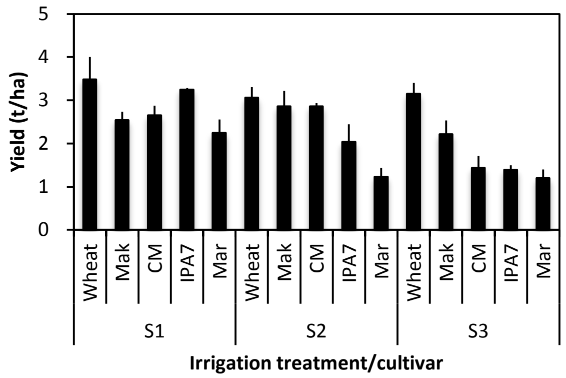

Figure 6. Grain yield final harvest. Each value is mean of 3 replicates. Bars are SEM. Cultivars are: California Marriott (CM), IPA7, Maknusa (Mak), Martin (Mar) and Kheder1 (wheat).

4-Yield and elements in grain

There were correlations between grain yield and the concentrations of B and Na in the grain (Figure 7a, b), but not Cl (data not presented). Across all cultivars and plots, there was a logarithmic decline in grain yield with increasing Na in the grain (r^2 = 0.693, *P*< 0.001; Figure 7a) and a linear decline with increasing B in the grain (r^2 = 0.414; *P*< 0.001; Figure 7b). The high grain yields in wheat (all greater than 2.5 t/ha) were associated with Na concentrations in the grain less than 0.4% and B concentrations in the grain less 14 ppm. In contrast, the decreased yields of barley (yields as low as 0.9 – 1.8 t/ha) were associated with Na concentrations in the grain greater than 2.0% and B concentrations in the grain greater than 20 ppm.

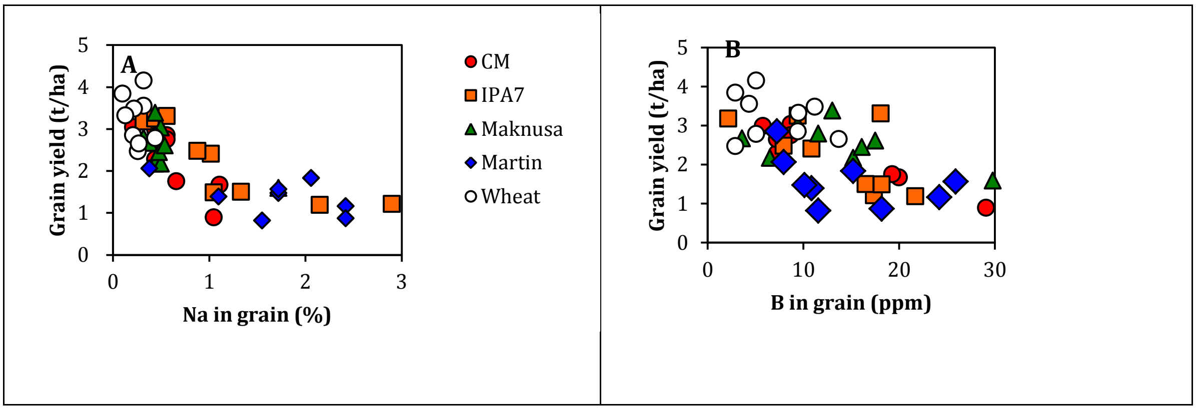

Figure 7. Relationship across all plots between elements in grain and grain yield for the cereal cultivars: (a) sodium, (b) boron, and (c) chloride.

Activities E1(B) and E2. Screening of sorghum, pearl millet and summer forages at Dujailah project (Wasit)

1-Soil salinity

Irrigation during the growing season played a major role in controlling soil salinity. At the start of the trial, the average soil salinity ($EC_{1:1}$) was ~8 dS/m at 0-50 cm and ~10 dS/m at 50-100 cm. However, these values decreased to ~6 and 4-5 dS/m respectively after 2 months (Figure 2).

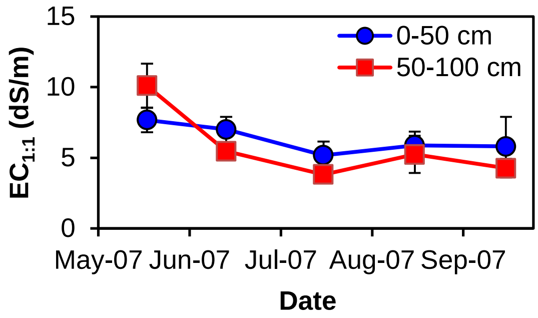

Figure 8. Variation in soil salinity with time. Each point is the mean of 5 replicates. Error bars are the SEM.

2-Soil boron

One issue being considered by our team is the potential importance of boron as an additional soil constraint on salt land. Before the trial was established, unreplicated samples gave B concentrations (ppm) of: 1.23 (0-10 cm), 1.59 (10-25 cm) and 1.42 (25-50 cm). Five months after the trial was established, B concentrations (mean of 5 samples ± SEM) were: 1.30 ± 0.23 (0-50 cm) and 1.33 ± 0.12 (50-100 cm). These concentrations are only about 10% of the damaging soil concentrations observed in the mirror trial in Syria (Activity E1A), and suggest that soil boron is not an issue at this site.

3- Groundwater properties

The groundwater was initially 1.5-2.0 m deep and relatively saline (70 dS/m declining to 40 dS/m in June). Water tables rose in August to within ~0.5 m of the soil surface (presumably because of local irrigation) and the salinity of the groundwater declined at this time to ~ 13 dS/m (Figure 9).

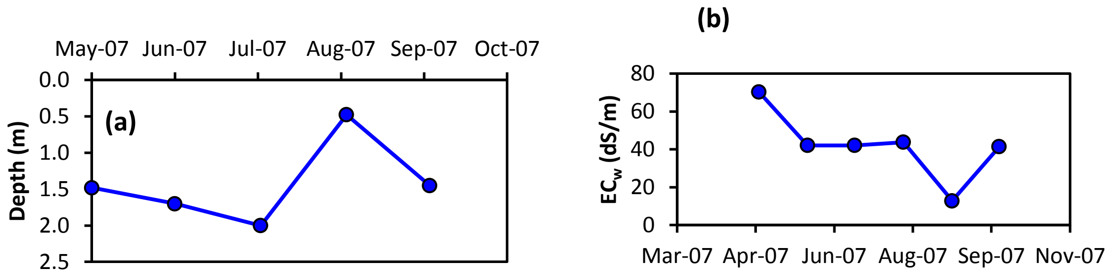

Figure 9. Variation in properties of the groundwater. A. Depth to water table. B. Salinity of groundwater.

3-Plant germination and growth

Apart from one Sesbania accession from ICBA (that had ~25% germination) all accessions trialled had 80-90% germination. The lower leaves of plants generally had high levels of necrosis (burning), presumably because of salinity (and possible drought) effects. Many accessions flowered but no seed was harvested because of the delay in planting; for pearl millets, the optimum time of cultivating is in April. Plant material was harvested on 13 October, transported back to the lab, dried and weighed. The biomass weights of the different genotypes are shown in Figure 10. Highest production occurred with one of the introduced Guar accessions (PI 263891; 14.8 t/ha) and one of the introduced Sesbania accessions (ILRI 15018; 13.1 t/ha. There was little production advantage in the pearl millets and sorghums introduced from ICBA; in each case, only one line had higher yields than the local line tested. All plants were palatable for livestock (sheep).

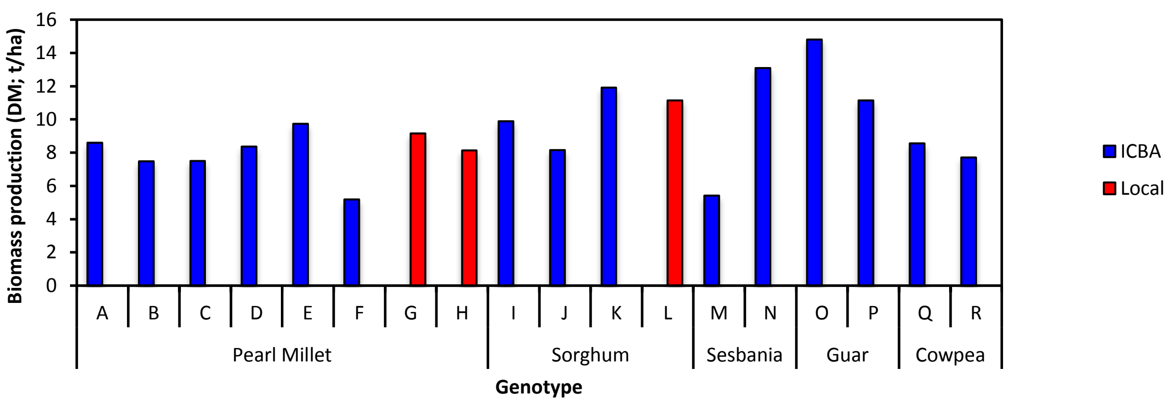

Figure 10. Biomass production of genotypes accessed from ICBA and local sources. Accessions are: A, IP 13150; B, IP 19586; C, IP 19612; D, IP 7704; E, MC 9462; F, IP 22269; G, Local 1; H, Local 2; I, ICSR 93034; J, ICSV 93046; K, S35; L, Local; M, ILRI 1198; N, ILRI 15018; O, PI 263891; P, PI 263896; Q, TVu 9498; and R, TVu 9716.

INITIAL FINDINGS (through March 2012)

Plant testing in Iraq

The soil at the al-Dujaela site had an $EC_{1:1}$ of 6-8 dS/m. Assuming that these soils had silty clay loam textures with saturation percentages of 46-53% (Slavich and Petterson 1993), then these soils would have had EC_e values of 12-16 dS/m. Based on our desktop analysis (Figure 2), we would expect these soils to have the highest growth of Sesbania and cowpea, and virtually negligible yields of guar and sorghum. Our results (Figure 10) are therefore quite surprising. Highest biomass production occurred with single lines of guar, sesbania and sorghum. These results suggest that there are far higher levels of variation in the salinity tolerance of these species than has been reported in the literature. The results show that it is critical to test the tolerance of species in the field using a broad range of cultivars. A range of further field testing experiments is on-going. Current trials are investigating the adaptation of winter cereals (wheat and barley cultivars, and halophytic forages), and a further trial of summer forages will be conducted.

Boron toxicity

In the mirror trial at DeirAzzor, EC_e values were around 4.4 dS/m when irrigated with non-saline water, increasing to ~8.8 dS/m when irrigated with the water of the highest salinity and boron content. This water allowed reasonably good yields of the relatively boron tolerant wheat (3.15 t/ha) but far lower yields of the more boron sensitive barley cultivars (1.2 – 2.2 t/ha) (Figure 6). This difference in boron tolerance between barley and wheat cultivars is clearly important because barley is normally planted as the cereal of choice in soils as they become highly saline (see Figure 2).

So how much of a problem could boron toxicity be in Iraq? In our work, extractable concentrations of B of 10-12 ppm occurred in the upper 10 cm of the soil profile with treatments S2 and S3, and these were clearly associated with the presence of leaf symptoms in barley (data not presented) and decreased yields (Figure 6). In the only survey of soil B concentrations in saline soils in Iraq,Al-Falahi (2000) noted that the hot water extractable boron concentrations of the studied saline soils could be high (ranging from 0.27 – 74.39 mg/kg), and that the upper values exceeded the critical level of B for most crops. The B extracted from the saturated soil paste amounted to about half of the hot water extractable values. The content of soluble B in most soil samples studied indicated a toxicity problem for the most economical crops.

The interaction between salinity and boron on yield is variable between species. In some species (eg. tomato, cucumber and wheat) salinity may increase B-related toxicity (Alpaslan and Gunes, 2001; Grieve and Poss, 2000; Wimmer et al. 2003, 2005). In other studies increases in salinity led to decreased B toxicity in vegetables (Ferreyra et al., 1997), chickpea (Yadav et al., 1989) and tomato (Ben-Gal and Shani, 2002).

One critical issue for forages growing on saltland is that Se and Mo may also occur in relatively high concentrations where B toxicity is a problem. These trace elements pose a potential toxicological risk to livestock whose diet relies almost entirely on forage grown in these high Se and Mo areas (Diaz and Grattan, 2009). Clearly, the most suitable forages need to be salt tolerant, tolerant to B, and have minimal accumulation of Se and Mo in their shoots (Diaz and Grattan, 2009).

One of the potential issues of concern for forages grown on saltland may be that B accumulates in the leaves to levels toxic to grazing animals. In the present study, we measured B concentrations in the leaves of 190-220 ppm (Figure 5). Such high concentrations of B could present toxicity problems for grazing animals. Boron is generally considered a relatively non-toxic element and it is well tolerated by most animals (Underwood and Suttle, 1999; NRC, 2005). However some evidence suggests that toxicity could occur in animals with very high B intake. Cattle consuming water containing 150–300 mg B/L, which was equivalent to >800mg B/kg DM in the diet, exhibited lethargy, loss of appetite and body weight, inflammation and decreasing blood hemoglobin concentrations (Green and Weeth, 1977). A range of animal studies has led to the established maximum tolerable level (MTL) of 135 mg B/kg DM for animals (NRC, 2005). This critical value is exceeded by the concentrations recorded in wheat and barley leaves at DeirAzzor.

Boron concentrations in tall wheatgrass leaves irrigated with water containing 10 mg B/L have also been reported to be above this MTL, regardless of salinity level (Diaz and Grattan, 2009). For example, under water with intermediate salinity and B levels, ECw = 10 dS/m and B = 10 mg/L, tissue B concentrations were 171-228 mg B/kg DM for composite leaf samples. Thus animals grazing on this forage could be exposed to high B intake and potential toxicity. On the other hand beneficial effects of B supplement for animals have been reported (Newnham, 2002).

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[i] Many saline soils, particularly in arid regions of the world, are also subject to the accumulation of toxic concentrations of boron (Diaz and Grattan, 2009). Compared to salt, boron is harder to leach from soil profiles (Kelly and Brown 1929). Soils irrigated with water containing some boron may therefore become at least partly toxic to susceptible plants.