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RESEARCH ARTICLE

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Planting trees in saline soil using ridge cultivation with drip irrigation in an arid region of China

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Abstract

Land degradation due to soil salinization is a widespread problem in arid and semiarid areas. In the Hetao Irrigation District in the upper reaches of the Yellow River in China, nearly one-third of the land is salinized. To improve the environment in these salt-affected regions, we conducted a field experiment in the Hetao Irrigation District from 2018 to 2020 that involved planting poplar and willow trees in saline soil using ridge cultivation with drip irrigation. After 3 years of water–salt regulation by drip irrigation, soil salinity at 0–40 and 0–120 cm with initial values of 12.22 and 8.27 dS m^{-1} was reduced by 85.19% and 68.56%, respectively. The survival rates of the seedlings were 99.3% (poplar) and 99.4% (willow) in the first year, and 90.6% (poplar) and 95.8% (willow) in the third year. Moreover, drip irrigation used 42.19% less water for salt leaching than other common methods. In addition, understory vegetation gradually established, and its species, coverage, and density increased year by year. A plant community structure gradually developed that comprised Poaceae and Asteraceae. In general, we found that ridge cultivation with drip irrigation led to an improved the soil environment which affected the development of the ecosystem shifting it in a stable, healthy, and sustainable direction. Taken together, our results indicate that ridge cultivation with drip irrigation can decrease soil salinity and produce ecological benefits.

KEYWORDS
drip irrigation, ecological conservation, saline soil reclamation, salt leaching, trees

1 | INTRODUCTION

Land degradation with salinity is a widespread problem in arid and semiarid areas, especially when seepage from irrigation systems increases the watertable and consequently builds up excessive salts in soils, which impair crop production (Minhas et al., 2020; Tejada et al., 2006; T. B. Zhang et al., 2016). The Hetao Irrigation District is located in the upper reaches of the Yellow River, and it is the main grain-producing area in China. Due to the influence of the arid climate in the region, coupled with the increased watertable from agricultural flood irrigation, a large area of moderately and severely saline soil has formed, and nearly 30% of the land is salinized (W. Zhang, Lou, et al., 2003). Most of the trees have died, and it is difficult to develop vegetation in these saline soils. The common method used for planting trees in this region is to replace saline soil with non-saline soil. Then, trees are planted in the non-saline soil under flat tillage and flood irrigation conditions. However, this method is expensive and unsustainable, due to the shallow and saline groundwater. Trees survival rates are usually less than 70% after the third year (Qiao & Sun, 1995; Shi et al., 2020; L. X. Zhang, Han, et al., 2003).

Planting salt-tolerant trees is an effective way to improve the ecology and environment in salt-affected regions. Although there are some salt-tolerant tree species, they are limited by climate and other conditions. In recent studies, drip irrigation was successfully applied to salt leaching to reclaim saline soils for agricultural production and afforestation in coastal regions and semiarid areas in China (Dong et al., 2017, 2020; Li et al., 2015a, 2015b, 2016). In these studies, the soil matric potential (SMP) was controlled and the soil was monitored using tensiometers at 20 and 50 cm under drip emitters. Salt leaching and improved survival rates were obtained using drip irrigation. Moreover, this approach requires less water, which is important to the ecology of arid and semiarid regions.

It is beneficial to plant trees to improve the environment in the saline regions of the Hetao Irrigation District and to build a farmland shelterbelt. *Populus alba* L. (silver poplar) and *Salix matsudana* Koidz (Chinese willow) have characteristics of well-developed roots, fast growth, strong wind resistance, cold and drought resistance, and smoke and dust pollution reduction. In addition, they can conserve water and help to maintain healthy soil. Poplar and willow grows best in moist and well-drained soil. They are more resistant to saline and alkali but grow poorly in unimproved saline alkali soils (Mirck & Zalesny, 2015; Zeng & Song, 2000). Poplar and willow are important greening and economic tree species in arid and semiarid areas in China, and they are widely used in landscaping, as windbreaks, and sand fixation (Wu et al., 2008; X. Y. Xu et al., 2011; T. Xu et al., 2017; Zeng & Song, 2000).

In China, with the development of the economy and the demand for a livable environment, there is an urgent need for methods and technologies to improve the ecology of saline areas. Vegetation restoration typically involves replacing saline soil with non-saline soil, and the soil replacement depth is usually less than 100 cm in arid saline areas. Soil replacement is unsustainable, however, because the surface of non-saline soil is shallow and there is little available non-saline soil due to government bans on removing soil from farmland. Moreover, this method consumes considerable water resources, due to the need for flood irrigation. As such, soil replacement is not conducive to the construction and restoration of large-scale vegetation in arid regions. Ridge cultivation combined with drip irrigation offers the potential for a new method of saving water and soil resources in arid saline soil. In this study, we investigated whether ridge cultivation with drip irrigation could reclaim saline soil for vegetation in the Hetao Irrigation District using the original saline soil. Our study offers theoretical guidance and practical applications for ecological construction in arid saline soil areas in the future.

2 | MATERIALS AND METHODS

2.1 | Experiment site

A field experiment that involved planting an ecological shelterbelt was conducted from 2018 to 2020 near Dashagedan Village (41°2′26″ N, 108°20′53″ E), located in Wuyuan, the northernmost county of the Yellow River in China. This area has a mid-temperate continental climate, characterized by abundant light energy and sufficient sunshine. The area is dry and windy. Rainfall in 2018, 2019, and 2020 totaled 210.2, 104.3, and 238.4 mm, respectively, mostly in summer and autumn. The average temperature in 2018, 2019, and 2020 was 7.76, 7.67, and 7.26°C, respectively. The groundwater depth is between 0.2 and 1.4 m. According to the USDA soil classification, the soil in our experiment field was silt loam soil, with clay (<0.002 mm) content of 9.65%, silt (0.002–0.05 mm) content of 69.62%, and sand (0.05–2 mm) content of 20.72%. This soil has a characteristically sticky structure, poor ventilation, and low permeability. The initial soil texture, electrical conductivity of the saturated soil paste (ECe), and pH of saturated paste (pHe) are shown in Table 1.

2.2 | Experimental design

2.2.1 | Planting pattern

The ecological shelterbelt was planted between the C031 road and farmland near Dashagedan Village to decrease wind speed, conserve water, and prevent soil erosion. In this area, the groundwater is high and there is much seasonal variation. To lower the groundwater depth and reduce the impact of salt returning to the plant roots from shallow groundwater evaporation, ridge cultivation was used. The saline soil structure is always destroyed owing to the poor water conductivity and air permeability that results from waterlogging (Li et al., 2016;

TABLE 1 Soil mechanical composition, ECe (electrical conductivity of saturated paste extracts), and pHe (pH of saturated paste) in initial soil

	Soil mechanical composition (%)					
Soil depths (cm)	<0.002 mm	0.002–0.05 mm	0.05–2 mm	Soil texture	ECe (dS m^{-1})	pHe
0–10	7.9	61.8	30.3	Silt loam	14.02	8.03
10–20	9.4	64.9	25.7	Silt loam	10.90	8.11
20–30	8.7	69.7	21.6	Silt loam	11.59	8.04
30–40	9.2	69.1	21.7	Silt loam	12.37	8.06
40–60	9.2	66.4	24.4	Silt loam	7.23	8.08
60–80	12.1	74.9	13.0	Silt loam	3.79	8.42
80–100	9.6	78.2	12.2	Silt loam	3.15	8.68
100–120	11.0	72.0	17.0	Silt loam	3.12	8.76

Tong, 2014; Ulrike et al., 2009). Moreover, ridge furrows are flooded after heavy rains. Therefore, trees should be planted on the ridge surface to avoid flooding. In addition, drip irrigation can ensure sufficient water for trees along the ridge surface. The saline soil was ridged to 0.5 m high at a spacing of 1.60 m. The ridge surface was curved at 0.4 m wide, and the widths of the ridge bottom and furrow were 1.3 and 0.9 m, respectively (Figure 1). Seven drip tapes were arranged at the ridge surface, spaced 0.3 m apart. There were three thick wall drip irrigation tapes (0.6 mm) and four thin wall drip irrigation tapes (0.2 mm). The specific layout is shown in Figure 1.

P. alba L. (silver poplar) and *S. matsudana* Koidz (Chinese willow) seedlings with a diameter at breast height (DBH) of 5–6 cm were transplanted into 25 × 25 × 25 cm holes in rows spaced 1.5 m apart and filled with the sand. Before planting, the branches were cutoff and shortened. The main stem was cutoff at 1.8 m in height. The seedlings were protected with paint or film to prevent water loss from affecting the survival rate. The ecological shelterbelt was 750 m long and 4.8 m wide, and comprised 1000 poplars and 500 willows. All plants were set at a lateral spacing of 0.05 m from the drip tapes.

2.2.2 | Irrigation management

According to existing research regarding coastal areas and semi-arid areas, the irrigation measures were divided into three stages: an enhanced salt leaching stage (stage I), a water-salt regulation stage (stage II), and a normal irrigation stage (stage III) (Dong et al., 2017). During stage I, the small flow rate of the emitter with hydraulic pressure of 0.02–0.04 mPa was controlled, and irrigation continued for 3–5 days using all drip irrigation tapes. At this stage, large areas of surface water were avoided, but irrigation continued after infiltrating the surface water. When the in situ electrical conductivity of 0–10 cm soil was lower than 4 dS m^{-1}, stage I was considered complete. Then, we buried tensiometers at 20 and 50 cm below the emitter nearest to the trees and proceeded to stage II.

During and after stage II, only three thick wall drip irrigation tapes were in operation. The other tapes were not used, and the hydraulic pressure was set at 0.1 mPa. At stage II, SMPs at 20 cm were set to −5 kPa for irrigation. The depth of the water for each irrigation event was 10 mm. If the tensiometers at 20 cm did reach the set value after irrigating, we irrigated the trees based on a single amount until the set reading was reached. When the ECe was lower than 4 dS m^{-1} in the 0–120 soil layer, this stage was considered complete. Stage II sometimes lasted 4–6 months.

Stage III resembled stage II, but SMPs at 20 cm were set to −15 kPa for irrigation. At this stage, twice the amount of water was used for irrigation. To replenish the soil water reservoir in time to meet the demand for water during winter and to mitigate soil water deficits in early spring and provide suitable conditions for plants to sprout, irrigation is necessary at the beginning (early April) and end (mid-October) of the growing season. The irrigation amount was about four times the signal irrigation amount according to soil water and salt conditions (Dong et al., 2020; Li et al., 2015b).

For water–salt regulation, drip irrigation was applied based on the SMP, which was monitored using a vacuum gauge tensiometer. In the field, one vacuum gauge tensiometer was installed 20 cm directly underneath an emitter, and irrigation was applied when the tensiometer reading exceeded the target SMP value. For large areas of farmland or regions lacking labor resources, electronic vacuum gauges can be used to monitor the SMP, and if the value exceeds the target SMP

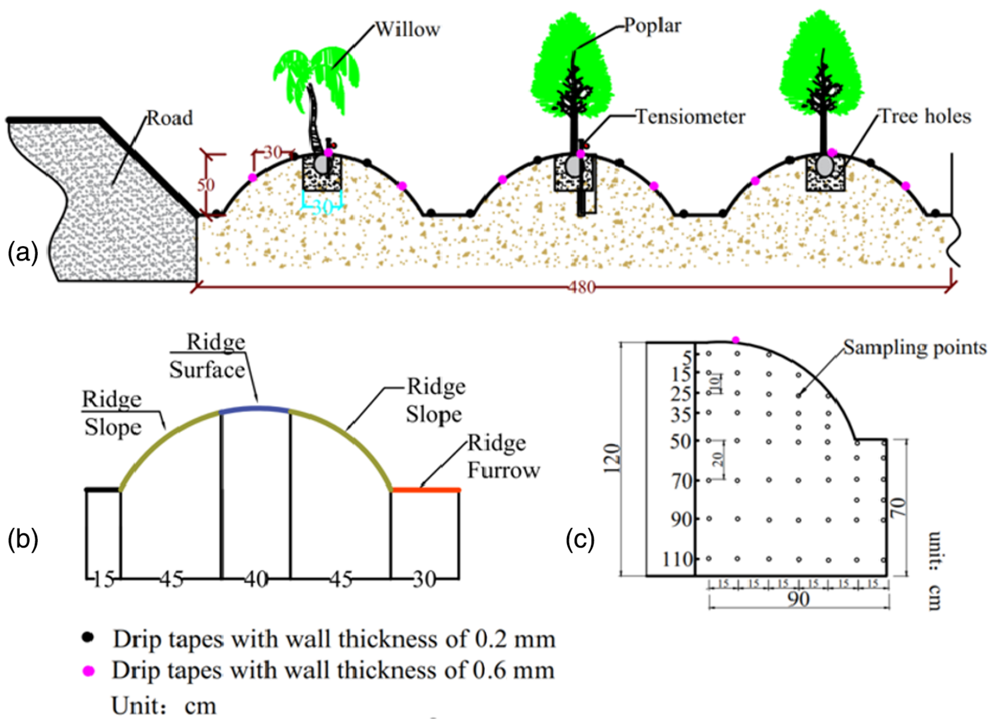

FIGURE 1 Vegetation planting pattern (a) the layout of vegetation planting, cross-section view of the ridge; (b) schematic diagram of ridge surface, ridge slope, and ridge furrow; (c) soil sampling) [Colour figure can be viewed at wileyonlinelibrary.com]

value, the electronic vacuum gauge will send a signal to initiate the irrigation system. Because this process is automated, it does not require human participation. It can be operated easily in the field based on information and automatization technology.

2.3 | Observation and measurement

2.3.1 | Irrigation

The amount of irrigation was determined using a water meter.

2.3.2 | Soil ECe

Soil samples were taken from each plot with an auger (4 cm in diameter and 10 cm high) at the beginning and the end of the second and third growing seasons. Before sampling, a drip emitter in the middle of a drip tape on the ridge surface was selected randomly in a plot. Then, samples were taken from one side based on the drip emitter. Each sample was taken three times (Figure 2c). All soil samples were air-dried and sieved through a 2-mm sieve. Each sample was made into an extract of saturated soil paste using a standard method (Robbins & Wiegand, 1990). The ECe was determined with a conductivity meter (DDS-11A, Yulong, Shanghai, China) based on extracts of the saturated soil paste.

In these trials, the average ECe values within the whole soil profile were integrated to account for spatial and temporal variation. The average values of ECe in the soil profile were calculated as follows:

$$ECe(t) = \frac{\Sigma_{j,k}^{n,m} ECe(t,j,k) \times S(j,k)}{\Sigma_{j,k}^{n,m} S(j,k)}, \quad (1)$$

Where: t represents the time at which soil samples were obtained, j is the distance from the emitter where the soil samples were attained, k is the depth of the soil samples, and $S(j, k)$ is the depth interval of the soil sample (Li et al., 2015a).

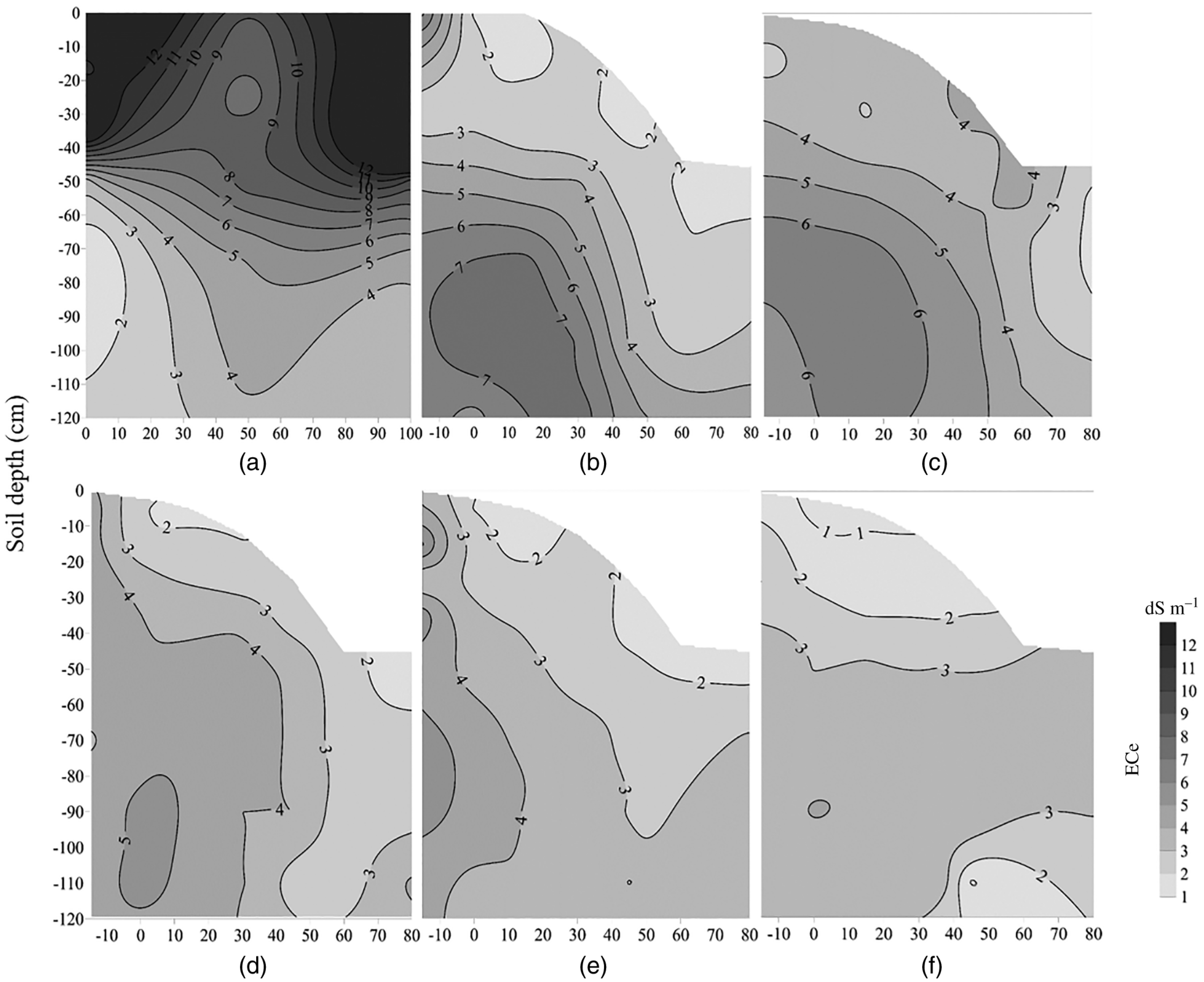

FIGURE 2 Spatial distributions of the electrical conductivity soil paste extracts (ECe) in different periods: (a) May 2018 before experiment; (b) Sep. 2018; (c) Apr. 2019; (d) Oct. 2019; (e) Apr. 2020; (f) Oct. 2020

2.3.3 | Plant survival rate and growth

Willow and poplar seedlings were planted in June 2018. After 15 days of planting, the germination rate was investigated. Then, at the end of 2018, 2019, and 2020 growing seasons (usually at the end of August), the growth indices of willow and poplar seedlings were measured: survival rate, height (H), ground diameter (GD), and diameter at breast-height (DBH). The seeds in the soil seed bank sprouted naturally with the improved soil environment, forming an understory vegetation community structure that changed year by year. The understory vegetation was measured using quadrats 1 m wide and 2 m long between trees and along the entire ridge. After dividing the ridge surface, ridge slope, and ridge furrow, observations were carried out. The coverage was measured visually; the herb species and their quantity in each quadrat were investigated, and the data were recorded and analyzed statistically.

2.4 | Statistical analyses

All data gathered in the study were recorded and classified in Microsoft Office EXCEL 2016. Data were analyzed using IBM SPSS Statistics version 24.0 (IBM Co., Armonk, NY, USA). Differences in pHe, ECe, and growth indexes over different time were compared by one-way ANOVA. Figures were created using SURFER version13.0 (Golden Software Inc., CO, USA) and ORIGIN 2020 (Origin Lab Inc., MA, USA).

3 | RESULTS AND DISCUSSION

3.1 | Irrigation amount

The amount of irrigation during the three growing seasons is shown in Table 2. The total amount of irrigation was 6460.5, 8244, and 6106.5 m^3 ha^{-1} in 2018, 2019, and 2020, respectively, under the pattern of original soil drip irrigation. The amount of flood irrigation with imported soil was relatively stable, and the annual water demand was about 12,000 m^3 ha^{-1}. We found that, compared to flood irrigation with imported soil, water consumption from drip irrigation of the original soil saved 42.19% freshwater. In general, the amount of irrigation water decreased each year. Water conservation is a significant feature of drip irrigation for water-salt regulation (Dong et al., 2020; Dou et al., 2011; Goldberg et al., 1976; Li et al., 2015a).

Vegetation needs a suitable soil environment for survival and growth (Qadir et al., 2008; Ravindran et al., 2007). With flood irrigation, however, the large amount of water needed for each irrigation period and the lower frequency of irrigation result in volatile changes in soil moisture, and this affects the growth of the vegetation in saline soil (Fan et al., 2014). Drip irrigation overcomes these problems to create more uniform soil moisture, fertilizer, air, and heat conditions that are more suitable for vegetation growth in saline soil (Chen et al., 2015; Li et al., 2016; Wang et al., 2011). This might be the reason why drip irrigation resulted in a higher survival rate than flood irrigation (see Table 2).

3.2 | Salt leaching

Before transplanting the trees, the average ECe values in the 0–40 and 0–120 cm soil profiles reached 12.22 and 8.27 dS m^{-1}, respectively (Figure 2a, Table 3). The soil type was moderate to severely saline soil. After 4 months of leaching with drip irrigation, the average ECe value in the 0–40 and 0–120 cm soil profiles reduced to 3.06 and 3.88 dS m^{-1}, respectively (Figure 2b, Table 3). The soil became mildly saline. Compared with the initial ECe, the reduction of the 0–40 and 0–120 cm soil profiles was 74.95% and 53.08%, respectively, which is in the range of the threshold salinity of 5.0 dS m^{-1} for poplar and willow (Hangs et al., 2011; Mirck & Zalesny, 2015). Compared with previous studies, the soil layer of 0–120 cm desalted rapidly and remained mildly saline (Dong et al., 2020; Li et al., 2015a). In the study by Dong et al. (2017), a low-salinity, irregular oval-shaped zone appeared as a result of drip irrigation. However, in their study, the soil profile was completely desalted. This was probably due to the wider ridge and the lower laying density of drip tapes than that in this study. Figure 2c shows that after the first winter, the soil salt content increased, and the average ECe value in the 0–40 and 0–120 cm soil profiles increased to 3.39 and 4.67 dS m^{-1}, respectively, probably due to freezing, thawing, and soil water evaporation (Cary & Mauland, 1972; L. X. Zhang, Han, et al., 2003). However, the amount of salt that

TABLE 2 Analysis of water consumption from afforestation using the original soil with drip irrigation, and using imported soil with flood irrigation

Irrigation pattern	Time (year)	Survival rate (%)	First irrigation amount (m^3/ha)	Irrigation amount in growing period (m^3/ha)	Irrigation amount before freezing (m^3/ha)	Total irrigation amount (m^3/ha)
Drip irrigation	2018	99.36	400.5	5400.0	660.0	6460.5
	2019	96.56	667.5	6328.5	1255.5	8244.0
	2020	94.07	400.5	5103.0	603.0	6106.5
Flood irrigation	2018	96.54	3000.0	6000.0	3000.0	12,000
	2019	80.54	3000.0	6000.0	3000.0	12,000
	2020	47.60	3000.0	6000.0	3000.0	12,000

returned was much lower than that of the in situ soil. After several months of drip irrigation and salt regulation, the salt was further leached in 2019 (Figure 2c,d). The process of water and salt regulation in 2020 was similar to that in 2019, and the salt content of the soil in 2020 was lower than that in 2019 (Figure 2c,e). The results showed that the soil salinity gradually decreased in terms of interannual change, and the soil salinity environment gradually improved. These results are consistent with those of previous studies that show good salt leaching under drip irrigation, with saline soil becoming mildly saline or even non-saline as the planting age increases (Dong et al., 2020; Dou et al., 2011; Li et al., 2015a). In addition, the salinity of the soil profile decreased each year under the salt control of drip irrigation. The pHe value in the 0–40 and 0–120 cm soil profiles first increased and then decreased, and reached the maximum at the end of the second year of water and salt regulation by drip irrigation, which is basically consistent with the results of Dong et al. (2020) in the Yinchuan Plain.

3.3 | Trees survival rate and growth

The survival rate and growth index of the two plants for different periods are shown in Table 4. The survival rates of the poplar and willow were 99.3% and 99.4% in the first year, decreasing to 90.6% and 95.8% in the third year, respectively. After the growth season in 2018, the poplar grew less quickly than the willow (Table 4). The root growth range of the poplar was small, which may have caused some weaker poplar trees to die, due to the influence of strip pumping and insufficient water supply in the alternating seasons of winter and spring. This can be attributed to the different water and salt tolerance of the individual trees. The survival rate of the poplar decreased between the first and second years. The main reason for this was that some poplars were sunburned in transit, leading to weak growth during the first year and death in the second year. The survival rate of the willow trees decreased between the second and third years. The main reason for this was that the roots of some weak willows that grew quickly in the second year plunged in the soil layer of the 40–120 cm profile, where the salt content was higher than that of the 0–40 cm profile, leading to considerable damage. Some weak willows did not sprout in the spring of the third year.

After 3 years, the growth of the trees was ultimately measured. The height, DBH, and ground diameter of the poplar trees were 65.8 cm, 2.5 mm, and 4.82 mm, respectively, and those of the willow trees were 118.6 cm, 6.07 mm, and 7.57 mm, respectively. In general, the willows grew better than the poplars. In addition, we found that the stem thickness of the willow trees increased significantly and that their height increased slowly after the second year. By comparison, the poplars increased significantly in height, although their stem thickness increased slowly. This is probably due to the control of the soil matrix potential during the process of drip irrigation, and because of the salt regulation and the water demand characteristics of poplars and willows. Willows are more robust to waterlogging than poplars (Tang et al., 1998).

The growth in vegetation at different periods (Figure 3) confirms that a suitable soil environment provides good habitat for the growth of vegetation. The survival rate and growth of the poplar and willow confirmed this phenomenon (Abella & Covington, 2006; Mahmood et al., 1994).

3.4 | Change of understory vegetation

In saline land, there is little or no vegetation. With salt leaching and an improved soil environment, however, vegetation communities can thrive (Qadir et al., 2008; Ravindran et al., 2007). In our study, the species and quantity of undergrowth vegetation changed

TABLE 3 ECe and pHe values of soil profiles at different times

Soil salinity index	Soil depth (cm)	2018.5	2018.9	2019.4	2019.9	2020.4	2020.9
ECe (dS m^{-1})	0–40	12.22	3.06	3.39	2.97	3.15	1.81
	0–120	8.27	3.88	4.67	3.90	3.15	2.60
pHe	0–40	8.06	8.51	8.59	8.72	8.46	8.49
	0–120	8.38	8.55	8.58	8.72	8.43	8.50

TABLE 4 Survival rate and increment of growth indexes of poplar and willow seedlings

	Growth index of poplar				Growth index of willow			
Date of determination	Survival rate (%)	H (cm)	DBH (mm)	GD (mm)	Survival rate (%)	H (cm)	DBH (mm)	GD (mm)
June 12, 2018	-	251.8	52.06	57.60	-	252.9	51.08	60.70
August 3, 2018	99.3	266.2	52.16	57.62	99.4	325.6	51.18	60.73
October 12, 2018	99.3	292.4	52.72	58.43	99.4	354.2	52.62	62.85
October 15, 2019	90.8	332.0	54.66	62.44	99.4	444.2	57.25	68.30
October 12, 2020	90.6	429.9	55.47	65.59	95.8	482.6	59.87	69.93

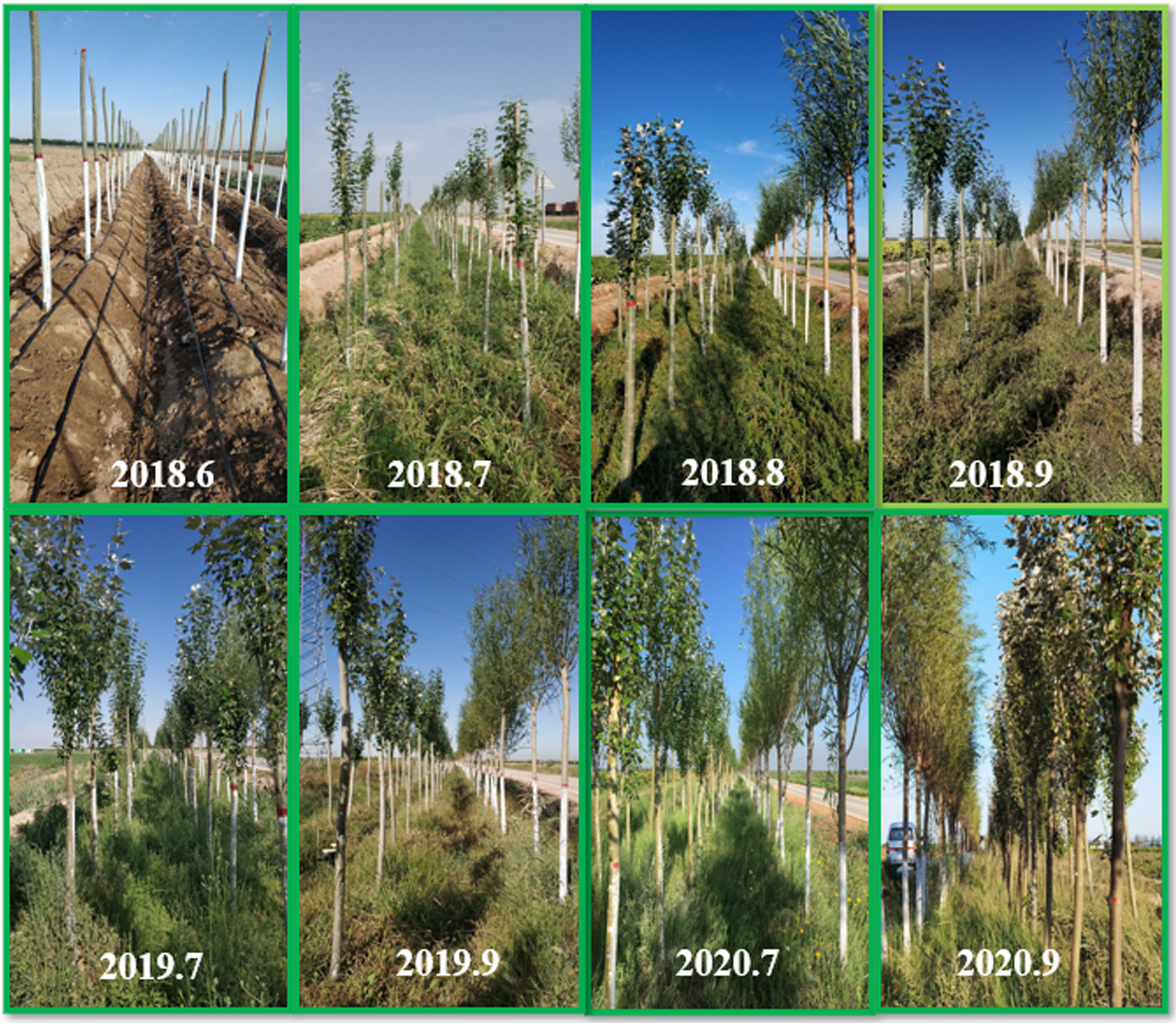

FIGURE 3 Vegetation growth in different periods [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 5 Coverage and density distribution of main undergrowth vegetation

			Vegetation density (plants/m^2)				
Year	Ridge position	Coverage (%)	Chenopodiaceae	Poaceae	Asteraceae	Polygonaceae	Fabaceae
2018	Surface	83	177.33	14.00	1.00	0.00	0.00
	Slope	58	104.72	5.00	0.56	0.00	0.00
	Furrow	21	90.83	4.17	0.00	0.00	0.00
2019	Surface	71	83.07	22.80	7.60	0.67	0.00
	Slope	81	66.13	24.27	9.20	0.67	0.00
	Furrow	90	136.13	22.27	0.67	1.20	0.00
2020	Surface	92	9.33	424.67	77.33	0.00	8.00
	Slope	98	8.00	258.67	398.00	0.00	9.33
	Furrow	93	9.00	165.33	58.00	0.00	8.00

TABLE 6 Herb species of main undergrowth vegetation

Year	Ridge position	Herb species: Chenopodiaceae	Poaceae	Asteraceae	Polygonaceae	Fabaceae
2017	Surface	1, 2	3, 4, 5	-	-	-
	Slope	1, 2	3, 4, 5	-	-	-
	Furrow	1, 2	3, 4, 5	-	-	-
2018	Surface	1, 2	3, 4, 6	7, 8, 9, 10, 11	12	14
	Slope	1, 2	3, 4, 6	7, 8, 9, 10, 11	12	14
	Furrow	1, 2	3, 4, 6	7, 8	12	-
2020	Surface	1	3, 4, 6	7, 8, 9, 10, 11	-	13, 14
	Slope	1	3, 4, 6	7, 8, 9, 10, 11	-	13, 14
	Furrow	1, 2	3, 4, 6	7, 8, 9	-	13, 14

Note: 1 *Suaeda glauca* (Bunge) Bunge, 2 *Chenopodium album* L, 3 *Phragmites communis* (Cav.) Trin. ex Steud., 4 *Eleusine indica* (L.) Gaertn., 5 *Chloris virgata* Sw., 6 *Leymus chinensis* (Trin.) Tzvel, 7 *Lxeris chinensis*, 8 *Inula japonica* Thunb., 9 *Saussurea japonica* (Thunb.) DC., 10 *Artemisia argyi* Levl. et Van, 11 *Juncellus serotinus*, 12 *Polygonum sibiricum* Laxm., 13 *Melilotu sofficinalis* (L.) Pall., 14 *Sphaerophysa salsula* (Pall.) DC.

considerably. As shown in Table 5, the coverage of undergrowth vegetation quickly increased from 0% to 54% and the density increased from 0 to 559.6 plants/m^2 after 2 months of salt regulation using drip irrigation. The coverage of undergrowth vegetation gradually increased from 54% to 94.3%, and the density increased from 559.6 to 1716.67 plants/m^2 over the next 2 years. In particular, the vegetation density doubled from 2019 to 2020. This shows that the experimental land was basically covered with vegetation, and formed a good vegetation ecosystem. It can be seen from Table 6, some early dominant species, like Chenopodiaceae, gradually degenerated with the change in the soil environment. Ultimately, the community was dominated by Poaceae and Asteraceae. The main reason for this succession was the improvement in soil conditions (Mahmood et al., 1994; Ravindran et al., 2007). An increase in vegetation coverage and species diversity is important for windbreak and sand fixation. Improvements to the underlying surface can also help adjust the local weather.

In general, compared to the common method of replacing saline soil with non-saline soil, water-salt regulation using drip irrigation resulted in sustainable afforestation, with better water and fertilizer management, an improved soil environment, and a higher tree survival rate. Furthermore, the investment cost for this improved technology is nearly two-thirds lower than the cost of replacing saline soil with non-saline soils. Therefore, this technology has wide application prospects for similar areas.

4 | CONCLUSIONS

Ridge cultivation with drip irrigation was used successfully to plant trees in arid saline regions of China. In moderately to severely saline soil, 0–120 cm of soil became non-saline soil after 2 years. With these improvements to the soil environment, poplars and willows grew vigorously and achieved survival rates of >90% in the third year. The richness, coverage, and density of the understory vegetation increased dramatically with decreasing salinity, and gradually formed a vegetation community dominated by Poaceae. This method has the advantages of improving salt leaching, water conservation, and the survival rate of plants. The results of this study have important implications for ecological construction in saline soil with high ECe under drip irrigation with ridge cultivation. And the study provides theoretical support and practice for vegetation construction in saline land in the future. However, long-term field monitoring is required, especially as the plant roots grow deeper, to clarify how the root distribution and absorption of shallow saline groundwater will affect tree growth.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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