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Acceptable Salinity Level for Saline Water Irrigation of Tall Wheatgrass in Edaphoclimatic Scenarios of the Coastal Saline–Alkaline Land around Bohai Sea

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Abstract: Saline water irrigation contributes significantly to forage yield. However, the acceptable salinity levels for saline water irrigation of tall wheatgrass remains unclear. In this study, field supplemental irrigations of transplanted-tall wheatgrass with saline drainage waters having salinities of electrical conductivity (EC_w) = 2.45, 4.36, 4.42, and 5.42 dS m^{-1} were conducted to evaluate the effects of saline water irrigation on forage yield and soil salinization. In addition, the effects of plastic film mulching, fertilization, and saline water irrigation on sward establishment of seed-propagated tall wheatgrass were determined. Finally, a pot experiment was carried out to confirm the above field results. The results showed that two irrigations with EC_w = 2.45 and 4.36 dS m^{-1} saline waters produced the highest dry matter yield, followed by one irrigation with EC_w = 4.42 or 5.42 dS m^{-1}. After rainfall leaching, the soil $EC_{1:5}$ was reduced by 41.7–79.3% for the saline water irrigation treatments. In combination with saline water irrigation, plastic film mulching promoted sward establishment and enhanced the plant height and dry matter yield of seed-propagated tall wheatgrass, while fertilization played a marginal role. However, two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline waters resulted in rates of 3.2% and 16.0% of dead plants under the mulching and no mulching conditions, respectively. Furthermore, a pot experiment demonstrated that irrigation with EC_w = 5.79 dS m^{-1} saline water led to the lowest reduction in forage yield and the highest crude protein content in leaves. However, the plants irrigated with $EC_w \geq 6.31$ dS m^{-1} saline water enhanced soil salinity and reduced the plant height, leaf size, and gas exchange rate. Conclusively, one irrigation with $EC_w \leq 5.42$ dS m^{-1} and SAR ≤ 36.31 saline water at the end of April or early May could be acceptable for tall wheatgrass production and minimize the soil salinization risk in the coastal saline–alkaline land around the Bohai Sea.

Keywords: saline water irrigation; saline–alkaline soil; forage yield; tall wheatgrass; coastal grass belt

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1. Introduction

According to the "14th Five-Year Plan", the National Forage Industry Development Plan, released by the Ministry of Agriculture and Rural Affairs of the People's Republic of China in 2022, there is an annual shortage of 5×10^7 t forage for Chinese animal husbandry. To meet the demand, marginal land has great potential to produce forage in the avoidance of competition with cereal crops for arable land and water [1–3]. For instance, in 2020, Zhensheng Li, the academician and former vice president of the Chinese Academy of Sciences, put forward a proposal to construct a Coastal Grass Belt through the cultivation of salt–alkali-tolerant forage crops on coastal saline–alkaline wasteland, which is unprofitable for food crops [4–6]. Tall wheatgrass (*Elytrigia elongata* (Host) Nevski = *Thinopyrum ponticum* (Podp.) Barkworth and D. R. Dewey (2n = 10x = 70)) is a perennial cool-season grass that confers tolerance to salt–alkali [7–11], drought [12–14], and waterlogging [15–17]. It has been widely cultivated in America, Australia, Argentina, Canada, and other European countries as a saline pasture or energy crop for more than half a century. However, tall wheatgrass has been neglected for 40 years since its introduction to Austral in the 1950s [18]. After tall wheatgrass cultivar Largo was introduced to Austral in the mid-1950s, two cultivars, Tyrrell and Dundas, were released in 1963 [18] and 2000 [19], respectively. Annually, 30–70 t of commercial seed of Tyrrell is produced in Australia [18], indicative of successful industrialization. The situation was even worse in China. Since its first introduction to China, tall wheatgrass has long been utilized as a disease-resistant germplasm resource for wheat's (*Triticum aestivum* L.) genetic improvement. Although some tall wheatgrass varieties such as Jose, Largo, and Alkar were introduced to China during the 1980s and 1990s, it has been ignored for a long time and is not widely cultivated as a forage crop in China. Considering its role in coastal saline–alkaline land, Zhensheng Li's group planted tall wheatgrass in Caofeidian, Haixing, and Nanpi in Hebei Province and Dongying in Shandong Province near the Bohai Sea to evaluate its adaptability and utility. They screened a salt–alkali-tolerant and highly productive line C2 [20], which is now named as Zhongyan 1 [21]. Due to its huge and complex genome, molecular breeding techniques in tall wheatgrass have lagged far behind the major cereal crops such as rice (*Oryza sativa*) and wheat. Now, new breeding methods in combination with genome sequencing information are under development to breed new varieties in China. Recently, Li et al. gave some suggestions for the industrialization of tall wheatgrass in China for the construction of the Coastal Grass Belt [6].

The optimum annual precipitations of tall wheatgrass range from 350 mm to 600 mm [22]. The average annual precipitations in the Coastal Grass Belt targeted region is 500–600 mm; however, 80% of the precipitation occurs from July to September. Drought stress usually occurs in spring in this region, which severely restricts forage production. Saline–alkaline drainage waters can sometimes be used as a supplementary irrigation resource for urgent purposes. For instance, recently, a long-term study demonstrated that irrigation with saline water having an electrical conductivity (EC_w) = 3.4 dS m^{-1} produced a similar yield as that using freshwater under maize–wheat crop rotation. However, irrigation with saline water with EC_w > 3.4 dS m^{-1} resulted in yield loss and soil salinity enhancement [23]. Saline–alkaline drainage waters (4 dS m^{-1} < EC_w < 30 dS m^{-1}; 10 < sodium adsorption ratio (SAR) < 40) have been recommended to be used to irrigate salt-tolerant forage crops [24]. The reuse or sequential use of saline–alkaline drainage waters has the potential for the production of salt-tolerant forage crops such as tall wheatgrass [24–27]. The forage yield of tall wheatgrass irrigated with saline water (EC_w = 10 dS m^{-1}) was 74% of that irrigated with freshwater [28]. The tall wheatgrass, grown on saline land with a salinity below 0.8% and irrigated with 5.84 g L^{-1} drainage water during the first year of sward establishment, produced 7.16 t ha^{-1} hay [29]. Tall wheatgrass, growing in the highly saline fields with an EC of "saturation paste extract" (EC_e) = 17.6–19.1 dS m^{-1}, produced 5.9–8.3 t ha^{-1} dry matter yield after being irrigated with drainage water having a salinity of EC_w = 10.5 dS m^{-1} [26]. Under high salinity (EC_e = 21.5 dS m^{-1}), it had a relative yield of 85%, whereas the relative yield of alfalfa was 43% [30]. Additionally, tall wheatgrass can stabilize the level of moderately saline groundwater and reduce the potential for soil salinization [31].

It is reasonable to irrigate tall wheatgrass with saline–alkaline drainage waters in the Coastal Grass Belt targeted region as the rainfall leaching will counteract the risk of soil salinization. For instance, more than 60% of drainage water is utilizable in Kenli district, Dongying city in the Yellow River Delta Region [32], indicating the significant potential of drainage water reuse for the cultivation of salt-tolerant corps including tall wheatgrass. However, the acceptable salinity levels for saline water irrigation of tall wheatgrass to maximize forage yield without soil salt accumulation remains unclear, which restricts the utilization of tall wheatgrass for the construction of the Coastal Grass Belt. Therefore, the first objective of this study was to determine the acceptable salinity level for saline water irrigation of tall wheatgrass in the Coastal Grass Belt targeted area.

Sward establishment is critical for saline forage pasture, especially for the cultivation of tall wheatgrass in coastal saline–alkaline wasteland. Plastic film mulching was considered as an effective technique to grow forage with a high productivity and good quality of forage-oriented maize in North China [33]. In addition, plastic film mulching promoted alfalfa (*Medicago sativa* L.) forage yield with less phosphorus application and soil nitrogen loss as well as improved soil moisture in a semiarid environment [34,35]. Currently, there is no report on the effects of plastic film mulching on tall wheatgrass planting. The role of plastic film mulching on tall wheatgrass seedling establishment in combination with saline water irrigation and fertilization was explored in this work. In addition, the effect of saline water irrigation on sward establishment of seed-propagated tall wheatgrass was also assessed. Finally, the photosynthetic responses of tall wheatgrass to saline water irrigation were also assayed to confirm the acceptable salinity level of saline water irrigation in the fields.

2. Materials and Methods

2.1. Plant Materials

A tall wheatgrass line C2, also named as Zhongyan 1, was used in this study, which was previously screened for salt–alkali tolerance and high productivity by Tong et al. [20]. The experiments were carried out at the Agricultural Experiment Station for Saline–Alkaline Land in the Yellow River Delta Region (118°84′03″ E, 37°68′74″ N), Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, from 2020 to 2023. The soil $EC_{1:5}$ in the 0–10 cm soil depth ranges from 0.2 to 4.0 dS m^{-1}. The soil type is coastal clay and poor drainage. The average annual precipitations in the Yellow River Delta Region are usually 500–600 mm. The precipitations, maximum and minimum air temperatures from 2020 to 2022 are shown in Figure 1. The maximum air temperatures of 36.8 °C, 37.9 °C, and 40.6 °C were observed in June 2020, 2021, and 2022, while the minimum air temperatures of −11.2 °C, −16.5 °C, and −9 °C were observed in December 2020, January 2021, and December 2022, respectively (Figure 1).

Both second-year transplanted and first-year seed-propagated plants were included in this study. After the small plantlets with 8–10 tillers were prepared by hand, they were transplanted into the fields with a 4-row transplanter (2ZBX-4, Chengfan Agricultural Equipment Co., LTD, Weifang, China) in autumn 2020, which was previously described by Li et al. [21]. The rows and plants were spaced by 0.3 m and the 4-row plots were spaced at intervals of 0.9–1.0 m. During the first establishing year, freshwater irrigations were conducted in spring. In March 2022, 187.5 kg ha^{-1} of diammonium phosphate (DAP) was applied. Subsequently, in combination with saline water irrigation treatments, 150 kg ha^{-1} of urea was top-dressed.

Additionally, the seed-propagated plants were used to explore the effects of saline water irrigation, plastic film mulching, and fertilization on sward establishment and the first-year forage yield. The seeds with the purity of 50–60% were sown at the seeding rate of 18 kg ha^{-1} on 23 October 2021, with a drill planter. The spacings between the rows and plants were 0.3 m and less than 0.2 m, respectively. A randomized block design involving three factors including plastic film mulching, saline water irrigation, and fertilization was performed. Plastic film mulching was started on 5 December 2021, and ended on 4 March 2022. Seven nitrogen (N) and phosphorus (P) levels including NP0 (no fertilizer), NP1 (56 kg N ha^{-1}, 158 kg P_2O_5 ha^{-1}), NP2 (73 kg N ha^{-1}, 205 kg P_2O_5 ha^{-1}), NP3 (90 kg N ha^{-1}, 252 kg P_2O_5 ha^{-1}), N4 (86 kg N ha^{-1}), N5 (138 kg N ha^{-1}), N6 (190 kg N ha^{-1}) were conducted by the application of DAP for NP1 to NP3 and urea for

N3 to N6 treatments without P application on 29 April 2022, respectively. Saline water irrigation treatments were carried out once and twice. The unmulched, NP0, and one-time irrigation treatment was taken as the control. The plot area for each treatment with three repeats was around 20 m^2.

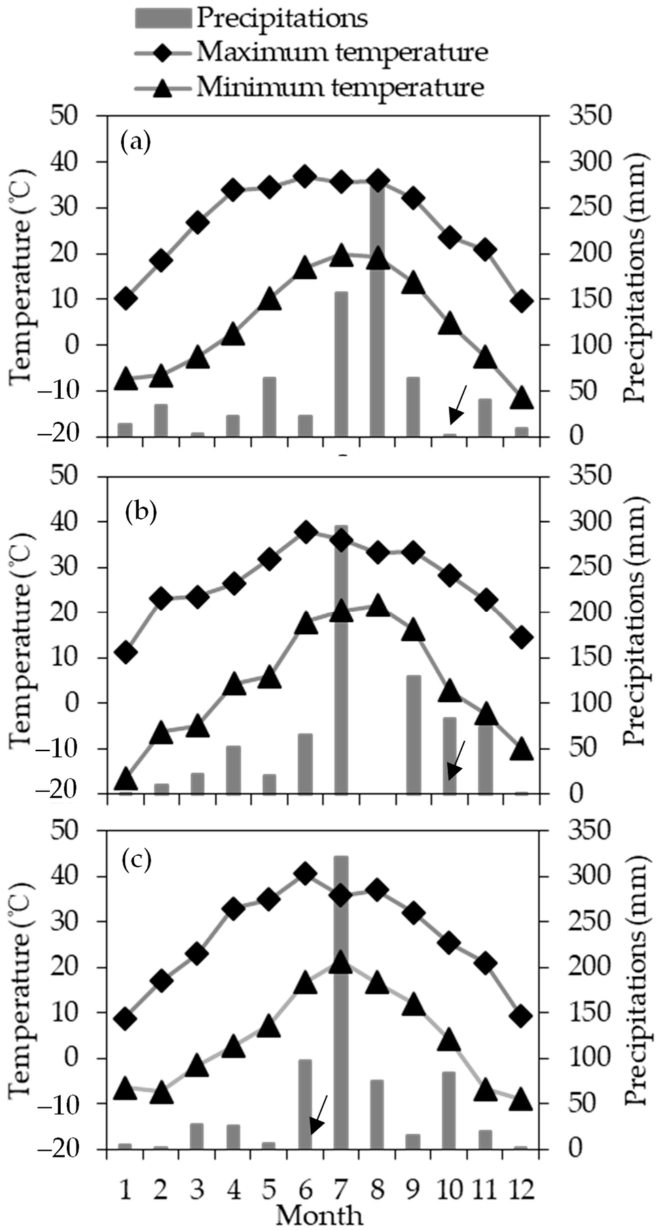

Figure 1. The maximum and minimum air temperatures and precipitations in 2020 (**a**), 2021 (**b**), and 2022 (**c**). The arrows indicate dates of transplanting and seeding in October 2020 and 2021, respectively, as well as date of harvesting in June 2022. Note: the precipitation data in August 2022 were missing.

2.2. Irrigation Treatments with Saline Drainage Water

The flooding irrigation treatments with saline drainage waters, pumped from a nearby drainage ditch, were performed in April and May 2022. The salinities of the available drainage waters varied depending on the month. Before irrigation, the salinity of the drainage water was determined by using a conductivity meter (DDS-12DW, Shanghai LIDA Instrument Factory, Shanghai, China). Usually, approximately 600 m^3 ha^{-1} of drainage water was used for the one-time irrigation. The salinities used for field supplemental irrigations were EC_w = 2.45 dS m^{-1} (pH = 8.3), 4.36 dS m^{-1} (pH = 8.5), 4.42 dS m^{-1} (pH = 8.5), 5.42 dS m^{-1} (pH = 8.5), and 7.13 dS m^{-1} (pH = 8.3). The concentrations of ions in the representative drainage waters with EC_w = 4.42 and 5.42 dS m^{-1} are shown in Table 1. Except for the saline water having a salinity of EC_w = 2.45 dS m^{-1} that came from a mixture of freshwater and saline water, the others were taken directly from the nearby drainage ditch. Supplemental saline water irrigation treatments performed on the transplanted-tall wheatgrass are shown in Table 2. The unirrigated treatment was taken as the control. The single irrigation with EC_w = 5.42, 4.42, or 4.36 dS m^{-1} saline waters was conducted on 24 April, 2 May, and 27 May, respectively. Two irrigations with EC_w = 2.45 dS m^{-1} followed by 4.36 dS m^{-1} saline waters were carried out on 26 April and 25 May, respectively. Moreover, further two irrigation treatments with EC_w = 5.42 dS m^{-1} followed by 4.36 dS m^{-1} saline waters were conducted on 26 April and 28 May, respectively. The irrigated areas for each treatment with three repeats were around 0.2 ha. In addition, for the seed-propagated tall wheatgrass, two irrigations with EC_w = 7.13 dS m^{-1} followed by 4.36 dS m^{-1} saline waters were performed on 3 May and 25 May, respectively, while one irrigation with EC_w = 4.36 dS m^{-1} saline water was carried out on 25 May.

Table 1. The concentrations of ions (mg L^{-1}) and sodium adsorption ratio (SAR) in the drainage waters used in this study.

EC_w (dS m^{-1})	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	$SO_4{}^{2-}$	$CO_3{}^{2-}$	$HCO_3{}^-$	B	Se	Mo	SAR [a]
4.42 [b]	1083 ± 8 c	27.5 ± 0.1 c	130.6 ± 0.8 c	153.0 ± 0.6 c	2373 ± 4 c	371.7 ± 1.8 c	22.5 ± 1.7 b	378.2± 1.3 b	0.45 ± 0.01 c	<0.01	<0.01	30.46 ± 0.19 a
5.42 [b]	1376 ± 34 b	40.2 ± 0.4 b	142.1 ± 1.2 b	177.4 ± 1.3 b	3335 ± 25 b	535.5 ± 1.5 b	27.2 ± 0.0 b	120.1 ± 1.7 c	0.56 ± 0.03 b	<0.01	<0.01	36.31 ± 0.76 b
8.61 [c]	1821 ± 24 a	53.8 ± 1.4 a	225.6 ± 2.9 a	236.3 ± 1.0 a	5815 ± 69 a	632.4 ± 7.1 a	54.9 ± 2.5 a	415.7 ± 5.9 a	0.65 ± 0.02 a	<0.01	<0.01	40.39 ± 0.52 c

Notes: [a] Computed according to Lesch and Suarez [36]. Data are represented as mean ± SD (n = 3). Different letters indicate significant differences at p < 0.05. [b] Used for field supplemental irrigation experiments. [c] Used for pot experiment.

Table 2. The soil electrical conductivity (EC) and pH as well as tall wheatgrass dry matter yield after saline water irrigation.

Water Salinity EC_w (dS m^{-1})	Irrigation Date (Day/Month)	$EC_{1:5}$ (dS m^{-1}) Sampling Dates (Day/Month) 17/05	21/10	$EC_{1:5}$ Percentage Change (%)	pH Sampling Dates (Day/Month) 17/05	21/10	pH Percentage Change (%)	Dry Matter Yield (kg ha^{-1})
CK [a]	- [b]	0.69 ± 0.36 c	0.64 ± 0.50 a	−7.2	8.44 ± 0.14 bc	8.70 ± 0.24 c	3.1 **	1839 ± 264 d
4.36	27/05	0.36 ± 0.13 d	0.21 ± 0.12 b	−41.7 **	8.74 ± 0.08 a	8.90 ± 0.09 b	1.8 **	3823 ± 676 c
4.42	02/05	0.58 ± 0.07 c	0.12 ± 0.01 b	−79.3 **	8.52 ± 0.08 b	9.08 ± 0.08 a	6.6 **	5838 ± 548 b
5.42	24/04	1.20 ± 0.49 a	0.69 ± 0.18 a	−42.5 **	8.28 ± 0.14 d	8.68 ± 0.10 c	4.8 **	5627 ± 242 b
2.45 + 4.36 [c]	26/04 + 25/05	0.91 ± 0.35 b	0.24 ± 0.12 b	−73.6 **	8.42 ± 0.18 c	8.84 ± 0.12 b	5.0 **	6962 ± 196 a
5.42 + 4.36 [c]	26/04 + 28/05	0.76 ± 0.05 b	0.24 ± 0.13 b	−68.4 **	8.53 ± 0.07 b	9.10 ± 0.19 a	6.7 **	4253 ± 461 c

Notes: [a] CK and - [b] indicate unirrigated control. [c] Two irrigations. Data are represented as mean ± SD (n = 5 for EC1:5 and pH as well as n = 3 for dry matter yield). Different letters indicate significant differences at p < 0.05. **, means the significant difference between two measurements (p < 0.01).

2.3. Determination of EC, pH, and Soil Water Content

The soil samples were collected at 0–10 cm, 10–20 cm, and 20–30 cm depths following the five-point diagonal sampling method. After air drying for one week, the soil samples were ground and passed through a 0.25 mm screen. When measuring, 3 g of soil powder sample was diluted in 15 mL of purified water. Then, the EC was measured with a conductivity meter (DDS-12DW, Shanghai LIDA Instrument Factory, Shangai, China), while the pH was measured with a pH meter (pH848, Smart Sensor, Guangdong, China). The soil water content was determined as the ratio of moisture mass to the soil dry mass.

2.4. Evaluation of Plant Height, Dry Matter Yield, and Death Rate

Before harvesting on 8 June 2022, the plant height from 10 plants was measured as the height from the soil surface to the highest plant tip. For each treatment, three randomly selected 2.0 m × 3.5 m plots were handily harvested with 10–15 cm of stubble height left. Then, the fresh forage yield was weighed immediately. The ratio of dry to fresh weight was determined with 1.2–2.0 kg plant samples oven-dried at 65 °C for 72 h, which was used to compute dry matter yield. Additionally, the death rate was also surveyed on five randomly selected plots the area of which was 3.4 m^2 (1.7 m × 2 m).

2.5. Pot Experiment: Sufficient Irrigation with Saline Water

A total of 25 plantlets, handily divided from a single two-year plant on 6 November 2022, were planted in plastic pots. Each plantlet was planted in one pot, the size of which was 24 cm × 26 cm × 18.8 cm (upper inner diameter × height × bottom inner diameter, respectively). Each pot was filled with 2.6 kg culture medium composed of field soil–substrate (0–10 mm, Pindstrup, Kongerslev, Denmark) = 1:3. The $EC_{1:5}$ and pH in the field soil were 4.03 dS m^{-1} and 8.4, while they were 2.13 dS m^{-1} and 6.7 in the mixed culture medium, respectively. The contents of available N and P_2O_5 in the culture medium were 744.0 mg kg^{-1} and 907.8 mg kg^{-1}, respectively. On 9 May 2023, 5 g urea was applied to each pot, resulting in a supplement of 885 mg N kg^{-1}. All the plants were cultured outdoors during the whole treatment.

The pot experiment sufficiently irrigated with saline water was carried out in two phases: a salt stress phase and a leaching phase. Salt stress was performed with five saline water irrigations including the salinities of EC_w = 1.02 dS m^{-1} (pH = 8.0), 5.79 dS m^{-1} (pH = 8.0), 6.31 dS m^{-1} (pH = 8.1), 8.61 dS m^{-1} (pH = 8.1), and 9.60 dS m^{-1} (pH = 8.5). The EC_w = 8.61 dS m^{-1} saline water was collected from a drainage ditch on 16 March 2023, and was diluted with tap water to the EC_w = 5.79 and 6.31 dS m^{-1} saline waters and concentrated to 9.60 dS m^{-1} in sunlight. The concentrations of ions in the drainage waters with EC_w = 8.61 dS m^{-1} are shown in Table 1. Saline water irrigation was started from 13 April to 23 May, followed by irrigation with tap water until harvesting on 26 June. For each pot, a volume of 10 L saline water was irrigated in the salt stress phase for 40 days, followed by luxurious leaching with 26 L tap water for 26 days. During rainy days, all the pots were covered with a plastic shed in avoidance of rainfall effects. The plant height, leaf size, and gas exchange were assessed on all five pots for each treatment at the end of each of the two phases. The curled leaf width ratio was determined as the ratio of curled leaf width to expanded leaf width. Dry matter yield per plant was determined ultimately.

2.6. Gas Exchange Measurement

The gas exchange parameters such as net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, and transpiration rate were determined in the middle parts of leaves from 9:00 a.m. to 11:00 a.m. by using a gas exchange system (GFS3000, WALZ, Effeltrich, Germany). When measuring, the light intensity was set as 1200 µmol m^{-2} s^{-1}, CO_2 concentration was around 410 µmol mol^{-1}, and airflow rate was 750 µmol s^{-1}. The mean ambient air temperature and relative humidity were 28 °C and 35% for the penultimate leaf measurements and 30 °C and 55% for the flag leaf measurements, respectively. The penultimate and flag leaves were assayed at the end of the salt stress phase and before harvesting, respectively. All five plants for each treatment were measured.

2.7. Crude Protein Content Determination

After being oven-dried at 65 °C for 72 h and ground with a ZM200 Ultra Centrifugal Mill (Retsch, Haan, Germany), about 0.1 g dry powder samples were used to determine the total N content by using a Kjeltec Analyser (8400, FOSS, Hilleroed, Denmark). Subsequently, the crude protein content (%) was calculated by multiplying the total N content with a factor of 6.25.

2.8. Assessment of Concentrations of Ions in the Representative Drainage Waters

The concentrations of ions in the drainage waters with salinities of EC_w = 4.42 dS m^{-1}, 5.42 dS m^{-1}, and 8.61 dS m^{-1} were determined by Beijing Yandu Taihua Enterprise Management Group Co., Ltd. The cations were assessed with an iCAP 6000 Series ICP Emission Spectrometer (Thermo Fisher Scientific, Waltham, MA, USA) while the anions were determined by using a Dionex ICS-1000 Ion Chromatography System (Thermo Fisher Scientific, Waltham, MA, USA) according to the manufacturer's instruction.

2.9. Data Summary and Statistical Analysis

One-way analysis of variance (ANOVA), univariate ANOVA based on the General Linear Model, multiple comparison, least significant difference (LSD) test, and an independent *t*-test were performed by using the SPSS software (version 19.0, IBM, Armonk, NY, USA). Data were expressed as mean $\pm$ standard deviation (SD), and were used for the figures.

3. Results

3.1. The Effects of Saline Water Irrigation on Soil Salinity and Forage Yield of Transplanted-Tall Wheatgrass

While using the unirrigated plot as the control, five supplemental saline drainage water irrigations, including three one-irrigation treatments and two two-irrigation treatments, were performed on the transplanted-tall wheatgrass. As shown in Table 1, the major ion components in the saline drainage waters were Na^+, Cl^-, SO_4^{2-}, Mg^{2+}, and Ca^{2+}. The pH in the drainage waters ranged from 8.3 to 8.5. Therefore, the drainage waters used for supplemental irrigation treatments in this study were saline and alkaline. The soil salinity and pH at 0–10 cm depth, sampled on 17 May and 21 October, and forage dry matter yield are summarized in Table 2. A total of 509.1 mm of precipitation occurred between June and September in 2022 (Figure 1), which caused considerable reductions in soil salinity. For instance, the $EC_{1:5}$ of the unirrigated control decreased from 0.69 dS m^{-1} to 0.64 dS m^{-1}, while for the saline water irrigation treatments, the reductions in $EC_{1:5}$ ranged from 41.7% to 79.3%. However, at the same time, the pH values increased for all the saline water irrigation treatments after rainfall leaching (Table 2). Therefore, it appeared that irrigation with saline water in the spring had little influence on the soil salinity due to rainfall leaching.

The dry matter yields in the plants irrigated with saline waters were significantly higher than in the unirrigated control (Table 2). The two-time irrigations with EC_w = 2.45 and 4.36 dS m^{-1} saline waters produced the highest dry matter yield (6962 kg ha^{-1}), followed by single irrigation with EC_w = 4.42 or 5.42 dS m^{-1} saline water. Next, the fields treated with two irrigations of EC_w = 5.42 and 4.36 dS m^{-1} saline waters produced less than those treated with one irrigation of EC_w = 4.42 or 5.42 dS m^{-1} saline water, but slightly more than one irrigation with EC_w = 4.36 dS m^{-1} saline water. The lower yield in the plants irrigated with EC_w = 4.36 dS m^{-1} saline water on 27 May relative to those irrigated with EC_w = 4.42 dS m^{-1} (2 May) or 5.42 dS m^{-1} (24 April) saline water indicated that the irrigation date played a key role in forage yield formation. The forage yield of tall wheatgrass irrigated with EC_w = 5.42 and 4.36 dS m^{-1} saline waters was significantly lower than that irrigated with EC_w = 2.45 and 4.36 dS m^{-1}, as well as that irrigated with EC_w = 5.42 dS m^{-1} or 4.42 dS m^{-1} saline water, demonstrating that high water salinity exerted a negative effect on forage yield. Taken together, it can be deduced that one-time irrigation with $EC_w \leq 5.42$ dS m^{-1} saline waters may be acceptable for tall wheatgrass with a low risk of soil salt accumulation.

3.2. The Effects of Saline Water irrigation on Forage Yield and Death Rate of Seed-Propagated Tall Wheatgrass

Three factors including plastic film mulching, fertilization, and saline water irrigation were considered to determine the key factor for the sward establishment of seed-propagated tall wheatgrass. ANOVA analysis showed that the plant height and forage yield in all three single factor treatments differed significantly ($p < 0.01$). In addition, the interactions of mulching × saline water irrigation as well as mulching × fertilization also differed significantly (Table 3). To explore the effects of saline water irrigation on soil salinization, the $EC_{1:5}$ in the soil depths of 0–10, 10–20, and 20–30 cm were determined on 17 May, 21 June, 21 October, and 10 December 2022, and 23 February 2023. The inconsistent difference of $EC_{1:5}$ between the mulched and unmulched treatment suggested that mulching with plastic film for 68 days appeared to have a marginal impact on soil salinization due to saline water irrigation (Table 4). The $EC_{1:5}$ peaked on 21 June but declined drastically after the rainy season's leaching, resulting in reductions of 15.9–75.8%, 23.5–69.4%, and 21.2–61.3% for two-time irrigations and 34.5–71.7%, 43.1–65.5%, and 39.7–48.7% for single irrigation on 21 October and 10 December 2022, and 23 February 2023, respectively (Table 5).

Table 3. ANOVA analysis of plant height and forage yield.

Variation Source	df	Plant Height		Dry Matter Yield	
		Mean Square	F	Mean Square	F
Corrected Model	27	2674.8	44.2 **	6,238,649	57.8 **
Intercept	1	1,428,151.6	23,600.2 **	227,600,000	2110.5 **
Saline water irrigation	1	16,417.7	271.3 **	13,137,343	121.8 **
Mulching	1	41,883.0	692.1 **	126,500,000	1173 **
Fertilization	6	610.6	10.1 **	672,596	6.2 **
Saline water irrigation × mulching	1	496.5	8.2 **	8,854,228	82.1 **
Saline water irrigation × fertilization	6	157.1	2.6 *	83,811	0.8
Mulching × fertilization	6	173.8	2.9 *	959,185	8.9 **
Saline water irrigation × mulching × fertilization	6	45.2	0.7	160,269	1.5

Notes: *, ** denote significant differences at $p < 0.05$ and $p < 0.01$, respectively.

Table 4. Comparisons of soil electrical conductivity (EC) from the fields irrigated with saline waters in combination with plastic film mulching or no mulching.

Irrigation Treatment [a]	Soil Depth	Mulching	$EC_{1:5}$ (dS m^{-1}) Sampled on Different Dates (Day/Month)				
			2022				2023
			17/05	21/06	21/10	10/12	23/02
Two irrigations	0–10 cm	Plastic film mulching	0.58 ± 0.24 c	1.00 ± 0.20 ab	0.40 ± 0.08 ab	0.40 ± 0.04 e	0.61 ± 0.17 bcd
		No mulching	1.17 ± 0.17 a	1.06 ± 0.03 a	0.34 ± 0.04 b	0.39 ± 0.08 e	0.55 ± 0.23 de
One irrigation		Plastic film mulching	0.83 ± 0.43 b	1.02 ± 0.16 ab	0.44 ± 0.12 a	0.46 ± 0.16 de	0.49 ± 0.18 e
		No mulching	0.53 ± 0.20 c	0.94 ± 0.04 b	0.45 ± 0.23 a	0.29 ± 0.07 f	0.47 ± 0.10 e
Two irrigations	10–20 cm	Plastic film mulching	-	-	-	0.58 ± 0.08 bc	0.60 ± 0.07 bcd
		No mulching	-	-	-	0.51 ± 0.08 cd	0.56 ± 0.17 cde
One irrigation		Plastic film mulching	-	-	-	0.69 ± 0.11 a	0.62 ± 0.13 bcd
		No mulching	-	-	-	0.53 ± 0.15 bcd	0.63 ± 0.16 bcd
Two irrigations	20–30 cm	Plastic film mulching	-	-	-	0.72 ± 0.14 a	0.76 ± 0.11 a
		No mulching	-	-	-	0.60 ± 0.11 b	0.64 ± 0.13 bcd
One irrigation		Plastic film mulching	-	-	-	0.73 ± 0.15 a	0.68 ± 0.11 ab
		No mulching	-	-	-	0.57 ± 0.08 bc	0.66 ± 0.10 abc

Notes: - denotes not sampled. [a] Two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline waters were performed on 3 May and 25 May, respectively, while one irrigation with EC_w = 4.36 dS m^{-1} saline water was carried out on 25 May. Data are represented as mean ± SD ($n = 5$). Different letters indicate significant differences at $p < 0.05$.

Table 5. The soil electrical conductivity (EC) from the fields irrigated with saline waters combined with plastic film mulching or no mulching.

Irrigation Treatments [a]	Soil De pth	$EC_{1:5}$ ($dS\ m^{-1}$) Sampled on Different Dates (Day/Month)					Reduction [b]		
		2022				2023	2022		2023
		17/05	21/06	21/10	10/12	23/02	21/10	10/12	23/02
Two irrigations	0–10 cm	1.17 ± 0.17 a	1.24 ± 0.15 a	0.30 ± 0.09 b	0.38 ± 0.15 c	0.48 ± 0.15 c	75.8%	69.4%	61.3%
	10–20 cm	-	0.88 ± 0.08 c	0.74 ± 1.08 a	0.61 ± 0.16 ab	0.62 ± 0.15 ab	15.9%	30.7%	29.5%
	20–30 cm	-	0.85 ± 0.17 c	0.49 ± 0.19 ab	0.65 ± 0.14 a	0.67 ± 0.10 a	42.4%	23.5%	21.2%
One irrigation	0–10 cm	0.53 ± 0.20 b	1.13 ± 0.18 ab	0.32 ± 0.14 b	0.39 ± 0.06 c	0.58 ± 0.20 b	71.7%	65.5%	48.7%
	10–20 cm	-	1.05 ± 0.22 b	0.57 ± 0.13 ab	0.55 ± 0.09 b	0.58 ± 0.13 b	45.7%	47.6%	44.8%
	20–30 cm	-	1.16 ± 0.14 ab	0.76 ± 0.09 a	0.66 ± 0.14 a	0.70 ± 0.13 a	34.5%	43.1%	39.7%

Notes: - denotes not sampled. [a] Two irrigations with EC_w = 7.13 and 4.36 $dS\ m^{-1}$ saline waters were performed on 3 May and 25 May, respectively, while one irrigation with EC_w = 4.36 $dS\ m^{-1}$ saline water was carried out on 25 May. [b] Percentage reduction in $EC_{1:5}$ in comparison with those sampled on June 21. Data are represented as mean ± SD (n = 5). Different letters indicate significant differences at $p < 0.05$.

Plastic film mulching markedly increased soil temperature at 10 cm depth compared with the unmulched control (Figure S1), which contributed to a taller plant height and higher forage yield. Under mulching conditions, the plant height of tall wheatgrass treated with two irrigations of EC_w = 7.13 and 4.36 $dS\ m^{-1}$ saline waters was significantly higher than that irrigated once with EC_w = 4.36 $dS\ m^{-1}$ saline water independent of fertilization levels (Figure 2a). It was similar for the plant height under the no mulching condition (Figure 2c) and for dry matter yield under the mulching condition (Figure 2b), although the difference was not significant at the NP0 level. Under the no mulching condition, the differences in the dry matter yield between the two irrigation treatments were significant only at the NP0 and NP1 levels ($p < 0.05$).

Under two irrigations and mulching conditions, the plant height and dry matter yield increased significantly from the NP1 level in comparison with the NP0 control. However, under single irrigation and mulching conditions, no significant increment was found for the dry matter yield due to fertilization (Figure 2b). It seemed that the effects of irrigation and fertilization on plant height and forage yield were negligible under the no mulching conditions (Figure 2c,d). Collectively, plastic film mulching, followed by saline water irrigation determined sward establishment and dry matter yield to a large extent. Relatively, fertilization appeared to play a marginal role in sward establishment and the first-year's forage yield of seed-propagated tall wheatgrass.

For the unmulched control, 16% of plants were dead when treated with two irrigations with EC_w = 7.13 and 4.36 $dS\ m^{-1}$ saline waters, which was significantly higher than those irrigated once with EC_w = 4.36 $dS\ m^{-1}$ saline water. In addition, for the plastic film mulching treatment, no dead plants were observed for one irrigation with EC_w = 4.36 $dS\ m^{-1}$ saline water, while 3.2% of plants were dead after two irrigations with EC_w = 7.13 and 4.36 $dS\ m^{-1}$ saline waters were applied (Figure 3). Therefore, one irrigation with low salinity water is favorable for the sward establishment of tall wheatgrass.

3.3. The Effects of Sufficient Irrigation with Saline Water on Soil Salinity and Forage Yield

To confirm the field supplemental saline water irrigation results, a pot experiment was carried out. Both the salt stress phase, no irrigation water leaked, and the leaching phase, nearly half of the irrigation water leaked, were conducted as a consecutive process. At the end of salt stress, the soil $EC_{1:5}$ in the culture medium increased from 2.13 $dS\ m^{-1}$ to 5.15 $dS\ m^{-1}$, 8.60 $dS\ m^{-1}$, 10.64 $dS\ m^{-1}$, 11.97 $dS\ m^{-1}$, and 12.06 $dS\ m^{-1}$ for irrigation with the salinities of EC_w = 1.02, 5.79, 6.31, 8.61, and 9.60 $dS\ m^{-1}$, respectively. Then, at the end of the leaching phase, the soil $EC_{1:5}$ was reduced to 1.29–1.52 $dS\ m^{-1}$, which was even lower than the pretreatment level (Table 6). Meanwhile, the soil pH decreased from 6.7 to 6.1–6.3 under salt stress but increased to 7.1–7.3 during the leaching phase. The soil water content elevated significantly when irrigated with saline waters during the salt stress phase. However, the difference was not significant at the leaching phase. Comparatively, the irrigation with EC_w = 5.79 dS m^{-1} salinity water had the lowest soil water content (81.9%) among all the four saline water irrigation treatments at the salt stress phase.

The dry matter yield per plant reached the highest value (44.74 g) when irrigated with tap water. However, yield reductions of 28.6%, 48.3%, 44.6%, and 50.8% occurred in plants irrigated with EC_w = 5.79, 6.31, 8.61, and 9.60 dS m^{-1} saline waters, respectively. Saline water irrigation appeared to improve the crude protein content in the leaves of tall wheatgrass (Table 6). For instance, the crude protein content in the leaves of plants irrigated with EC_w = 5.79 dS m^{-1} saline water reached the highest value (15.45%). However, no significant difference was observed in the stems. Comparatively, irrigation with EC_w = 5.79 dS m^{-1} saline water resulted in the least yield reduction and enhancement of the crude protein content in leaves.

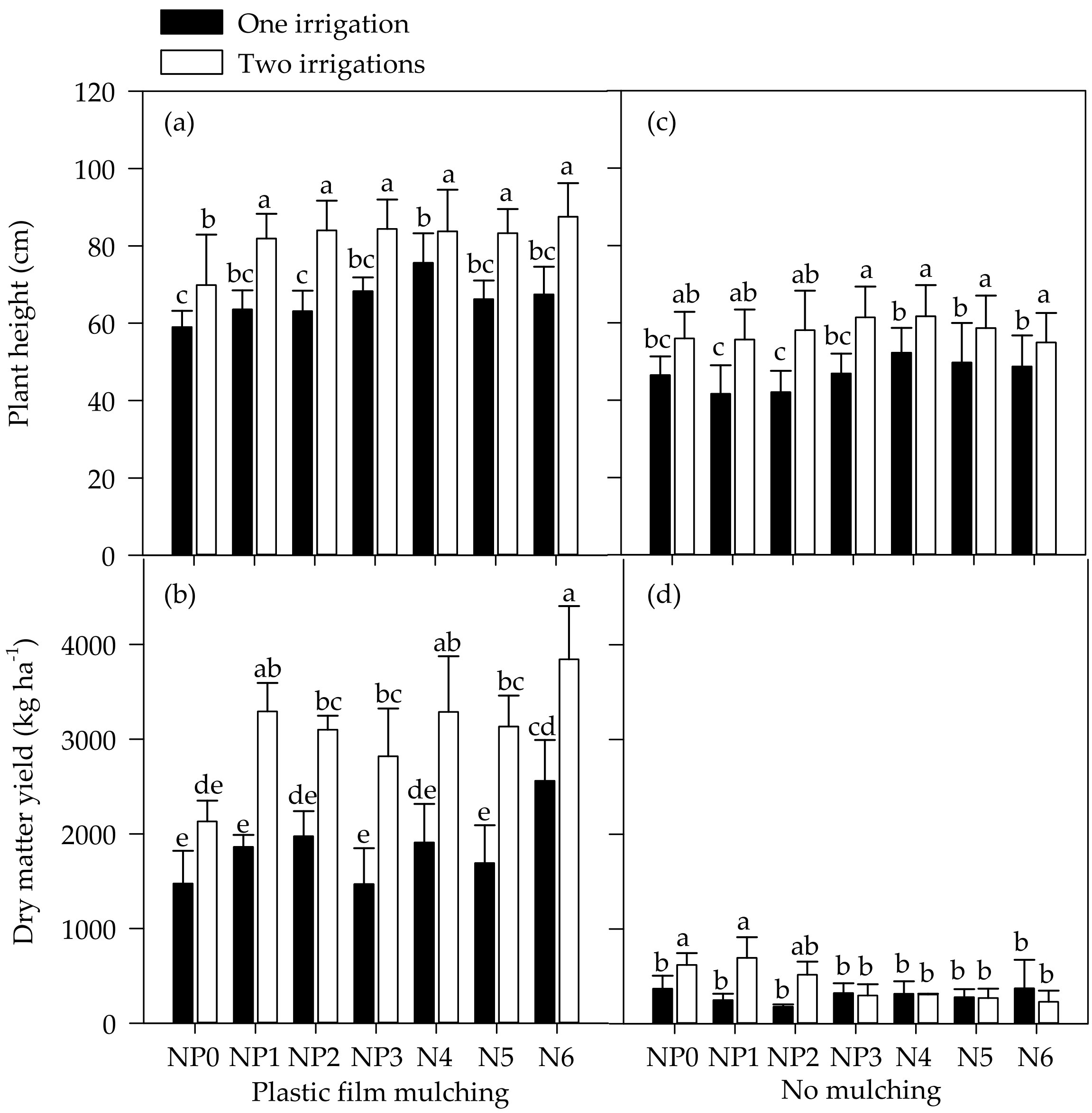

Figure 2. The effects of saline water irrigation, plastic film mulching, and fertilization on plant height (**a**,**c**) and forage yield (**b**,**d**) of tall wheatgrass. Two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline water were performed on 3 May and 25 May, respectively, while one irrigation with EC_w = 4.36 dS m^{-1} saline water was carried out on 25 May. Data are represented as mean ± SD (n = 10 for plant height and n = 3 for dry matter yield). Different letters indicate significant differences at $p < 0.05$.

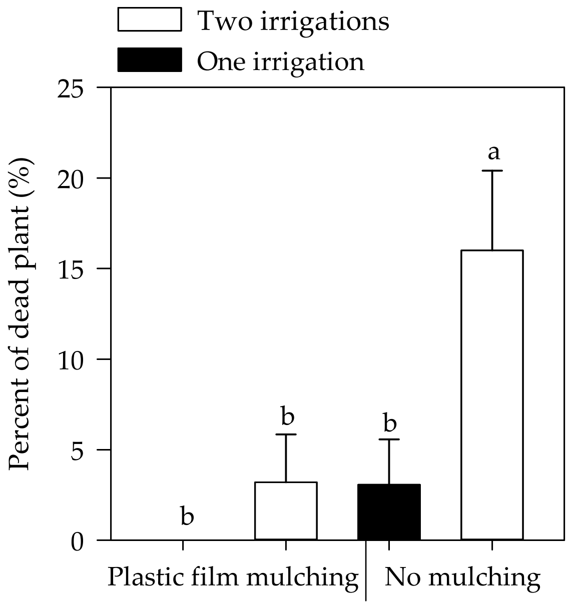

Figure 3. The percentage of dead plants irrigated with saline waters. Two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline waters were performed on 3 May and 25 May, respectively, while one irrigation with EC_w = 4.36 dS m^{-1} saline water was carried out on 25 May. Data are represented as mean ± SD (*n* = 5). Different letters indicate significant differences at $p < 0.05$.

Table 6. The soil electrical conductivity (EC), pH, and water content as well as dry matter yield and crude protein content of tall wheatgrass after saline water irrigation and tap water leaching.

Water Salinity (dS m^{-1})	Salt Stress Phase			Leaching Phase			Dry Matter Yield (g $plant^{-1}$)	Crude Protein Content (%)	
	$EC_{1:5}$ (dS m^{-1})	pH	Water Content (%)	$EC_{1:5}$ (dS m^{-1})	pH	Water Content (%)		Leaf	Stem
1.02	5.15 ± 1.69 d	6.1 ± 0.2 a	64.1 ± 10.1 c	1.29 ± 0.28 b	7.24 ± 0.15 ab	120.2 ± 5.7 a	44.74 ± 9.03 a	13.58 ± 0.64 b	9.32 ± 0.48 a
5.79	8.60 ± 0.54 c	6.2 ± 0.1 a	81.9 ± 7.6 b	1.46 ± 0.34 ab	7.14 ± 0.09 c	120.8 ± 8.8 a	31.93 ± 6.85 b	15.45 ± 1.52 a	9.09 ± 0.59 a
6.31	10.64 ± 0.51 b	6.2 ± 0.2 a	104.4 ± 9.0 a	1.45 ± 0.21 ab	7.16 ± 0.08 bc	123.9 ± 7.4 a	23.12 ± 5.29 bc	14.31 ± 1.00 a	8.99 ± 0.43 a
8.61	11.97 ± 0.77 a	6.3 ± 0.3 a	98.7 ± 11.5 a	1.44 ± 0.22 ab	7.26 ± 0.15 a	112.3 ± 6.7 b	24.78 ± 8.13 bc	14.11 ± 0.71 a	9.10 ± 0.56 a
9.60	12.06 ± 1.22 a	6.1 ± 0.0 a	104.9 ± 5.0 a	1.52 ± 0.25 a	7.30 ± 0.15 a	120.1 ± 7.7 a	22.00 ± 2.51 c	14.25 ± 1.38 a	8.80 ± 0.20 b

Notes: Data are represented as mean ± SD (*n* = 5). Different letters indicate significant differences at $p < 0.05$.

3.4. The Effects of Sufficient Irrigation with Saline Water on Plant Height and Tiller Number

As shown in Figure 4a, the plants' statuses were reduced with the increase in the water salinity for irrigation. Additionally, more curled and yellow leaves were found in the plants irrigated with $EC_w \geq 6.31$ dS m^{-1} saline water (Figure 4a). The plant height and tiller number were surveyed at the start and end of salt stress as well as after tap water leaching. No significant differences were observed for both the plant height and tiller number after saline water irritation for 6 days. However, the plant height was reduced significantly by irrigation with $EC_w \geq 6.31$ dS m^{-1} saline waters for 40 days. It was significantly lower in plants irrigated with saline water than in those irrigated with tap water (Figure 4b). Interestingly, no significant difference was observed for the tiller number at both the start and end of saline water treatment. However, at the end of the leaching phase, the plants irrigated with $EC_w \geq 6.31$ dS m^{-1} saline waters had a slightly lower tiller number (Figure 4c).

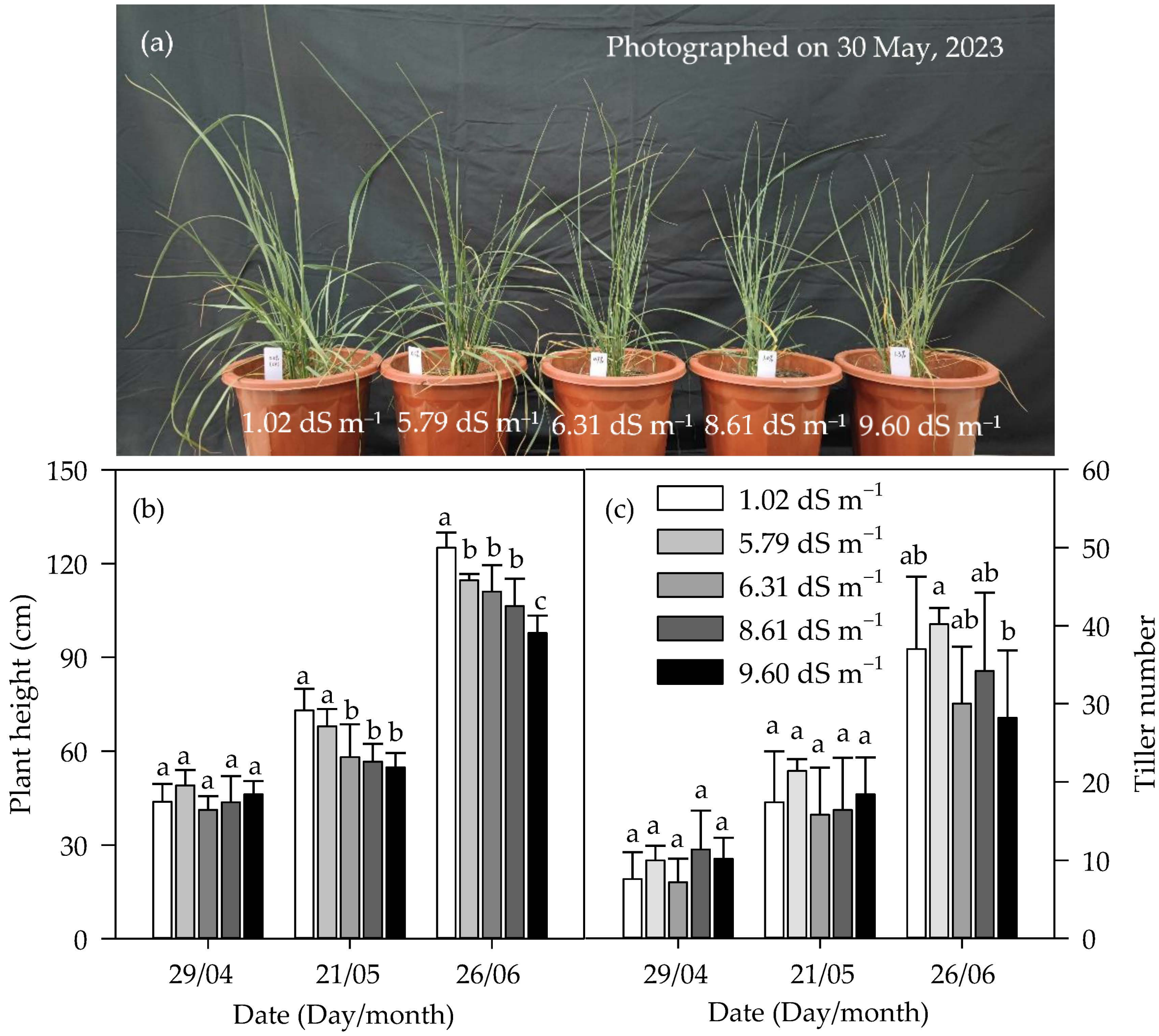

Figure 4. The photograph (**a**), plant height (**b**), and tiller number (**c**) of tall wheatgrass irrigated with saline (salt stress, before 21 May) and tap water (leaching phase, before 26 June). Data are represented as mean ± SD (n = 5). Different letters indicate significant differences at $p < 0.05$.

3.5. The Effect of Sufficient Irrigation with Saline Water on Leaf Size

The leaf width and length of the penultimate leaves reduced significantly in plants irrigated with $EC_w \geq 5.79$ dS m^{-1} and $EC_w \geq 6.31$ dS m^{-1} saline waters under salt stress (Figure S2a), respectively. Even at the leaching phase, the sizes of flag leaves also reduced in plants irrigated with $EC_w \geq 5.79$ dS m^{-1} saline water for leaf length and $EC_w \geq 6.31$ dS m^{-1} saline water for leaf width (Figure S2b). The curled leaf width ratio declined in the penultimate leaves in plants irrigated with $EC_w \geq 8.61$ dS m^{-1} saline water, while it changed little in the flag leaves after the leaching treatment.

3.6. The Effect of Sufficient Irrigation with Saline Water on Gas Exchange

Further gas exchange analysis demonstrated that at the end of salt stress, the net photosynthetic rate in the penultimate leaves declined consistently with the increase in irrigation water salinity (Figure 5a). The stomatal conductance and transpiration rate showed a similar trend as the net photosynthetic rate (Figure 5b,d). The intercellular CO_2 concentrations in the plants irrigated with EC_w = 5.79 dS m^{-1} and 6.31 dS m^{-1} saline waters were significantly lower than the control at the salt stress phase (Figure 5c), suggesting that the lower net photosynthetic rate was majorly determined by stomatal closure. The intercellular CO_2 concentrations in the plants irrigated with EC_w = 8.61 dS m^{-1} and 9.60 dS m^{-1} saline water were not significantly different from the control (Figure 5c), indicating that the decline in the net photosynthetic rate was not only due to the closure of the stomata but also due to the restriction of the carbon fixation enzymes' activity. At the end of the leaching phase, the net photosynthetic rate, stomatal conductance, intercellular CO_2 concentration, and transpiration rate in the flag leaves of plants irrigated with saline water were all significantly lower than those irrigated with tap water, demonstrating that saline water irrigation exerted profound impacts on gas exchange. The effects of saline water irrigation on gas exchange in this study appeared to be unable to be eliminated after the leaching treatment. In particular, the stomatal conductance and transpiration rate seemed to be more sensitive to saline water irrigation with $EC_w \geq 8.61$ dS m^{-1} saline water (Figure 5b,d).

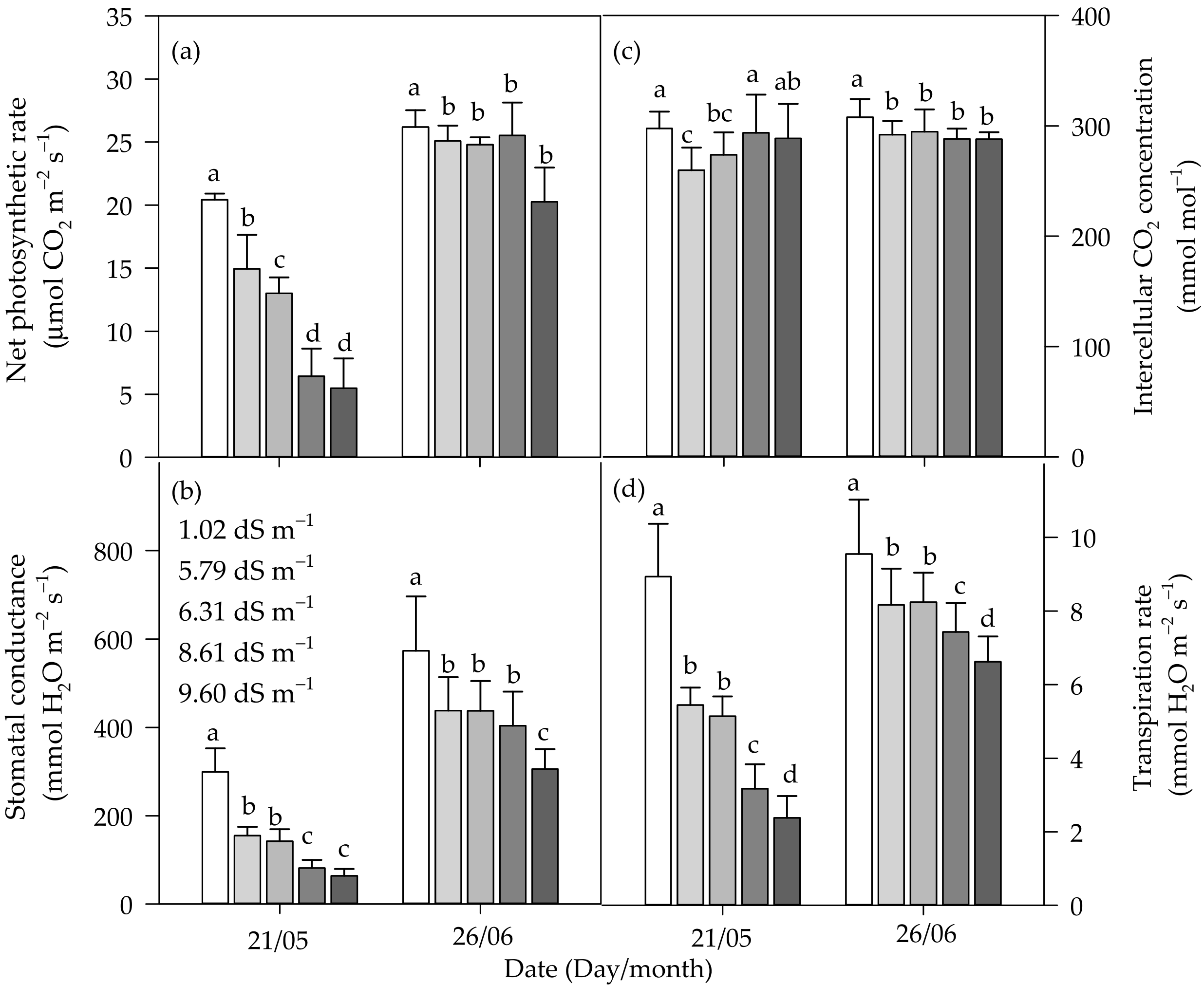

Figure 5. Gas exchange parameters in the penultimate and flag leaves after saline water irrigation on 21 May, followed by tap water leaching on 26 June, respectively. (**a**) Net photosynthetic rate; (**b**) stomatal conductance; (**c**) intercellular CO_2 concentration; (**d**) transpiration rate. Data are represented as mean ± SD (n = 5). Different letters indicate significant differences at $p < 0.05$.

4. Discussion

4.1. Supplemental Saline Water Irrigation of Transplanted-tall wheatgrass Enhanced Forage Yield

The reuse of saline drainage waters for the cultivation of salt-tolerant crops including forage grass is practical for improving coastal agriculture [32,37]. However, long-term irrigation, especially with saline water, may enhance soil salinity [37]. Therefore, it is important to balance forage production and soil salinization, which may in turn reduce forage yield for long-term saline water irrigation. Tall wheatgrass is a salt–alkali-tolerant grass that can accumulate a high content of Na, K, Mg, and Ca ions [38]. In this study, one-time and two-time irrigation with various salinities of saline–alkaline drainage waters were carried out in the field in the Yellow River Delta Region to determine the acceptable salinity levels for saline water irrigation of tall wheatgrass. The field experiments revealed that tall wheatgrass irrigated once with EC_w = 5.42 dS m^{-1} saline water produced a significantly higher forage yield (5627 kg ha^{-1}) than the unirrigated control. Irrigation with lower salinity water increased forage yield. For instance, one irrigation with EC_w = 4.42 dS m^{-1} saline water produced 5838 kg ha^{-1} dry matter, which was higher than that irrigated with EC_w = 5.42 dS m^{-1} saline water. However, two irrigations with EC_w = 5.42 and 4.36 dS m^{-1} saline waters produced a lower yield (4253 kg ha^{-1}) compared with one irrigation with EC_w = 5.42 dS m^{-1}, indicating that further irrigation with EC_w = 4.36 dS m^{-1} reduced forage yield. The highest dry matter yield was observed in two irrigations with EC_w = 2.45 and 4.36 dS m^{-1} saline waters (6862 kg ha^{-1}). Hence, two irrigations with $EC_w \leq$ 4.36 dS m^{-1} or one irrigation with $EC_w \leq$ 5.42 dS m^{-1} saline water produced a high dry matter yield in the transplanted two-year tall wheatgrass. A previous study showed that tall wheatgrass, growing in the highly saline fields with EC_e = 17.6–19.1 dS m^{-1}, produced 5.9–8.3 t ha^{-1} dry matter yield after irrigation with EC_w = 10.5 dS m^{-1} drainage water [26]. The lower dry matter yield in this study may be due to the harvest time, sampling method, or environmental factors. Highly saline waters not only reduce dry matter yield but also enhance the death rate of the first-year seed-propagated tall wheatgrass. For instance, two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline waters of the first-year seed-propagated tall wheatgrass resulted in 3.2% and 16.0% of dead plants under the mulching and no mulching conditions, respectively.

There is usually a 500–600 mm average annual precipitation in the coastal region around Bohai Sea. For instance, in total, 509.1 mm of precipitation occurred from June to September 2022, which caused a large reduction in soil salinity in the saline-water-irrigated fields. For example, the soil $EC_{1:5}$ at a 0–10 cm soil depth was reduced by 41.7–79.3% whether irrigated with saline water once or twice, indicating that little accumulation of salt due to saline water irrigation was detected. The same trends were also found for the soil $EC_{1:5}$ at both 10–20 cm and 20–30 cm soil depths. A three-year study demonstrated that about a 30% forage yield reduction and a measurable salt enhancement in soil and shallow groundwater were observed when alfalfa was irrigated with EC_w < 6 dS m^{-1} saline drainage water [39]. Additionally, the appropriate irrigation water salinity for maize production should be 4.0–4.4 dS m^{-1} [40]. The rainy season's rainfall leaching in the coastal area and drainage system make saline water irrigation acceptable for salt-tolerant crops such as tall wheatgrass, which was more tolerant than alfalfa, maize, and other cereal crops.

4.2. Saline Water Irrigation in Combination with Plastic Film Mulching Promoted Sward Establishment of Seed-Propagated Tall Wheatgrass

Sward establishment of seed-propagated tall wheatgrass is critical for saline pasture and forage production. In combination with saline water irrigation, the roles of fertilization and mulching on sward establishment were also assayed in this work. Comparatively, plastic film mulching, followed by saline water irrigation determined sward establishment and dry matter yield to a large extent. Relatively, fertilization appeared to play a marginal role in sward establishment and the first-year forage yield. Plastic film mulching in winter increased the temperature (Figure S1) and protected soil moisture, which promoted the plant growth of tall wheatgrass in the winter in coastal regions around the Bohai Sea. It is an effective technique for sward establishment of tall wheatgrass in this region to mulch plastic film in mid–late November and uncover at the end of February or the start of March. Plastic film mulching can increase tillers by one time, and forage yield by one to two times in comparison with the unmulched control which was consistent with the forage-oriented maize [33] and alfalfa [34,36]. This is the first report on the role of plastic film mulching on the sward establishment of tall wheatgrass, which can guide the cultivation of tall wheatgrass on highly saline–alkaline soils. Although the forage yield increment for plastic film mulching is significant, it is not recommended to be performed on tall wheatgrass from the second year when considering mulching costs. The marginal effects of fertilization on the sward establishment of tall wheatgrass may be due to the fertile fields used in this work, which are sufficient to support the first-year's sward establishment. Hence, fertilization is possibly essential for the sward establishment of tall wheatgrass in barren and highly saline–alkaline soils. Although two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} saline waters enhanced the death rate, such treatment produced more dry matter than one irrigation with EC_w = 4.36 dS m^{-1} saline water. Therefore, saline water irrigation can contribute a positive effect on the forage yield of seed-propagated tall wheatgrass in its first year of establishment. Irrigation with highly saline drainage water should be avoided to minimize the risk of enhancing the percentage of dead plants.

4.3. Confirmation of Acceptable Salinity Level for Saline Water Irrigation of Tall Wheatgrass

In addition, the pot experiment demonstrated that sufficient irrigation with $EC_w \geq 6.31$ dS m^{-1} saline water doubled soil salinity and reduced the plant height, leaf size, and leaf gas exchange rate compared to the tap water irrigation control. Moreover, significant salt-induced damage such as leaf yellow and necrosis was observed in plants irrigated with $EC_w \geq 6.31$ dS m^{-1} saline water. Relatively, among the four saline water treatments, the irrigation with EC_w = 5.79 dS m^{-1} had the least reduction in forage yield. Bazzigalupi et al. recommended that the NaCl solution with EC_w = 18 dS m^{-1} can be used to screen and breed salt-tolerant tall wheatgrass [41]. Bennett et al. reported that the tall wheatgrass plants cultured in a nutrient solution with EC_w = 10 dS m^{-1} resulted in a 50% reduction in dry matter yield [15], which was consistent with the EC_w = 9.6 dS m^{-1} saline water irrigation in this study. However, Riedell found that the nutrient cultivation with EC_w = 10 dS m^{-1} did not reduce growth, but that with EC_w = 30.2 dS m^{-1} resulted in a 50% reduction in dry matter yield in tall wheatgrass plants [42]. These above results were from laboratories or pot experiments, which might be inconsistent with the field situation. Considering land sustainability and forage yield persistence, EC_w = 5.79 dS m^{-1} (equal to 5 g L^{-1}) was recommended as the acceptable salinity level for saline water irrigation of tall wheatgrass in the Coastal Grass Belt targeted area. Interestingly, a recent study demonstrated that 5 g L^{-1} desalinated saline water is the salinity threshold for drip irrigation to avoid emitter clogging [43]. Additionally, Wu et al. predicted that the highest soil salt content of 0.497% is the salinity threshold of the cotton root zone in arid areas [44]. In addition with regards to the effects of saline water irrigation on plant growth and forage yield, saline water irrigation also enhanced the leaf crude protein content, which was consistent with Temel et al. [45] and Ayars et al. [39]. A previous pot experiment showed that the net photosynthetic rate and stomatal conductance in tall wheatgrass changed little when cultivated in soils having salinities of $EC_{1:5}$ = 0, 2, and 4 dS m^{-1} [46]. However, in this study, at the end of the salt stress phase, the net photosynthetic rate, stomatal conductance, and transpiration rate in tall wheatgrass declined drastically and consistently when the soil $EC_{1:5}$ increased from 2.13 dS m^{-1} to 8.60–12.06 dS m^{-1}. The net photosynthetic rate was restored significantly when the soil $EC_{1:5}$ declined to 1.46–1.52 dS m^{-1} at the end of the tap water leaching phase. Relatively, the tall wheatgrass plants sufficiently irrigated with EC_w = 5.79 dS m^{-1} saline water had the least reduction in the net photosynthetic rate and forage yield in this study.

4.4. The Quality of Saline Drainage Water Used for Irrigation Could Have Profound Effects on Forage Products

Usually, the composition of drainage water is complex and may contain potentially toxic trace elements. For instance, in California's San Joaquin Valley, the drainage waters contain high concentrations of selenium (Se), boron (B), and molybdenum (Mo) [24,28,30,47,48].

Se toxicity is of little concern, but high concentrations of both Mo and sulfur (S) in the herbage may lead to copper (Cu) deficiency in ruminants. Se is accumulated in forage hay of tall wheatgrass when grown in Se-enriched soils or irrigated with saline–alkaline drainage waters with high concentrations of Se, which can be used as a value added in the base diet [48]. In addition, the Na_2SO_4-dominated drainage waters probably increase S concentrations in forage products to high levels, which may result in the excessive accumulation of S in the rumen and potentially cause serious animal neurological diseases [47]. Therefore, for safe irrigation with saline–alkaline drainage waters, in addition to salinity, the concentrations of toxic trace elements should be considered to produce high-quality commercial forage products. According to the concentrations of ions in the drainage waters used in this study, the water salinity is NaCl-dominated. The SAR was 30.46, 36.31, and 40.39 for the salinities of EC_w = 4.42, 5.42, and 8.61 dS m^{-1} drainage waters, respectively. The concentrations of the trace element of B (<1 mg L^{-1}), Mo (<0.01 mg L^{-1}), and Se (<0.01 mg L^{-1}) in the drainage waters were very low, which means a low risk of toxicity to plant growth and forage quality when irrigating tall wheatgrass. However, the ratios of Mg/Ca were 1.93, 2.06, and 1.72 for the salinities of EC_w = 4.42, 5.42, and 8.61 dS m^{-1} drainage waters, respectively, indicative of high Mg concentrations. Mg is important for plant growth for its roles as an activation agent of enzymes and a component of chlorophyll. However, similar to Na^+, high levels of Mg^{2+} may cause deleterious effects on soil structure, with reduced soil permeability and significantly reduced crop yield [49]. When the ratios of Mg/Ca in irrigation waters were over 1, the risk of soil structure deterioration increased [50]. Therefore, irrigation with a high ratio of Mg/Ca in the drainage waters from the Yellow River Delta Region may have a risk of deteriorating soil structure. In combination with the field supplemental saline water irrigation and pot experiments, it appeared that EC_w = 5.42 dS m^{-1} and SAR = 36.31 may be considered as the acceptable salinity level for the irrigation of tall wheatgrass with drainage water in coastal regions around the Bohai Sea. Although the quality of drainage water with EC_w = 5.42 dS m^{-1} and SAR = 36.31 used in this study was harmful and unsuitable to be used for cereal crops [32], it appeared to be acceptable for tall wheatgrass. The field supplemental saline water irrigation, confirmed by pot experiment, was conducted on one growth season, so further long-term research is needed. Long-term continuous irrigation with saline drainage water should be carefully handled. In particular, for the highly saline–alkaline soils, the risk of irrigation with saline water should be considered.

5. Conclusions

Irrigation with saline waters increased the forage yield of tall wheatgrass compared with the unirrigated control. Two irrigations with EC_w = 2.45 and 4.36 dS m^{-1} saline waters produced the highest dry matter yield, followed by one irrigation with EC_w = 4.42 or 5.42 dS m^{-1} saline water. Two irrigations with EC_w = 5.42 and 4.36 dS m^{-1} saline waters produced less than one irrigation with EC_w = 4.42 or 5.42 dS m^{-1} saline water, suggesting that cumulative irrigation with saline water may cause soil salinity accumulation and reduce forage yield. Additionally, two irrigations with EC_w = 7.13 and 4.36 dS m^{-1} drainage water resulted in death rates of 16% and 3.2% of the seed-propagated tall wheatgrass under the no mulching and mulching conditions, respectively. In combination with plastic film mulching, saline water irrigation promoted sward establishment and dry matter yield, while fertilization played a marginal role. Sufficient irrigations with saline water $EC_w \geq 6.31$ dS m^{-1} for 40 days reduced the plant height, leaf size, gas exchange rate, and dry matter yield to a large extent, while irrigation with EC_w = 5.79 dS m^{-1} had the fewest negative effects on dry matter yield-related traits in this study. Irrigation with saline–alkaline drainage waters having various salinities, followed by the rainy season's rainfall or freshwater leaching, restored the soil salinity to the unirrigated levels. Taken together, supplemental irrigation with drainage water having $EC_w \leq 5.42$ dS m^{-1} and SAR ≤ 36.31 may be acceptable for tall wheatgrass and minimize the risk for soil salinization in coastal saline–alkaline land.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture13112117/s1, Figure S1: The variations of temperature in 10-cm soil depth from early January to mid-March in 2022 under no mulching and plastic film mulching conditions; Figure S2: Leaf length, width, and curled width ratio of tall wheatgrass irrigated with saline water.

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