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Urease activity and its relationships to soil physiochemical properties in a highly saline-sodic soil

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Abstract

To ascertain the levels of urease activities (UA) and their relationships with soil physicochemical properties in salt-affected soils during reclamation, soil transects of a saline-sodic soil with different planting years under drip irrigation were intensively sampled. An enhanced soil UA in root zone (0-40 cm beneath drip emitter) was found as the planting years increased. In all transects, soil UA ranged from 0.38 to 8.53 µg NH_4^+-N released g^{-1} dry soil h^{-1} at 37 ºC, and showed a large spatial variability within transect. R^2 of multiple regressions increased gradually with planting years, indicating that variations in UA could be better predicted after amelioration. Path analysis showed that the negative direct effects of soil pH on UA were clearly dominant, with the direct path coefficients of -0.357 ~ -0.666 ($p < 0.05$). Soil organic matter yielded greater positive indirect path coefficients through pH and total nitrogen. An exponential relationship was found between soil UA and pH values ($p < 0.01$). Our findings demonstrate that after the cultivation under drip irrigation for 3 years, soil biological activities and fertility level increased, with the decrease of soil salinity and sodicity.

Keywords: Soil enzyme, wolfberry, takyric solonetz, drip irrigation, path analysis

1. Introduction

Large area of salt-affected wasteland, covering about 1× 10^9 ha area of the world, restricts the crop production in arid/semi-arid regions of the world (Abrol *et al*., 1988). Under different categories of salt-affected soils, sodic and saline-sodic soils constitute about 60% of the world's salt-affected area (Qadir *et al*., 2001). A highly saline-sodic soil, classified as takyric solonetz (IUSS Working Group WRB, 2007), covers about 2.3 × 10^4 ha of Ningxia Plain, northwest China (Wang, 1990). The soil is characterized by the occurrence of extremely excessive sodium (ESP of 15–60 or even > 90 at some locations and pH of 9–10), which leads to deterioration of soil structure. This soil does not support any vegetation except some blue-green algae, such as microcoleus, growing in patches during the monsoon season (Wang *et al*., 1993).

In the recent decades, many methods have been attempted to reclaim the saline-sodic soil. They included deep ploughing, application of organic fertilizer, rice cropping along with frequent irrigation and drainage, replacement of the entire surface soil with a good soil, and use of gypsum (Wang *et al*., 1993). However, many methods were not effective primarily because of the very low saturated hydraulic conductivities of the soil in Ningxia Plain (K_s < 0.1 mm/d) (Wang, 1990; Wang *et al*., 1993), or were thwarted by the long amelioration period and the high costs involved.

With precise application of water and nutrients, drip irrigation has been used widely to reclaim many salt-affected soils in recent years, including some saline-sodic soils (Hanson and May, 2003; Burt and Isbell, 2005; Liu *et al*., 2011). In 2009, drip irrigation was adopted on this highly saline-sodic soil in Ningxia Plain for cropping wolfberry (*Lycium barbarum* L.), and considerable reclamation was achieved: an improved soil water-salt environment for crop growth was formed, and the fruit yield after planting 3 years reached the level of local farmland (Zhang *et al*., 2013).

Due to the sensitivity to the environmental changes, soil enzymes activities have been proposed to evaluate the sustainability and economic effects of agricultural practices, and even to diagnose the soil categories (Garcia *et al*., 1997; Tripathi *et al*., 2006). Among many soil enzymes, urease (urea amidohydrolase, EC 3.5.1.5), closely associated with the transformation, biological turnover and bioavailability of nitrogen (Liang *et al*., 2003; Yuan *et al*., 1997), is a key enzyme. Meanwhile, since the relationship between increased salinity (or/and sodicity) and reduced UA appears to be highly predictable, it was suggested that the changes in UA could be developed into a sensitive and early indicator of soil quality (Sinsabaugh, 1994; Cookson and Lepiece, 1996). So it is helpful and necessary to predict UA level for the subsequent fertilizer management during the land utilization. However, the studies about the changes in UA during the reclamation of the saline-sodic soils with drip irrigation is absent until now.

The objectives of the present study were, (1) to determine the changes of UA in saline-sodic soils with different planting years under drip irrigation and the spatial distribution of UA in fine scales around individual wolfberry, and (2) to compare the relative importance of soil salinity and sodicity, as well as nutrient concentrations in predicting UA.

2. Materials and Methods

2.1. Study site

The study was undertaken in Xidatan Agricultural Comprehensive Development Experimental Station (latitude 38°52′ N; longitude, 106°27′ E; altitude 1095 m), Pingluo County, Ningxia Hui Autonomous Region, northwest China. Located in the floodplain area on the east side of Helanshan Montain, and the north of Ningxia Plain, the station has a typical arid continental climate, with a mean annual temperature of 9.4 °C, and an average annual rainfall of 178 mm. The annual potential evaporation is > 2000 mm. The average water table is at a depth of ~2.5 m.

A highly saline-sodic wasteland exists in the area. Developed in alluvial deposits, the experimental soil is classified as takyric solonetz (IUSS Working Group WRB, 2007), which is widespread in semi-arid and semi-desert saline regions. With the homogeneous soil structure and properties, the soil in this area does not support any vegetation except some blue-green algae, such as microcoleus growing in patches during the monsoon season. The average soil EC_e, pH and SAR in 0–30 cm were 12.3 dS m^{-1}, 9.4 and 44.1 (mmol $L^{-1})^{0.5}$, respectively. The other detailed soil properties in the uncultivated soil profile are depicted in Table 1.

Table 1. Soil UA and main physicochemical properties in uncultivated soil.

Soil depth (cm)	UA ($\mu g\ g^{-1}\ h^{-1}$)	Moisture (%)	EC_e ($dS\ m^{-1}$)	pH	SAR ($(mmol\ L^{-1})^{0.5}$)	TN ($g\ kg^{-1}$)	TP ($g\ kg^{-1}$)	OM ($g\ kg^{-1}$)	C/N
0-10	1.49	7.64	18.54	8.90	39.76	0.23	0.74	6.28	13.88
10-20	1.67	9.44	11.66	9.58	54.01	0.39	0.74	6.79	8.43
20-30	1.78	10.51	6.69	9.52	38.59	0.24	0.73	6.56	11.08
30-40	1.71	11.70	4.16	9.51	23.15	0.36	0.57	6.39	6.92
40-60	2.26	13.61	2.45	9.50	15.43	0.37	0.64	4.00	7.38
60-80	1.68	11.27	1.89	9.43	7.72	0.31	0.65	4.32	9.46
80-100	1.57	11.20	1.67	9.24	7.72	0.28	0.58	2.04	9.43

UA, urease activities; ECe, electrical conductivity of saturated paste extract; pH, pH value of saturated paste; SAR, sodium adsorption ratio of the saturated paste extract; TN, total nitrogen; TP, total phosphorus; OM, organic matter; C/N, ratio of organic carbon-to-total nitrogen.

2.2. Agronomy practices

In April 2009, a plot of the highly saline-sodic wasteland was reclaimed for cropping wolfberry (*Lycium. barbarum* L.) with ridge culture under drip irrigation. The ridge was constructed with a height of 0.5 m, a width of 1 m, and 3 m between ridge centers (Figure 1). Drip irrigation tapes with an emitter spacing of 0.2 m and a flow rate of 0.76 L/h at an operating pressure of 0.03 MPa, were placed onto the center of each raised bed. Wolfberry (cultivars: Ningqi No. 1) seedlings were transplanted into the center of the beds at intervals of 1 m and the ridges were mulched with white polyethylene film (Figure 1). Irrigation was triggered by controlling the soil matric potential, measured at depth of 0.2 m beneath the drip emitter, higher than −15 kPa (Zhang *et al.*, 2013). Urea, phosphoric acid and potassium nitrate were dissolved and applied with the irrigation water. The fertilizing amount was half of the corresponding level in local farmland. In the successive two years (2010 and 2011), a new plot was reclaimed with the same method in each year adjacent to the plot reclaimed in 2009.

2.3. Soil sampling and analysis

Soils were sampled at the end of growing season (9th October) in 2011, when there were 3 plots with different planting years, i.e. plot 1, 2 and 3, reclaimed in 2011, 2010 and 2009 respectively. Nine vertical transects perpendicular to the drip tapes in the location of the nearest drip emitter around wolfberry (3 transects per plot) were selected for soils sampling. 62 soil samples were sampled per transect with an auger (diameter, 4.0 cm; length, 20 cm), the horizontal distances of sampling points from the drip emitters were 0, 10, 20, 30, 40, 60, 80, 100, 120 and 150 cm, and the sampling depths were 0–10, 10–20, 20–30, 30–40, 40–60, 60–80 and 80–100 cm (Figure 1). At the same time, soils were also sampled at the depth of 0–100 cm in 3 uncultivated soil profiles adjacent to the studied plots.

Immediately after sampling and carefully removing the surface organic materials and fine roots, soil moisture (%) was determined gravimetrically on the field moist subsamples. Then three replicates of the remaining subsamples from each plot were mixed into one sample. Soil transects from the plots with 1, 2 and 3 planting years were labeled as transect 1, transect 2 and transect 3 respectively, and the samples from the uncultivated soil profiles was labeled as transect 0 with 0 planting year. The remaining soil subsamples were air-dried, passed through a 1-mm sieve, and stored in closed, rigid polypropylene boxes at room temperature for less than 8 weeks before being assayed for soil physicochemical properties and UA.

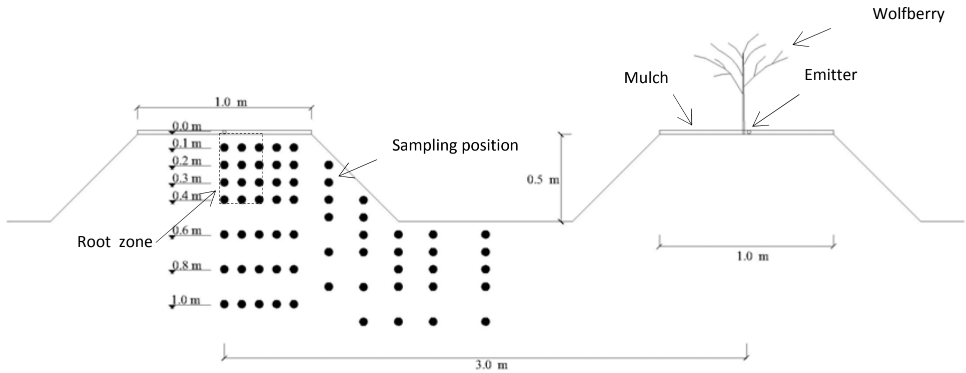

Figure 1. Vertical view of planting pattern and soil sampling positions

Saturated soil paste was prepared for the chemical analysis. The pH of saturated paste was measured with a pH meter (PHS-3C, Shanghai Precision & Scientific Instrument Co., LTD. Shanghai, China). Then clear extracts of the saturated soil pastes were obtained by centrifugation (4000 rpm, 30 min) and analyzed for the electrical conductivity of saturated paste extract (ECe), Ca^{2+}, Mg^{2+} and Na+ concentrations. ECe was measured with a conductivity meter (DDS-11A, Shanghai Precision & Scientific Instrument Co., LTD. Shanghai, China). Ca^{2+} and Mg^{2+} were measured by an EDTA titration method, and Na^+ by flame photometry as described (Bao, 2000). The sodium adsorption ratio of the saturated paste extract (SAR) was calculated using the formula:

$$SAR = \frac{[Na^+]}{\left([Ca^{2+}]+[Mg^{2+}]\right)^{0.5}} \quad (1)$$

where the concentration of each cation is in mmol L^{-1}.

The sieved soils were ground again to pass through a 0.15-mm sieve for the assay of organic matter and total nutrients. Total nitrogen (TN) content was determined by Kjeldahl method. Total phosphorus (TP) was determined by plasma spectrometer after soil samples were igested with $HClO_4$.

Soil organic matter (OM) concentration was calculated by multiplying the organic carbon (OC) concentration, measured by dichromate oxidation method, by 1.724 (Bao, 2000). The ratio of soil organic carbon-to-total nitrogen (C/N) was calculated based on soil OC and TN concentration. Soil UA, which was expressed as µg NH_4^+-N released g^{-1} dry soil h^{-1} at 37 ºC (µg g^{-1} h^{-1} in abbreviation), was assayed spectrophotometrically by the indophenol blue method described by Guan (1986).

2.4. Data analysis

The root zone was defined as a section of 0–20 cm horizontal distance from the drip emitter and 0–40 cm at depth, the spatial weighted mean of soil UA in root zone was calculated as follows:

$$\mathrm{UA}(i) = \frac{\sum_{j=0,10,20 \atop k=10,20,30,40} \mathrm{UA}(i,j,k)\times \mathrm{S}(j,k)}{\sum_{j=0,10,20 \atop k=10,20,30,40} \mathrm{S}(j,k)} \quad (2)$$

where UA(*i*) is the spatial weighted mean of UA in root zone from transect *i* (*i* = 1, 2, 3), UA(*i, j, k*) is the UA of the soil sample from transect *i*, in which *j* is the horizontal distance from drip emitter and *k* is the sampling depth to soil surface.

S(*j, k*) is the representative area of the soil sample. The other soil properties in root zone were measured by the same calculation above.

General linear model (GLM) method of Analysis of variance (ANOVA) was used to examine the main effects of planting year (n = 3), horizontal distance from the drip emitter (n = 3) and soil depth (n = 4) on soil UA in root zone, and differences among transects were tested with Duncan's Multiple Range Test (DMRT). The significance level was $p < 0.05$ unless otherwise stated.

A stepwise multiple linear regression option was used to relate UA to soil physicochemical properties. The significance of regression coefficients (*t* values) and determination coefficient (R^2 value) were given for each regression equation.

After calculation of simple correlations coefficients between UA and soil properties, a path analysis was used to estimate the magnitude and significance of causal-relationships from soil physicochemical properties to UA. The direct and indirect path coefficients of each soil physicochemical property to UA were given (Wright, 1934; Bhatt, 1973). Last, the relationship between soil pH and UA was examined using linear regression analysis.

All the data analyses were conducted by using SPSS 11.5 statistical software (SPSS Inc., Illinois, USA). Figures were created using Surfer 8.0 (Golden Software Inc., Colorado, USA) and SigmaPlot 10.0 (Systat Software Inc. California, USA).

3. Results

3.1. Changes and distributions of UA

UA in uncultivated soil ranged 1.49–2.26 $\mu g\ g^{-1}\ h^{-1}$, with the mean of 1.66 $\mu g\ g^{-1}\ h^{-1}$ in 0–40 cm (Table 1). The soil UA in root zone presented an increasing trend with the planting years. The weighted means were 1.76, 2.51 and 4.32 $\mu g\ g^{-1}\ h^{-1}$, respectively in the 3 transects (Table 2), increased by 6.0%, 51.2% and 160.2%, relatively to the uncultivated soil.

A large spatial variability was found within transect. Generally, the farther from the drip emitter, the lower activities of urease were detected. Descriptive statistics of UA for the whole transects showed that the standard error of the mean of observations (SEM) and the standard deviation (SD) increased with increasing planting years (Table. 2).

3.2. Stepwise multiple regression analysis between UA and soil physicochemical properties

The t values associated with each variable indicated that only pH and C/N contributed significantly to the variation in UA in transect 1, and R^2 was only 0.218. In transect 2, pH and TN entered into the regression equation and accounted for 45.4% total variation in UA, while TP, pH and moisture entered into the equation in transect 3, and 64.8% variation was explained. Based on combined data from all transects, pH, TP, TN, C/N and moisture contributed significantly to the variation in UA and accounted for 47.0% variation in UA (Table 3).

3.3. Path analysis of soil physicochemical properties towards UA

Significant negative correlations between soil pH and UA were always found in the 3 and combined transects, with the correlation coefficients of -0.382, -0.643,-0.689 and -0.555 respectively ($p < 0.05$) (Table 4). While, the negative correlations between soil ECe and UA never reached the significant level ($p < 0.05$).

Path analysis showed that soil pH had the largest negative direct path coefficient to UA in transect 1, and C/N had the largest positive. TN and TP had the larger indirect path coefficients through soil pH. In transect 2, the direct effect of pH was still clearly dominant, with the path coefficient of -0.666. TP had the positive indirect effect through soil pH.

Table 2. Descriptive statistics of the soil urease activities from different transects.

Transects	Planting years	Weighted means in root zone*	For the whole transect				
			Minimum	Maximum	Means	SEM	SD
1	1	1.76c	0.68	3.18	1.56	0.06	0.45
2	2	2.51bc	0.38	3.93	1.50	0.11	0.88
3	3	4.32a	1.37	8.53	2.70	0.17	1.37

SEM, the standard error of the mean of observations within each transect. SD, the standard deviation. *Values in this column followed by different letters are significantly different at $p < 0.05$.

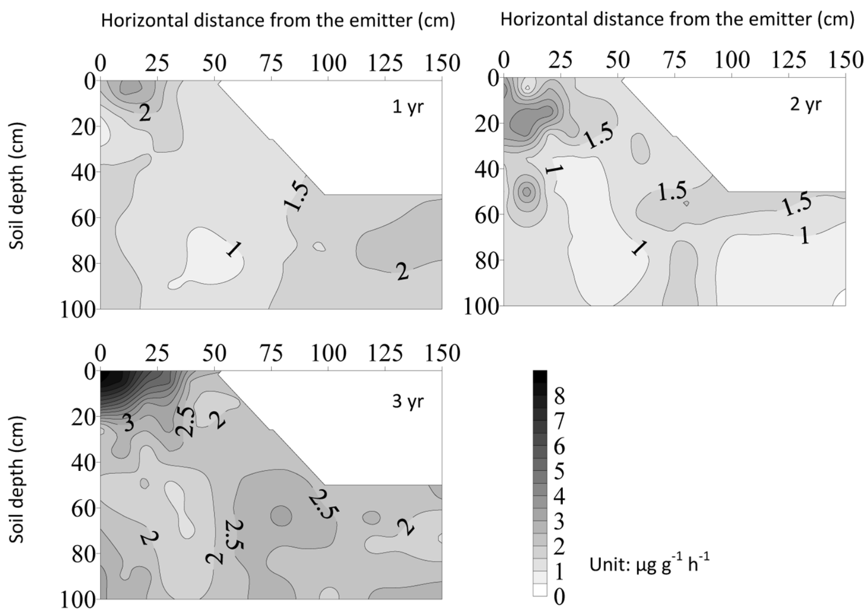

Figure 2. The spatial distribution of urease activities in transects with different planting years

In transect 2, the direct effect of pH was still clearly dominant, with the path coefficient of -0.666. TP had the positive indirect effect through soil pH. In transect 3, besides the negative direct effect, soil pH also had considerable negative indirect effect through soil TP and OM (Table 4). Analysis of combined data from 3 transects showed that soil pH had the largest negative direct path coefficients on UA, while TN and TP had larger positive path coefficients. Soil moisture and TP had positive indirect effects through pH.

With respect to OM, Table 4 also showed a smaller direct path coefficient against UA, and larger indirect path coefficients through soil pH, TN and TP.

Table 3. Stepwise multiple regression equations, significance of regression coefficients, and coefficient of determination (R^2) for relationship between soil UA and physicochemical properties.

Transects	Regression equation for UA (μg g^{-1} h^{-1})	N	*t* values and significance								R^2
			Moisture	EC_e	pH	SAR	TN	TP	OM	C/N	
1	8.089-0.733pH+0.028C/N	62	NS	NS	-3.769**	NS	NS	NS	NS	2.335*	0.218
2	9.864-0.963pH+1.672TN	62	NS	NS	-4.961**	NS	2.106*	NS	NS	NS	0.454
3	10.516+2.581TP -0.889pH-0.074Moisture	62	-2.276*	NS	-3.187**	NS	NS	4.103**	NS	NS	0.648
1+2+3	8.645-0.893pH+1.863TP+1.905TN+0.038C/N-0.041Moisture	186	-3.574**	NS	-5.492**	NS	5.585**	4.083**	NS	3.963**	0.470

UA, urease activities; *, Significant at $p < 0.05$; **, Significant at $p < 0.01$; ECe, electrical conductivity of saturated paste extract; pH, pH value of saturated paste; SAR, sodium adsorption ratio of the saturated paste extract; TN, total nitrogen; TP, total phosphorus; OM, organic matter; C/N, ratio of organic carbon-to-total nitrogen; NA, not significant.

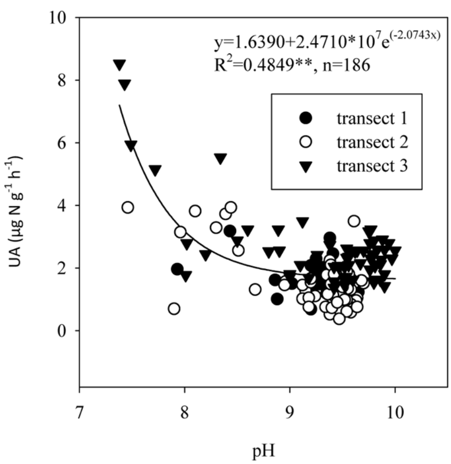

Figure 3. Relationship of soil urease activities (UA) with soil pH. Regression equation, line of best fit and level of statistical significance shown. ** $p < 0.01$.

3.4. Relationship between soil UA and pH

The relationship between soil UA and pH using combined data from 3 transects is shown in Figure 3. Soil UA decreased generally with increasing pH. The relationship could be expressed by exponential equation ($p < 0.01$).

4. Discussion

4.1. Levels of UA

The magnitudes of UA as observed herein in uncultivated saline-sodic soil were lower than the ranges of values recorded in other soils (Kandeler and Gerber,1988; Tripathi *et al*., 2006; Yuan *et al*., 2007), indicating that soil biochemical quality was negatively affected in the saline-sodic soil. Considering the fact that urease originates either from plant shoot litter, living or dead roots, or microorganisms and animal life (Zahir *et al*., 2001), the reduced UA could be ascribed to the following facts. Firstly, the less enzyme secretion was secreted by the lower populations of soil microorganisms as most of the microorganisms could not survive in the high salinity and sodicity of the soil. Secondly, urease is extracellular, stable and form complexes with the organic and mineral colloids (Garcia and Hernandez, 1996; Tripathi *et al*., 2006), while salinity induced degradation in arid or semiarid soils is characterized by low soil OM content (Wang *et al*., 1993; Kaur *et al*., 2000; Yuan *et al*., 2007). The average soil OM concentration in the studied soil was only 2.04–6.79 g kg^{-1}. These low values might be the cause of low microbiological activities. Thirdly, the experimental soil was characterized by excessive Na^+, resulting in the high SAR and ESP. In comparison to other cations, Na^+ has a deleterious effect on soil aggregate stability by increasing clay dispersion (Wang *et al*., 1993).

Table 4. Correlation coefficients and path coefficients of soil physicochemical properties (factors) to urease activities.

Transects	Factors	Correlation coefficients	Path coefficients[a]							
			Moisture	EC_e	pH	SAR	TN	TP	OM	C/N
1	Moistur	0.205	0.326	0.001	0.163	0.001	0.087	-0.23	-0.18	0.041
	EC_e	-0.165	0.008	0.037	-0.02	-0.00	0.024	-0.07	-0.16	0.032
	PH	-0.382**	-0.123	0.002	-0.43	-0.00	-0.08	0.188	-0.02	0.098
	SAR	-0.160	-0.059	0.019	-0.07	-0.00	-0.05	-0.02	-0.00	0.041
	TN	-0.075	0.126	0.004	0.171	0.001	0.226	-0.20	-0.10	-0.30
	TP	-0.016	0.199	0.007	0.216	0.000	0.120	-0.37	-0.06	-0.112
	OM	-0.110	0.158	0.016	-0.02	0.000	0.060	-0.06	-0.37	0.130
	C/N	0.172	0.032	0.003	-0.10	0.000	-0.16	0.101	-0.117	0.418
2	Moistur	0.260*	0.132	0.004	0.092	0.001	0.132	-0.05	-0.03	-0.01
	EC_e	-0.021	0.006	0.095	-0.13	-0.02	0.030	-0.00	-0.04	0.054
	PH	-0.643**	-0.018	0.019	-0.66	-0.00	-0.14	0.107	0.009	0.055
	SAR	-0.076	-0.006	0.071	-0.16	-0.02	0.006	0.039	-0.04	0.051
	TN	0.476**	0.057	0.009	0.307	-0.00	0.307	-0.06	-0.06	-0.07
	TP	0.228	0.032	0.002	0.345	0.005	0.094	-0.20	-0.03	-0.01
	OM	0.219	0.050	0.044	0.059	-0.01	0.191	-0.06	-0.10	0.055
	C/N	-0.184	-0.009	0.030	-0.21	-0.00	-0.13	0.014	-0.03	0.172
3	Moistur	0.163	-0.311	0.027	0.199	-0.01	0.033	0.133	0.111	-0.01
	EC_e	-0.216	0.044	-0.19	-0.08	0.047	0.035	-0.07	0.029	-0.02
	PH	-0.689**	0.174	-0.04	-0.35	0.014	-0.00	-0.36	-0.116	0.005
	SAR	-0.200	0.076	-0.17	-0.09	0.051	0.024	-0.07	0.013	-0.01
	TN	-0.018	-0.075	-0.05	0.005	0.009	0.135	-0.04	0.074	-0.06
	TP	0.764**	-0.085	0.030	0.266	-0.00	-0.01	0.486	0.084	0.005
	OM	0.457**	-0.212	-0.03	0.255	0.004	0.062	0.251	0.162	-0.03
	C/N	0.087	0.039	0.030	-0.01	-0.00	-0.07	0.018	-0.03	0.129
1+2+3	Moistur	0.040	-0.192	0.005	0.131	-0.00	0.057	0.085	-0.02	-0.01
	EC_e	-0.021	0.017	-0.06	-0.08	0.050	0.114	-0.02	-0.01	-0.02
	PH	-0.555**	0.060	-0.01	-0.41	0.015	-0.04	-0.20	0.019	0.030
	SAR	-0.063	0.029	-0.04	-0.10	0.062	0.066	-0.04	-0.00	-0.01
	TN	0.255**	-0.028	-0.01	0.049	0.010	0.390	0.008	-0.02	-0.13
	TP	0.514**	-0.052	0.005	0.276	-0.00	0.011	0.310	-0.01	-0.00
	OM	0.261**	-0.073	-0.01	0.143	0.010	0.146	0.103	-0.05	0.004
	C/N	0.029	0.012	0.005	-0.04	-0.00	-0.19	-0.00	-0.00	0.269

a, the data with underline are direct path coefficients, and the rests are indirect path coefficients. *, Significant at $p < 0.05$; **, Significant at $p < 0.01$; ECe, electrical conductivity of saturated paste extract; pH, pH value of saturated paste; SAR, sodium adsorption ratio of the saturated paste extract; TN, total nitrogen; TP, total phosphorus; OM, organic matter; C/N, ratio of organic carbon-to-total nitrogen.

Garcia *et al.* (1997) reported that if the soil clays were dispersed by soil salinity, the extracellular enzymes would be less protected and perhaps denatured by proteolysis. Additionally, due to the higher salts concentration in soil, the “salting-out” effect (Tejada *et al*., 2006), the change in osmotic potential and specific ion toxicities (Rietz and Haynes, 2003) should also be taken into consideration for the reduced UA. The enhanced soil UA is believed to be direct indicator of the improvement of soil fertility, which helps increase N uptake by plants (Liang *et al*., 2003; Acosta-Martínez *et al.*, 2007).

In this study, soil UA, particularly in root zone, increased with the planting years (Table 2). The increase should be attributed to the improvement of corresponding soil environment, mainly including salt leaching, decrease of soil pH, and rise in concentrations of nutrients (Table 5). This result coincided partly with that of Speir *et al.* (1980), who found that UA decreased gradually over 5 months in barren soils, whereas it increased with time in vegetated soils. Plant litter in the soil as well as root exudates provides nitrogenous substrates, which can induce the synthesis of these enzymes in arid soils (Liang *et al.*, 2005).

Table 5. Soil physicochemical properties in root zone.

Transects	Planting years	Moisture (%)	EC_e (dS m^{-1})	pH	SAR (mmol $L^{-1})^{0.5}$	TN (g kg^{-1})	TP (g kg^{-1})	OM (g kg^{-1})	C/N
0[a]	0	9.82	10.26	9.38	38.88	0.31	0.70	6.09	10.08
1[b]	1	27.75	7.31	9.04	10.96	0.38	0.77	6.51	10.93
2[b]	2	26.01	7.18	8.38	10.16	0.47	0.86	6.32	6.74
3[b]	3	21.79	5.15	8.08	7.19	0.51	1.03	7.58	9.16

Note: a, data in this low were calculated as the depth weighted mean of 0-40 cm in uncultivated soil; b, data in this law were calculated as the spatial weighted mean in root zone. ECe, electrical conductivity of saturated paste extract; pH, pH value of saturated paste; SAR, sodium adsorption ratio of the saturated paste extract; TN, total nitrogen; TP, total phosphorus; OM, organic matter; C/N, ratio of organic carbon-to-total nitrogen.

All soil UA revealed large within-transect variability (Table 2, Figure 2). The main reason for this was the changes of micro-area environment induced by drip irrigation, where small difference in the position from the drip emitter could cause strong variability in salt accumulation and fertilizer level (Liu *et al*., 2011; Zhang *et al*., 2013), and consequently differences in the growth of plant roots and soil microorganisms.

It was also found that the substantial enzyme activities could persist even at high soil salinity and sodicity, which was supported by Rietz and Haynes (2003). Indeed, Zahran (1997) noted that the production and activity of enzymes from the saline soil bacteria had greater salt requirements than those of corresponding enzymes from non-saline bacteria.

4.2. Relationships between UA and soil properties

In order to relate soil properties to UA, stepwise multiple regression analyses were performed on data compiled from each transect, and on combined data from all transects. In transect 1, only 21.8% variation in UA was accounted for by the regression equation, which included soil pH and C/N. This suggested that although variations in soil pH and C/N were important in predicting UA, there remained other determining variables not involved in this study, and the similar result was reported by Cookson (1999). The increase in R^2 and grow in number of factors entered into the regression equations indicted that UA in saline-sodic soils became more predictable during the amelioration. This could also be proved by the correlation analysis, which showed that the number of soil properties significantly correlated with UA increased with planting years (Table 4). Cookson (1999) reported that in non-saline soils, the UA was closely associated with several soil properties, whereas at saline conditions, it was only significantly associated with soil salinity.

As a straightforward extension of multiple regression, path analysis has been applied in quite a variety of cases to estimate the magnitude and significance of hypothesized causal connections among variables (Ball *et al.*, 2001). Direct path coefficients implied that soil pH values had a negative effect on UA. Although a significant positive correlation existed between soil OM and UA in transect 3 and in combined transects, OM never entered into stepwise regression equations (Table 3) and the direct path coefficients of soil OM to UA were also relatively smaller (Table 4). Soil OM influenced UA mainly through other factors such as soil pH and TN, which was indicated by the indirect path coefficients.

Both stepwise regression and path analysis showed that soil pH had a dominant effect on UA, so soil pH was chosen solely for the linear regression against UA. And enzyme activity has been suggested to be used to assess soil pH because of its sensitivity to soil pH (Guan, 1986). Soil samples in this study, coming from different plots and different positions from the drip emitter, had a wide gradient of soil salinity and sodicity. The range of soil pH in present study, from 7.38 to 10.00, represented almost the entire range of alkalinity observed in cultivated salt-affected soils of arid/semi-arid regions, northwest China (Wang *et al.,* 1993). The exponential relationship between soil UA and pH demonstrated the highly detrimental effect that small increase in soil pH exerted on soil UA, especially in the low pH section, a small increase in soil pH could trigger great decrease in UA, which was more evident for transect 3. While at high pH section, the UA was not so sensitive to the changes in pH, possibly because of the extremely low UA level in high soil pH. High soil pH affects availability of nutrients, and controls the composition and diversity of the microbial community (Dick *et al*., 2000). Moreover, soil pH had significant negative effects on soil organic matter, as reported by Muhammad *et al*. (2008). The low content of soil organic matter may make the enzyme more prone to denaturation and biological degradation by soil humic polymers (Baligar *et al.*, 1991; Zahir *et al.*, 2001), and also create an unsuitable substrate for the development of soil microbial.

5 Conclusions

Urease presented a lower activity in the uncultivated saline-sodic soils in Ningxia Plain, northwest China. Drip irrigation-induced changes of salinity and sodicity greatly affected soil microbial and biochemical properties, reflected by the increase in UA. With an increase of planting years, the significances of multivariate correlations between UA and soil properties increased gradually. Among the 8 soil properties studied, soil pH was the only factor that could significantly affect the soil UA in the first planting year. Nevertheless, after 3 planting years, soil UA could be predicted by interactions of several soil properties. Path analysis indicated that pH had a larger negative direct effect on UA, and the relationships between UA and soil pH showed that a small increase in soil pH could exert a highly detrimental effect on UA.

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