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Effect of Tillage and Humidification Conditions on Desalination Properties of Chickpea (*Cicer arietinum* L.)

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ABSTRACT
Chickpea is supposed to be a prospective crop for soil reclamation. The goal of this study was to determine the effect of tillage and humidification conditions on the chickpea desalination properties. The study was conducted by using the randomized split plot method in four replications during 2012–14 at the Agricultural Cooperative Farm «Radianska Zemlia» of Kherson region in Ukraine. The results of the study showed that the maximum salts uptake of 2.516 t ha^{-1} from the 0–50 cm soil layer and the maximum chickpea grain yield of 3.33 t ha^{-1} were provided under irrigated conditions with moldboard plowing on the depth of 28–30 cm. It was established that the higher chickpea grain yield is, the greater the salts uptake rate from the soil. It was also proven that the plowing depth has no significant effect on the chickpea grain yield and desalination properties. It should be mentioned that chickpea showed limited desalination properties. The crop was not able to adsorb all the sodium from the soil when irrigated with saline water.

Keywords: chickpea, irrigation, plowing depth, salinity, desalination.

INTRODUCTION

Due to the high proteins content in grain [Hulse 1991] and drought-tolerance [Katerji et al. 2001], chickpea (*Cicer arietinum L.)* is one of the most important and strategic crops grown on saline soils in arid regions [Dua 1998, Rao et al. 2002]. At the same time, soil salinity is supposed to be a severe constraint for the growth and high productivity of chickpea [Lauter, Munns 1986, Chaunan 1987, Singh 2004]. A decrease of dry biomass from 15 to 50% in different chickpea cultivars was determined due to the artificial increase of the NaCl content from 0 to 100 mM in nutrition solution [Tejera, Soussi, Lluch 2006]. Salt stress resulted in a decrease of length, fresh and dry biomass of chickpea plants roots and shoots [Van Hoorn et al. 2001, Singla, Garg 2005, Fusum, Mehmet 2007]. Total dissoluble salts content (TDS) at 4.0 dS m^{-1} in nutrition solution inhibited nodulation, and further increasing of TDS to 7.0 dS m^{-1} stopped it. TDS at 8.0 dS m^{-1} resulted in complete death of chickpea plants [Elsheikh, Wood 1990]. Significant variations in the salt-tolerance were determined in different chickpea cultivars [Serraj, Krishnamurthy, Upadhyaya 2004, Vadez et al. 2007, Sohrabi, Heidari, Esmailpoor 2008]. Some of chickpea cultivars showed high salt-tolerance and yields under saline soil conditions due to their symbiosis with specific strains of *Rhizobium* [Saxena, Rewari 1992]. Besides, legumes and chickpea in particular are considered to have soil desalination properties [Qadir et al. 2003, Qadir et al. 2007, Patel et al. 2012, Kambhampati, Vu 2013]. Chickpea desalination properties under saline soil conditions have not been determined yet. The goals of this study were to determine the effect of tillage and humidification conditions on the chickpea desalination properties and productivity.

MATERIALS AND METHODS

The field trials were conducted from 2012 to 2014 in a dark-chestnut soil at the Agricultural Cooperative Farm «Radianska Zemlia» of Kherson region, Ukraine (latitude 46°43'N and longitude 32°17'E and 42 m above sea level). The humus content in the soil was 2.5%. The soil potential of hydrogen (pH) in the 0–50 cm layer was neutral. Bulk density of the soil was 1.29 g cm^{-3} in the 0–50 cm layer. The least soil water holding capacity was 20.8% in 0–50 cm layer. Lightly hydrogenated nitrogen content in the soil was 35 mg kg^{-1}. The mobile phosphorus content in the soil was 32 mg kg^{-1}, and the exchangeable potassium content was 430 mg kg^{-1}. The groundwater level was 3 m below the ground. The water from the Ingulets irrigation system (latitude 47°0'N and longitude 32°47'E) was used for irrigation. The quality of the water was determined by using common methods [APHA 1995]. The irrigation water quality parameters were calculated by using the following formulas:

$$KR = Na^+ / (Ca^{2+} + Mg^{2+}) \quad (1)$$

where: *KR* – Kelly's ratio [Kelly 1963],
Na^+, Ca^{2+}, Mg^{2+} – content of ions expressed in me L^{-1}.

$$SAR = Na^+ / \sqrt{0.5 \times (Ca^{2+} + Mg^{2+})} \quad (2)$$

where: *SAR* – sodium adsorption ratio expressed in me/l [Ayers, Westcott 1985],
Na^+, Ca^{2+}, Mg^{2+} – content of ions expressed in me L^{-1}.

$$SP = 100 \times (Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \quad (3)$$

where: *SP* – sodium percentage, % [Todd,1980],
Na^+, K^+, Ca^{2+}, Mg^{2+} – content of ions expressed in me L^{-1}.

$$PI = (Na^+ + \sqrt{100 \times HCO_3^-}) / (Ca^{2+} + Mg^{2+} + Na^+ + K^+) \quad (4)$$

where: *PI* – permeability index [Doneen 1964],
Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^- – content of ions expressed in me L^{-1}.

Kelly's ratio and sodium adsorption ratio are used to determine the alkalinity and salinity hazard. Permeability index is used to determine the impact of irrigation water on soil permeability. The sodium percentage is used to determine the sodium hazard.

The climate of the area is characterized as very dry and moderately hot. The annual average temperature is 9.8°C. The coldest month is January, and the hottest one is July. The annual January temperature is 3.0°C below zero, and an annual July temperature is 21.9°C. The annual rainfall amount is 441 mm. The annual evaporation is about 1000 mm. The meteorological data during the chickpea vegetation were recorded at the nearest meteorological station of Kherson region (latitude 46°38'N and longitude 32°36'E and 41 m above sea level).

The experimental design was built by using the randomized split plot method in four replications. The factors studied were: factor A – tillage (A_1 – moldboard plowing on a depth of 20 to 22 cm, A_2 – moldboard plowing on a depth of 28 to 30 cm); factor B – mineral fertilizers application rate (B_1 – no fertilizers applied , B_2 – $N_{45}P_{45}$, B_3 – $N_{90}P_{90}$); factor C – plants density (C_1 – 50 plants m^{-2}, C_2 – 100 plants m^{-2}, C_3 – 150 plants m^{-2}); D – humidification conditions (D_1 – rainfed conditions, D_2 – irrigated conditions). The study on the chickpea desalination properties was conducted in the case of treatments with mineral fertilizers application rate B_3 ($N_{90}P_{90}$) and plants density C_2 (100 plants m^{-2}).

The chickpea cultivar *Rosanna* was used in the study. The cultivar is recorded in the State register of plant varieties suitable for dissemination in Ukraine. The cultivar belongs to the euroasiaticum subspecies of the Kabuli type. The plants are high (55 to 60 cm). The lowest pods are at the height of 22 to 24 cm. The seeds are round, light yellow, smooth. The mass of 1000 seeds ranges from 290 to 310 g. The proteins content in the seeds ranges from 25 to 26%. The cultivar is middle-ripening and resistant to lodging.

The previous crop for chickpea was winter wheat (*Triticum aestivum* L.). Land preparation included two-time harrowing on the depths of 6 to 8 cm and 10 to 12 cm followed by the moldboard pre-winter plowing with accordance to the experimental design. Mineral fertilizers (such as *ammonium nitrate* and *super phosphate*) were applied before plowing with accordance to the experimental design. Then, cultivation on a depth of 12 to 14 cm was conducted to control weeds. An early-spring dragging was conducted for soil leveling. Pre-sowing cultivator tillage was conducted on a depth of 5 to 7 cm. Sowing of chickpea with John Deere 740A drill was conducted on 28 March in 2012, on 4 April in 2013 and on 23 March in 2014. The seeds were dressed by the symbiotic bacteria (*Rhizobium cicer, Enterobacter nimipressuralis, Paenibacillus polymyxa* in 10:1:1 proportion) two hours before sowing. The soil was rolled after sowing. The Gezaguard 500 FW herbicide (an active substance is *prometryn,* 500 g L^{-1}) in a dose of 3.0 L ha^{-1} was used in the pre-emergence period to control weeds. The Nurell D insecticide (the active substances include *chlorpyrifos*, 500 g L^{-1} and *cypermethrin*, 50 g L^{-1}) was used at the beginning of the flowering stage to control insects.

The moisture in the 0–50 cm soil layer was maintained at 75% of the least water holding capacity. The soil moisture control was performed by using the balance-drier method. Irrigation was conducted by using the «Kuban» irrigation machine. The irrigation water was applied to the field in different amounts: three times at the rate of 45 mm in 2012; once at the rate of 50 mm in 2013; twice at the rate of 50 mm in 2014.

The samples of the soil were collected by using the soil auger at the emergent stage and after harvesting. Total dissoluble salts content in the soil samples was determined by using the saturation extract method [Jackson 1958, Hardie, Doyle 2012]. Total dissoluble salts uptake by chickpea crops expressed in t/ha was calculated by using the formula:

$$TDS_t = TDS_{\%} \times BD \times SL \quad (5)$$

where: TDS_t – total dissoluble salts uptake by chickpea crops expressed in t ha^{-1},
$TDS_{\%}$ – total dissoluble salts uptake by chickpea crops expressed in percents (%),
BD – bulk density of the soil expressed in g cm^{-3},
SL – soil layer expressed in cm.

The chickpea grain yield was determined by harvesting at the full ripeness of pods with CLAAS Lexion self-propelled harvester. The yield was to standard grain moisture of 14%. The harvesting was conducted:

- in the rainfed treatments: 2012 – on 18 July, 2013 – on 22 July, 2014 – on 13 July;
- in the irrigated treatments: 2012 – on 3 August, 2013 – on 6 August, 2014 – on 31 July.

Analysis of variance (ANOVA) was performed to determine the influence of studied factors on total dissoluble salts (TDS) content in the 0–50 cm soil layer, salts uptake and chickpea grain yield (CGY). Significant differences in treatments were determined by using the least significant differences (LSD) test at $p < 0.05$.

RESULTS AND DISCUSSION

The water of the Ingulets irrigation system had moderate restrictions on use for irrigation due to the high total dissoluble salts, sodium and bicarbonate content. The calculated value of sodium percentage was higher than the permissible one. The sodium adsorption ratio and Kelly's ratio were too close to the permissible values (Table 1). The water of the Ingulets irrigation system is considered to be dangerous due to the salinity and

Table 1. Irrigation water quality during the vegetation period of chickpea in the field experiments (average for 2012–2014 years)

Quality parameters	True values	Permissible values	Optimal values
Ca^{2+}, me/l	6.02 ± 1.00	N/A	N/A
Mg^{2+}, me/l	6.96 ± 0.43	N/A	N/A
Na^{+} + K^{+}, me/l	12.82 ± 1.87	3.00–9.00	<3.00
Cl^{-}, me/l	9.75 ± 0.31	10.00	<3.00
SO_4^{2-}, me/l	10.25 ± 0.34	N/A	N/A
HCO_3^{-}, me/l	3.86 ± 0.20	1.50–8.50	<1.50
TDS, mg/l	1549.67 ± 69.01	450–2000	<450
PH, units	8.30 ± 0.05	8.40	6.00–7.00
SAR, me/l	5.03 ± 0.75	6.00	<3.00
KR, me/l	0.99 ± 0.16	<1.00	<1.00
PI, me/l	1.26 ± 0.05	>1.00	>1.00
SP, %	49.77 ± 3.61	<60.00	<40.00

Note. Average values ± standard deviation (SD) for the studied period are given. The content of ions is expressed in me L^{-1}. N/A means that the permissible and optimal values of the quality parameter are not determined by FAO [Ayers, Westcott 1985].

sodium hazard (Wilcox 1955, Kelly 1963, Ayers and Westcott 1985).

Warmth came late in 2012. There was too little rainfall in spring, whereas the summer was hot and dry in 2012. In 2013, the spring was characterized with high air temperatures and little rainfall and the summer came early. It was comparatively dry and hot. In 2014, the spring was warm and with normal rainfall, while the summer was dry and hot again (Table 2). Little rainfall, together with high air temperatures, had a negative effect on the chickpea productivity under the rainfed conditions.

The results of the soil saturation extract analysis determined higher total dissoluble salts content at the emergent stage than after harvesting in all the studied treatments. The saline water of the Ingulets irrigation system increased the total dissoluble salts content in the 0–50 cm soil layer in irrigated treatments (Table 3).

Better humidification conditions resulted in higher chickpea grain yield. Similar results reporting positive response of chickpea to irrigation were obtained by some other researchers [Zhang et al. 2000, Rajin Anwar et al. 2003, Jalota et al. 2006]. The effect of the plowing depth on soil salinity, salts uptake from the soil and chickpea grain yield was not significant. This is verified by the results of some other investigations [Emenky et al. 2010]. It was proven that the higher grain yield is, the greater the desalination effect of chickpea. The desalination effect of the crop was little under the rainfed conditions. At the same time, chickpea crops decreased the total dissoluble salts content in the 0–50 cm soil layer by 2.451 to 2.516 t ha^{-1} with irrigation.

It should be mentioned that the chickpea ions uptake from the soil was not similar with different treatments. Irrigation with the saline water of the Ingulets irrigation system resulted in an increase of sodium content in the soil. It is supposed that chickpea was not able to adsorb all the applied amounts of sodium due to its high toxicity. It was also determined that the chickpea uptake of calcium, magnesium and bicarbonates under rainfed conditions was very small (Table 4).

The above-mentioned facts point to the limited desalination properties of chickpea. These peculiarities should be taken into account while using chickpea in soil reclamation.

Table 2. Meteorological conditions during the chickpea vegetation in the field experiments (2012–2014 years)

Months of the vegetation	Air temperature, ºC				Rainfall, mm			
	2012	2013	2014	long-term mean	2012	2013	2014	long-term mean
March	2.5	3.1	7.4	2.3	25.6	38.8	32.0	26.0
April	13.2	11.9	11.5	10.0	5.9	3.7	29.5	33.0
May	20.8	20.7	18.0	16.0	39.6	0.3	38.2	42.0
June	23.4	23.0	20.8	19.9	20.1	79.1	64.4	45.0
July	26.6	23.2	25.1	21.9	40.2	44.1	19.4	49.0
August	23.6	24.2	24.5	21.3	79.2	12.4	20.7	38.0

Note. Long-term mean meteorological data are given for the period of 1986–2005.

Table 3. Effect of plowing depth (factor A) and humidification conditions (factor D) on total dissoluble salts content in the 0–50 cm soil layer and chickpea grain yield in the field experiments during the period from 2012–2014 years

Factor A	FactorD	TDS, %		TDS uptake by chickpea crops from the soil layer of 0–50 cm		Chickpea grain yields, t ha^{-1}
		at emergent stage	after harvesting	in %	in t ha^{-1}	
A_1	D_1	0.146±0.004a	0.141±0.004a	0.005±0.001a	0.323±0.065a	1.80±0.23a
	D_2	0.298±0.005b	0.260±0.005b	0.038±0.007a	2.451±0.452b	3.24±0.28b
A_2	D_1	0.145±0.002a	0.140±0.003a	0.005±0.001a	0.323±0.065a	1.85±0.22a
	D_2	0.268±0.010b	0.229±0.012b	0.039±0.006a	2.516±0.387b	3.33±0.26b
LSD	A	0.121	0.096	0.102	1.557	0.05
	D	0.121	0.096	0.102	1.557	0.10
	A×D	0.171	0.135	0.144	2.203	0.14

Notes. Average values for the studied period ± standard deviation (SD) are given; means with the same letter within one column are not significantly different at p<0.05. LSD – the least significant difference.

Table 4. Effect of plowing depth (factor A) and humidification conditions (factor D) on ions content in the 0–50 cm soil layer under the chickpea crops in the field experiments during 2012–2014 years

Treatments		Ions content, me L^{-1}					
Factor A	Factor D	HCO_3^-	Cl^-	SO_4^{2-}	Na^+	Ca^{2+}	Mg^{2+}
At the emergent stage							
A_1	D_1	0.40±0.07	0.22±0.06	1.41±0.18	1.80±0.07	0.18±0.04	0.05±0.03
	D_2	1.14±0.37	0.52±0.13	2.81±0.20	1.01±1.12	1.26±0.10	2.20±1.22
A_2	D_1	0.52±0.05	0.17±0.02	1.30±0.04	1.76±0.06	0.16±0.02	0.08±0.05
	D_2	1.36±0.13	0.30±0.09	2.50±0.31	0.05±0.01	0.72±0.12	3.38±0.10
After harvesting							
A_1	D_1	0.47±0.07	0.15±0.05	1.33±0.10	1.65±0.02	0.19±0.01	0.10±0.05
	D_2	0.86±0.31	0.25±0.07	2.56±0.27	2.21±0.21	0.92±0.21	0.54±0.19
A_2	D_1	0.51±0.01	0.20±0.01	1.19±0.04	1.64±0.04	0.17±0.02	0.11±0.02
	D_2	0.56±0.12	0.04±0.03	2.37±0.08	2.26±0.13	0.69±0.08	0.36±0.03

Note. Average values of the ions content in me/l for the studied period ± standard deviation (SD) are given.

CONCLUSIONS

The results of our investigations proved that chickpea can be used in soil reclamation. It is a prospective crop for the desalination of saline soils. The highest salts uptake by chickpea crops from the 0–50 cm soil layer was 2.516 t ha^{-1} in irrigated treatments with moldboard plowing on a depth of 28 to 30 cm. Our study has some limitations; therefore, further investigations of chickpea desalination properties under different weather and technological conditions are required.

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