Wetlands (2021) 41: 13
https://doi.org/10.1007/s13157-021-01412-x

WETLANDS RESTORATION

Plant Diversity and Soil Properties at Different Wetland Restoration Stages along a Major River in the Arid Northwest of China

Ruifeng Zhao[1,2] · Xiaoya Zhang[1] · Lihua Zhang[1] · Yuanbo Wang[1]

Received: 12 January 2020 / Accepted: 9 November 2020 / Published online: 31 January 2021
© Society of Wetland Scientists 2021

Abstract
Agricultural activity is widely recognized as one of the leading drivers of natural wetland loss in many parts of the world. The suitability of farmland abandonment as the wetland restoration has not been well studied in arid regions. The plant growth, community structure and soil property were examined in three farmlands abandoned for 2 (W2), 6 (W6) and 15 (W15) years and reference wetland (Wr) in the Zhangye National Wetland Park in Gansu province. The results showed that the plant abundance, soil organic carbon, total nitrogen, soil water content increased and pH value decreased along the wetland restoration stages. Shannon-Wiener diversity and Pielou's evenness index moved towards natural wetland with increasing time of farmland abandonment, the plant community composition of the three abandoned farmlands also changed from annual to perennial dominant species. The farmland abandonment is conducive to improve soil nutrients and quality. Soil and vegetation facilitated one another in the abandonment stages. Thus, farmland abandonment is rational for wetland restoration. The mechanism of interaction between plant and soil can be used to guide wetland restoration of abandoned farmland.

Keywords Wetland restoration · Abandoned farmland · Vegetation · Soil nutrient · Soil quality

Introduction

The wetland is a unique ecosystem formed by the interaction between water and land on Earth. It is the cradle of biodiversity and one of the environments in which human beings live (Engelhardt and Ritchie 2001). The wetland area is shrinking away from an alarming rate because of climate change and human activities such as drainage and cultivation. Wetland degradation impacts the plant community, soil, hydrology and the balance of the wetland ecosystem (Wood et al. 2017). Agricultural activity is widely recognized as one of the leading drivers of natural wetland loss in many parts of the world. Consequently, many countries adopted the policy of returning cultivated land to wetland so as to restore wetland to a state of natural wetland (Inglett and Inglett 2013; Ballantine et al. 2017). However, other studies reported that abandoned farmlands can be a source of emissions. It is necessary to discover the suitability of abandoned farmland as the wetland restoration.

Researchers have analyzed the soil and vegetation changes of the riparian wetlands for different farmland abandonment stages and discussed the effectiveness and feasibility of returning farmland to wetland. Most documents have reported that soil organic matter, total carbon, total nitrogen and phosphorus contents of abandoned land have increased (Bruland et al. 2003; Ballantine et al. 2017; Yu et al. 2017), and the plant species composition shifted towards the characteristic of natural wetlands (Lu et al. 2007). These studies demonstrate that farmland abandonment benefits the restoration of wetlands. However, not each abandoned farmland could reach its target (Toth 2010, 2015). The effects of different farmland abandonment stages in riparian wetland on the soil and plant properties are not well known.

At the same time, Wang et al. (2018) reported that the increasing plant community diversity benefits the soil properties including soil structure and nutrients during the abandonment stages. However, other researches showed that the plant

✉ Ruifeng Zhao
zhaoruifeng@126.com

[1] College of Geography and Environment Science, Northwest Normal University, Lanzhou 730070, China

[2] Gansu Engineering Research Center of Land Utilization and Comprehension Consolidation, Lanzhou 730070, China

diversity and soil properties are negatively correlated or unrelated (Russell et al., 2017; Li et al. 2016). Therefore, it is recommended that overall plant-soil feedback effects should be studied in different farmland abandonment stages to determine its suitability of wetland restoration.

Especially, the natural wetlands in Northwest China demand special attention because of the notable increase in agricultural encroachment (Mao et al. 2018). The health of the wetland in the middle reaches of the Heihe River is important to biodiversity conservation and oasis development in the Hexi Corridor (Zhao et al. 2015). However, the natural wetland in the middle reaches of the Heihe River has degraded due to the influence of the climate and over-reclamation (Zhao et al. 2013). In order to restore wetland, Zhangye Municipal Government has implemented the project of returning farmland to wetland since March 2009. However, what will be the status of soil and plant properties in different farmland abandonment stages? Could abandoned farmland be restored to wetland successfully? In order to answer these questions, the aims of this research were to examine the changes of the soil physical-chemical properties and of the plant community structure in three abandoned farmlands with a restoration wetland sequence of 2 (W2), 6 (W6) and 15 (W15) years, and explore the potential relationships between soil and plant properties.

Materials and Methods

Study Site Description

The study sites are in the Zhangye National Wetland Park (100°06′—100°55′ E, 38°32′—39°24’ N) in the middle reaches of the Heihe River in Gansu province (Fig. 1). The climate is typical temperate continental climate. The average annual precipitation is 129 mm and the average annual temperature is 7.4 °C (Zhao et al. 2015). The zonal soil types include gray-brown desert soil and gray desert soil. Silt loam and loam are widely distributed in cultivated farmlands (Xu et al. 2019). The dominant species are *Suaeda glauca, Salsola collina, Leymus secalinus, Phragmites australis, Amaranthus retroflexus* and *Chenopodium glaucum.*

The wetland in the middle reaches of the Heihe River is located in oasis agricultural area, and the collective farmland area accounts for a large proportion. The Zhangye National Wetland Park is characterized by flat terrain and fertile land. Since the 1960s, driven by economic interest, local residents have blindly destroyed wetlands in order to expand cultivated land. The crops were mainly wheat and corn, and the main management measure was farmland irrigation and fertilization (Mao et al. 2018; Xu et al. 2019). Excessive industrial, agricultural and residential water use has reduced the groundwater level of wetlands (Wang et al. 2015), resulting in the reduction of natural wetland areas and decline in wetland functions. Zhangye Municipal Government began to implement the project of returning farmland to wetland in March 2009.

Sampling and Analysis Methods

Three age classes (2, 6 and 15 years since abandonment) and the reference wetland (Wr) in the Zhangye National Wetland Park in Gansu province were selected in 2017, all of which were flat and subject to similar altitude, hydrology and climate conditions (Table 1). There is no human interference and artificial participation in management after abandonment. Therefore, the Park provides a good sample for us to study three different restoration stages. The abandonment ages were determined through interviews with local farmers.

The plant community composition and distribution in study sites were uniform and stable. The site conditions such as latitude, longitude and altitude were recorded. To avoid subjective effect, the plot was placed in the centre of each study site. Then, three 1 m × 1 m quadrats were randomly set in each plot. The individual number, height and coverage of each plant species in the quadrat were measured. Specimens of individual species not identified within sites were collected and brought back to the laboratory for identification.

We used the soil core method to take soil samples in each quadrat at depths of 0–10, 10–20 and 20–40 cm. The soil cores at each soil layer were mixed so that 9 soil samples (3 × 3) were obtained in each study site, and a total of 36 samples were collected. The evenly mixed soil samples were placed into plastic bags and brought to the laboratory to determine the soil physical and chemical properties. Samples of soil bulk density were taken at each soil layer using the steel cutting ring method. Soil water content (SWC) at the depths of 0–10, 10–20 and 20–40 cm were measured using the oven-drying method.

In the laboratory, the soil samples were air-dried at ambient temperature and sieved using 1, 0.250, and 0.149 mm mesh sizes to remove animal and plant residues and gravel. The physical and chemical properties of soil were determined using conventional methods. The soil organic carbon (SOC) concentration was measured using the Walkley–Black dichromate oxidation method (Bai et al. 2005). The total nitrogen (TN) content was measured with the Kjeldahl method. The determination of the total phosphorus (TP) concentration was based on digestion using perchloric acid and sulfuric acid. The pH value was obtained using an acidity agent (soil–water ratio of 1:5; PHS-3C pH acidometer, China). The salinity was determined using a gravimetric method.

Data Analysis

All data onto the four sites are expressed as mean values ± standard error (SE). All variables were transformed to satisfy

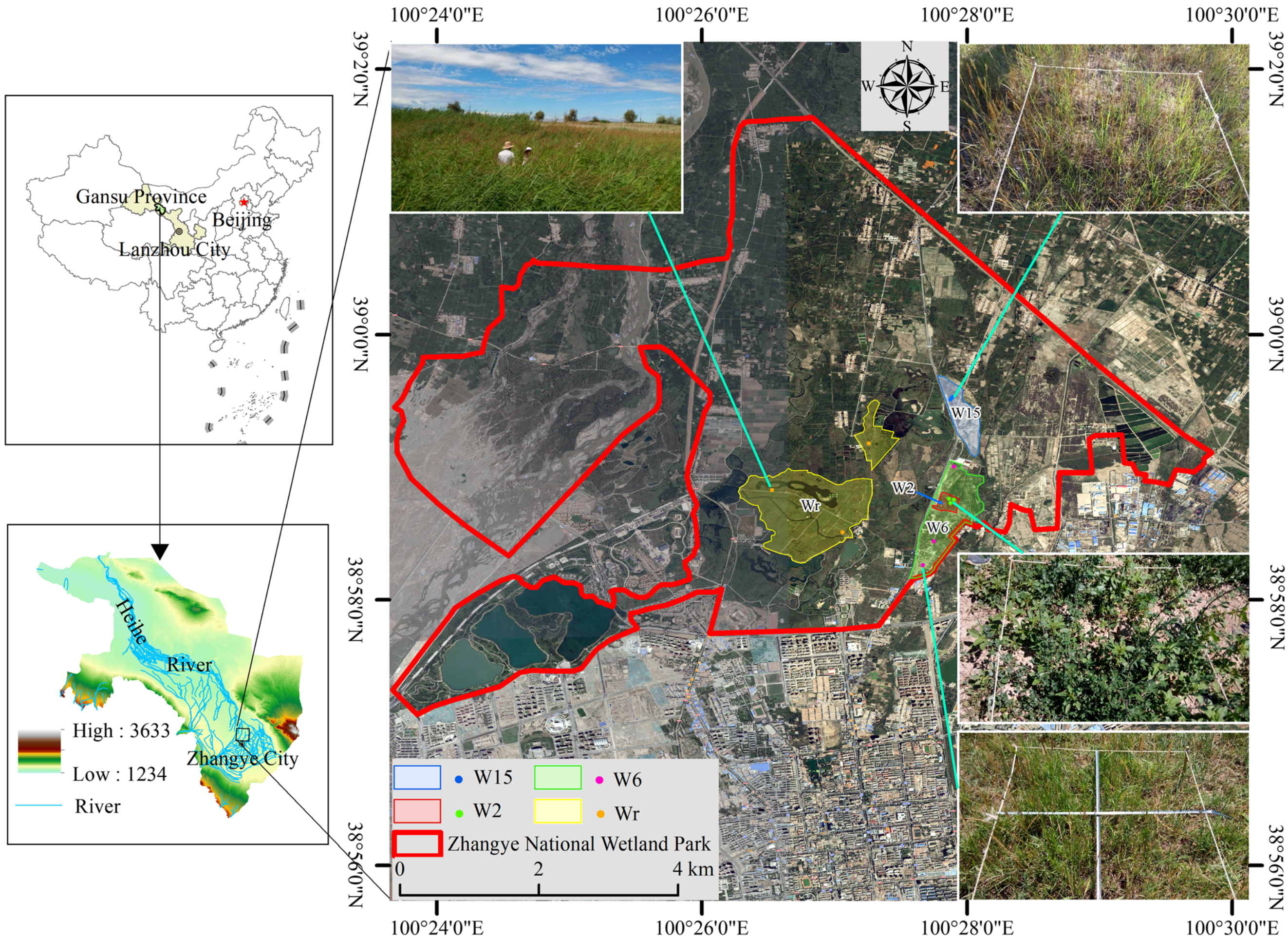

Fig. 1 Spatial distribution of the study sites. W2, W6, W15: abandoned cropland for 2, 6 and 15 years, respectively; Wr: reference wetland

the normality criteria and the test of the homogeneity of variances. The effects of the abandonment time (W2, W6, W15 and Wr) and soil depth (0–10, 10–20 and 20–40 cm) on the soil properties were assessed by using two-way ANOVAs with Duncan multiple comparisons. The significant differences in soil properties and plant properties among the four study sites were assessed using one-way ANOVA with Duncan multiple comparisons. The Spearman correlation analysis and Canonical Correspondence Analysis (CCA) were employed to assess the relationships between the species diversity and environmental factors. Significant differences were evaluated at the 0.05 level, unless otherwise noted. All

Table 1 Basic information about the study site

Restoration time (year)	Altitude (m)	Longitude (N)	Latitude (E)	Dominant plant species	Accompanying species
2	1460	38°58′40”	100°28′40”	*Amaranthus retroflexus L, Chenopodium glaucum L.*	*Phragmites australias Trin, Malva verticillata Linn, Pharbitis nil Choisy*.et al
6	1462	38°58′40”	100°28′01”	*Phragmites australias Trin, Suaeda Glauca Bunge, Salsolacollina Pall.*	*Agropyron cristatum Gaertn,Leymus secalinus Tzvel, Calamagrostis epigeios Roth, Amaranthus retroflexus L* .et al
15	1458	38°59′29”	100°28′65”	*Leymus secalinus Tzvel.*	*Suaeda glauca, Achnatherum splendens,Phragmites australias Trin*.et al
Reference wetland	1459	38°59′23”	100°27′40”	*Phragmites australias Trin.*	*Leymus secalinus Tzvel, Suaeda glauca, Elymus dahuricus Turcz* .et al

statistical tests were performed using SPSS 17.0 and Excel 2007 and the results were plotted using Origin 2017. Spearman's correlation analysis was confirmed using the R packages spaa and corrgram. The CCA was performed using CANOCO 5.0.

The Shannon–Wiener diversity index (*H*) and Pielou's evenness index (*E*) were used according to the statistical methods of community ecology (Zhang et al. 2015):

$$H = -\sum_{i=1}^{s} P_i lnP_i$$
$$E = H/lnS,$$

where *S* is the total species number of the community and P_i is the relative importance value of species *i*.

Results

Effects of the Wetland Restoration Time on the Plant Properties

Table 1 shows that the dominant plant species change in the 15 years after the fields were abandoned. In the first 2 years, the abandoned land was covered by a plant community dominated by *Amaranthus retroflexus L.* and *Chenopodium glaucum L.*, which were common to most abandoned fields. At the 6-year site, several wetland species, such as *Phragmites australis Trin*, could be observed. However, annual species, such as *Suaeda glauca Bunge* and *Salsolacollina Pall*, accompanied by perennial herbaceous species, were still the dominant species. After 15 years, the amount of several initial annual species, such as *Amaranthus retroflexus L.* and *Chenopodium glaucum L.*, decreased. The site was dominated by perennial species such as *Leymus secalinus Tzvel* and *Achnatherum splendens*. The natural wetland was dominated by *Phragmites australis Trin.*

The plant abundance increased with increasing abandonment time. One-way analysis of variance (ANOVA) indicated that species abundance was significantly different between W2 and Wr ($p < 0.05$). However, there was no significant difference between Wr and W6, W15. All these illustrated that plant abundance of abandonment wetlands became more and more similar to that in natural wetland with increasing abandonment time (Fig. 2C). However, plant height and coverage of farmlands abandoned for 15 years were still different from those in natural wetlands (Fig. 2A, Fig. 2B). The Shannon–Wiener diversity index (*H*) and Pielou's evenness index (*E*) increased firstly and then decreased near to natural wetland community with increasing abandonment time (Fig. 3).

Effects of the Wetland Restoration Time on the Soil Properties

The SOC, TN, TP, SWC, SA and pH differed significantly among the abandonment stages (Table 2, Figs. 4 and 5). The soil depth significantly affected the SOC and TN (Table 2, Fig. 4). There were insignificant interactions of abandonment time and soil depth on the soil nutrients (Table 2). Neither abandonment time nor soil depth affected soil BD (Table 2, Fig. 5).

Table 2. Effects of the abandonment time (Time) and soil depth (Depth) on the soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), soil water content (SWC), salinity (SA), bulk density (BD) and soil pH value.

The SOC contents at the depth of 0–10 cm increased along the wetland abandonment chronosequence. The SOC contents in sites of W6 and W15 were close to that in Wr. Except W2, the SOC content decreased with increasing soil depth (Fig. 4A). The change of the TN content was similar to that of the SOC (Fig. 4B). The TP content decreased along the abandonment sequence at each soil depth and those in W6 and W15 were similar to that in Wr. The TP content insignificantly changed with increasing soil depth (Fig. 4C).

The SWC increased along the wetland abandonment chronosequence at each soil depth. The SWC in Wr was significantly higher than that in W2. The SWCs in W6 and W15 were the closest to that in Wr. The SWC decreased with increasing soil depth (Fig. 5A). The SA increased firstly and then decreased along the abandonment chronosequence. In addition, the SA decreased with increasing soil depth (Fig. 5B). The soil BD did not change significantly with increasing abandonment time. The soil BD tended to increase with increasing soil depth (Fig. 5C). The pH value was greater than 8. The pH values at each soil depth decreased with increasing wetland abandonment time and it was the lowest in Wr ($p < 0.05$). The pH value changed insignificantly with increasing soil depth (Fig. 5D).

Relationships between Soil and Plant Properties

The plant height had a significant negative correlation with the pH value ($p < 0.01$). The plant coverage was negatively correlated with the pH value and positively correlated with the SOC content ($p < 0.05$). The plant abundance was negatively correlated with the SOC content and positively correlated with the SWC and SA ($p < 0.01$). However, the correlation between the plant diversity index (*H*) and nutrient content was not observed (Fig. 6).

Axes 1 and 2 explained 34.7% and 23.5% of the total variance, respectively. The species changed from annual to perennial herbaceous plants during the recovery along CCA axis 1. With decreasing soil pH and increasing SWC and salt, the dominant species in the plant community changed from

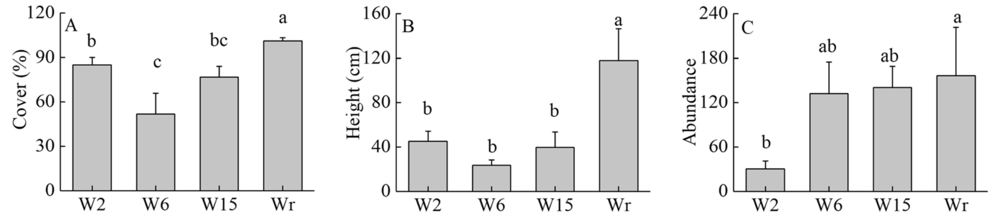

Fig. 2 Plant characteristics in the four study sites. The letters above the bars indicate the significant difference ($p < 0.05$) among the four study sites

annual herbs, such as *Amaranthus retroflexus*, *Chenopodium glaucumin,* and *Pharbitis nilamaranth*, to perennial herbs, such as *Phragmites australis*, *Leymus secalinus Tzvel* and *Mulgedium tataricum*, along the wetland abandonment chronosequence. Based on axis 2, perennial plants had a greater influence on the BD. However, annual herbaceous plants had a greater effect on the TN (Fig. 7).

Discussion

Wetland Restoration Affects Plant Community Structure

In this study, plant community showed a clear succession with increasing abandonment time. At first, the W2 site was covered by a xerophyte plant community dominated by *Amaranthus retroflexus L.* and *Chenopodium glaucum L.* And then, several wetland species, such as *Phragmites australis Trin*, appear in W6. However, annual species were still the main species, accompanied by perennial herbaceous species. Finally, the amount of initial annual species continuously declined. The land was dominated by perennial species such as *Leymus secalinus Tzvel* and *Achnatherum splendens* in W15. This suggests that abandoned wetlands in agricultural settings can develop toward diverse and native wetland plant communities within 15 years. This result is consistent with previous findings (Hopple and Craft 2013; Yepsen et al. 2014).

This study showed that the plant abundance, Shannon-Wiener diversity and Pielou's evenness index in the different abandonment stages moved towards a natural wetland community, suggesting that abandonment is beneficial to the restoration of species diversity. Species diversity can reflect the stability and sustainability of ecosystems (Joyce 2014; Moges et al. 2016). However, there were complex relationships between diversity and stability. Higher diversity did not mean higher stability, and similarly, the lower diversity did not mean instability (Wang et al. 2019). In our study, plant Shannon-Wiener diversity and Pielou's evenness index were higher in the early stage of abandonment than those in the later stage, as experienced over 10-year restoration, species richness decreased and species tended to be mesophyte and hygrophyte in W15 site. Although plant diversity decreased, the system is more stable (Nedland et al. 2007). Therefore, species diversity reduction should be considered as a positive phenomenon in the restoration of wetlands (Wang et al. 2019).

Wetland Restoration Affects Soil Properties

In the study, the SOC contents at the depth of 0–10 cm increased along the wetland abandonment chronosequence, indicating that soil organic carbon accumulated in agricultural abandoned land. The change of TN concentration is closely related to SOC (Segura et al. 2016). In this study, the lower contents of SOC and TN in W6 than W2 was probably related to previous farming practices, such as fertilization. Fertilization may result in higher concentrations of SOC and TN in W2 (Chmolowska et al. 2016). The higher contents of SOC and TN in W15 than W6 might resulted from the vegetation restoration with increasing abandonment chronosequence and more input of litter with plant community succession (Mazzoncini et al. 2016). Moreover, the mineralization of soil organic matter was inhibited due to the moister soil environment. Different from other sites, the lower SOC and TN concentration in the topsoil than that in subsurface soil in W2, is attributed to the accelerated erosion and loss of topsoil nutrients due to previous agricultural activities such as ploughing (Salekgilani et al. 2013). The SOC and TN were found to develop toward the natural wetlands, however,

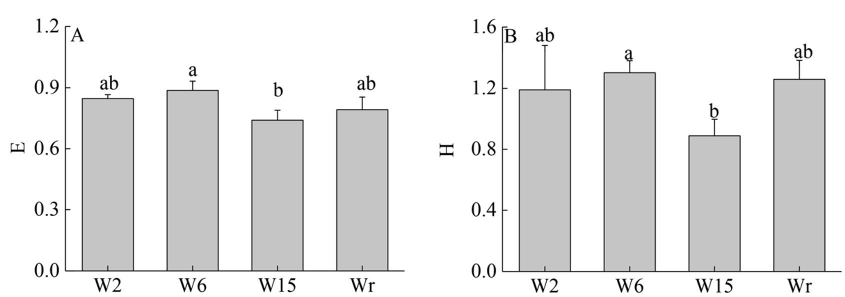

Fig. 3 Shannon–Wiener diversity index *H* (A) and Pielou's evenness index *E* (B) in the four study sites. The letters above the bars indicate the significant difference among the four study sites

Table 2 Effects of the abandonment time (Time) and soil depth (Depth) on the soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP), soil water content (SWC), salinity (SA), bulk density (BD) and soil pH value

Factors	Time		Depth		Time×Depth	
	F	P	F	P	F	P
SOC	3.073	0.047	9.293	0.001	1.495	0.222
TN	5.382	0.006	5.600	0.01	1.406	0.253
TP	27.443	<0.001	1.565	0.23	1.17	0.355
SWC	8.08	0.001	1.65	0.213	0.828	0.559
SA	4.093	0.018	2.416	0.111	0.732	0.629
BD	0.249	0.861	3.116	0.063	0.708	0.646
pH	5.307	0.006	0.858	0.436	0.324	0.918

restoration of degraded wetland ecosystems might need a long time.

In this study, the TP content decreased with the wetland restoration chronosequence in each soil layer. Higher soil phosphorus levels in earlier abandonment stages were possibly due to residual phosphorus from previous fertilization practices, while the decrease in the phosphorus concentration in later abandonment stages might be ascribed to the more phosphorus uptake from plants (Marie et al. 2016). It was different from the result of Lu et al. (2007) who reported that the phosphorus concentration increased with restoration time. The soil phosphorus content of natural wetland in arid regions in the present study is lower than that of the lake wetland in humid regions. Therefore, the reduction of soil phosphorus content towards natural wetlands should be rational in the restoration of reclaimed wetlands in this study.

In the study, the pH values decreased with increasing wetland restoration time at each soil depth, as recovery of vegetation and more litter decomposition resulted in lower soil pH during abandonment (Lu et al. 2007). Meanwhile, natural wetlands are found to be less frequently acidic than fallow, suggesting natural wetland provides a better habitat for plants and soil microorganisms. In the present study, the SA increased firstly and then decreased along the abandonment chronosequence, which was possibly related to the increased evapotranspiration with increasing species abundance in sites of W6 and W15. The decreased SA with increasing soil depth was also due to the high rates of evapotranspiration at soil surface (Jolly et al. 2010).

The changes and differences in the physical properties can be used to determine the intensity of the land degradation and development, which provides a reference to the management of abandoned farmland (Guo et al. 2016). The results of this study showed that the SWC increased along the abandonment chronosequence toward natural wetlands, which was consistent with SOC dynamics. The more amount of plant residues such as aboveground litter and dead roots entering the soil contributed to the increased SOC content, improved soil water holding capacity and consequently increased soil water content (Mazzoncini et al. 2016; Chmolowska et al. 2016).

The Relationships between Soil and Plant Properties during Wetland Restoration

This study showed that soil properties had a significant effect on the vegetation characteristics along the

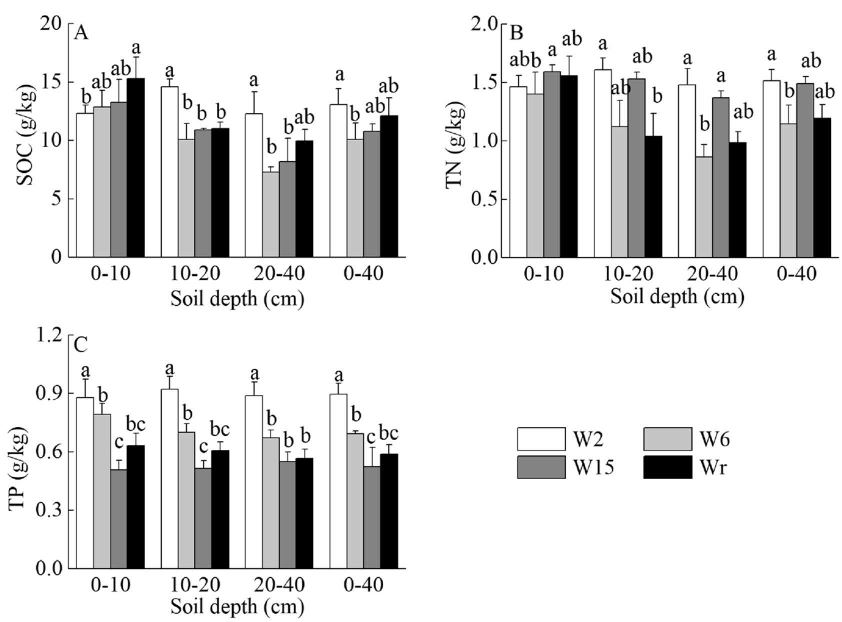

Fig. 4 Soil organic carbon (A), total nitrogen (B) and phosphorus (C) contents in the four sites and different soil layers. The letters above the bars indicate the significant difference ($p < 0.05$) among the four sites at each soil layer

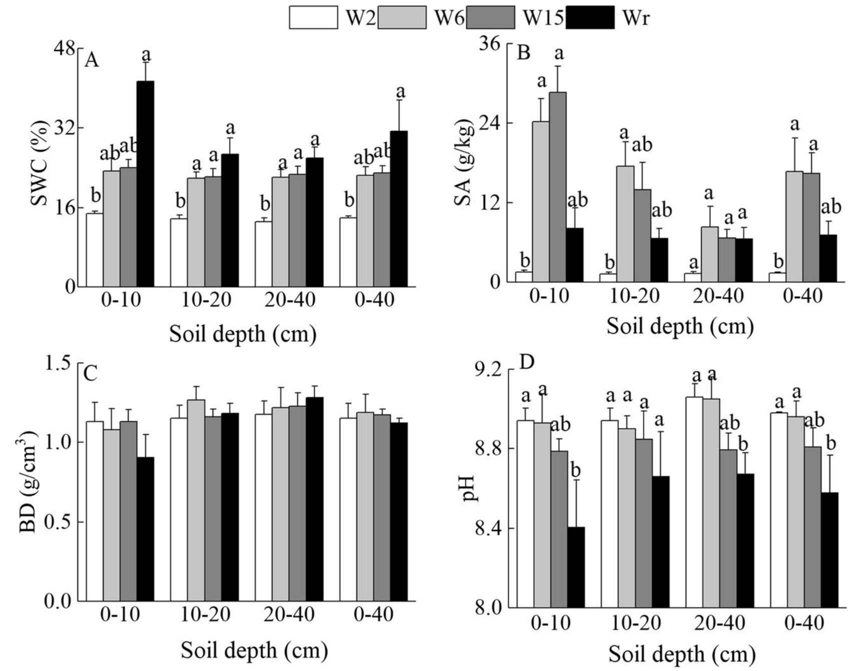

Fig. 5 Soil water content (A), soil salt content (B), soil bulk density (C), and soil pH (D) at different soil layers in the four study sites. The letters above the bars indicate the significant difference among the four study sites at each soil layer ($p < 0.05$)

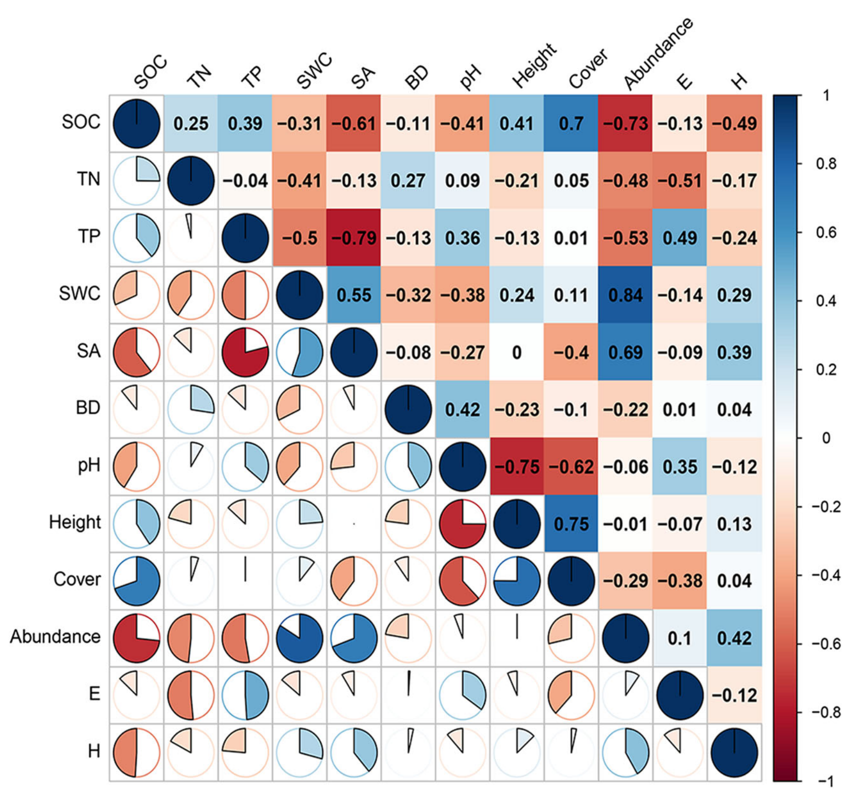

Fig. 6 Semi-matrices of the Spearman correlation coefficients between the species diversity and environmental factors. Legend: 0 represents no correlation, 1 represents the greatest correlation, and − 1 represents the smallest correlation. The same colours are used for the squares and circles and the proportion of the filled area represents the absolute value of the correlation. The value of the correlation is indicated by the shaded colour and saturation. A circular clockwise-filled area represents a positive correlation and a counterclockwise-filled area represents a negative correlation. In terms of the filled areas, a circle with $S \geq 2/3$ indicates a very significant positive correlation, a circle with $1/3 \leq S < 2/3$ indicates a significant correlation, and a circle with $S < 1/3$ and non-filled circles indicate no correlation. SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; SWC, soil water content; SA, salinity; BD, bulk density; *H*, Shannon–Wiener index; *E*, Pielou's index

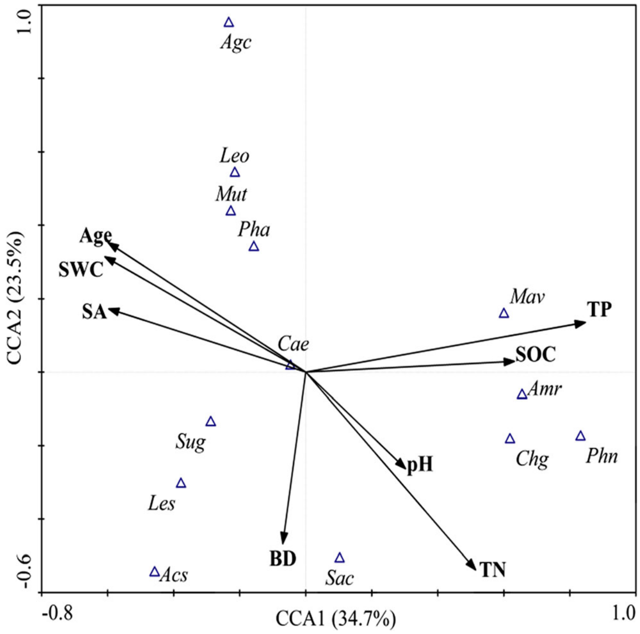

Fig. 7 CCA ordination for the first two axes of the floristic composition data and soil organic carbon (SOC), total nitrogen (TN), total phosphorus (TP) contents, soil water content (SWC), salinity (SA), bulk density (BD), and soil pH in the four study sites. Species codes: *Amaranthus retroflexus* (*Amr*), *Chenopodium glaucum* (*Chg*), *Pharbitis nil* (*Phn*), *Phragmites australis* (*Pha*), *Mulgedium tataricum* (*Mut*), *Leymus secalinus Tzvel* (*Les*), *Salsola collina* (*Sac*), *Malva verticillata* (*Mav*), *Achnatherum splendens* (*Acs*), *Suaeda glauca* (*sug*), *Calamagrostis epigeios* (*Cae*), *Agropyron cristatum* (*Agc*) and *Lepidium obtusum* (*Leo*)

abandonment stages. The correlations between the plant characteristics and soil factors indicated that the plant coverage was positively correlated with the SOC and the plant abundance was positively correlated with the SWC ($p < 0.05$). When soil nutrient conditions are relatively poor, vegetation growth state will become better with the increase of limited water and fertilizer (Ma et al. 2017; Russell and Beauchamp 2017). However, the correlation between the plant diversity index and nutrient contents cannot be observed. This is because soil nutrient concentration does not affect plant diversity, while sufficient nutrients can effectively promote plant growth and reproduction (Petersen et al. 2015).

Based on the CCA analysis, the main plant species in the community changed from annual to perennial herbs with the decline of the soil pH value and rise of the SWC and SA, suggesting that the stability of the plant communities and soil quality improved along the abandonment chronosequence. Wang et al. (2018) also found that development of perennial grass species can improve the stability of the plant community in farmland abandoned soils. The main species of the plant community in the later succession periods were *Phragmites australis* and *Mulgedium tataricum* (perennial grass), which may improve soil quality of abandoned farmlands in some extent.

Implications for Wetland Management

By the second year, these sites and zones showed higher richness and species diversity values close to those of the reference wetlands, indicating that vegetation recovery occurred. However, wetlands restored for 15 years were still different from natural wetlands (e.g. plant height and coverage). Thus, it is necessary to conduct the long-term monitoring and research on vegetation restoration as the natural restoration and succession of the vegetation are relatively slow process in arid areas (Joyce 2014; Yepsen et al. 2014). The soil salt content of abandoned farmland was higher than that of natural wetland in this study, consequently attention should be paid to the elimination of salt and alkalinity during restoration management of abandoned farmland. The soil phosphorus content generally increases during the wetland recovery in humid region (Lu et al. 2007), however, soil phosphorus content reduced in the restoration of reclaimed wetlands due to the relatively low phosphorus content in the natural wetland in this study. Therefore, a present natural wetland should be selected as a reference target for the management of wetland restoration (Wang et al. 2019).

Conclusion

Land use change for abandoned farmlands may exert a profound influence on soil and vegetation. With increasing abandonment time, plant abundance, Shannon-Wiener diversity and Pielou's evenness index moved towards a natural wetland community. Soil nutrients and soil quality improved with increased abandonment time. Soil and vegetation facilitated one another in the abandonment stages. The results could supply scientific evidence for restoration and protection of degraded wetland in arid region.

Acknowledgments We thank the Administration of Zhangye National Wetland Park for their supports to the data collection and the field investigation, as well as Dr Haili Zhao at College of Geography and Environment Science, Northwest Normal University for her help with field experiments.

Data Availability(Data Transparency) Not applicable.

Authors' Contributions Ruifeng Zhao (RF Zhao) contributed to the conception of the study and formal analysis and investigation; Xiaoya Zhang (XY Zhang) performed the data analyses and wrote the manuscript; Lihua Zhang (LH Zhang) contributed to the review and editing; Yuanbo Wang (YB Wang) helped perform the experiment.

Funding The research is supported by the National Natural Science Foundation of China (41261047, 41761043), the Scienceand

Technology Project of Gansu Province (20YF3FA042) and the Youth Teacher Scientific Capability Promoting Project of Northwest Normal University (NWNU-LKQN-17-7, NWNU-LKQN-2020-06).

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no competing interests or conflicts of interest.

Ethics Approval Not applicable.

Consent to Participate (Include Appropriate Statements) Not applicable.

Consent for Publication (Include Appropriate Statements) Not applicable.

Code Availability (Software Application or Custom Code) Not applicable.

References

Bai JH, Ouyang H, Deng W, Zhu YM, Zhang XL, Wang QG (2005) Spatial distribution characteristics of organic matter and total nitrogen of marsh soils in river marginal wetlands. Geoderma 124:181–192. https://doi.org/10.1016/j.geoderma.2004.04.012

Ballantine KA, Anderson TR, Pierce EA, Groffman PM (2017) Restoration of denitrification in agricultural wetlands. Ecological Engineering 106:570–577. https://doi.org/10.1016/j.ecoleng.2017.06.033

Bruland GL, Hanchey MF, Richardson CJ (2003) Effects of agriculture and wetland restoration on hydrology, soils, and water quality of a Carolina bay complex. Wetlands Ecology and Management 11:141–156. https://doi.org/10.1023/a:1024244408577

Chmolowska D, Kozak M, Laskowski R (2016) Soil physicochemical properties and floristic composition of two ecosystems differing in plant diversity: fallows and meadows. Plant and Soil 402:317–329. https://doi.org/10.1007/s11104-015-2788

Engelhardt KAM, Ritchie ME (2001) Effects of macrophyte species richness on wetland ecosystem functioning and services. Nature 411:687–689. https://doi.org/10.1038/35079573

Guo CX, He F L, Ma JP, An FB, Ma JM, Yuan HB, Zhao P, Liu KB, Shen GF (2016) Studies of soil physical properties and community characteristics of different abandoned lands in the Minqin oasis, Downstream of the Shiyang River. Agricultural Science & Technology 17(7):1697–1701. https://doi.org/10.16175/j.cnki.1009-4229.20160715.002

Hopple A, Craft C (2013) Managed disturbance enhances biodiversity of restored wetlands in the agricultural Midwest. Ecological Engineering 61:505–510. https://doi.org/10.1016/j.ecoleng.2012

Inglett PW, Inglett KS (2013) Biogeochemical changes during early development of restored calcareous wetland soils. Geoderma 192:132–141. https://doi.org/10.1016/j.geoderma

Jolly ID, Mcewan KL, Holland KL (2010) A review of groundwater–surface water interactions in arid/semi-arid wetlands and the consequences of salinity for wetland ecology. Ecohydrology 1:43–58. https://doi.org/10.1002/eco.6

Joyce CB (2014) Ecological consequences and restoration potential of abandoned wet grasslands. Ecological Engineering 66:91–102. https://doi.org/10.1016/j.ecoleng.2013.05.008

Li Y, Gao Z, Tang L (2016) Soil-plant characteristics in an age sequence of Coronilla varia L. plantations along embankments. Journal of Soil Science and Plant Nutrition 16:187–199. https://doi.org/10.4067/s0718-95162016005000015

Lu J, Wang H, Wang W, Yin C (2007) Vegetation and soil properties in restored wetlands near lake Taihu, China. Hydrobiologia 581:151–159. https://doi.org/10.1007/s10750-006-04

Ma MJ, Baskin CC, Yu KL, Ma Z, Du GZ (2017) Wetland drying indirectly influences plant community and seed bank diversity through soil pH. Ecological Indicators 80:186–195. https://doi.org/10.1016/j.ecolind.2017.05.027

Mao D, Luo L, Wang Z, Wilson MC, Zeng Y, Wu B, Wu J (2018) Conversions between natural wetlands and farmland in China: a multiscale geospatial analysis. Science of the Total Environment 634:550–560. https://doi.org/10.1016/j.scitotenv.2018.04.009

Marie S, Tibor József N, József I, Giani L (2016) Dynamics of soil carbon, nitrogen, and phosphorus in calcareous soils after land-use abandonment –a chronosequence study. Plant and Soil 401:185–196. https://doi.org/10.1007/s11104-015-2513-6

Mazzoncini M, Antichi D, Bene CD, Risaliti R, Petri M, Bonari E (2016) Soil carbon and nitrogen changes after 28 years of no-tillage management under mediterranean conditions. European Journal of Agronomy 77:156–165. https://doi.org/10.1016/j.eja.2016.02.011

Moges A, Beyene A, Ambelu A, Mereta ST, Triest L, Kelbessa E (2016) Plant species composition and diversity in wetlands under forest, agriculture and urban land uses. Aquatic Botany 138:9–15. https://doi.org/10.1016/j.aquabot.2016.12.001

Nedland TS, Wolf A, Reed T (2007) A reexamination of restored wetlands in Manitowoc County, Wisconsin. Wetlands 27:999–1015 10.1672/0277–5212(2007)27[999: ARORWI]-2.0.CO;2

Petersen JE, Brandt EC, Grossman JJ, Allen GA, Benzing DH (2015) A controlled experiment to assess relationships between plant diversity, ecosystem function and planting treatment over a nine year period in constructed freshwater wetlands. Ecological Engineering 82:531–541. https://doi.org/10.1016/j.ecoleng.2015.05.002

Russell KN, Beauchamp VB (2017) Plant species diversity in restored and created Delmarva Bay wetlands. Wetlands 37:1–15. https://doi.org/10.1007/s13157-017-0945-x

Salekgilani S, Raiesi F, Tahmasebi P, Ghorbani N (2013) Soil organic matter in restored rangelands following cessation of rainfed cropping in a mountainous semi-arid landscape. Nutrient Cycling in Agroecosystems 96:215–232. https://doi.org/10.1007/s10705-013-9587-4

Segura C, Jiménez MN, Nieto O, Navarro FB, Fernández-Ondoño E (2016) Changes in soil organic carbon over 20 years after afforestation in semiarid SE Spain. Forest Ecology and Management 381:268–278. https://doi.org/10.1016/j.foreco.2016.09.035

Toth LA (2010) Unrealized expectations for restoration of a floodplain plant community. Restoration Ecology 18:810–819. https://doi.org/10.1111/j.1526-100X.2010.00731.x

Toth LA (2015) Invasibility drives restoration of a floodplain plant community. River Research and Applications 31:1319–1327. https://doi.org/10.1002/rra.2836

Wang B, Deng ML, Wang G, ZB FU (2015) Causes for wetland degradation and its control in middle reaches of Heihe Basin in Zhangye of Gansu. Wetland Science & Management 11:36–38 (in Chinese with English abstract)

Wang D, Zhang B, Zhu LL, Yang YS, Li MM (2018) Soil and vegetation development along a 10-year restoration chronosequence in tailing dams in the Xiaoqinling gold region of Central China. Catena 167:250–256. https://doi.org/10.1016/j.catena.2018.05.007

Wang XH, Tong SZ, Li YZ, Qi Q, Zhang DJ, Lu XG, Guo Y, Liu Y (2019) Plant diversity performance after natural restoration in reclaimed *Deyeuxia angustifolia* wetland. Chinese Geographical Science 29(3):437–445. https://doi.org/10.1007/s11769-019-1043-1

Wood SE, White JR, Armbruster CK (2017) Microbial processes linked to soil organic matter in a restored and natural coastal wetland in

Barataria Bay. Louisiana Ecol Eng. 106:507–514. https://doi.org/10.1016/j.ecoleng.2017.06.028
Xu X, Jiang Y, Liu MH, Huang QZ, Huang GH (2019) Modeling and assessing agro-hydrological processes and irrigation water saving in the middle Heihe River basin. Agricultural Water Management 211: 152–164. https://doi.org/10.1016/j.agwat.2018.09.033
Yepsen M, Baldwin AH, Whigham DF, Mcfarland E, Laforgia M, Lang M (2014) Agricultural wetland restorations on the Usa Atlantic coastal plain achieve diverse native wetland plant communities but differ from natural wetlands. Agriculture, Ecosystems & Environment 197:11–20. https://doi.org/10.1016/j.agee.2014.07.007
Yu L, Huang Y, Sun F, Sun W (2017) A synthesis of soil carbon and nitrogen recovery after wetland restoration and creation in the United States. Scientific Reports 7:7966. https://doi.org/10.1038/s41598-017-08511-y
Zhang Y, Wang R, Kaplan D, Liu J (2015) Which components of plant diversity are most correlated with ecosystem properties? A case study in a restored wetland in northern China. Ecological Indicators 49:228–236. https://doi.org/10.1016/j.ecolind.2014.10.001
Zhao RF, Xie ZL, Zhang LH, Zhu W, Liang D (2015) Assessment of wetland fragmentation in the middle reaches of the Heihe River by the type change tracker model. Journal of Arid Land 7(2):177–188. https://doi.org/10.1007/s40333-014-0047-z
Zhao RF, Zhang LH, Zhao HL, Jiang PH, Wang JZ (2013) Distribution of soil organic carbon of wetlands in the middle reaches of the Heihe River and its influencing factors. Scientia Geographica Sinica 33: 363–370 (in Chinese with English abstract)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.