Evaluating the Productivity Potential of Chickpea, Lentil, and Faba bean under Saline Water Irrigation Systems

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Abstract

As supplies of good-quality irrigation water are expected to further decrease in dry areas of the Mediterranean region, available water supplies need to be used more efficiently, where one of the approaches can be the use of saline drainage water generated by irrigated agriculture or pumped from saline aquifers. Owing to increased demand for food legumes to fulfill human protein requirements amid increasing meat prices, food legumes can be candidate crops to be grown with saline water. However, the information on their salinity threshold levels is extremely limited and old. In a multi-year study undertaken at two sites (Raqqa and Hassake) within Euphrates Basin in Syria, we aimed at (1) evaluating the potential of saline water irrigation for food legume (chickpea, faba bean, and lentil) production; and (2) using SALT-MED [WRITE IN FULL] model to determine 50% threshold yield of these crops based on irrigation water salinity levels in equilibrium with ambient soil solution salinity levels. To evaluate 15 accessions, each of lentil and chickpea, and 11 accessions of faba bean, three irrigation treatments were used with electrical conductivity (EC) levels of 0.87, 2.50, and 3.78 dS m^{-1} at Hassake and with 0.70, 3.0, and 5.0 dS m^{-1} at Raqqa. Aggregated grain yields for both experimental sites revealed significant differences ($P<0.05$) among accessions of each food legume crop. Calibration and validation of SALT-MED model revealed close relationship between actual grain yields from the field sites and those predicted by the model ($r = 0.99$, $P<0.01$???PLEASE CHECK). Based on salinity levels in irrigation waters, the 50% yield reduction (π_{50} value) in chickpea, lentil, and faba bean occurred at salinity levels of 4.2 dS m^{-1}, 4.4 dS m^{-1}, and 5.2 dS m^{-1}, respectively. These results suggest that among three food legume crops, faba bean can withstand relatively high levels of salinity in irrigation water followed by chickpea.

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Key words: Food legumes; crop salt tolerance; SALT-MED model; irrigation water salinity; Mediterranean region

1 Introduction

Irrigation has played an important role in crop production and agricultural development in dry areas of the Mediterranean region. While freshwater in the region is not only a scarce resource but also unevenly distributed (FAO-AQUASTAT, 2013) due to which a competition among different water-use sectors is already increasing for freshwater in the Mediterranean region (Guardiola-Claramonte et al., 2012). The consequence would be a gradual decrease in freshwater allocation to agriculture. Furthermore, there is the uncertain umbrella of global climate variability. Climate predictions anticipate not only increase in temperatures, but a pronounce decrease in precipitation in most of the Mediterranean region (Giorgi and Lionello, 2008; IPCC, 2007).

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As supplies of good-quality irrigation water are expected to decrease in dry areas of the Mediterranean region, available water supplies need to be used more effectively and efficiently (Guardiola-Claramonte et al., 2012), where one of the approaches can be the reuse of marginal-quality water such as saline drainage water generated by irrigated agriculture or pumped from saline aquifers (Tanji and Kielen, 2002; Qadir and Oster, 2004). The same applies to salt-affected soils, which warrant attention for efficient, inexpensive and environmentally acceptable management to improve crop production. Beresford et al. (2001) and Munns (2002) reported that half of the irrigation schemes in the world have been subjected to varying levels of salinization.

A number of bioprocesses such as photosynthesis and respiration can be affected under saline water irrigation and saline soil conditions, in addition to the effect of salinity on the morphological construct of plant. Salinity may cause nutritional disbalance and affect biochemical properties of the plant such as enzymes, nuclear acids, and hormones (Krishnamoorthy, 1993). Based on the crop salt tolerance, there may be reduction in the effective green surface in the photosynthesis and reduction in dry matter production, reflecting negatively at the end on the decrease in economic yield (Munns, 1993).

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Food legumes — chickpea, lentil, and faba bean — are generally classified as sensitive to salinity. At the same level of root zone salinity, the yield of legumes tends to be more affected than that of cereals (Katerji et al., 2011). The information on their salinity threshold levels and slope of yield decline with salinity is extremely limited (Steppuhn et al., 2005) and old (Ayers and Eberhard, 1960). Growing food legumes and evaluating their growth and yield response in the Mediterranean region under saline conditions is important because of (1) scarcity of freshwater resources to grow food legume crops; (2) increasing areas of irrigated land under salt-affected soils and/or irrigated with saline water in the semi-arid and arid areas; and (3) increasing demand for food legumes due to increasing meat prices, need to meet human requirements for proteins from food legumes, and population growth.

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In this study undertaken in the Euphrates Basin within Syria during 2009/10-2010/11, we aimed at (1) evaluating the potential of saline water irrigation for food legume (chickpea, faba bean and lentil) production and characterizing them for salt tolerance; and (2) using SALT-MED model to determine salinity level for 50% yield threshold, π_{50} value, of chickpea, faba bean, and lentil based on irrigation water salinity levels in equilibrium with ambient soil solution salinity levels.

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2 Materials and Methods

The study sites were located in two agro-ecological zones in Syria, namely, Zone 3 where the study site was nearby Hassake city and Zone 5 where study site was located close to Raqqa (Figure 1). In these areas, soils are formed over Neogene limestone, marl, gypsum, and conglomerates.

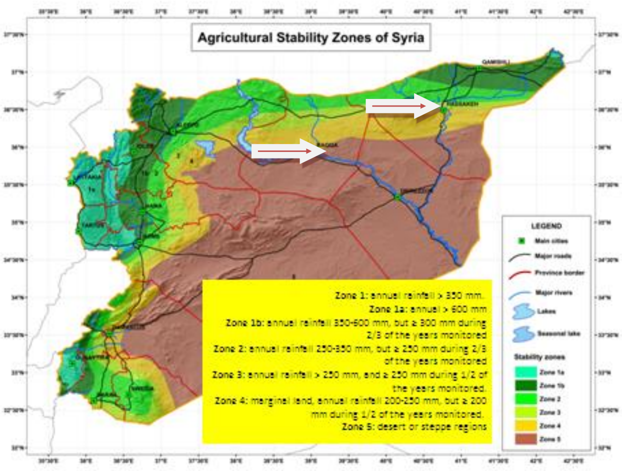

Figure 1 Map of agricultural stability zones of Syria based on the average annual rainfall (REFERENCE)

2.1 Site characterization: Hassake

The Hassake study site is located 7 km northwest of Hassake city. The site is surrounded by rainfed agriculture system where the main crop is wheat. For site characterization, representative soil samples from 3 randomly selected sites were collected from the experimental field before planting from 0–20, 20–40, 40–60, 60-80 and 80-100 cm depths (15 samples). These soil samples were processed and analyzed by standard procedures for texture, calcite ($CaCO_3$), organic matter, cation exchange capacity, major nutrients, pH and EC of saturated extract, and major cations and anions.

The experimental soil is deep clay loam to clay, slightly alkaline pH with high percentage of calcium carbonate (about 32%) and affected slightly by salinity and moderate in nutrient availability status (Table 1). There a general decline in the EC, OM, ….silt with the depth. A FEW MORE LINES

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Soil surface laser leveling was performed prior to start of the experiment to improve surface irrigation water application efficiency. The electrical conductivity (EC) of groundwater is close to 4 dS m^{-1} while the SAR[in FULL, once] is less than 2 [unit dS m^{-1}?] due to the presence of high concentrations of calcium, sulfate, and magnesium. Long term average climatic data (1995-2009) of the experimental station are presented in Table 2. A FEW MORE SENTECES.

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Table 1 Soil properties of the experimental site at Hassake before sowing of crops (pre-experiment soil before 2009-2010 cropping season)

Depth	pH	EC_e	OM	$CaCO_3$	Total N	P	K	Sand	Silt	Clay	Texture
cm		dS m^{-1}	%	%	%	mg kg^{-1}	mg kg^{-1}		%		
0-20	7.7	3.32	1.22	32.2	0.093	12.37	405.0	30.00	36.67	33.33	Clay loam
20-40	7.7	3.38	0.82	31.6	0.077	3.42	274.3	28.67	26.00	45.33	Clay
40-60	7.8	3.22	0.31	32.2	0.060	2.80	140.1	26.67	24.67	48.67	Clay
60-80	7.7	2.86	0.25	33.4	0.050	2.89	126.2	24.00	24.67	51.33	Clay
80-100	7.7	2.54	0.13	31.9	0.050	2.91	126.2	23.33	23.33	53.33	Clay
SE	+/-	+/-	..								

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Table 2 Climatic data of the experiment site at Hassake during YEAR/PERIOD??

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total or Mean
Rainfall (mm)	53	39	41	47	20	1	0	0	1	10	17	43	272
Temperature (ºC)	8.6	9.2	13	18	26	31	32	34	28	22	15	11	20.7
Humidity (%)	78	64	70	67	56	45	48	53	55	50	62	70	60
Evaporation (mm)	28	36	78	105	160	297	324	289	195	114	60	28	1714
Wind speed (m/s)	2	2	2.2	2.5	2.5	2.5	2.7	2.6	2.9	1.9	2.1	1.7	2.2
Sunshine (h)	5.1	6.4	7	8.7	11	13	13	13	10	9.1	6.9	5.6	9.1

J – D: stand for abbreviation of January – December in order.

2.2 Site characterization: Raqqa

The experimental site in Raqqa is located 16 km northeast of Raqqa city. It receives freshwater for irrigation from the Euphrates River through an open channel, 12 km from the experimental site. The experimental site is located in the stability zone 5 (Figure 1) with an average rainfall of 218 mm during 1974-1994. Recent rainfall pattern reveals that the amount of rainfall has decreased perceived to be a result of climate change. Climatic data (average of 20 years) of the experiment site at Raqqa are presented in Table 3.

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Table 3 Climatic data (average of 20 years) of the experiment site at Raqqa

Parameter	J	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{average}$ (C)	6.5	8.8	12.5	17.4	23.8	28.2	30.1	29.5	25.6	19.9	12.8	8
$T_{maximum}$ (C)	11.7	14.4	19	24.7	30.5	36.2	38.7	38	34.4	28.3	20.3	13.5
$T_{minimum}$ (C)	1.9	3	6.3	10.4	15.5	19.4	21.7	21.2	17	12.4	6.1	3.3
A Pan Evap (mm/d)	1.1	1.8	3.5	5.1	7.5	10.9	11.8	9.5	6.9	3.9	2	1.1
RH (%)	79	72	63	55	44	34	38	41	44	52	65	79
Sun chine (h)	4.6	5.9	6.9	8	10.4	12	12.2	11.5	10.5	8.4	7	4.9
Wind speed (m/s)	2.6	2.8	3.3	3.6	3.6	4.8	5.4	4.4	2.8	2	1.7	2.3
Wind direction	E	E	W	W	W	W	W	W	W	W	S.W	E
Rainfall (mm)	35.1	39	36.2	17.3	14.5	3.8	-	-	2.7	22	17.6	29.4

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The soil at the experimental site is clay loam to clay, slightly alkaline with a pH around 7.7. The soil contains a large percentage of calcium carbonate (about 32%) and surface soil affected slightly by salinity and moderate in fertility (Table 4). Except for soil texture, which is loam to clay loam at Raqqa, other properties of the study site are similar to those at Hassake site, where soil texture is clay loam to clay, i.e. soil texture is relatively fine at Hassake site than at Raqqa site. Soil surface laser leveling was performed prior to the execution of the experiment to improve surface irrigation water application efficiency.

Table 4 Soil properties of the experimental site at Raqqa before sowing of crops (pre-experiment soil before 2009-2010 cropping season)

Depth	pH	EC_e	OM	$CaCO_3$	Total N	P	K	Sand	Silt	Clay	Texture
cm		dS m^{-1}	%	%	%	mg kg^{-1}	mg kg^{-1}		%		
0-20	7.6	3.48	1.73	23.8	0.1	14.1	436.0	42.7	32.0	25.3	Loam
20-40	7.9	1.78	0.66	29.2	0.1	4.3	233.1	36.7	29.3	34.0	Clay loam
40-60	7.9	2.09	0.38	28.3	0.1	4.2	169.2	37.3	26.0	36.7	Clay loam

60-80	7.8	2.47	0.07	33.2	0.0	5.1	112.8	36.0	26.7	37.3	Clay loam
SE	+/-		…								

Average SE

2.3 Irrigation treatments

Three irrigation treatments at each site were used. At Hassake site, the treatments had average electrolyte concentrations of 0.87, 2.50, and 3.78 dS m^{-1}. The treatment referred to as Irrig-1 had different levels of electrical conductivity (EC) ranging from 0.52 to 1.19 dS m^{-1} with an overall average of 0.87 dS m^{-1} (good-quality water). The treatment, denoted as Irrig-3, consisted of pumped groundwater with EC level varying in the range 2.96-4.62 dS m^{-1} at different pumping times and had an average EC value of 3.78 dS m^{-1}. The treatment referred to as Irrig-2 was based on a mix of good-quality water and groundwater from treatments Irrig-1 and Irrig-3 at the ratio of 1:1, respectively. The EC levels in this blended treatment were also variable contingent upon the water EC variability in Irrig-1 and Irrig-3 treatments. The average EC in Irrig-2 treatment was 2.50 dS m^{-1}. Blending in the case of preparing water for treatment Irrig-2 was done in a place large enough to store water for irrigation of three food legume crops.

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At Raqqa site, the irrigation treatments had more stable EC values than Hassake site. The treatments (Irrig-1, Irrig-2, and Irrig-3) had average electrolyte concentrations of 0.70, 3.0, and 5.0 dS m^{-1}. Blending in the case of treatment Irrig-2 was undertaken in a way similar to that followed at Hassake site.

2.4 Experimental and statistical procedures

Experimental design and layout and field management practices used at both the sites were the same. The experiment was laid out using split plot design with water quality in the main plots in three complete blocks and food legume accessions in the sub-plots. There were three separate split-plot experiments, one for each of the food legumes [and laid out in nearby fields ??? PLEASE CHECK] Basin irrigation method, a prevalent method of irrigation in the area, was used after laser leveling. At the time of each irrigation application, samples of the irrigation water were collected and analyzed for pH, EC, major cations and anions, in addition to boron and mineral nitrogen.

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Soil samples from the 5 depths, 0-20, 20-40, 40-60, 60-80, 80-100 cm, and each of the 9 [main??]plots were collected (45 samples) at mid-season and after crop harvest and analyzed for major nutrients (N, P, and K), pH and EC of saturated extract, major cations and anions in addition to percent moisture.[IS THERE A REPEATITION WITH PREVIOUS SECTION 2.1] The amount of applied irrigation water was calculated from the water balance equation including rainfall. Fertilizers were applied before seeding as: N [or N2O3, N2O5 etc?]at 10 kg ha^{-1}, P_2O_5 at 50 kg ha^{-1}, K_2O at 20 kg ha^{-1}.

Fifteen accessions each of lentil and chickpea and eleven accessions of faba bean were used in the experiments in Hassake and Raqqa sites. These food legume accessions were provided by the International Center for Agricultural Research in the Dry Areas (ICARDA). Lentil accessions were planted in rows 35 cm long and 4 cm apart while chickpea accessions were planted in rows at 35 cm row spacing and 7 cm apart. In the case of faba bean, the accessions were planted in rows at 50 cm row spacing and 25 cm apart. During the 2009-2010 crop season, sowing at Hassake and Raqqa was done on 2 December 2009 and 3 December 2009, respectively. In the 2010-2011 season, the crops were sown about a month late than the 2009-2010 season with respective sowing dates for Hassake and Raqqa sites being 4 January 2011 and 5 January 2011.

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Statistical analysis, for each crop, was performed on each site (Hassake and Raqqa) and combined over the sites using the split plot design on the grain yield where the same accessions and experimental layout and similar field management practices were used. The combined analysis of variance of data over the site and years was carried out to evaluate the interaction of salinity levels, accessions and salinity x accession interaction with site and years within site using the blocking structure for the split-plot design. The multiple comparison test based on Bonferroni adjustment was use to compare the accessions for their mean productivity values.

2.5 SALT-MED model for crop threshold levels for salinity

SALT-MED model was used to calibrate the relative yield of the food legume crops obtained from the field with the model predicted values. This was followed by validating the model calibration. The model calibration was undertaken from the data generated from the field site in Raqqa in 2009-2010. It was validated from the data generated from the same site in 2010-2011. The model was run in the predictive mode with the anticipated yield loss of food legume crops when exposed to incremental increase in irrigation water salinity beyond the irrigation water salinity used in the experiment. The model was run to predict yields of the crops exposed to irrigation water salinity as high as 19 dS m^{-1}.

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As initially developed, SALT-MED model included the following key processes: evapotranspiration, plant water uptake, water and solute transport under different irrigation systems, drainage and the relationship between crop yield and water use, and relationship between salinity and crop yield and yield components (Ragab, 2002; Ragab et al., 2005a; Ragab et al., 2005b). Later improvements in the model have added several important features (Hirich et al., 2012; Silva et al., 2013).The model can be used for a variety of irrigation systems, soil types, soil stratifications, crops and trees, water management strategies (blending or cyclic), leaching requirements, and water quality. The model is based on established water and solute transport, evapotranspiration and crop water uptake equations (Oster et al., 2012). The model is a free download as well as its supporting document and example at the EU funded project SWUP-MED website at: http://www.swup-med.dk/SALTMED.aspx.

3 Results and Discussion

3.1 Response of food legumes to irrigation water quality

3.1.1 Lentil

Analysis of variance of lentil grain yield for both experimental sites, Raqqa and Hassake, years 2009-2011 and three irrigation water salinity levels revealed significant differences (P<0.01) among lentil accessions (Table 5). There was no significant (P>0.05) interaction between accessions and salinity levels, nor were any higher order interactions significant. Averaged over all the salinity levels, lentil accession 10712 produced highest grain yield (1676 kg ha^{-1}), closely followed by accession 7947 (1673 kg ha^{-1}), accession 10707 (1669 kg ha^{-1}), and accession 10691(1652 kg ha^{-1}). These accessions remained statistically at par using a multiple comparison test (Table 5). The accession 10712's performance was significantly superior to that of the accession 6037 (1215 kg ha^{-1}). Among the lentil accessions, accession 10707 had the highest average grain yield (2050 kg ha^{-1}) when irrigated with good-quality water under Irrig-1 treatment where irrigation water salinity was less than 1 dS m^{-1} at both the experimental sites. This accession was followed by accession 10712, which yielded lentil grain at 1879 kg ha^{-1}. In the case of treatment with blended water (Irrig-2), the same accession (10707) performed better for grain yield (1838 kg ha^{-1}) than other accessions. At the highest irrigation water salinity (Irrig-3), accession 10712 took over with grain yield of 1503 kg ha^{-1}. It is interesting to note that most accessions followed the same pattern as was found in the drought tolerance studies undertaken at ICARDA's research station nearby Aleppo. This may be due to the effect of water stress in the first phase of salt stress, which has also been documented by several studies evaluating crops and their same accessions for salt and drought tolerance (Fortmeier and Schubert, 1995).

The overall lentil response to irrigation treatment revealed a yield decreasing trend with increasing salinity levels in irrigation water. The average yield for all lentil accessions was in the order: 1591 kg ha^{-1} (Irrig-1) > 1548 kg ha^{-1} (Irrig-2) > 1252 kg ha^{-1} (Irrig-3).

Table 5 Mean grain yields (kg ha^{-1}) of 15 accessions of lentil, 15 accessions of chickpea, and 11 accessions of faba bean under three irrigation water quality treatments applied at the experimental sites in Hassake and Raqqa, years 2009-2011

Faba bean		Lentil		Chickpea	
Accession	Yield	Accession	Yield	Accession	Yield
DT/B7/9028/2005/06	2162 ab	590	1464 abcd	ILC3182	1871 defg
DT/B7/9013/2005/06	2665 bc	6002	1416 abcd	FLIP03-145C	2023 g

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If there is no clear advantage of keeping the accessions in the order presented, you may keep them in the order of the yield, highest to lowest, for each crop

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DT/B7/9043/2005/06	2483 ab	6037	1215 abc	CPI 060546	836 a
DT/B7/9035/2005/06	2391 ab	7947	1673 cd	ILC 5948	1714 bcdefg
DT/B7/9005/2005/06	2657 bc	6994	1638 bcd	FLIP03-2C	1127 ab
DT/B7/9020/2005/06	2494 ab	7210	1141 a	FLIP03-46C	1781 cdefg
DT/B7/9008/2005/06	2041 a	7537	1313 abcd	FLIP87-59C	1416 abcdef
ILB1270 Reina Blanca	2449 ab	7670	1654 bcd	ILC216	1328 abcd
DT/B7/9009/2005/06	1991 a	7979	1211 ab	FLIP87-8C	1301 abcd
ILB1814 (Syrian local)	3190 c	8068	1496 abcd	ILC588	2159 g
ILB1266 (Aguadolce)	3231 c	10072	1275 abcd	ILC 1283	1273 abc
		10135	1458 abcd	FLIP04-19C	1383 abcde
		10691	1652 bcd	ILC3279	1726 cdefg
		10707	1669 bcd	ILC1302	1997 fg
		10712	1676 d	ILC10722	1947 efg
SE	± 107	SE	±82	SE	±106

Means with different letters under the columns yield for each food legume crop are statistically different at 5% level of significance.

3.1.2 Chickpea

Significant ($P<0.01$) accession differences were found for chickpea yield. The average values for chickpea grain yield suggest chickpea accession ICL588 as the most promising accession with the ability to withstand high levels of salts in the irrigation water. This accession produced highest average grain yield (2159 kg ha^{-1}), closely followed by accession FLIP03-145C (2023 kg ha^{-1}); both accessions remained statistically at par (Table 5). The accession ICL588 also produced the highest average grain yield (2441 kg ha^{-1}) when irrigated with good-quality water under Irrig-1 treatment where irrigation water salinity was less than 1 dS m^{-1} at both the experimental sites. The same accession produced the highest yield in Irrig-2 treatment (2257 kg ha^{-1}). In the case of Irrig-3 treatment, this accession was again among the highest grain yield producing chickpea accessions. ICL588 has also emerged as one of the top accessions in case of drought tolerance by producing significantly higher grain yield under water stressed conditions, again demonstrating the crucial effect of water stress in the first phase of salt stress.

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The overall chickpea response to irrigation treatment revealed a yield decreasing trend with increasing salinity levels in irrigation water. The average yield for all chickpea accessions was in the order: 1751 kg ha^{-1} (Irrig-1) > 1599 kg ha^{-1} (Irrig-2) > 1427 kg ha^{-1} (Irrig-3).

3.1.3 Faba bean

For faba bean too, the accession differences were statistically significant ($P<0.01$). On the average, faba bean accessions produced more grain than chickpea and lentil accessions. Among the faba bean accessions, accession ILB1266 Aguadolce had the highest average grain yield (3787 kg ha^{-1}) when irrigated with good-quality water under Irrig-1 treatment where irrigation water salinity was less than 1 dS m^{-1} at both the experimental sites. This accession was followed by accession ILB 1814 Syrian local, which yielded faba bean grain at 3571 kg ha^{-1}. In the case of treatment with blended water (Irrig-2), the same accession (ILB 1814 Syrian local) performed better for grain yield (3420 kg ha^{-1}) closely followed by the accession ILB1266 Aguadolce, which produced grain at 3180 kg ha^{-1}. Both accessions performed better than other faba bean accessions at the highest irrigation water salinity (Irrig-3) treatment where accessions ILB1266 Aguadolce and ILB 1814 Syrian local produced grain yield at 2727 and 2578 kg ha^{-1}, respectively. In terms of aggregated grain yield from both sites and three irrigation salinity levels, faba bean accession ILB1266 Aguadolce produced highest grain yield (3231 kg ha^{-1}) followed by ILB1814 Syrian local (3190 kg ha^{-1}); both remained statistically at par using the multiple comparison test based on Bonferroni adjustment (Table 5).

The overall faba bean response to irrigation treatment revealed a yield decreasing trend with increasing salinity levels in irrigation water. The average yield for all faba bean accessions was in the order: 2702 kg ha^{-1} (Irrig-1) > 2563 kg ha^{-1} (Irrig-2) > 2304 kg ha^{-1} (Irrig-3).

3.2 Estimation of crop threshold levels using SALT-MED

Using the SALT-MED model, $\pi50$ values for three food legumes (faba bean, chickpea and lentil) were calibrated and validated using field data from 2009-2010 and 2010-2011 seasons, respectively. For the model calibration, the values of $\pi50$ used for the food legume crops at three growth stages (initial, middle, and late) are given in Table 6.

Table 6 Calibrated $\pi50$ values (dS m^{-1}) for three food legume crops (faba bean, chickpea, and lentil) for the 2009-2010 crop season

Crop stage	Faba bean	Chickpea	Lentil
Initial	7.00	5.50	5.75
Mid	8.00	6.50	6.75
Late	9.00	7.50	7.75

Comment [MS5]: Keep crop columns in the same order, in all the tables, results or discussions etc

Is there no SE here for estimates of the salinity levels?

3.2.1 Lentil

Based on the average of 15 accessions for the 2009-2010 data from Raqqa site yields of lentil from the field data for Irrig-2 and Irrig-3 relative to that of Irrig-1 were 0.7166 and 0.4168,

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respectively. As predicted by the SALT-MED model during the model calibration process, the corresponding relative yields for Irrig-2 and Irrig-3 treatments were very close, i.e. 0.6951 and 0.4377, respectively. The difference (or, error) between the average measured results from the field site and model calibrated results for Irrig-2 and Irrig-3 treatments was 2.99% and -4.99%, respectively (Table 7). Figure 2 shows the measured average relative yield of lentil accessions and model calibrated results for lentil based on the 2009-2010 season data. The linear regression equation for field obtained relative yield (y) and model predicted relative yield (x), was $y = 0.9633x + 0.0259$ ($R^2 = 0.996$).

Table 7 Average and range of differences between yields, relative to the lowest salinity level (0.7dSm^{-1}), observed from the field site and calibrated from model

Water salinity	Faba bean	Chickpea	Lentil
dS m^{-1}	%	%	%
3.0	-5.84 (--, --)	-10.96 (--,--)	2.99 (--,--)
5.0	1.61 (--,--)	8.79 (--,--)	-4.99 (--,--)

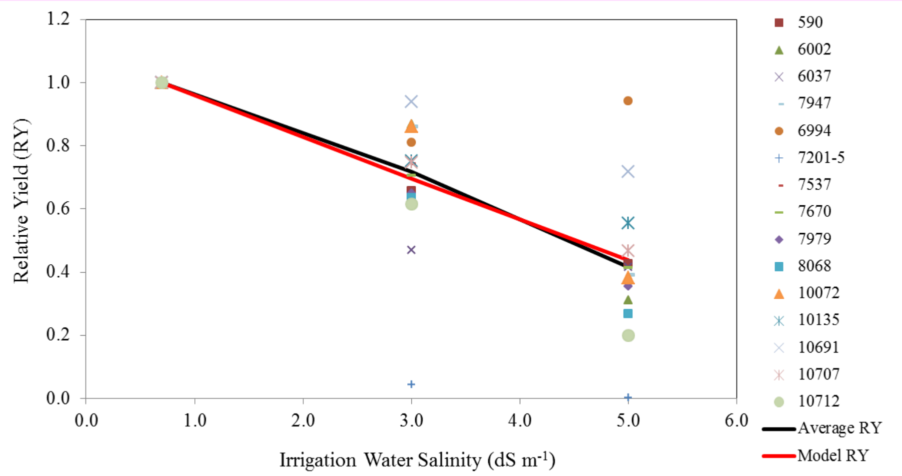

Figure 2 Measured average relative yield of lentil accessions and model calibrated results for lentil based on the 2009-2010 season data

During the model validation process for the field data for the next season (2010-2011) from the same site using calibrated π50, the relative yields of lentil from the field data for Irrig-2 and Irrig-3 treatments were 0.8337 and 0.2623, respectively. The corresponding relative yields for Irrig-2 and Irrig-3 treatments as predicted by the SALT-MED model were 0.6215 and 0.3232, respectively. In terms of using SALT-MED model to determine 50% threshold yield of lentil (π_{50} value) based on salinity levels in irrigation water in equilibrium with

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ambient soil solution salinity levels, the 50% yield reduction occurred at salinity of 4.4 dS m^{-1} during the model validation process based on 2010-2011 data for lentil (Figure 3).

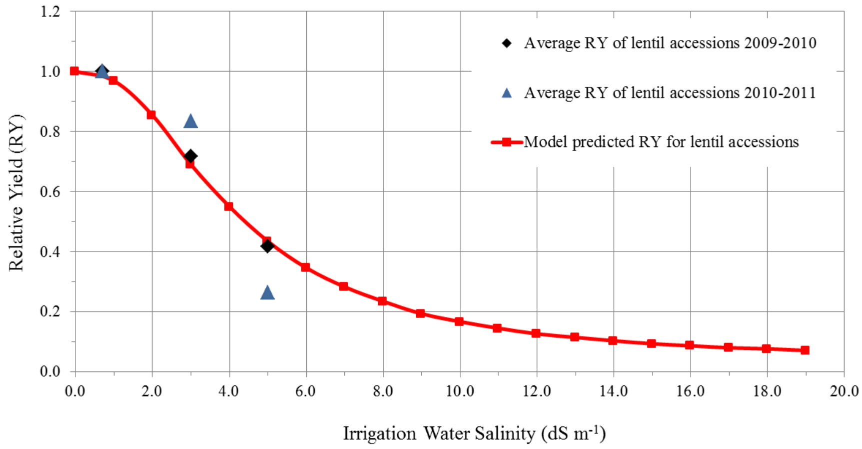

Figure 3 As predicted and validated by SALT-MED model, decrease in relative grain yield of lentil as affected by the incremental increase in irrigation water salinity up to 19 dS m^{-1}

As predicted and validated by SALT-MED model, yield potential of lentil increased with decreasing levels of irrigation water salinity. For example, yield potential of lentil was 100% at irrigation water salinity of 0.8 dS m^{-1}; 75% at 2.7 dS m^{-1}; and 25% at 7.7 dS m^{-1} (Table 7).

Table 8 As predicted and validated by SALT-MED model, yield potential (%) of food legume crops at specified levels of irrigation water salinity expressed as dS m^{-1}

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Crop	Yield potential (%) at specified salinity (dS m^{-1})			
	25%	50%	75%	100%
Faba bean	9.7	5.2	3.2	0.9
Lentil	7.7	4.4	2.7	0.8
Chickpea	7.2	4.2	2.6	0.7

3.2.2 Chickpea

The relative yields of chickpea from the field data for Irrig-2 and Irrig-3 treatments were 0.6062 and 0.4487, respectively. These relative yields were based on the average of 15 accessions for the 2009-2010 data from Raqqa site. As predicted by the SALT-MED model during the model calibration process, the corresponding relative yields for Irrig-2 and Irrig-3 treatments were very close, i.e. 0.6727 and 0.4093, respectively. The percentage of error between the average measured results from the field site and model calibrated results for Irrig-2 and Irrig-3 treatments was -10.96 and 8.79, respectively (Table 6). Figure 4 shows the

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measured average relative yield of chickpea accessions and model calibrated results for chickpea based on the 2009-2010 season data. The linear regression equation for field obtained relative yield (y) and model predicted relative yield (x) was y = 1.0253x - 0.0083 (R^2 = 0.968).

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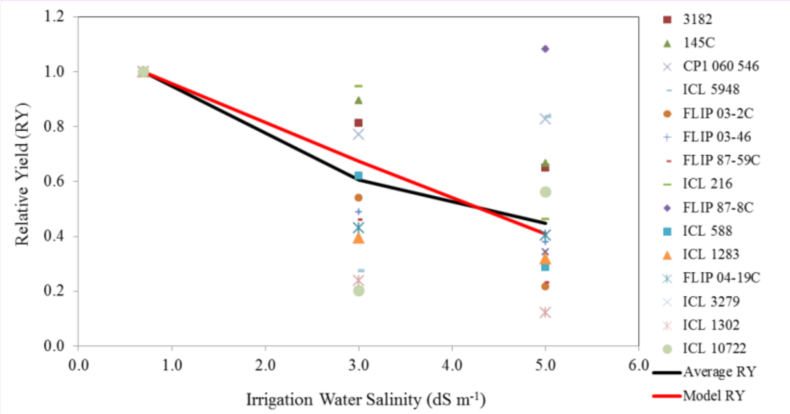

Figure 4 Measured average relative yield of chickpea accessions and model calibrated results for chickpea based on the 2009-2010 season data

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During the model validation process for the field data for the next season (2010-2011) from the same site, the relative yields of chickpea from the field data for Irrig-2 and Irrig-3 treatments were 0.6497 and 0.4654, respectively. The corresponding relative yields for Irrig-2 and Irrig-3 treatments as predicted by the SALT-MED model were 0.7281 and 0.4245, respectively. In terms of using SALT-MED model to determine 50% threshold yield of chickpea (π_{50} value) based on salinity levels in irrigation water in equilibrium with ambient soil solution salinity levels, the 50% yield reduction occurred at salinity of 4.2 dS m^{-1} during the model validation process (Figure 5). As predicted and validated by SALT-MED model, 100% yield potential of chickpea was at irrigation water salinity of 0.7 dS m^{-1}; 75% at 2.6 dS m^{-1}; and 25% at 7.2 dS m^{-1} (Table 7).

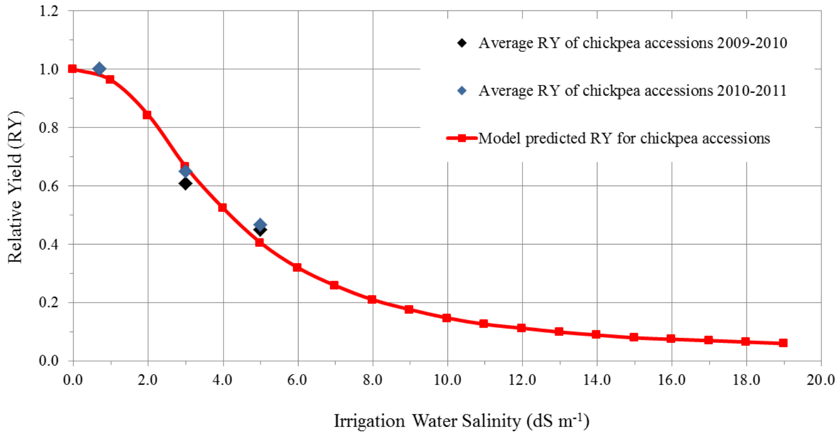

Figure 5 As predicted and validated by SALT-MED model, decrease in relative grain yield of chickpea as affected by the incremental increase in irrigation water salinity up to 19 dS m^{-1}

3.2.3 Faba bean

The relative yields of faba bean from the field data for Irrig-2 and Irrig-3 treatments were 0.7374 and 0.5347, respectively. These relative yields were based on the average of 11 accessions for the 2009-2010 data from Raqqa. As predicted by the SALT-MED model during the model calibration process, the corresponding relative yields for Irrig-2 and Irrig-3 treatments were very close, i.e. 0.7805 and 0.5260, respectively. The percentage of error between the average measured results from the field site and model calibrated results for Irrig-2 and Irrig-3 treatments was -5.84 and 1.61, respectively (Table 6). Figure 6 shows the measured average relative yield of faba bean accessions and model calibrated results for chickpea based on the 2009-2010 season data. The linear regression equation for field obtained relative yield and model predicted relative yield was y = 1.0097x + 0.0041 (R^2 = 0.986).

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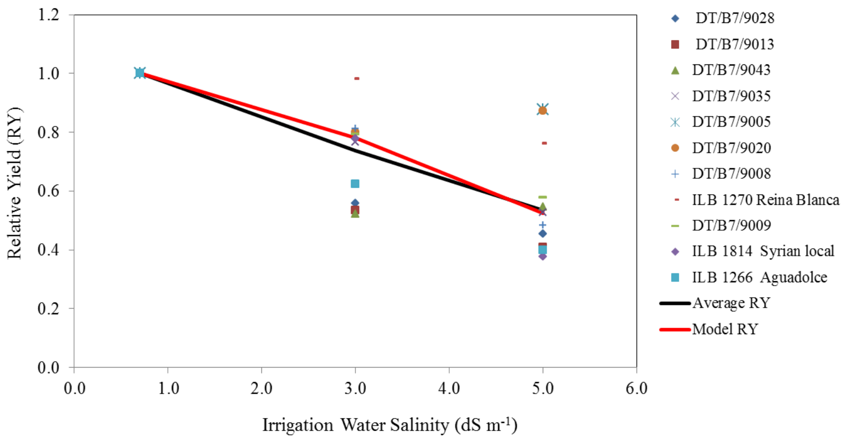

Figure 6 Measured average relative yield of faba bean accessions and model calibrated results for faba bean based on the 2009-2010 season data

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During the model validation process for the field data for the next season (2010-2011) from the same site, the relative yields of faba bean from the field data for Irrig-2 and Irrig-3 treatments were 0.7395 and 0.5903, respectively. The corresponding relative yields for Irrig-2 and Irrig-3 treatments as predicted by the SALT-MED model were 0.8012 and 0.5461, respectively. In the process of determining 50% threshold yield of faba bean (π_{50} value) based on salinity levels in irrigation water in equilibrium with ambient soil solution salinity levels, the 50% yield reduction as predicted by SALT-MED model occurred at salinity of 5.2 dS m^{-1} during the model validation process (Figure 7). As predicted and validated by SALT-MED model, 100% yield potential of faba bean was at irrigation water salinity of 0.9 dS m^{-1}; 75% at 3.2 dS m^{-1}; and 25% at 9.7 dS m^{-1} (Table 7). These results are in line with those of Katerji et al. (2011) who reported that soil salinity levels equal to or higher than 6.5 dS m^{-1} affected faba bean growth, reduced number of grains, and grain yield.

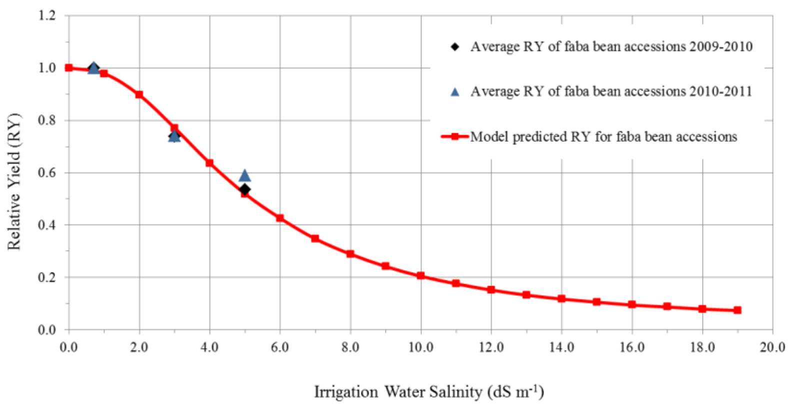

Figure 7 As predicted and validated by SALT-MED model, decrease in relative grain yield of chickpea as affected by the incremental increase in irrigation water salinity up to 19 dS m^{-1}

4 Conclusions

Combined analysis of grain yields for both experimental sites and three irrigation water salinity levels revealed significant differences among accessions of each food legume crop. There were no significant interaction with the salinity over its experimented range at any of the locations. This genetic diversity provides the opportunity to select a specific food legume accession that can withstand ambient level of salts in irrigation water. In addition, most accessions followed the same pattern for grain yield production as was found in the drought tolerance studies concurrently undertaken during these years at ICARDA's research station nearby Aleppo. This may be due to the effect of water stress in the first phase of salt stress, which has also been documented by several other studies evaluating crops and their same accessions for salt and drought tolerance.

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Calibration and validation of SALT-MED model revealed close relationship between actual grain yields from the field sites and those predicted by the model. Based on salinity levels in irrigation waters, yield potential of lentil was 100% at irrigation water salinity of 0.8 dS m^{-1}; 75% at 2.7 dS m^{-1}; 50% at 4.4 dS m^{-1}; and 25% at 7.7 dS m^{-1}. As predicted and validated by the model, 100% yield potential of chickpea was at irrigation water salinity of 0.7 dS m^{-1}; 75% at 2.6 dS m^{-1}; 50% at 4.2 dS m^{-1}; and 25% at 7.2 dS m^{-1}. For faba bean, 100% yield potential was at irrigation water salinity of 0.9 dS m^{-1}; 75% at 3.2 dS m^{-1}; 50% at 5.2 dS m^{-1}; and 25% at 9.7 dS m^{-1}. The yield potential of food legume crops as predicted by SALT-MED model reveals that faba bean can withstand relatively high levels of irrigation water salinity. These results are expected to help extensions workers and farmers in making informed decisions in selecting appropriate food legume crop and crop accessions based on salinity level of the water available as an irrigation source.

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