Climate Change and Terrestrial Carbon Sequestration in Central Asia

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CHAPTER 11

Salinity effects on irrigated soil chemical and biological properties in the Aral Sea basin of Uzbekistan

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1 INTRODUCTION

Accelerated secondary salinization of irrigated soil is recognized as the major agricultural problem in Uzbekistan. The history of irrigation development in Central Asia has more than 2500 years in the deltas of the Amu Darya and SyrDarya. The Amu Darya basin in the south covers about 86.5% and the Syr Darya basin in the north about 13.5% of Uzbekistan.

Prior to independence in 1991, Uzbekistan was socio-economically integrated within the centrally managed Soviet economy for agricultural production. Uzbekistan within Soviet Union was agriculturally specialized according to its agroclimatic and soil conditions for cotton (*Gossipium hirsutum*) production. A massive expansion of irrigated agriculture was initiated making Uzbekistan one of the largest cotton producing countries in the world. However, the expansion of irrigated agriculture was limited by available water resources. The success was achieved through massive construction of long networks of irrigation canals and the diversion of the waters from the Syr Darya and the Amu Darya away from the Aral Sea, the 4th largest terminal lake (without surface outflow) in the world. Simultaneously land development began for planting rice (*Aryza sativa*) in the Amu Darya basin in Karakalpakstan. Total volume of water flows in the Amu Darya and Syr Darya is about 116 $km^3\ yr^{-1}$, and about 19% of that water is generated within Uzbekistan.

Irrigated lands produced over 96% of the gross agricultural output in Uzbekistan. Of that, about 44% of the total irrigated area is concentrated in the Syr Darya basin and 56% in the Amu Darya basin. Because of large scale water withdrawal from both rivers for irrigated agriculture, especially for high water consumptive cotton production, the water flow reaching the Aral Sea is limited ($<$15% in the driest years) over time. Since 1961, the Aral Sea has been declining progressively with increasing water salinity. The former bed of the Aral Sea is now a source of windblown dust, pesticides, and salt, adversely affecting the surrounding ecosystems. Extensive flood irrigation with poor quality water and inefficient drainage facilities have accelerated salinization of irrigated soils with severe degradation of water ecosystems in the Amu Darya and Syr Darya deltas. Out of total available water flow, Uzbekistan is now using about 42 $km^3\ yr^{-1}$ of the transboundary rivers flow, and $>$80% of that volume of water is from Amu Darya and Syr Darya. Since the demand for water is growing in the Central Asian region with time especially in view of the population growth and irrigated agriculture; a possible increase in transboundary water use by Afghanistan and other countries may accelerate soil salinization of irrigated soils, and subsequently affect agricultural production in Uzbekistan.

Soil biological properties are one of the most important components to evaluate functional stability of agroecosystems in response to environmental degradation. They are very sensitive to environmental changes and can be used as indicators to evaluate the effects of soil degradation on agroecosystems. Therefore, the objectives of this chapter are to discuss soils, temporal changes in irrigation and soil salinization, and their effects on selected chemical and biological properties of soils in the Sayhunobod district of the Syr Darya basin in Uzbekistan.

2 DATA SOURCE AND METHODOLOGY

This study was conducted on a silty clay loam soil (typical sierozems) at farmer's fields in the Sayhunobod district of Syr Darya province in the republic of Uzbekistan. The irrigated soils in this region were severely affected by pollution and secondary salinization from Syr Darya and Aral Sea degradation. The mean values of the selected soil properties were: pH 7.9; cation exchange capacity 1.98 meq $100\,g^{-1}$; sand $186\,g\,kg^{-1}$; silt $514\,g\,kg^{-1}$; clay $300\,g\,kg^{-1}$; particle density $2.65\,g\,cm^{-3}$; bulk density $1.41\,g\,cm^{-3}$; total porosity $0.47\,m^3\,m^{-3}$; and field moisture capacity $3.25\,mm\,cm^{-1}$(need reference).

The existing farming system includes a range of irrigated crops including cotton, corn (*Zea mays*), (*Triticum aestivum*), wheat, fodder, vegetables, and pulses. The average annual rainfall is 324 mm and more than 90% of the rainfall occurs during October to May. The mean annual minimum temperature is −2°C in January and the mean maximum temperature is 34°C in July. The average highest soil temperature is 35°C in July and the lowest is −2°C in January. The mean relative humidity is 66% with a maximum of 82% in December and January, and a minimum of 48% in June.

Soil cores (divided into 0–28, 28–49, 49–96, and 96–120 cm depths) were randomly collected from weak and saline irrigated fields in spring (April), summer (July), and autumn (September) in 2004. Soil cores were pooled and mixed to obtain a composite sample for each depth. Field-moist soils were then gently sieved through a 2-mm mesh, and a portion of the soil was incubated or analyzed to measure selected soil biological properties within 72-h of sampling and processing. Another portion of the field-moist soil was air-dried at room temperature, ground and analyzed for soil chemical and physical properties. Soil biological properties such as basal respiration (CO_2 evolution), and catalyse, invertase, and urease activities were measured using *in vitro* static incubation of unamended field-moist soil at room temperature. Soil chemical properties such as pH, total organic C, total N, P_2O_5, K_2O, Na_2O, CaO, MgO, chloride, sulfate, and various salts [$Ca(HCO_3)_2$, $CaSO_4$, $MaSO_4$, $MgCl_2$, Na_2SO_4 and NaCl] were measured. [How?] Soil physical properties such as particle size analysis (sand, silt and clay), particle density, bulk density and moisture content were determined. [How] All the analyses were done by following standard procedures. The mass of total organic C, total N, P_2O_5, K_2O, Na_2O, CaO, MgO, chloride, sulfate, and salts at different depths of soil was calculated by multiplying their concentration with each sampling depth and concurrently measured soil bulk density.

Regression and correlation were performed to predict Aral Sea degradation using data from Micklin (1994), and establish relationship between salt and total organic C content with biological properties for different soil depths.

3 RESULTS AND DISCUSSION

3.1 *Soils of Uzbekistan*

On the basis of surface territory, Uzbekistan is divided into two unequal parts. About 78.7% of the territory of Uzbekistan is desert plains which are predominantly covered with brown meadow and sierozems soils; the remaining 21.3% is high mountainous ridges and intermountain valleys which comprise of sands, takir, marsh and Solonchaks soils (Table 1). Typical sierozems are the dominant (∼7%) group of soils in high belt and Grey brown soil covers about 25% of the desert zones.

3.2 *Major water resources and the Aral Sea*

Almost all of the water used for irrigating crops is withdrawn from the two main rivers in Uzbekistan, the Amu Darya and Syr Darya. Both discharge into the Aral Sea, an inland sea without an outlet.

Table 1. Soil types of Uzbekistan.

Soil types	Area (km^2)	Area (%)
Mountainous regions		
1. Light-brown, meadow steppe	540	1.2
2. Brown mountain forest	1660	3.7
3. Dark sierozems	1050	2.4
4. Typical sierozems	3050	6.8
5. Light sierozems	2590	5.8
6. Meadow sierozems	780	1.8
7. Meadow sierozems belt	670	1.5
8. Marsh-meadow sierozems belt	70	0.2
Total	10410	23.4
Desert zones		
9. Grey brown	11025	24.8
10. Desert sandy	1370	3.1
11. Takir soils and takirs	1780	4.0
12. Meadow takir and takir meadow	460	1.0
13. Meadow desert soils	1790	4.1
14. Marsh meadow desert zones	50	1.0
15. Solonchaks	1270	2.9
16. Sands	12100	27.2
Total	29845	67.2
Other land and rocks	4155	9.4
Total all soils	44410	100

Source: Umramov (1989).

The water supply is about 79 km^3 in the Amu Darya basin compared to 37 km^3 in Syr Darya basin. However, the Syr Darya no longer reaches the Aral Sea because of excessive use enroute. Most of its upstream discharge is now being used for irrigation. Only about 10% of the Aquaria's surface water reaches the Aral Sea. Because in arid regions, where irrigation is essential for agriculture, the highest volume of water is used for irrigated agriculture. As a result, the Aral Sea has lost much of its volume (from 1090 km^3 to 196 km^3) and area (from 67,000 km^2 to 23,000 km^2) between 1960 and 2000 (Figure 1). At the same time, the water level fell by more than 16 m (from 53 m to 37 m) and its salinity quadrupled (from 10 $g\,L^{-1}$ to 40 $g\,L^{-1}$) over time (Figure 1). Presently, the dry seabed exposed to weathering has increased desertification around the sea, and accelerated soil salinization in the Amu Darya and Syr Darya deltas. Salinization of irrigated lands resulting from over irrigation and poor drainage as well as the wind transport of salts from the exposed sea bed confounded the environmental problems within these rivers basin. Annually, 15–75 $\times$ 10^6 Mg of dust and salt are carried over long distances of up to 400 km from the Aral Sea dry bed. The total mass of sediment deposited in one of the major storms was estimated as 1.68 $\times$ 10^6 Mg in the surrounding areas. If everything goes as it is, a projection on the basis of available data suggests that by 2030, the Aral Sea will be completely dried out and will not exist on earth (Figure 1).

3.3 *Irrigation and secondary soil salinization*

Progressive degradation of Aral Sea has intensified, and will continue to intensify the secondary salinization of irrigated soils (~65%) in the Amu Darya and Syr Darya deltas (Table 2). Consequently, most of the arable lands are suffering from various degrees of soil salinity. In 1990, about 48% of the total irrigated lands were suffering from soil salinity, by 2000, salinity increased to 64% of the lands. A decrease in 80,000 ha of irrigated lands with 16% increase in soil salinity

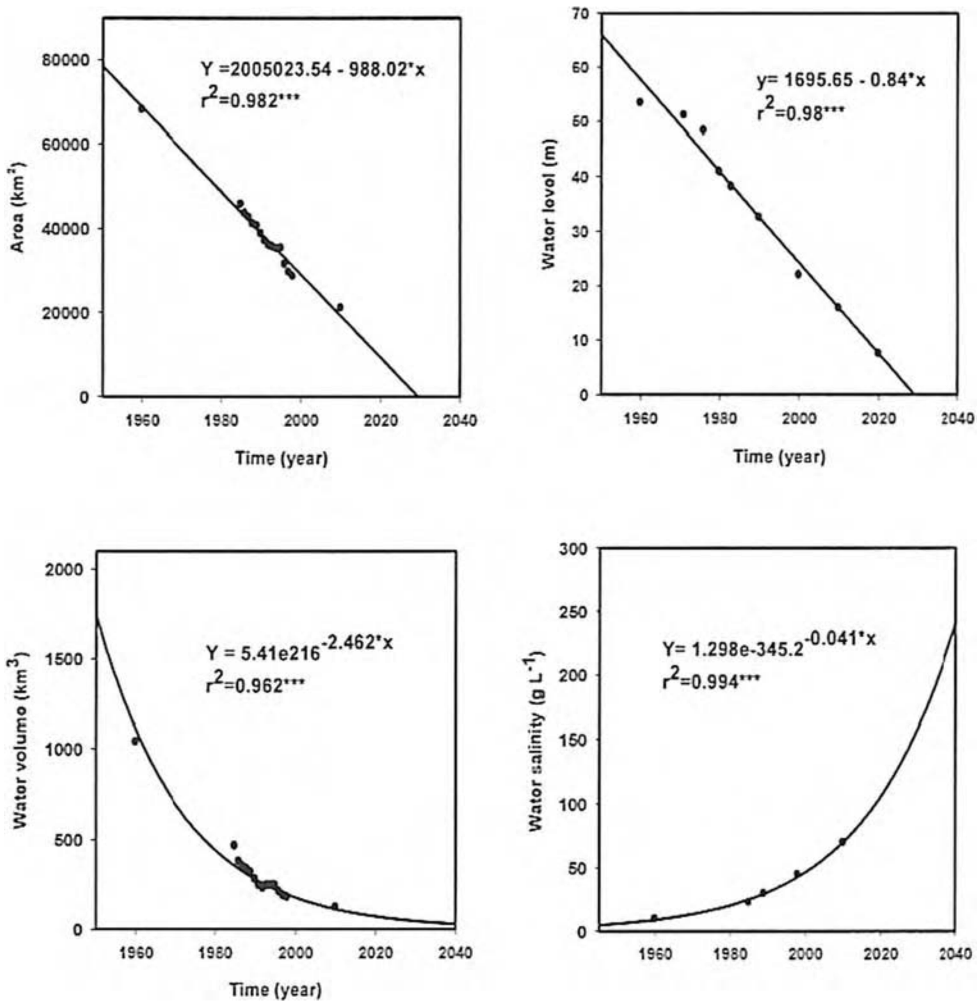


Figure 1. A projection of Aral Sea degradation over time (Adapted and projected from Micklin, 1994).

occurred within a decade (Table 2). Irrigated lands substantially decreased in Andijan, Namangan, Samarkand, Surkhandarya, Syr Darya, Tashkent and Fergana regions between 1990 and 2000. However, soil salinity in Andijan, Djizak, Namangan, Samarkand, Surkhan Darya, Syr Darya, Tashkent, Fergana, and Kashka Dariya regions increased.

Out of total irrigated lands affected by various degrees of soil salinity, 35% were weakly saline, 18% were moderately saline, and 11% were strongly saline in 2000 compared to 27% weakly saline, 16% moderately saline, and 5% were strongly saline in 1990. In other words, about 7% increase in strongly saline soil occurred between 1990 and 2000. In fact, 80–95% of the irrigated lands were saline in Karakalpakya, Bukhara and Syr Darya regions, and 60–70% of the lands were saline in Kashka Dariya and Khorezm regions. The degrees of irrigated soil salinization in the Syr Darya region were presented in Table 3. Out of 216,101 ha of salinized lands in the Syr Darya region, about 47% were weakly saline followed by 35% moderately saline and 18% strongly saline. A widespread salinization of irrigated soil occurred in Arnasoy, Forish, Gallaorol, and Zomin where more than 20–40% of the lands were strongly saline. The change from moderate to strong salinity severely affected soil fertility and agricultural productivity in the Syr Darya basin.

Table 2. Temporal change in irrigated lands and soil salinization in Uzbekistan (1990 to 2000).

Region	Years	Irrigation ($10x^3$ ha)	Degree of salinization: Weak ($10x^3$ ha)	(%)	Moderate ($10x^3$ ha)	(%)	Strong ($10x^3$ ha)	(%)	Total salinized lands ($10x^3$ ha)	(%)
Republic of	1990	457.2	167.3	36.6	183.7	40.2	74.6	16.3	425.6	93.1
Karakalpakstan	2000	462.1	110.4	23.9	151.7	32.8	142.9	30.9	405.0	87.6
Andijan	1990	245.1	42.3	17.3	16.5	6.7	4.8	2.0	63.6	25.9
	2000	227.4	51.8	22.8	20.3	8.9	4.9	2.2	77.0	33.9
Bukhara	1990	228.1	133.2	58.4	57.3	25.1	16.5	7.2	207.0	90.7
	2000	229.2	125.8	54.9	48.2	21.0	31.2	13.6	205.2	89.5
Djizak	1990	267.3	61.8	23.1	20.0	7.5	8.4	3.1	90.2	33.8
	2000	275.7	101.0	36.6	75.7	27.5	38.8	14.1	215.5	79.2
Navoi	1990	102.1	17.5	17.1	71.7	70.2	3.3	3.2	92.5	90.6
	2000	108.1	49.8	46.1	19.6	18.1	6.7	6.2	76.1	70.4
Namangan	1990	239.7	28.1	11.7	17.5	7.3	6.8	2.8	52.4	21.8
	2000	236.1	51.1	21.6	18.1	7.7	13.1	5.5	82.3	34.9
Samarkand	1990	356.5	39.1	11.0	5.6	1.6	0.1	0.0	44.8	12.6
	2000	309.5	104.3	33.7	19.9	6.4	4.6	1.5	128.8	41.8
Surkhan Darya	1990	287.0	65.2	22.7	44.7	15.6	7.2	2.5	117.1	40.8
	2000	279.3	108.4	38.8	70.0	17.0	48.9	8.1	178.5	63.9
Syr Darya	1990	283.0	129.8	45.9	59.3	21.0	38.5	13.6	227.6	80.4
	2000	273.8	115.7	42.3	47.6	25.6	22.5	17.8	234.6	85.7
Tashkent	1990	351.1	29.6	8.4	2.9	0.8	0.3	0.1	32.8	11.4
	2000	337.4	67.6	20.0	13.07	3.9	5.3	1.6	86.0	25.5
Fergana	1990	307.7	33.2	10.8	10.8	3.5	2.8	0.91	46.8	15.2
	2000	296.0	108.0	36.5	67.5	22.8	42.9	14.5	218.4	73.8
Khorezm	1990	234.3	119.0	50.8	35.7	15.2	14.8	6.3	169.5	72.8
	2000	240.1	106.8	44.5	50.6	21.1	23.2	9.7	180.6	75.2
Kashka Dariya	1990	452.5	163.3	36.1	76.6	16.9	28.4	6.3	268.3	59.3
	2000	452.2	216.9	48.0	63.3	14.0	31.5	7.0	311.7	68.9
Total in Republic	1990	3811.6	1029.4	27.0	602.3	15.8	206.5	5.4	1838.2	48.2
	2000	3726.9	1317.6	35.4	665.6	17.9	416.5	11.2	2399.7	64.4

Table 3. Various degrees of irrigated soil salinity in the Syr Darya region of Uzbekistan.

Region	Total salinized lands (ha)	Weakly saline (%)	Moderately saline (%)	Strongly saline (%)
Arnasoy	32911	24.9	32.5	42.6
Bahmal	334	91.0	9.0	–
Gallaorol	761	42.2	32.4	25.4
Djizak	17975	74.7	24.2	1.1
Dustlik	33986	39.1	44.7	16.2
Zomin	30952	43.9	35.0	21.1
Zarbdor	26367	50.7	32.2	17.1
Mirzachul	29073	22.3	59.9	17.8
Zafarobod	19394	88.4	11.6	–
Pahtakor	20210	67.9	24.5	7.6
Forish	3104	29.5	30.6	39.9
Yangiobod	1053	35.9	64.1	–
Total	216101	46.8	35.2	18.0

Source: Anonymous (1994).

Table 4. Chemical properties of farmer's field soil (typical sierozems) in the Sayhunobod district of Syr Darya province of Uzbekistan, 2004.

Soil depth (cm)	TC	TN	P_2O_5	K_2O	CaO	MgO	Na_2O	Cl^-	SO_4^{-2}
	g kg^{-1}								
0–28	6.17	0.96	4.8	27.8	9.0	63.1	18.4	3.29	71
28–49	2.4	0.92	4.8	26.0	7.8	50.2	24.5	25.5	145.8
49–96	2	0.87	5.2	29.7	10.1	44.5	24.5	16.1	82.1
96–120	1.64	0.79	0.42	27.8	6.7	24.3	22.1	20.3	71.8
Total (Mg ha^{-1})	49.8	15	69.7	478.1	151.2	755.2	390.7	266.4	1507.8

TC = Total organic C; TN = Total N; Cl = Chloride; and SO_4 = Sulfate.

A greater accumulation of salts in the irrigated soils in the Syr Darya basin is due to accelerated evaporation from inefficient flood irrigation and poor drainage systems. During hot summer spells (air and soil temperatures range from 35 to 45°C), soil water evaporates and salts move upward to the surface by capillary movement from the saline groundwater. The salts are leached into the groundwater in response to irrigation and rainfall, and are then transported upward, eventually increasing salt accumulation in both soil and groundwater.

3.4 *Soil chemical properties*

Progressive soil salinization in response to inefficient flood irrigation and poor drainage managements for cotton production under continental climates has affected degradation of soil fertility. Total organic C and N, available P, and K of the soil (typical Sierozems) in the Sayhunobod district of the Syr Darya province of Uzbekistan were severely affected by salinity (Table 4). A total mass of only 50, 15, and 69 Mg ha^{-1} of organic C, N, and P was present up to 120 cm depth. More than 475, 150, and 75 Mg ha^{-1} of K_2O, CaO, and MgO accumulated in the soil. However, Na, chloride and sulfate concentration were even higher. More than 260 Mg chloride ha^{-1} accumulated in the soil from irrigation over time. Total mount of Na was 400 Mg ha^{-1} within 120 cm soil depth. Abnormally high accumulation of sulfate (1508 Mg ha^{-1}) was also observed. However, higher concentrations of chloride and sulfate were at 28–49 cm soil depth. Soils in the plains of Uzbekistan are characteristically low in total organic C, total N and P concentrations due to lack of organic amendments and accelerated mineralization of organic matter under arid climate.

Among the salt types, Ca, Mg and Na associated sulfates, chlorides and bicarbonates were dominant within soil (Table 5). The concentrations of various salts were higher in surface soil layers. Among the salt types, greater amount of Na-sulfate (>40%) was accumulated within the soil profile (0–120 cm depth) followed by Ca-sulfate (∼ 29%), NaCl (18%), and MgCl (10%). A total amount of 328 Mg ha^{-1} of salts was accumulated in the soil. Out of that total amount, 70% of the salts (Mg and Na sulfates and chlorides) were highly toxic to plant growth. In this region, the groundwater is saline and contains 5–24 gL^{-1} of salts. As a result, salt accumulation in irrigated soil differs seasonally. In spring, the salt accumulation at 0–100 cm depth is 180 Mg ha^{-1} followed by 140 Mg ha^{-1} at 1–2 m depth. In autumn, the salt content increased up to 200 Mg ha^{-1} in 0–1 m depth and 160 Mg ha^{-1} in 1–2 m depth. In arid or semiarid climates of Uzbekistan, salinity is usually combined with high soil pH, because of Na, Ca, and Mg associated carbonate, chloride and sulfate salts accumulation in the uppermost soil horizons.

3.5 *Soil biological properties*

Soil biological activities were influenced greatly by salinity and seasonal variations (Figures 2–5). Average across soil depth and season, base respiration (BR) (CO_2 evolution) rate was 5 mg kg^{-1} d^{-1}

Table 5. Toxic and non-toxic salt species in irrigated soil (typical sierozems) in the Sayhunobod district of Syr Darya province of Uzbekistan, 2004.

Soil depth (cm)	$Ca(HCO_3)_2$	$CaSO_4$	$MgSO_4$	$MgCl_2$	Na_2SO_4	NaCl	Total	Non-toxic	Toxic
	g kg^{-1}								
0–28	0.32	12.99	5.86	0.19	7.6	6.52	33.48	13.31	20.17
28–49	0.24	5.74	0.95	0.18	8.77	2.70	18.58	5.98	12.60
49–96	0.28	3	1.03	0.17	7.24	2.93	14.65	3.28	11.37
96–120	0.24	1.16	1.04	0.18	7.91	1.08	11.61	1.40	10.21
Total (Mg ha^{-1})	4.4	92.6	36.9	3.07	133	57.6	327.6	97	230.6

$Ca(HCO_3)_2$ = Calcium Na_2SO_4 bicarbonate; $CaSO_4$ = Calcium sulfate; $MgSO_4$ = Magnesium sulfate; $MgCl_2$ = Magnesium chloride; Na_2SO_4 = Sodium sulfate; and NaCl = Sodium chloride.

in moderately saline irrigated soil compared to 3.91 mg kg^{-1} d^{-1} in weakly saline irrigated soil (Figure 2). In other words, about 22% increase in BR rate was measured in response to increasing soil salinity. However, the BR rates differ among over seasons. The highest BR rate (12.5 and 9.55 mg kg^{-1} d^{-1}) was recorded in spring (April), intermediate (5.2 and 4.5 mg kg^{-1} d^{-1}) in summer (July), and lowest (2 and 1.97 mg kg^{-1} d^{-1}) in autumn (September) in both moderately and weakly saline irrigated soils. Higher BR rate was recorded in surface layer (0–28 cm) of both soils.

Similarly, the catalase activity was affected by soil salinity, and also different among seasons (Figure 3). The average catalase activity was higher in moderately saline irrigated soil (1.46 mL O_2 kg^{-1} min^{-1}) compared to weakly saline irrigated soil (1.24 mL O_2 kg^{-1} min^{-1}). On average, there was a 15% increase in catalase activity from weakly to moderately saline of soil. Averaged across soil depth, catalase activity was recorded highest (1.97 and 1.68 mL O_2 kg^{-1} min^{-1}) in spring, intermediate (1.63 and 1.47 mL O_2 kg^{-1} min^{-1}) in summer, and lowest (0.78 and 0.56 mL O_2 kg^{-1} min^{-1}) in autumn for both moderately and weakly saline soils. The decrease in catalase activity was more pronounced in autumn which is about 50% less than that in spring. In both soils, the catalase activity decreased with increase in soil depth in all seasons.

Averaged across seasons and soil depths, the invertase activity was higher (1.31 mg glucose kg^{-1} d^{-1}) in moderately saline soil than in weakly saline (0.9l mg glucose kg^{-1} d^{-1}) irrigated soil (Figure 4). On average, the moderately saline soil had ~30% more invertase activity than weakly saline soil. Highest invertase activity was recorded at surface depth of both weakly and moderately saline soils. The activity was more for all depths in moderately saline soil than weakly saline irrigated soil. The invertase activity was higher (1.56 and 1.06 mg glucose kg^{-1} d^{-1}) in summer, intermediate (1.36 and 0.9 mg glucose kg^{-1} d^{-1}) in autumn, and lower (1 and 0.77 mg glucose kg^{-1} d^{-1}) in spring.

Likewise, the urease activity was higher (0.85 mg NH_4 kg^{-1} d^{-1}) in moderately saline soil than in weakly (0.59 mg NH_4 kg^{-1} d^{-1}) saline soil (Figure 5). In other words, more than 30% increase in urease activity occurred due to increase in soil salinity. Averaged across soil depth, urease activity was higher in summer (0.96 and 0.68 mg NH_4 kg^{-1} d^{-1}) followed by that in autumn (0.83 and 0.56 mg NH_4 kg^{-1} d^{-1}), and spring (0.77 and 0.54 mg NH_4 kg^{-1} d^{-1}). Greater urease activity was measured in surface depth of both soils.

Biological activities are potential indicators of the extent to which soil disturbance by a given activity may affect the immediate environment (Figures 6–8). Adverse effects of soil salinity on soil biological properties have long been recognized. Higher BR rates and enzyme activities in moderately saline irrigated soil during summer and autumn than in weakly saline irrigated soil in spring may be attributed to several factors. During hot summer months (with air and soil temperature ranging from 35 to 45°C) under continental climate, salt moves to the surface by upward capillary from saline ground water in response to high evaporation, and results in greater accumulation of salts in summer and autumn than in spring.

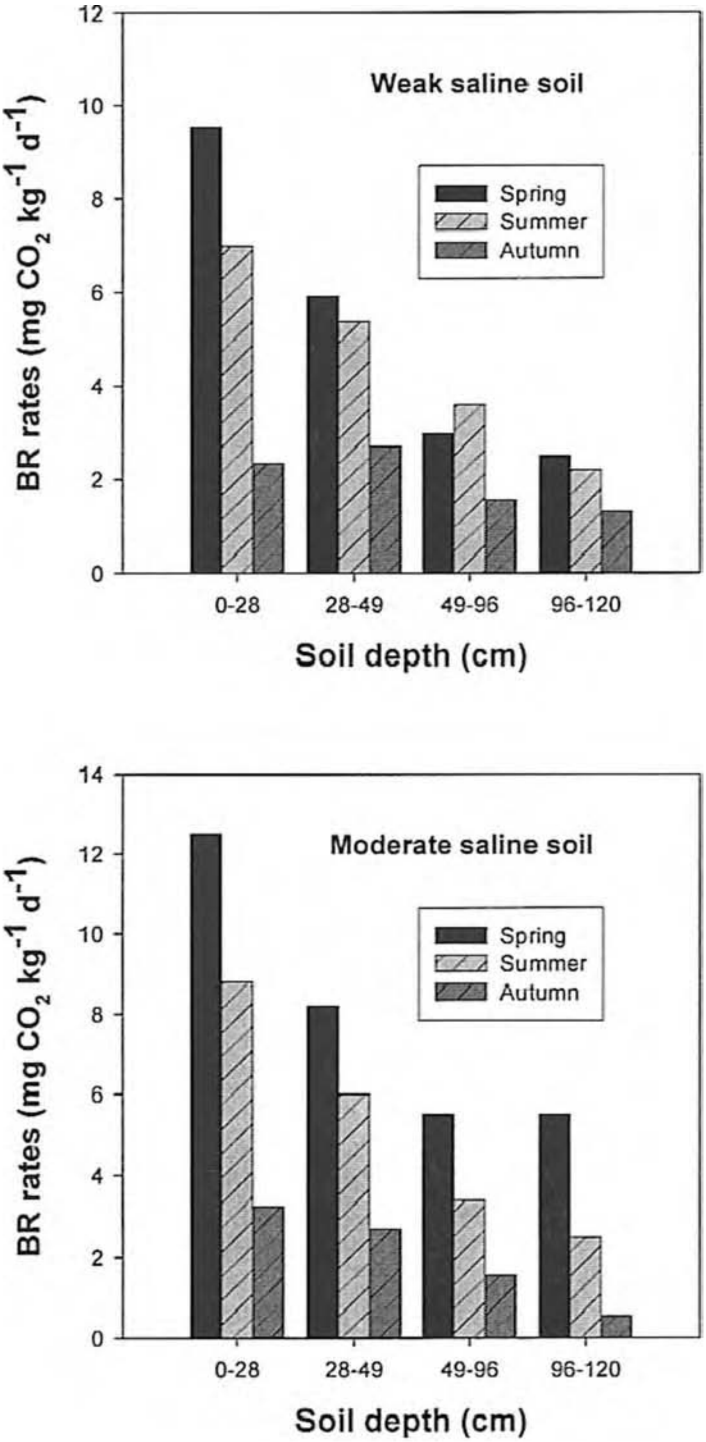


Figure 2. Base respiration rates of varying saline soils.

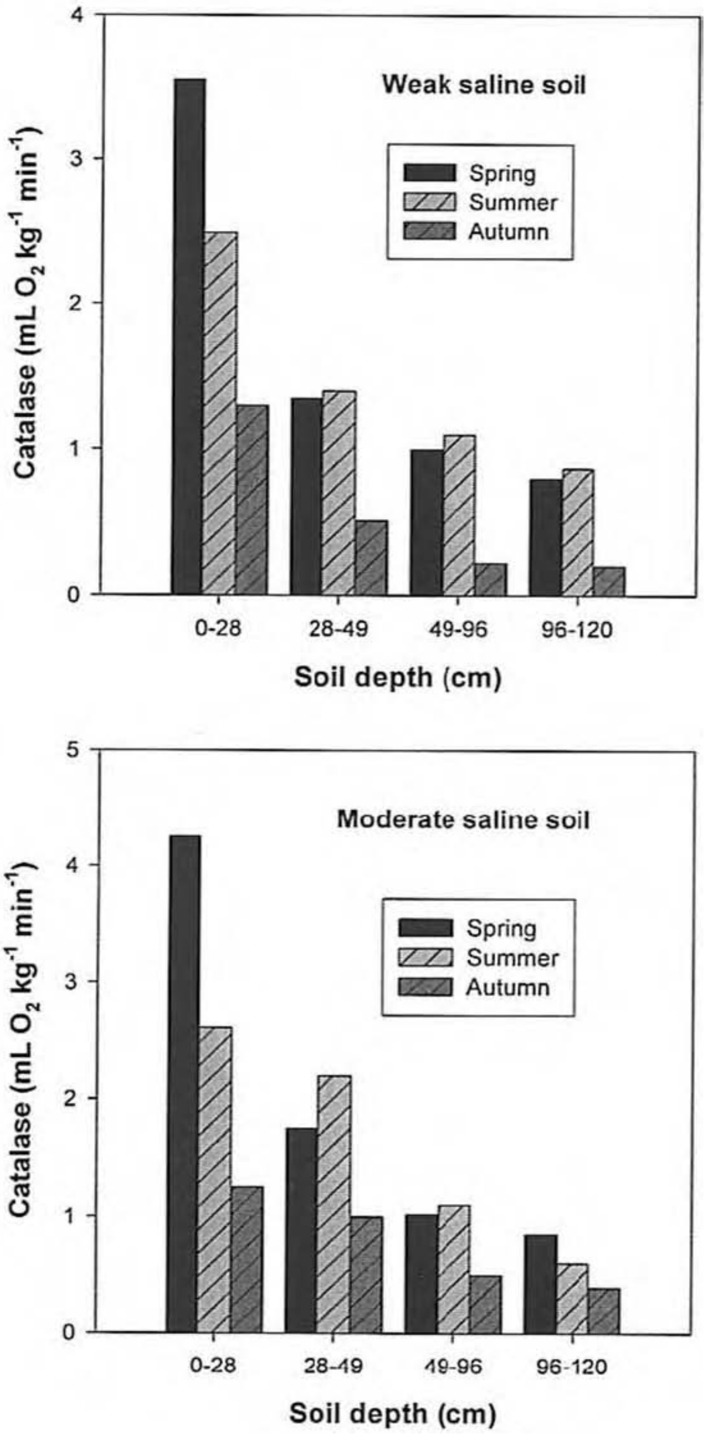


Figure 3. Catalase activity rates of varying saline soils.

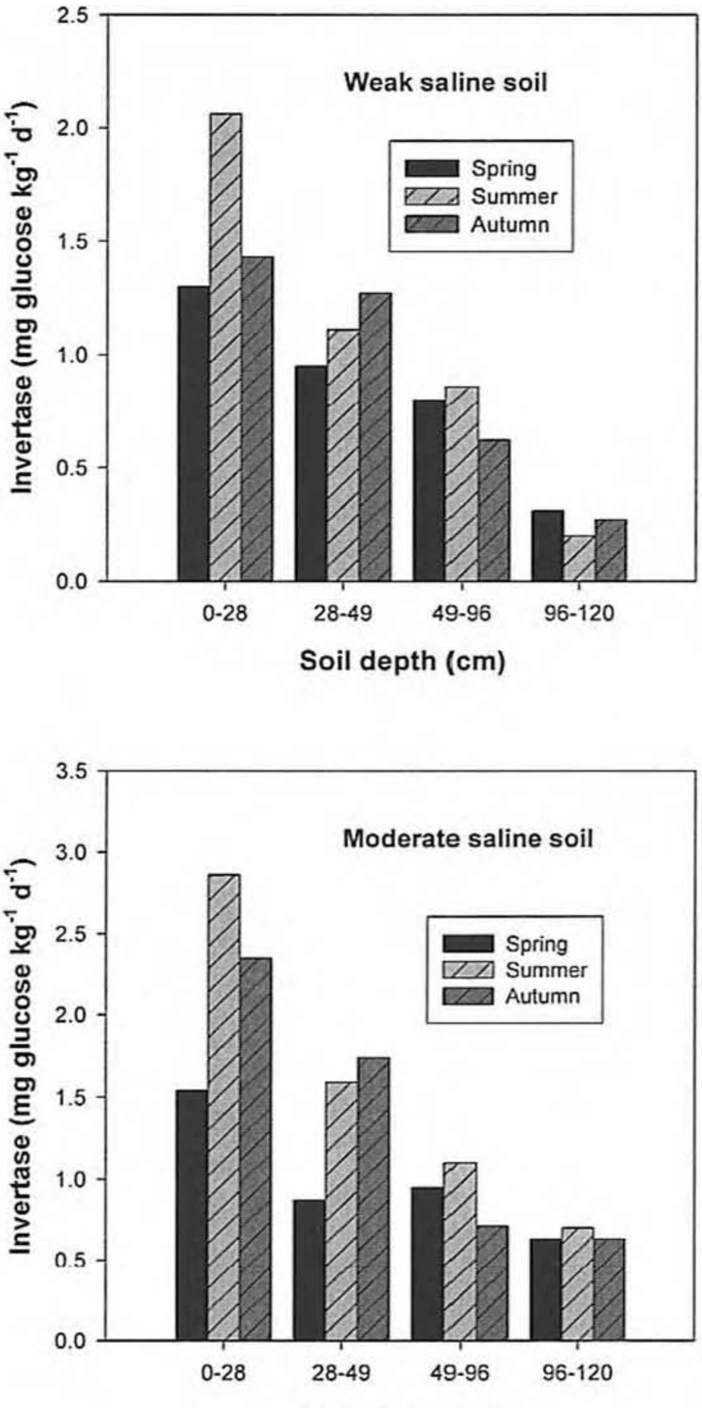


Figure 4. Invertase activity rates of varying salinity soils.

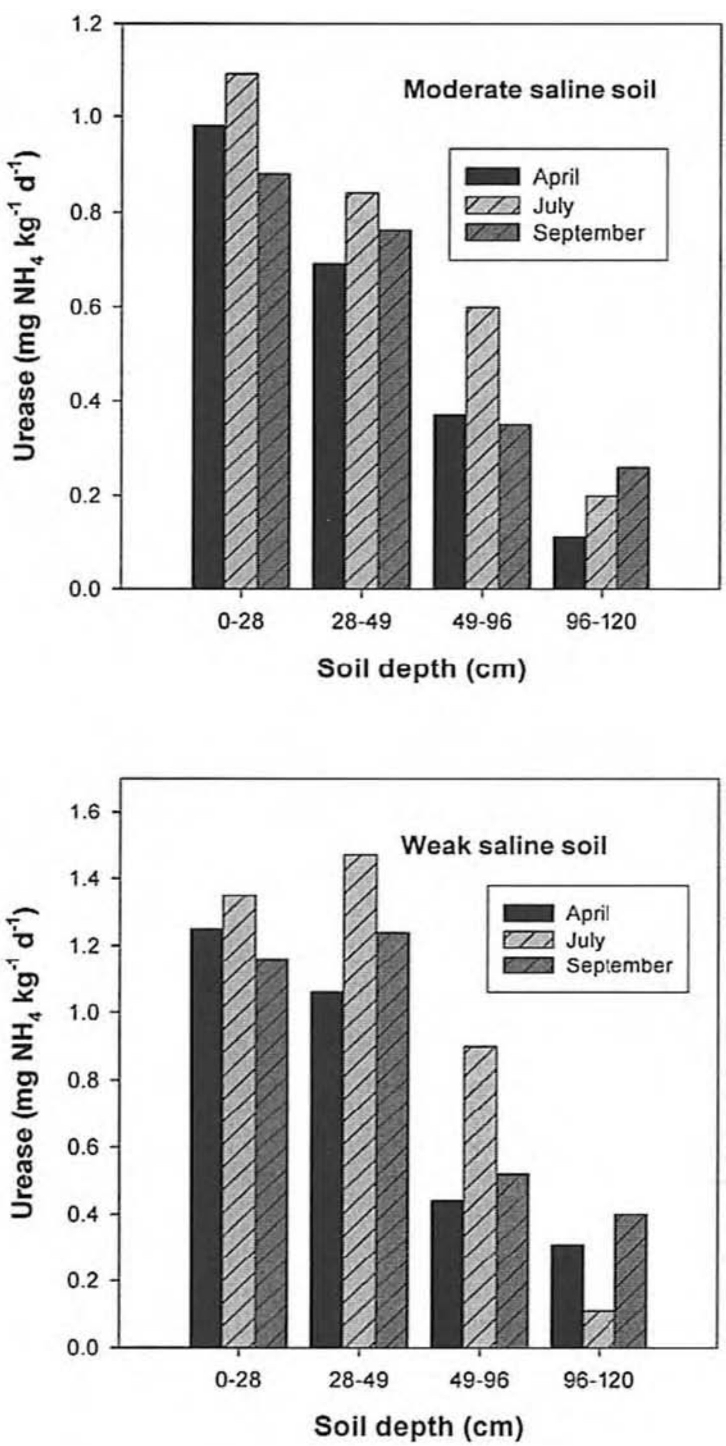
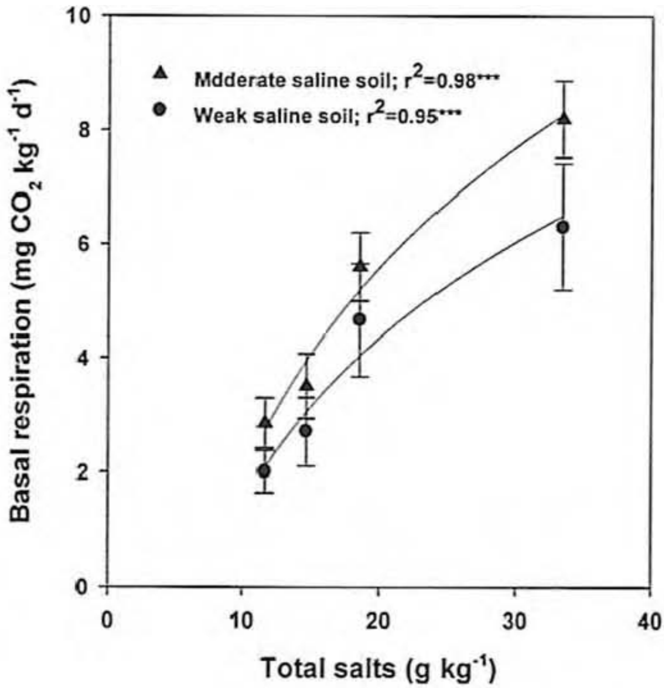


Figure 5. Urease activity rates of varying saline soils.



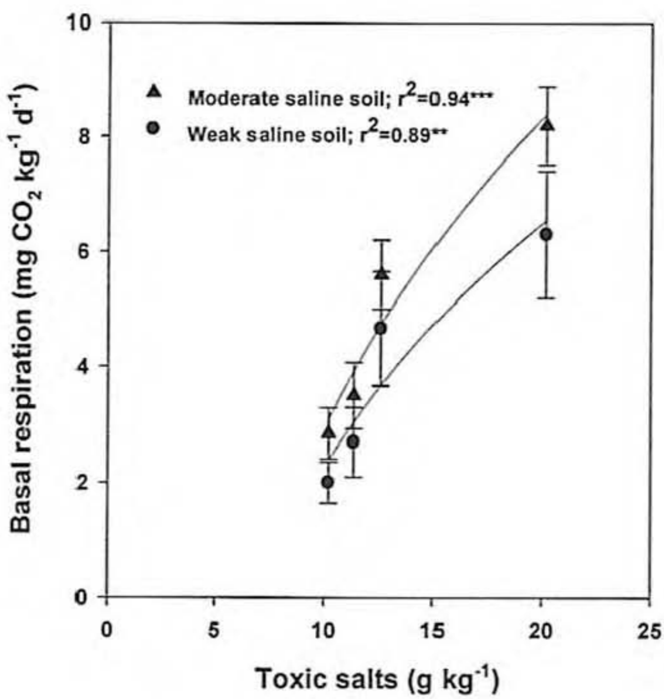


Figure 6. Basal respiration rates for toxic and total salts in varying saline soils.

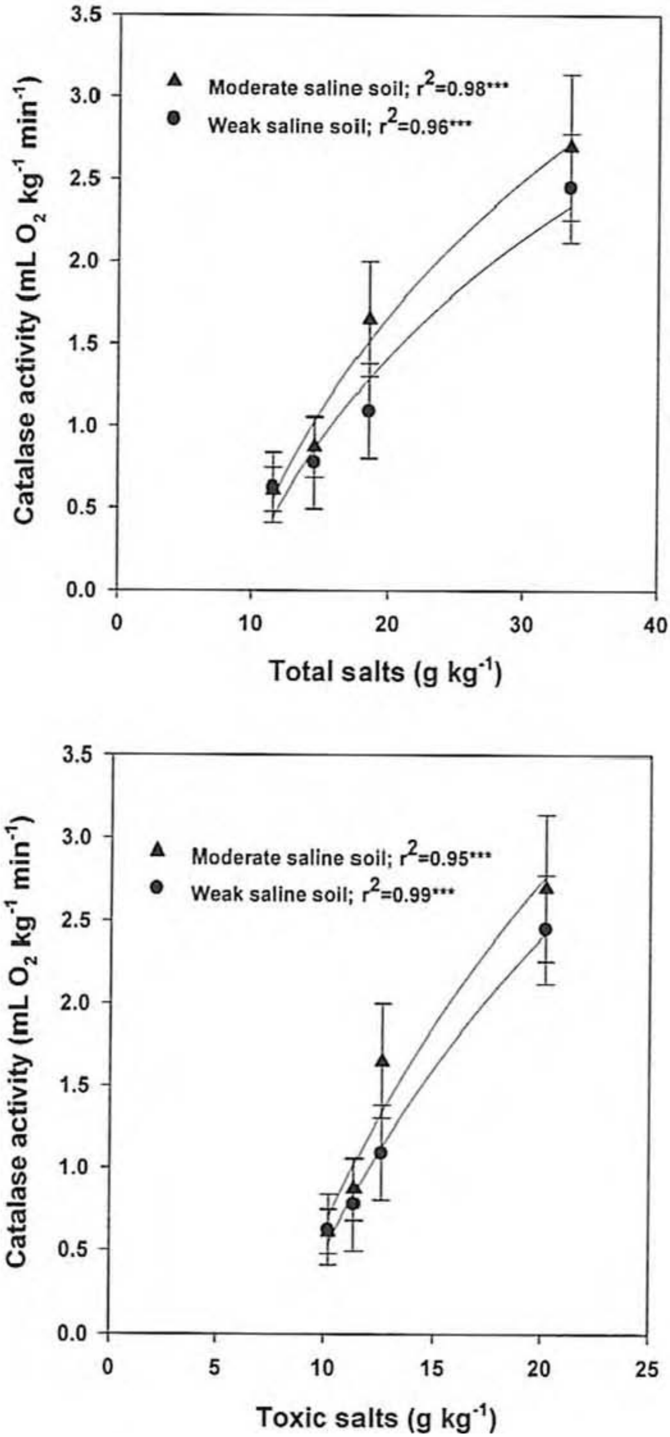


Figure 7. Catalase activity rates for toxic and total salts in varying salinity soils.

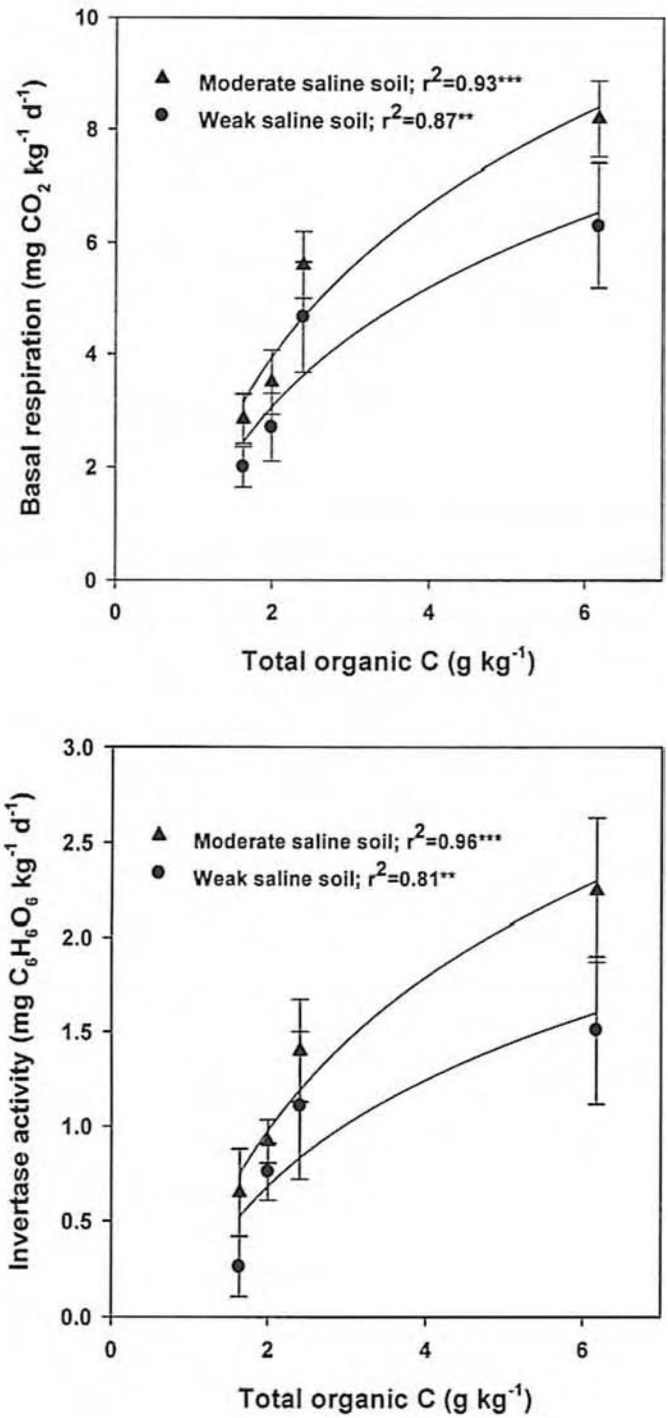


Figure 8. Invertase activity rates for increasing organic carbon contents in varying salinity soils.

Since salt content of soil is considered to be the limiting factor for the survival of microorganisms, higher BR rates suggest that moderately saline soil environment is unfavorable for microorganisms due to the osmotic effects (Figure 6). In high stress environments (e.g., moderately saline soil); microbial cells may be forced to maximize their catabolism for survival than anabolism (growth) in response to increasing salt content (Figures 6 and 7). The catabolic effect is more pronounced in response to toxic contents of salt (e.g., $MaSO_4$, $MgCl_2$, Na_2SO_4 and NaCl) than total salt contents. A significant relationship between biological activities and salt contents (total and toxic) supports the conclusion that increasing salt content increases microbial catabolism for survival under saline environment (Figures 6 and 7).

Significant relationships between BR rates and invertase activity with increasing C substrate availability suggest a greater microbial catabolism to use organic matter for sustaining biological activity in saline soil (Figure 8). Greater invertase and urease activities during the summer are most probably related to greater transformations of organic matter by microorganisms for their increasing energy and nutrients demand for survival than assimilation in response to high temperature and salinity stresses.

4 CONCLUSIONS

Irrigation is essential to high agricultural production in the Aral Sea basin. About 44% of the land is concentrated in the Syr Darya and 56% in the Amu Darya river basin. In response to large scale withdrawal of water for irrigated agriculture especially for cotton production, the river water flows to the Aral Sea severely decreased over the years. As a result, the Aral Sea, once the fourth largest inland body of water in the deserts of Central Asia, has lost much of its volume (82%) and area (∼66%) and quadrupled in salinity. Indiscriminate flood irrigation with poor quality of water and inefficient drainage systems accelerated secondary salinization of irrigated soils with severe degradation of ecosystems. Aral Sea degradation has caused varying degrees of salinity of irrigated soil in the Amu Darya and Syr Darya basins. Increase in soil salinity (16%) spread to Andijan, Djizak, Namangan, Samarkand, Surkhan Darya, Syr Darya, Tashkent, Fergana, and Kashka Dariya regions between 1990 and 2000. In Syr Darya region alone, about 47% of the irrigated lands are weakly saline followed by 35% moderately saline, and 18% strongly saline. Among the salts, Ca, Mg, and Na associated sulfates, chlorides, and bicarbonates are dominant in the soil profile. Highest amount of Na-sulfate (>40%) followed by Ca-sulfate (∼29%), NaCl (18%), and MgCl (10%) have accumulated within 0–100 cm depth of typical sierozems soils. More than 70% of the salts are highly toxic to plant growth and soil biological activities. As a result, the BR and enzyme activities are influenced strongly by soil salinity in different seasons. There were 22, 15, and 30% increase in BR rates, catalase, invertase, and urease activities in moderately saline soils compared to weakly saline irrigated soils. The BR rates and catalase activities were higher in spring than in summer in both weakly and moderately saline irrigated soils. However, the invertase and urease activities are higher in summer than in spring. Abnormally high biological activities in moderate saline irrigated soil during summer and autumn than in weakly saline irrigated soil during spring may be due to osmotic effects on microorganisms. Under high salinity stress, microbial cells use more energy and nutrients (catabolism) for survival than growth (assimilation). The catabolic effects on microbial cells were more pronounced in moderately saline soil and in response to toxic salt concentration ($MaSO_4$, $MgCl_2$, Na_2SO_4 and NaCl) than total salt concentration in both weakly and moderately saline soils.

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