Groundwater Salinity/Sodicity Impact on Soil Characteristics and Crops of Wheat and Maize

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ABSTRACT

A field experiment was conducted to study the effect of brackish water on plant growth and yield of wheat and maize genotypes at the farmer field. Two salt tolerant genotypes for each crop were selected from previous hydroponic and lysimeter studies. Wheat-maize cropping system was followed using tubewell brackish water alone and with chemical (gypsum) and organic (FYM) amendments. The results revealed that treatments have significant effect on all growth and yield parameters and follow the trend of $T_1 > T_4 > T_5 > T_2 > T_3$. Maximum reduction in wheat grain and maize fodder yield observed in T_3 where high EC, SAR and RSC water was applied that was 39&57% for 1st year and 89 & 74% for 2nd year respectively. Data revealed that use of gypsum and FYM along with brackish water improve the wheat grain yield and maize fodder as compared to T3. More adverse effect of brackish water was observed in clay texture as compared to others. Among genotypes SARC-1 and Sahiwal-2002 performed better in all treatments and textures especially under brackish water treatments.

KEYWORDS: brackish water, textures, genotypes and crop production.

INTRODUCTION

The rate of growing global population warrants increase in the area under irrigated agriculture to fulfill the future food and fiber needs, which will need additional amounts of water. Competition for freshwater already exists among the municipal, industrial and agricultural sectors in several regions due to an increase in population. The consequence has been a decreased allocation of freshwater to agriculture [1-2]. This phenomenon is expected to continue and to intensify in less developed, arid region countries such as Pakistan, that already have high population growth rates and suffer from serious environmental problems [3]. As supplies of good-quality irrigation water are expected to decrease, available water supplies need to be used more efficiently [4-6], where one of the techniques can be the reuse of saline and or sodic drainage waters [7-9], or of marginal-quality waters generated by municipalities [10]. The shortfall in irrigation water requirement is likely to reach 107 MAF by 2013 [10]. In Pakistan, to supplement the present canal water availability at farm-gate (43 MAF), more than 531,000 tube wells are pumping 55 MAF water. Estimates show that about 70–80% of pumped water in Pakistan (67,842 million m³) contains soluble salts and/or sodium ions (Na$^+$) levels above the permissible limits for irrigation water [12]. The use of underground water for irrigation resulted in deterioration of soil physical and chemical properties [13-15].

There are two major approaches for improving and sustaining productivity in a saline environment: modifying the environment to suit the plant and modifying the plant to suit the environment. Both these approaches have been used, either singly or in combination [16], but the former has been used more extensively because it facilitates the use of alternative production inputs. Maize (*Zea mays* L.) is an important crop and provides raw material for agro-based industry. It is not only consumed by human beings in the form of food grains, but also provides feed for livestock and poultry. Maize is moderately salt tolerant crop; the threshold salinity for corn is 1.7 dSm^{-1} [17]. In another report by Rhodes et al. [18] maize can be grown at EC$_e$ 1.5 to 3.0 and reduction in yield of maize is a common phenomenon because of poor quality irrigation water. Sufficient information is not available about the performance of different maize varieties and changes in chemical and physical properties of soil under our field conditions by irrigated with brackish tube well water. Wheat is the most important and largest cereal crop in Pakistan. It covers a large proportion of the total area under cultivation. Total wheat area of Pakistan is about 8.5 million hectares and the majority of wheat is grown in Punjab. In Pakistan the most efficient way to increase wheat yield is to improve the salt tolerance of wheat genotypes because increasing the salt tolerance of wheat is much less expensive for poor farmers in developing countries than using other management practices, e.g. leaching salt from the soil surface etc. [19]. The main objective of this work was developed a successful planning of brackish water use for wheat yield and maize fodder production, observed soil deterioration and select best genotypes which can be economically grown by irrigating with brackish tube well water.

MATERIALS AND METHODS

Experimental site and seed source

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Field experiments were conducted to study the performance of wheat and maize genotypes under natural field conditions, using available brackish water at farmer field in T. T. Singh District. Wheat genotypes (SARC-1 & V-8670) and Maize (Sahiwal & Akbar) which were already tested in hydroponic and lysimeter study in wire house at University of Agriculture, Faisalabad. Seed of wheat genotypes (8670 & SARC-1) and maize genotypes (Sahiwal-2002 & AKBAR) were collected from the Saline Agriculture Research Centre, Institute of Soil and Environmental Sciences and Plant breeding and genetic Department, University of Agriculture, Faisalabad and Fodder Research Institute, Sahiwal.

Experimental procedure

In these experiments wheat-maize (fodder) cropping rotation was followed. Two genotypes for each crop were selected from solution culture and lysimeter experiments which are SARC-1 and V-8670 for wheat while Akbar and Sahiwal-2002 for maize fodder. The tube well water contains EC 6.5 dSm^{-1}, SAR 10 (m mol L^{-1})$^{1/2}$ and RSC 4.50 meL^{-1}. The soil was prepared with ploughing and planking. Recommended dose of NPK was applied (120-90-60 kg ha^{-1}) for wheat and (200-150-200 kg ha^{-1}) for maize in each lysimeter. Half of the N and all P and K were applied at the time of sowing while the remaining half N was added in two equal doses at tillering and booting stages in wheat and for maize fodder 2nd dose of N was applied after 30 days of germination. Farm Yard Manure (FYM @ 25 Mg ha^{-1}) and gypsum was applied according to gypsum requirement of water [20] at sowing time. The five irrigations (2inch) of brackish water were applied.

RESULTS AND DISCUSSION

The study was carried out to determine the possibility of drainage water for crop production. Impact of different brackish water treatments with and without amendments on ECe, SAR, infiltration rate, Na:K ratio in leaf sap and crop yield and is discussed as under.

Soil salinity (EC$_e$ dSm^{-1})

Soil analysis at different stages indicated that application of four types irrigation have affect the soil salinity. The data regarding to change in ECe due to application of brackish water with and without amendments is shown in Table-2. Maximum increase of 199% of basic salinity level was observed in T$_2$ in which brackish water was applied without any amendments. However, same brackish tubewell water with gypsum (on RSC basis) minimized the adverse effect and reduced salinity buildup (94% of basic

salinity level) as compared to brackish water application. Similarly application of FYM also reduced salinity development (137%).

Table- 2: Impact of irrigation treatments on EC$_e$ of soil

Irrigation Treatments	EC$_e$ (dSm^{-1})			Increase or decrease in S$_3$ over S$_1$ (%)
	S$_1$	S$_2$	S$_3$	
Canal water	3.15	3.05	2.71	-14
Tubewell water	3.15	7.34	9.43	+199
Tubewell water+GR*	3.15	5.28	6.10	+94
Tubewell water+FYM**	3.15	6.25	7.48	+137

S$_1$ Soil analysis before sowing wheat
S$_2$ Soil analysis after harvesting wheat
S$_3$ Soil analysis after harvesting maize
* Gypsum requirement on water RSC basis
** FYM @ 25 Mg ha^{-1}

Soil salinity increased due to accumulation of salts with brackish water application. Cucci *et al.* [21] reported that salt build up in soil increased with irrigation water salinity and mean increase in EC$_e$ of soil was 13.9 (dSm^{-1}) in 1st year. An increase in EC$_e$ upto 14.0 dSm^{-1} with application of brackish water (EC 3.6-7.4 dSm^{-1}) was also observed by Yadav *et al.* [22]. Similarly, Sail *et al.* [23] observed increase in EC$_e$ from 1.5 to 4.60 (dSm^{-1}) with waste water application. Similar observations were also reported by Al-Rashed and Al-Senafy [24] that increases in EC$_e$ was directly proportional to EC$_{iw}$. Soil salinity almost static with a slight decrease of 14% over the basic salinity level in the case of canal water irrigation. The effect of different treatments on ECe is clearly shown in Fig.-1 indicated that ill effect on brackish water can be minimized with use of gypsum (on RSC basis) and to some extant with application of FYM @ 25 Mg ha^{-1}. Application of EC-SAR-RSC water along with gypsum and FYM minimized the adverse effect of brackish water and lowered the salt accumulation by improving soil aggregation and downward movement of water. Chaudhry *et al.*, [25] observed that gypsum application is required for maintaining yield of the crops irrigated with alkali water (RSC > 10 me L^{-1}).

Fig.-1 Impact of irrigation treatments on final EC$_e$ of soil
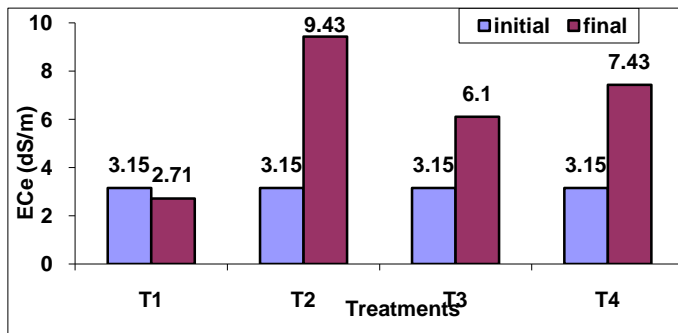
Soil Sodicity (SAR)

The data regarding SAR of soil as effected by application of brackish tubewater alone and with amendments was represented in table-3.

Table-3: Impact of irrigation treatments on SAR of soil

Irrigation Treatments	SAR $(mmol\ L^{-1})^{1/2}$			Increase or decrease over S_1
	S_1	S_2	S_3	
Canal water	3.39	4.00	4.55	+22
Tubewell water	3.39	7.05	9.07	+168
Tubewell water+GR*	3.39	5.58	6.63	+95
Tubewell water+FYM**	3.39	6.48	7.30	+115

S_1 Soil analysis before sowing wheat

S_2 Soil analysis after harvesting wheat

S_3 Soil analysis after harvesting maize

* Gypsum requirement on water RSC basis

**   FYM @ 25 Mg ha^{-1}

Results indicated that application of canal water caused minimum increase in SAR (22% over baseline salinity), however irrigation with brackish water (T2) caused maximum soil salinity (168%). Increase in soil SAR with brackish water was due to deterioration of soil structure, low infiltration rate and deficiency of nutrients. It is evident from previous observations by Ahmad et al. [26] that increase in soil SAR is directly proportional to SAR_{iw} under average management conditions. Increase in soil salinity in T3 and Y4 was 95% and 115% respectively. This reduction in SAR was due to use of Gypsum (RSC basis) and FYM that eliminated the adverse effect of brackish water. It is easily be deduced that gypsum application has help to reducing the soil SAR. The impact of brackish water

treatments on soil Sodicity is fairly visible in Fig.2.Our results correlated with Murtaza et al. [27] they observed significant increase in EC_e and SAR with the application of saline sodic water in sandy clay loam soil. Use of amendments like gypsum is recommended especially when RSC > 5 me/L, soils are medium textured and annual rainfall of the area is less than 500 mm [28]. Previously it was also reported that Use of higher EC and SAR water increased soil EC ranged from 12-100% with in three years along with increase in SAR of soil, but when this water is used with 100% gypsum applied to soil on RSC based of water, it decreased soil SAR.

Fig. 2: Impact of irrigation treatments on final SAR of soil
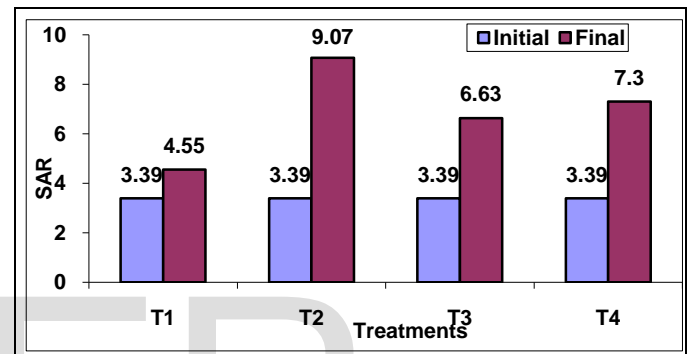
Infiltration Rate (IR)

Infiltration rate of soil was monitored before sowing and after harvesting of each crop to evaluate the changes due to application of brackish water application with and without amendments. Canal water application showed some improvement in the soil permeability and it was increased (9%) over initial level at the end of experimental period. Application of brackish tubewell water continuously decreased infiltration rate and it was 26% less than initial rate at the end of experiment. Application of brackish water caused clay dispersion, which decreased infiltration rate and hydraulic conductivity. Swelling and dispersion increase with increasing SAR_{iw} and decreasing EC_{iw} that effect the physical properties of soil [29]. The application of irrigation water having different Mg:Ca ratios (2, 4, 8 and 16), SAR (10, 25 and 50) and EC (2.0 and 8.0 dS m^{-1}) increased the dispersion from 6.7 to 8.1, 5.8 to 7.25, 3.0 to 5.6, 3.5 to 4.6 respectively, whereas hydraulic conductivity decreased from 6.5 to 5.5, 1.55 to 1.40, 14.3 to 13.1 and 34.0 to 32.0 mm h^{-1} respectively [30]. Similarly decrease in infiltration rate and increase in bulk density also reported by Murtaza et al. [31] when they used higher SAR (16.43) and RSC (5.57me L^{-1}) water.

Table-4: Impact of irrigation treatments on infiltration rate of soil

Irrigation Treatments	Infiltration rate (cm hr⁻¹)			Increase or decrease over S₁
	S_1	S_2	S_3	
Canal water	0.92	0.98	1.00	+9
Tubewell water	0.92	0.73	0.68	-26
Tubewell water+GR*	0.92	0.92	0.98	+7
Tubewell water+FYM**	0.92	0.95	0.96	+4

S_1 Soil analysis before sowing wheat
S_2 Soil analysis after harvesting wheat
S_3 Soil analysis after harvesting maize
* Gypsum requirement on water RSC basis
**   FYM @ 25 Mg ha⁻¹

Salts like calcium and magnesium, do not adversely affect infiltration rate because they tend the cluster to clay particles. Calcium and magnesium will generally keep soil flocculated because they compete for the same spaces with sodium to bind to clay particles. Increased amounts of calcium and magnesium can reduce the amount of sodium-induced dispersion. The main concerns related to the relationship between salinity and sodicity of irrigation water are the effects on soil infiltration rate. It was also reported that the application of higher SAR water affect the infiltration rate besides giving rise to specific ion effect and nutrition imbalance in soil plant ecosystem [32]. In this study, infiltration rate was observed with brackish water application. The data regarding infiltration rate as effected by brackish water application with and without amendments, for wheat and maize crop production are presented in Table-4. The results revealed that application of gypsum and FYM along with brackish tubewell water improved the infiltration rate that was 34% and 30% as compared to irrigation with brackish water alone.

Sodium Potassium Ratio in Cell Sap

In present study brackish water treatments have significant effect on Na^+ and K^+:Na^+ ratio. The maximum concentration of Na^+ was found in leaf sap of wheat and maize genotypes in the brackish tubewell water treatments that were 176.9 & 210.9 mol m⁻³ in leaf sap of SARC-1 and V-8670 respectively, similarly 186.5 & 210.5 mol m⁻³ in leaf sap of Sahiwal-02 and Akbar followed tubewell water with FYM and tubewell water with gypsum (Table 5 & 6). Our results confirmed the earlier finding of Wang et al. [33] that irrigation waters differing in salt concentration effect growth and salt ion (Na^+) accumulation in leaf of soybean. Cicek ad Cakirlar [34] also observed an increase in Na^+ concentration and decrease in K^+:Na^+ under saline condition.

Table- 5: Impact of brackish water application on ionic concentration in leaf sap of wheat genotypes.

Irrigation Treatments	Ionic concentration				Decrease over control			
	Na⁺ conc. (mol m⁻³)		K⁺:Na⁺ ratio		Na⁺ conc. (%age)		K⁺:Na⁺ ratio (%age)	
	SARC-1	8670	SARC-1	8670	SARC-1	8670	SARC-1	8670
Canal water	54.2	50.75	2.85	2.5				
Tubewell water	176.9	210.9	0.81	0.64	226	316	-72	-74
Tubewell water+GR*	127.8	135.7	1.17	1.05	136	167	-59	-58
Tubewell water + FYM**	145.4	142.5	0.98	0.98	168	181	-66	-61

Table- 6: Impact of brackish water application on ionic concentration in leaf sap of maize genotypes

Irrigation Treatments	Ionic concentration				Decrease over control			
	Na⁺ conc. (mol m⁻³)		K⁺:Na⁺ ratio		Na⁺ conc. (%)		K⁺:Na⁺ ratio (%)	
	Sahiwal-02	Akbar	Sahiwal-02	Akbar	Sahiwal-02	Akbar	Sahiwal-02	Akbar
Canal water	48.05	40.5	3.72	4.01				
Tubewell water	186.5	210.5	1.08	0.82	288	338	-71	-80
Tubewell water+ GR*	144.5	183.13	1.20	0.91	201	281	-68	-77
Tubewell water+ FYM**	150.25	180.13	1.22	0.9	213	275	-67	-78

The results of this study shows that K^+:Na^+ ratio in leaf sap varies among the genotypes as well as treatments. Highest K^+:Na^+ ratio was observed in cell sap of SARC-1 (wheat genotype) and Sahiwal-02 (maize genotype) as compared to

other genotypes sown in same growth conditions. Lowest ratio was observed in wheat and maize genotypes with brackish water irrigation. However, use of Gypsum and FYM along with brackish water minimized the adverse effect of high salt concentration in irrigation water. It has been suggested by Vetteriein *et al.* [35] that tolerant species have ability to maintain higher K^+ and lower Na^+ uptake as compared to salt sensitive species, while the most sensitive variety contained a 4-fold greater Na^+ concentration in shoots than the most tolerant variety. Our results confirmed the finding of Azevedo Neto and Tabosa [36] that Na^+ concentration increased in leaf of salt stressed maize plant. Increase in Na^+ concentration under salt stress become toxic and adversely effect plant growth [37]. It was inferred that the genotypes possess high K^+:Na^+ ratio can be used as selectivity characteristic of salt tolerance. Therefore, SARC-1 and Sahiwal-02 maintained high K^+:Na^+ ratio even at high salt concentration in irrigation water and it tolerated these adverse conditions. It was due to K^+ versus Na^+ selectivity that was an affective strategy for identifying salt tolerance in plant species [38].

Crop Yield

The plant height of randomly selected plants of wheat and maize genotypes were measured at maturity stage. However, wheat grain yield and maize fodder weight were evaluated on whole plot basis to avoid any variation in experimental area and explained as under:

Wheat grain yield (kg/ha) and plant height (cm)

The data regarding the grain yield and plant height of wheat genotypes are presented in Fig. 3 and 4 showing reduction in plant height and grain yield with brackish water application. Lowest plant height was observed in tubewell water application which was 62 cm and 49cm as compared to canal water treatment which was 83 cm and 82 cm in SARC-1 and V-8670 respectively. Similar effect was observed on grain yield of wheat genotypes that was decreased 30% and 42% over canal water treatment in SARC-1 and V-8670, with application of brackish tubewell water. These findings are correlated with ealier studies of Singh [39] that wheat grain yield reduced up to 47% in saline water treatments. Similarly Hamdy *et al.* [40] observed that saline water (9 dSm^{-1}) decreased wheat grain yield upto 25% when compared with canal water treatment. The results also confirmed the finding of El-Hendawy *et al.* [41] that salinity (upto 150 m M NaCl) reduced number of tillers and yield upto 41 and 221% respectively. The variation in the behavior of wheat genotypes indicated that SARC-1 produced better yield as compared to V-8670 under all treatments. Overall results show that application of brackish water along with FYM was comparatively more

effective than other brackish water treatments in overcoming the adverse effect of poor quality water due to addition of organic matter which improved the soil physical conditions and improved infiltration rate. Use of gypsum minimized the deleterious effect of brackish water and improved soil conditions and crop yields [42].

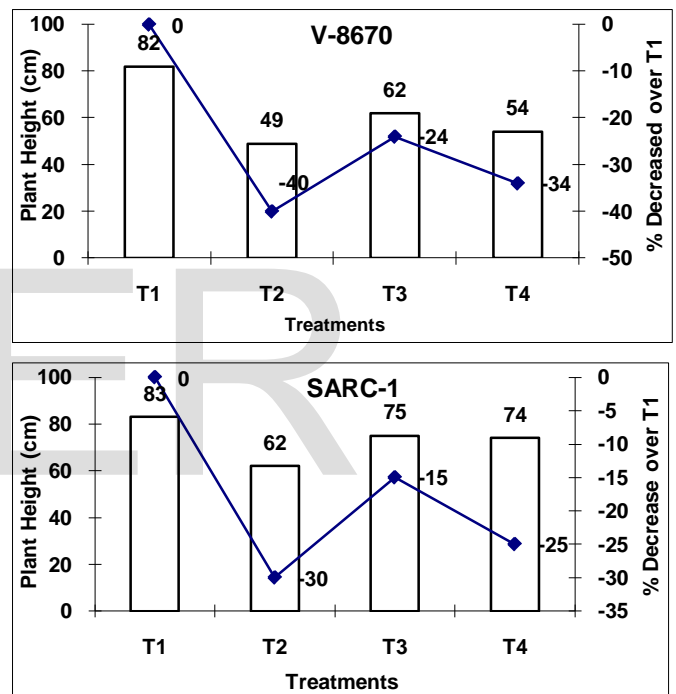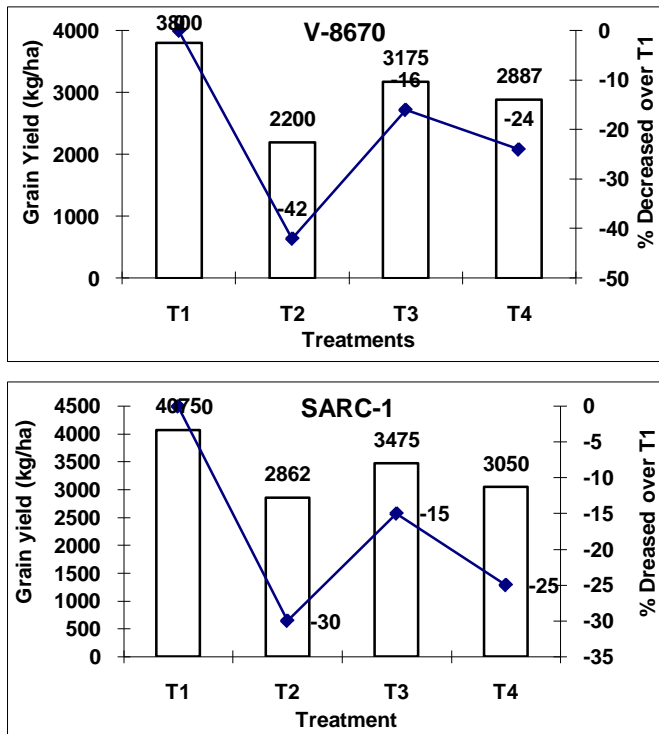Fig 3: Impact of brackish water application on plant height of wheat genotypes

Fig 4: Impact of brackish water application on grain yield of wheat genotypes

V-8670

SARC-1

T₁   Canal water3.15
T₂   Tubewell water
T₃   Tubewell water+GR
T₄   Tubewell water+FYM

Maize fodder yield (kg/ha) and plant height (cm)

On an overall average basis, maize plant height and fodder yield reduced in brackish water treatments. The maximum plant height was obtained by Sahiwal-02 with canal water treatment (315, 195, 260 and 245 cm in T_1, T_2, T_3 and T_4 respectively) and similarly, maximum fresh biomass also gain by Sahiwal-02 (96250kg ha⁻¹) with canal water application. Application of brackish tubewell water reduced growth parameters of both maize genotypes, maximum reduction in plant height (49%) and fresh biomass (75%) was observed in Akbar as compared to Sahiwal-02. Salinity inhibits maize growth and reduction in plant height and biomass [43]. Relative yield decrease with increasing irrigation water salinity and time interval between irrigations [44].

Irrigation with brackish water reduces plant growth and biomass. As shown in Fig. 5 & 6, the reduction in plant height and fodder yield was maximum in brackish tubewell water application treatment as compared to control and other treatment. The reduction in fresh biomass was more with tubewell brackish water application due to more accumulation of salts which deteriorate the soil physical condition. Previously, Hussain *et al*. [45] also

reported same effect of brackish water application. Application of tubewell brackish water along with gypsum and FYM reduced the adverse effect of brackish water. The management practices to be followed for optimal crop production with brackish water must aim at preventing the buildup of salinity, sodicity and toxic ions in the root zone to levels that limit the productivity of soils. In another study maximum barley fodder yield (40t ha⁻¹) was obtained when brackish water (EC 6.5 and 11dSm⁻¹) applied along with 30 t ha⁻¹ poultry manures [46].

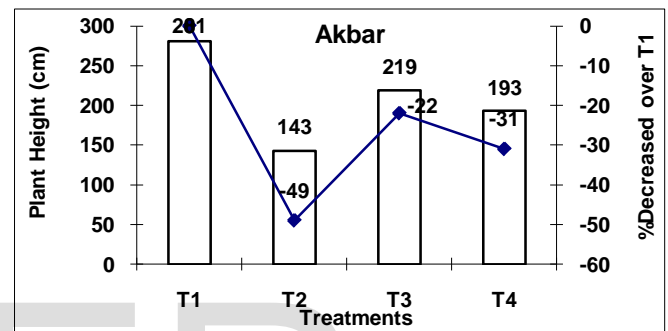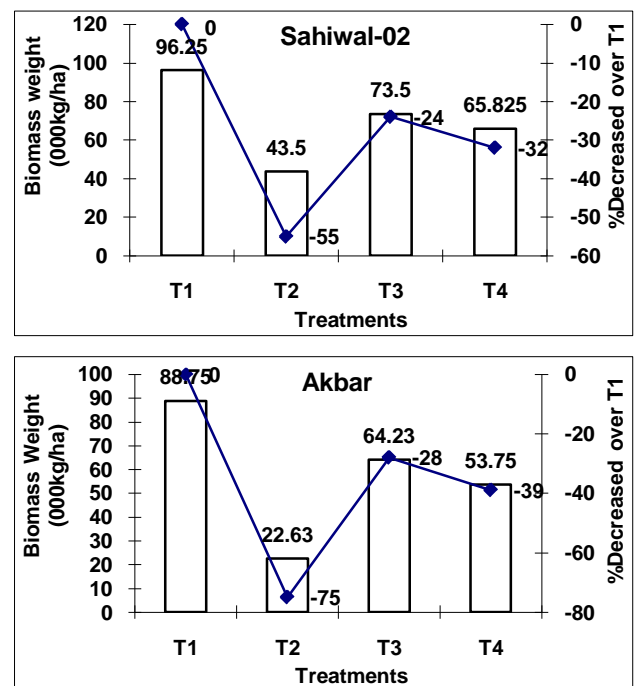**Fig 5: Impact of brackish water application on plant height of maize genotypes**

Akbar

Fig 6: Impact of brackish water application on biomass weight of maize genotypes

Sahiwal-02

Akbar

T₁   Canal water3.15

T₂   Tubewell water

T₃   Tubewell water+GR

T₄   Tubewell water+FYM

CONCLUSIONS

1. Application of brackish tubewell water for crop production results in build up of soil salinity and cause in reduction in yield.

2. Results presented here reveal that wheat and maize fodder yield are enhanced if brackish tubewell water applied with gypsum requirement. It has observed that FYM also have important role to minimized adverse effect of brackish tubewell water on crop production.

3. Wheat genotype SARC-1 and maize variety Sahiwal-2002 can grown profitably when apply brackish tubewell water alone and/or with amendments.

References

1. D. Tilman, K.G. Cassman, P.A. Matson, R. Naylor and S. Polasky, "Agricultural sustainability and intensive production practices". *Nature,* 2002, 418, 671–677.

2. S. A. Malik, T. Z. Bokhari, A. A. Dasti and S. Z. Nisa, "Effect of Waste Water Effluents From a Tannery on the Growth of some Crop Plants". Asian Journal of Plant Sciences, 2003, 2(8): 623-626.

3. M. Qadir and J.D. Oster, "Crop and irrigation management strategies for saline-sodic soils and water aimed at environmentally sustainable agriculture" Sci. Total Environ. 2004, 323:1–19.

4. T. Oweis, A. Hachum and J. Kijne, "Water harvesting and supplemental irrigation for improved water use efficiency in dry areas. SWIM Paper 7, Colombo: International Water Management Institute: p. 41, 1999.

5. J. L. Hatfield, T.J. Sauer and J. H. Prueger, "Managing soils to achieve greater water use efficiency: a review". Agron .J. 2001, 93:271 –280.

6. D. Wichelns, "An economic perspective on the potential gains from improvements in irrigation water management" Agric Water Manage, 2002, 52, pp. 233–248.

7. J. Shalhevet, "Using water of marginal quality for crop production: major issues" Agric. Water Manage. 1994, 25: 233–269.

8. J. D. Rhoades, "Intercepting, isolating and reusing drainage water for irrigation to conserve water and protect water quality" Agric. Water Manage. 1989, 16 : 37–52.

9. J. D. Oster, "Irrigation sustainability. In: Proceedings of the Sixth International Micro-irrigation Congress, 22–27 October 2000. Cape Town. ICID-CIID. Plenary Session, P6. CD Rom. Document Transformation Technologies, POB 560, Lirene, 0062, South Africa.

10. H. Bouwer, "Integrated water management for the 21st century: problems and solutions" J. Irrig. Drain. Eng. 2002, 28:193 – 202.

11. A. Ghafoor, M. Qadir, and G. Murtaza, "Agriculture in the Indus Plains: Sustainability of Land and Water resources: A Review" Int. J. Agric. Biol., 2002, 4(3): 428-437.

12. M. Latif and A. Beg, "Hydrosalinity issues, challenges and options in OIC member states. In: M. Latif, S. Mahmood and M.M. Saeed, Editors, Proceedings of the International Training Workshop on Hydrosalinity Abatement and Advance Techniques for Sustainable Irrigated Agriculture, 20–25 September Lahore, Pakistan (2004), pp. 1–14.

13. J. L. Costa, L. Prunty, B.R. Montgomery, J.L. Richardson and R.S. Alessi, "Water quality effect on the soils and alfalfa" Soil Sci. Soc. Am. J. 1991, 55: 203-209.

14. R. B. Singh, P. S. Minhas, C. P. S. Chauhan and R. K. Gupta " Effect of high salinity and SAR waters on salinization, sodication and yields of pearl-millet and wheat" Agric. Water Manage. 1992, 21. 93-105.

15. G. Sarwar, N. Hussain, J. Iqbal, M. Aslam and A. Hassan, "Correlation of brackish water and physical properties of silty clay loam soil" Pak. J. Agric. Sci. 2002, 39: 250-257.

16. P.S. Minhas, "Saline water management for irrigation in India. Agric. Water Manage. 1996, 30, 1–24.

17. E. V. Maas and S. R. Grattan, "Crop yield as affected by salinity. In. R.W. Skaggs and J. van Schilfgaarde, eds., agricultural Drainage" Agron. Monograph, 1999, 38. ASA, CSSA, SSSA, Madison, WI.

18. J. D. Rhoades, A. Kandiah and A.M. Mashali, "The use of saline waters for crop production" FAO Irrigation and Drainage Paper 48, Rome, 1992.

19. R. H. Qureshi. and E.G. Barrett-Lennar, "Three approaches for managing saline, sodic and waterlogged soils. P: 19-24 In: Saline Agriculture for irrigated land in Pakistan" A Hand book, ACIAR, Cambera, Australia, 1998.

20. U. S. Salinity Laboratory Staff. 1954. Diagnosis and improvement of saline and alkali soils.USDA Handbook, vol. 60. US Government Printing Office, Washington, DC, USA.

21. R. P. Eaton, "Significance of carbonates in irrigation waters" Soil Sci., 1950, 69: 123-133.

22. G. Cucci, P. Rubinoand, A. Caliandro, Effects of Irrigation Water with Different Salt Concentrations and SAR Values on Soil Salinisation and Sodification" Ital. J. Agron. 2002, 7(1):41-48.

23. R. K. Yadav, A. Kumar, D. Lal And L. Batra, Yield responses of winter (rabi) forage crops to irrigation with saline drainage water" Expl. Agric. 2004, 40: 65–75.

24. J. K. Sail, S. Bibi and A.S.Qurashi, "Environmental impact of sewage water irrigation on ground water quality" Pak. J. Water Res. 2005, 9: 49-53.

25. M. Al- Rashed and M. Al- Senafy, "Assessment of ground water salinization and soil degradation in Abdally Farm, Kuwait" Agric and Marine Sci., 2004, 9: 17-19.

26. M. R. Chaudhary, M. Iqbal, K. M. Subhani, M "Use of brackish drainage water effluent for crop production 9th International Drainage Workshop, September 10– 13, 2003, Utrecht (The Netherlands).

27. N. Ahmad, "Evaluation of effectiveness of sulphurous acid generator in treating the sodic under different scenarios for wheat crop. M. Phil. Thesis, Water Resources Management, Center of Excellence in Water Resources Engineering, Univ. of Engg. & Tech., Lahore, Pakistan, 2002.

28. G. Murtaza, A. Ghafoorand M. Qadir, "Irrigation and soil management strategies for using saline-sodic water in a cotton–wheat rotation" Agri. Water management, 2006, 81: 98-114.

29. P.S. Minhas, D.R. Sharma, C.P.S. Chauhan, "Management of saline and alkali waters for irrigation. In: Advances in Sodic Land Reclamation, International conference on ''Sustainable Management of Sodic management" Pak. J. Agri. Sci. 2004, 35:16-23.

30. J. D. Oster, "Irrigation with poor quality water" Agric. Water Manage. 1994, 25, 271–297.

31. J. S. P. Yadav, "Use of saline ground water for irrigation. In Proceeding of the international symposium on salt-affected soils" 1982, 281-290. Karnal, India, CSSRI.

32. G. Murtaza, S.H. Shah, A. Ghafoor, S. Akhtar and N. Mahmood, "Management of brackish water for crop production under arid and semi-arid conditions" Pak. J. Agric. Sci. 2002, 39:166-170.

33. M. J. Azhar, M. T. Yamin and C. K. Ali, "Ground water exploitation and application: the major issues" Paper prepared for 3rd International civil Engineering Congress,21st- 22nd Feb., 2003, Karachi Bajawa, M. S. and A. S. Josan. 1989b. Prediction of sustained sodic irrigation effects on soil sodium saturation and crop yield. Agric. Water Manage. 16: 217-228.

34. D. Wang, C.M. Grieve and D.L Suarez, "Composition of irrigation water salinity affects growth characteristics and uptake of selenium and salt ions by soybean" J. plant nutrition, 2005, 28: 1073-1088.

35. N. Cicek and H. Cakirlar, "The effect of salinity on some physiological parameters in two maize cultivars" Bulg. J. Plant Physiol, 28(1-2): 66-74er yield. Agric. Water Manage. 2002, 85:151-156.

36. D. Vetterlein, K. Kuhn, S. Schubert and R. Jahn, "consequences of sodium exclusion for the osmotic potential in the rhizosphere- Comparison of two maize cultivars differing in Na^+ uptake" J. Plant Nutr. Soil Sci. 2004, 167: 337-344.

37. A. D. Azevedo Neto and J.N. Tabosa, "Salt stress in maize seedling: II. Distribution of cation macronutrients and its relation with sodium. Rev" Bras. Agric. Amb. 2000, 4: 165-171.

38. P.M. Hasegawa, R.A. Bressan, J. K. Zhu and H.J. Bohnert, „Plant cellular and molecular responses to high salinity. Annaul Rev." Plant Physiol. Plant Mol. Biol. 2000, 51:463-499.

39. G. N. Al-Karaki, "Growth, water use efficiency, and sodium and potassium acquisition by tomato cultivars grown under salt stress" J. Plant Nut. 2000, 33:1-8.

40. R. K. Singh, K.N. Singh, B. Misra, S.K. Sharma, N.K. Tyagi, "Harnessing plant salt tolerance for overcoming sodicity constraints. In: Advances in Sodic Land Reclamation" International Conference

on Sustainable Management of Sodic Lands, 9–14 Febraury 2004, Lucknow, India, pp. 81–120.

41. A. Hamdy, V. Sardo , K.A. Farrag Ghanem, "Saline water in supplemental irrigation of wheat and barley under rain fed agriculture" Agric. Water Manage. 2005, 78, 122-127.

42. S. E. El- Hendawy, Y. Hu.,G. M. Yakout, A. M. Awad, S. E. Hafiz and U. Schmidhalter, "Evaluating salt tolerance of wheat genotypes using multiple parameters" Europ. J. Agron. 2005, 22: 243-253.

43. M. R. Chaudhary, M. Iqbal and K.M. Subhani, "Use of Poor Quality Drainage Water for Crop Production and Its Impact on Soil" Pakistan. J.of. Water Resources, Vol.8 (1) January-June 2004.

44. M. Irshad, S. Yamamoto, A. E. Eneji and T. Honna, "Influence of composed manure and salinity on growth and nutrient contents of maize tissue" Sympo. No. 58, Paper No. 96. 17th WCSS, 14-21 August, Thailand, 2002.

45. Y. Y. Feng and C.Z. Cong, "Equilibrium of organic matter in heavy fraction for three long term experimental field soils in China" Pedosphere, 2003, 16(2):177-184.

46. N. Hussain, R.A. Jakhar, M. Tahir, R. Noreen, N.M. Hassan, and F. Mujeeb, "Impact of Ca/Mg Ratios of Irrigation Water on Soil Properties and Crop Yields" Asian J. Plant Sci. 2002, 1: 51-52.

47. M. A. Gilani, M. Hachicha, J. Soiuci and H. Elgassier, Utilization of Brackish Saline Water in North Africa" The 18th World Congress of Soil Science (July 9-15, 2006) Philadelphia, Pennsylvania, USA.