agronomy

MDPI

Article

Influence of Fly Ash and Polyacrylamide Mixtures on Growth Properties of *Artemisia ordosica* in the Desert Region of North China

Jiping Niu [1], Xiaoling Su [1,*] and Zejun Tang [2]

[1] College of Water Resources and Architectural Engineering, Northwest A&F University, Yangling 712100, China; niujp@nwafu.edu.cn
[2] College of Water Resources and Civil Engineering, China Agricultural University, Beijing 100083, China; tangzejun@sina.com
* Correspondence: xiaolingsu@nwafu.edu.cn

Abstract: This study investigated the effects of consolidated soil layer (CSL) composed of fly ash (FA) and polyacrylamide (PAM) on the growth of *Artemisia ordosica* through plot experiments in Inner Mongolia, North China. It could provide a feasibility reference for ecological restoration and combating desertification in the desert areas. The germination and growth characteristics of *Artemisia ordosica* were studied in the control soil and 6 kinds of CSL, which were formed with 3 addition rates of FA (5%, 10%, and 15% (w/w) soil) and 2 addition rates of PAM (0.006% and 0.012% (w/w) soil). The results showed that CSL could provide good growth conditions for *Artemisia ordosica* in arid regions, especially for plant height, basal diameter, total fresh weight, and total dry weight in F5P1 as seen in 2017 and 2018. The FA, the PAM, and the interaction of FA and PAM all had significant impacts on the percentage of seedling emergence and total fresh weight ($p < 0.05$). The effects of CSL on the emergence and growth properties of *Artemisia ordosica* were evaluated by principal component analysis, and the CSL consisting of 5% FA and 0.006% PAM was recommended for plant growth.

Keywords: *Artemisia ordosica*; consolidated soil layer (CSL); fly ash (FA); polyacrylamide (PAM); growth properties

check for updates

Citation: Niu, J.; Su, X.; Tang, Z. Influence of Fly Ash and Polyacrylamide Mixtures on Growth Properties of *Artemisia ordosica* in the Desert Region of North China. *Agronomy* **2021**, *11*, 590. https://doi.org/10.3390/agronomy11030590

Academic Editor: Javier M. Gonzalez

Received: 11 February 2021
Accepted: 16 March 2021
Published: 20 March 2021

1. Introduction

Desertification is defined as land degradation characterized by wind erosion, resulting from climate change and human activities, and mainly occurs in the arid, semi-arid, and semi-humid regions of northern China [1,2]. China is one of the countries most seriously affected by desertification in the world, and the area of the Gobi desert and desertified land in China is about 1.7×10^6 km^2 [3]. The average annual growth rate of desertification increased from 2100 km^2 through 1976–1988 to 3600 km^2 recently [4]. Zhao [5] investigated the changes in soil resulting from desertification, and found that the soil environment had degraded significantly due to wind erosion. In addition, plant height, basal diameter, biomass, and yield of maize had all decreased to different degrees. Desertification had reduced the soil quality and hindered plant growth, which seriously restricted the economic development and ecological environment improvement in the desert region of North China [5–7].

Research and evaluation results [4] show that 60% of the desertified land in North China could be remediated under reasonable land use and intensity conditions. Traditional means of combating desertification include: fixed mechanical sand barriers, fencing vegetation, sandy cropland stubble, and spring irrigation. Nowadays, research on new means of desertification control in arid and semi-arid areas has become a hot topic, and establishing the artificial consolidated soil layer technique (CSL) has become a new way in recent years [8]. The related research [9–12] indicates that the widely distributed spontaneous soil crust plays an important role in the desert ecosystem with the effect of increasing soil fertility and stability; therefore, the soil biological crust and its continued development was artificially induced to fix sand and improve soil moisture and nutrients [13,14]. Therefore, artificial CSL was put forward. Artificial CSL has more significant advantages than the artificial soil biological crust in the remedial process, expenses, sand-fixing effect, consolidated speed and strength. In addition, the material we selected to construct CSL should improve the physical and chemical properties of the soil. Fly ash (FA) is a kind of industrial waste from thermal power plants [15–17]. Adding an appropriate amount of fly ash to soil could increase the availability of B, K, and other nutrients in soil [18], and ameliorate the physical and chemical properties of soil, such as improving soil structure, soil water content, and water holding capacity [19–21]. Mishra [22] found that under the 2 g/(m^2·day) and 4 g/(m^2·day) fly ash application regime, the plant height, metabolic rate, photosynthetic pigment content, and dry weight of roots, stems, and leaves of maize and soybean increased. However, the content of photosynthetic pigments and the dry weight of root and stem were reduced at 8 g/(m^2·day) of fly ash application. Pathan [23] added fly ash to sandy soil, then compared with a control group without fly ash: the phosphorus content in soil increased by 2.5–4.5 times, and turf root biomass increased by 1.2–1.5 times. In agriculture, a large number of field experiments have proven that fly ash can be used as an effective and safe soil amendment/fertilizer [24]. Polyacrylamide (PAM) is a kind of high molecular compound, which has a strong flocculation effect [25–27]. Stern [28] found that the yield and biomass of wheat grown on PAM-treated soil increased compared with control group. The researches of Levy [29] and Flanagan [30] also demonstrated the effect of PAM in enhancing vegetation growth.

The Hobq Desert, one of the most severe wind sand damage regions, has a distinct ecological environment mainly characterized by a dry climate and the serious hazard of wind sand. *Artemisia ordosica* is the local dominant species and a typical desert plant [9]. Consequently, the Hobq Desert in Inner Mongolia, North China was chosen as the study area to explore the effects of CSL on vegetation growth properties, desertification control, and vegetation restoration in desert zones. In the Hobq Desert, at present the research on desertification control is mostly concentrated on the effects of soil crust/CSL on soil structure, soil water, microbial biomass, and enzyme activities [9–12], as well as surface soil fixing and wind erosion resistance [31–33]. Although effective vegetation restoration was the ultimate purpose of desertification control, only a few studies had focused on the role of CSL in promoting the restoration of desert vegetation, especially the influence on emergence, growth, and biomass accumulation characteristics of local typical desert plants.

Specifically, we addressed the following aims: (1) to explore the growth characteristics of *Artemisia ordosica* in CSL in the Hobq Desert; (2) to evaluate the comprehensive effects of CSL, and to select the optimum proportion by principal component analysis; (3) to analyze the mechanism of the actions of CSL in North China. This study could provide data for desertification control and vegetation restoration in weak ecologic environments with serious soil erosion, and could even offer a reference for the feasibility and sustainability of ecosystem restoration in desert zones.

2. Materials and Methods

2.1. Study Area

The experimental site (40°16′ N–40°39′ N, 107°45′ E–109°50′ E, altitude 1020–1097 m) was located in the Hobq Desert, Inner Mongolia, North China. The site has a typical semi-arid temperate continental monsoonal climate with mean annual temperature of 6.1 °C, with mean annual precipitation of 250 mm. The lowest and highest monthly mean temperatures were −34.5 °C and 40.2 °C, respectively. The mean annual pan evaporation was 2160 mm. The land desertification in the study area was serious, the wind-sand movement of surface was strong. The soil type in the study area was sandy soil, and soil pH and electrical conductivity (EC) were 7.25 and 0.31 ms/cm, respectively. The main composition of the soil was sand, with clay content of 0.07%, silt content of 2.03%, and sand content of 97.9%.

2.2. Experimental Design

The experiment was conducted between May and October from 2016 to 2018. The field experiment treatments are shown in Table 1; the CSL were formed with 3 addition rates of FA (5%, 10%, and 15% (*w*/*w*) soil) and 2 addition rates of PAM (0.006% and 0.012% (*w*/*w*) soil). In this study, CSL was formed by mixing FA with PAM in soil. The FA was sieved through a 2-mm stainless steel sieve before the experiment, then FA and PAM were evenly applied to 0–30 cm soil depth, and an appropriate amount of water was sprayed uniformly onto the surface. All treatments were equilibrated to achieve moisture contents close to the initial soil moisture content [34]. The FA applied in the experiment was taken from Inner Mongolia Hong Zhu Thermal Power Plant, and gently crushed. The PAM used in the experiment was a white powder with a relative molecular mass of more than 3 million anions and a solid content of 85% (*w*/*w*). Physicochemical properties of the FA and soil used in the experiment are shown in Table 2, and the soil in Table 2 was the control treatment soil (CK). Subsequently, the *Artemisia ordosica* was planted in the CK and CSL. The growth properties of *Artemisia ordosica* including the daily emergence number, percent of seedling emergence, plant height, basal diameter, leaf number, and biomass were monitored. Each of the experimental units was 1.2 m × 2.5 m in size and was separated from the others by 1 m furrows to prevent mutual interference among units.

Table 1. Design of experiment.

Treatment	Fly Ash (FA) (%, The Weight Ratio to Soil)	Polyacrylamide (PAM)(%, The Weight Ratio to Soil)
CK	0	0
F5P1	5	0.006
F5P2	5	0.012
F10P1	10	0.006
F10P2	10	0.012
F15P1	15	0.006
F15P2	15	0.012

Table 2. Physicochemical properties of the fly ash and soil used in the experiment.

Element	Fly Ash	Soil
Bulk density (g/cm^3)	1.07	1.52
Sand (20−2000µm) (%)	27.4	97.9
Silt (2−20µm) (%)	70.8	2.03
Clay (0.01−2µm) (%)	1.8	0.07
Texture	Silt loam	Sand
pH	8.42	7.25
Electrical Conductivity (EC) (ms/cm)	1.62	0.31

2.3. Data Analyses

IBM® SPSS® Statistics 20 (Statistical Product and Service Solutions, IBM Company, Chicago, IL, USA) was used to analyze the data. The one-way and two-way analysis of variance (ANOVA) by least significant difference (LSD) were conducted at the significance level of 0.05. Comprehensive evaluation of the influence of CSL on *Artemisia ordosica* growth was conducted by principal component analysis.

3. Results

3.1. Seed Emergence

The effects of CSL on the emergence time and total emergence rate of *Artemisia ordosica* are shown in Figures 1 and 2, respectively. With the construction of CSL, the percent of seedling emergence in CSL was significantly lower than CK except the CSL of F5P2 ($p < 0.05$). In terms of time, the emergence of the germination peak was delayed with the use of CSL, especially in the CSL of F15P1 and F15P2; F10P1 and F10P2 were the second, while F5P2 and F5P1 got the minimal negative impact. The results indicated that CSL had a certain retarding effect on the emergence time and rate of *Artemisia ordosica* seeds.

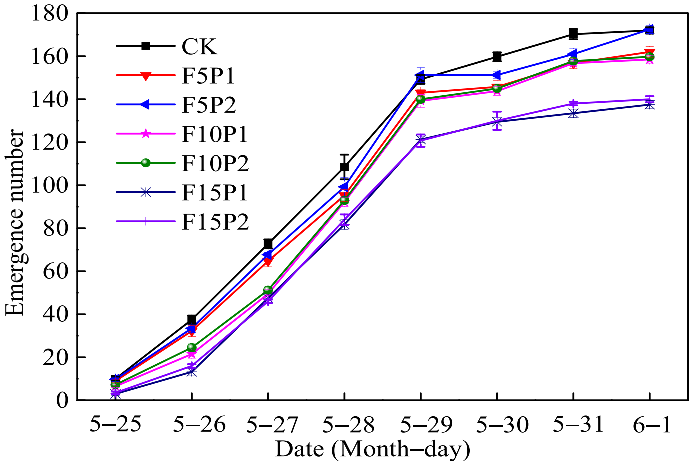


Figure 1. The daily emergence number of *Artemisia ordosica* in consolidated soil layer (CSL).

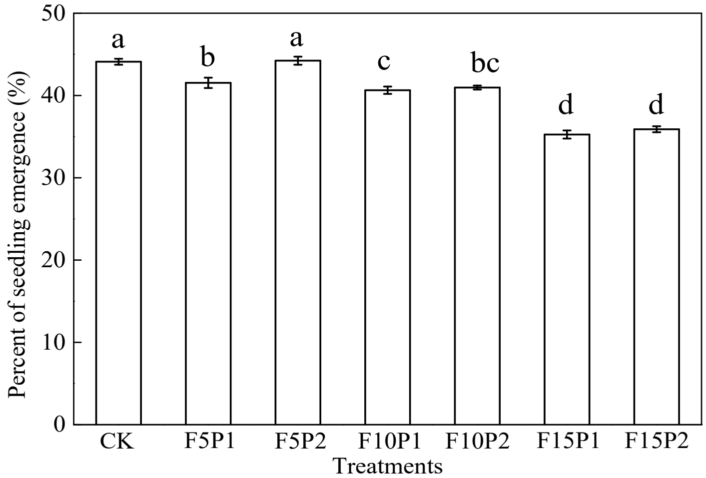


Figure 2. Percent of seedling emergence of *Artemisia ordosica* in CSL. Note: Letters indicate significant differences.

3.2. Growth Properties in 2016

In the desert area of North China, it was not enough to choose suitable mixture ratios of CSL according to the rate of seed germination. Therefore, it was necessary to monitor the growth characteristics and adaptability of *Artemisia ordosica* in CSL.

Figures 3–6 show the growth properties of *Artemisia ordosica* in CSL including plant height, basal diameter, leaf number, and biomass during the whole growth period from May 31st to October 13th in 2016. It can be concluded that the various growth indexes of *Artemisia ordosica* showed the same growth pattern in CSL, meaning that the plant height, basal diameter, and leaf number first increased rapidly, reaching the maximum in the middle of August. The photosynthetic organs then gradually entered the aging period, and stopped growing at the end of September. The *Artemisia ordosica* growth declined slowly and basically stopped in October.

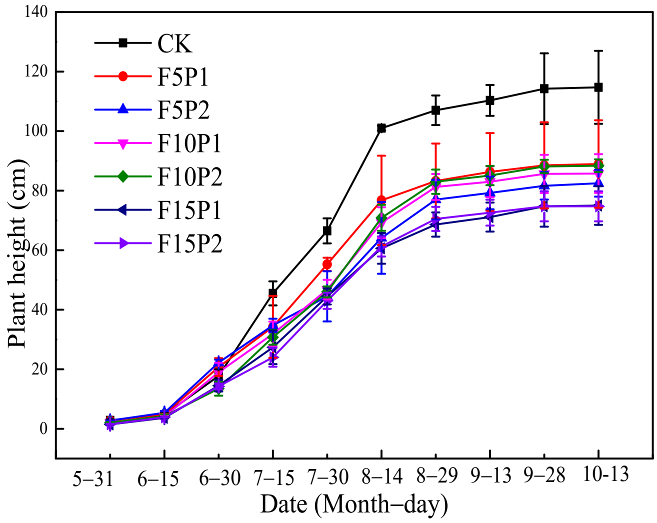


Figure 3. Effects of CSL on plant height of *Artemisia ordosica*.

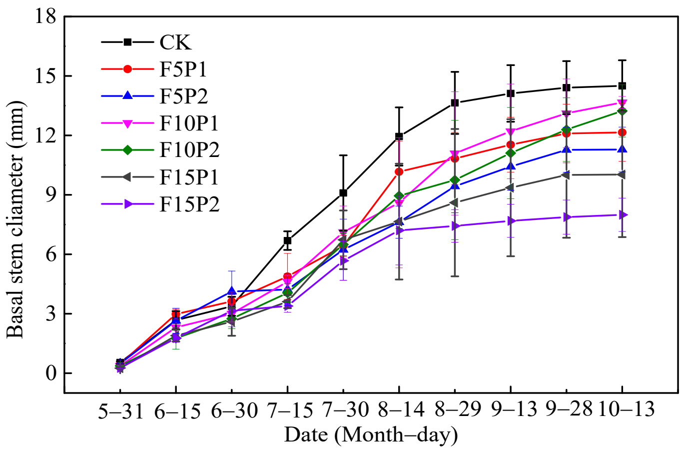


Figure 4. Effects of CSL on basal stem diameter of *Artemisia ordosica*.

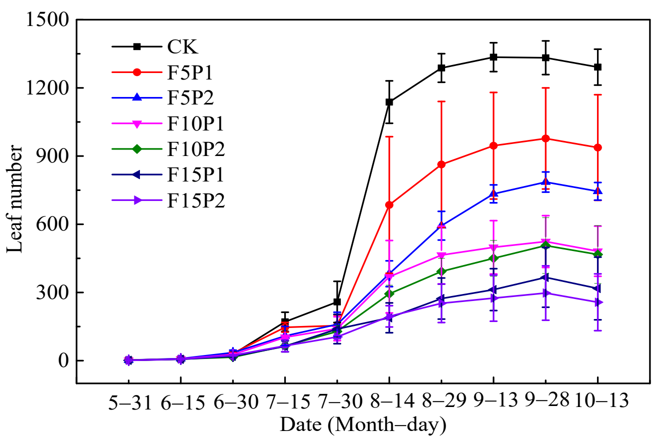
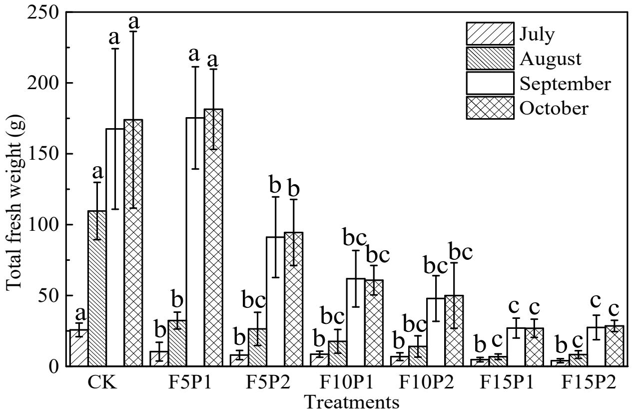
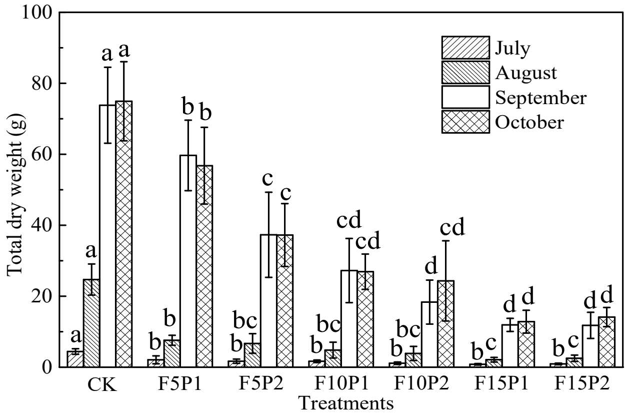


Figure 5. Effects of CSL on leaf number of *Artemisia ordosica*.



(**a**) Total fresh weight



(**b**) Total dry weight

Figure 6. Effects of CSL on total fresh weight (**a**) and total dry weight (**b**) of *Artemisia ordosica*. Note: Letters indicate significant differences of biomass in CK and CSL in the same month.

The biomass was also analyzed, taking October 2016 as an example in this paper. The total fresh weight of *Artemisia ordosica* in CK was 174 g, and it increased to 181 g in F5P1, while the total fresh weight in CSL of F10P1 and F10P2, as well as F15P1 and F15P2, decreased by an average of 68% and 84%, respectively, compared with CK. The total dry weight in the CSL of F5P1 and F5P2, F10P1 and F10P2, as well as F15P1 and F15P2, decreased by an average of 37%, 66%, and 82%, respectively. In terms of significance, the difference of total dry weight of *Artemisia ordosica* in CSL was the most significant, while the total fresh weight in CSL ranked second.

3.3. Effects of CSL on Plant Growth in Time Series

Table 3 indicates the growth properties of *Artemisia ordosica* in CSL with different FA and PAM quantities in time series. From the time the growth index maximum value appears, in 2016 the maximum value of plant height (PLH), total fresh weight (TFW), and total dry weight (TDW) all appeared in F5P1 among the six CSL treatments, while the maximum basal diameter (BD) occurred in F10P1. In 2017 and 2018, the growth indexes all reached the maximum value in F5P1 among the CSL treatments.

Table 3. Effects of CSL on *Artemisia ordosica* growth in time series.

		CK	**F5P1**	**F5P2**	**F10P1**	**F10P2**	**F15P1**	**F15P2**
2017	PLH (cm)	167.00 a	166.50 a	145.00 b	129.50 bc	116.00 cd	122.00 cd	107.00 d
	BD (mm)	17.42 a	16.69 ab	15.58 ab	13.69 abc	13.28 abc	10.37 bc	8.87 c
	TFW (g)	619.52 b	658.69 a	220.94 d	264.67 c	80.09 e	200.12 d	66.62 e
	TDW (g)	260.19 b	279.19 a	85.92 e	116.42 c	37.84 f	98.97 d	37.83 f
2018	PLH (cm)	168.50 a	170.75 a	150.50 b	136.75 bc	127.00 c	127.50 c	120.25 c
	BD (mm)	19.27 a	19.32 a	17.59 ab	14.49 ab	14.22 ab	11.64 b	11.17 b
	TFW (g)	774.98 a	771.37 a	295.32 b	283.18 b	257.11 b	270.10 b	210.65 c
	TDW (g)	314.00 a	323.88 a	178.94 bc	170.65 bc	201.34 b	163.73 bc	135.79 c

Note: PLH: plant height (cm), BD: basal diameter (mm), TFW: total fresh weight (g), TDW: total dry weight (g). Letters indicate the significant differences of PLH/BD/TFW/TDW in control soil (CK) and CSL.

From the view of significance, in 2016 there was no significant difference in basal diameter (BD) among CSL of F5P1, F5P2, F10P1, F10P2, and CK, as well as in total fresh weight (TFW) between F5P1 and CK. In 2018, there was no significant difference in plant height (PLH), total fresh weight (TFW), and total dry weight (TDW) between CSL of F5P1 and CK, or in basal diameter (BD) among CSL of F5P1, F5P2, F10P1, F10P2, and CK. However, differences were found among the six CSL treatments of the same growth index.

Therefore, the excellence order of the six CSL addition rates on emergence and growth of *Artemisia ordosica* was not always the same. For example, F5P2 was the optimum proportion for seedling emergence, while F10P1 and F10P2 were better for basal diameter growth. In addition, it was difficult to describe the effects of CSL with a single indicator, as the seedling emergence and growth properties of *Artemisia ordosica* in CSL were determined by complex genetic factors and environmental factors. Consequently, a statistical analysis method was needed to evaluate the comprehensive effects of CSL.

3.4. Comprehensive Evaluation on the Effects of CSL

The comprehensive evaluation of the effect of CSL on *Artemisia ordosica* growth was very complicated [35], including the selection of evaluation indexes, monitoring of indicators, and the choice of evaluation method; each step would affect the accuracy of evaluation results. A large number of studies [36,37] have shown that principal component analysis is the most widely used mathematical statistics method in evaluation, as well as an effective method of data dimension reduction. This is a multivariate statistical analysis method, which compresses the original data variables and transforms several original variables into a few independent new variables. During this process, it reflects most of the data information.

In this study, a multi-index principal component analysis method was applied with 5 indexes (including the percentage of seedling emergence, plant height, basal diameter, total fresh weight, and total dry weight) to comprehensively evaluate the influences of CSL with different FA + PAM addition rates. As shown in Table 4, it turned out that the excellence order of CSL composition was: F5P1 > F5P2 > F10P1 > F10P2 > F15P1 > F15P2.

Table 4. The principal component indexes of CSL.

Treatment	F1	F2	F	Ranking No.
CK	4.96	−1.15	3.91	1
F5P1	3.90	1.20	3.29	2
F5P2	−0.25	1.55	−0.05	3
F10P1	−0.79	−0.35	−0.68	4
F10P2	−1.43	−1.54	−1.31	5
F15P1	−2.62	0.20	−2.11	6
F15P2	−3.76	0.10	−3.05	7

4. Discussion

4.1. Influence of CSL on Seed Emergence Properties of Artemisia ordosica

Seed germination and seedling survival are the key steps of plant sexual reproduction. The adaptability of seeds and seedlings at seedling stage is also a decisive factor for the distribution and development of *Artemisia ordosica* communities. The study of the response of seed germination of dominant species in CSL in desert areas, was of theoretical and practical value to reveal the germination mechanism and vegetation restoration possibilities.

In this study, the total emergence rate of *Artemisia ordosica* showed a certain degree of reduction in CSL, and the time of emergence was delayed. The main factors affecting seed emergence and seedling growth in this experiment were as follows. One factor was the tightness degree of the soil around the seed, which was related to the structure and texture of the soil. If the soil compactness (the tight degree of the soil) increased, the resistance of the plant apical meristem growth would increase; this would lead to the delay of seedling emergence. Pandey's research [15] showed that the application of FA and PAM could reduce soil bulk density; this might be because the bulk density of FA was very low (Table 2), while PAM increased the number of sand aggregates and further increased soil pores. Nadler [38] discovered that comparing soil with 22, 45, 67, and 90 kg/ha PAM with the soil without PAM (CK), the emergence rate of maize was enhanced by 60%, 68%, 64%, and 76%, respectively [38]. Second, the acid and alkali environment, as well as the soluble salt content of soil were also considered. In this experiment, the soil pH increased from

7.25 (CK) to 8.07 at high FA addition rate of 15%. The study of Zheng [39] found that mild stress in the environment could promote the germination of plant seeds, while severe stress inhibited the emergence of seedlings. This was consistent with the conclusion of this paper that the total emergence rate was highest in CSL of F5P2, then gradually declined as the proportion of FA increased. It also indicated that the acid and alkali environment of the soil was overwhelming the bulk density for the emergence of *Artemisia ordosica*. Third, the quality of the seed itself and the energy contained in the endosperm or cotyledons were considered [40]. According to the literature [41], *Artemisia ordosica* seed has a mucilage structure; this structure could delay germination of seeds. The germination mechanism further ensures the seed germination of *Artemisia ordosica* in suitable conditions, as well as improving the ability to adapt to various environmental stresses and reducing the risks to survival.

4.2. Influence of CSL on Growth Properties of Artemisia ordosica

The possible mechanism of CSL affecting *Artemisia ordosica* growth was studied by analyzing the data from the experiments and reviewing the literature. On the one hand, FA in CSL could ameliorate some soil physical properties. FA also contains essential nutrients for plant growth, such as Mg, K, Na, B, Zn, and Cu. However, FA is strongly alkaline, and the content of salt and boron is high (Table 2). The content of carbon and nitrogen could be ignored as they oxidize to gaseous form during combustion in the process of forming FA [24]. In addition, from the perspective of microbiological survival, the high pH and electrical conductivity in the soil, as well as the lack of substrate C as an energy source for heterotrophic microorganisms and the lack of an adequate N supply might all affect the colonization of microbes, restricting microbial activity and enzyme activity in CSL [42]. The flocculation of PAM in CSL could reduce the negative impacts of FA on the emergence and growth of plants, so as to achieve better performance than single inorganic/organic materials (FA/PAM). Two-way ANOVA was used to analyze the effects of CSL on the growth of *Artemisia ordosica* in 2016, as shown in Table 5. FA had significant influence on the percentage of seedling emergence, plant height, basal diameter, total fresh weight, and total dry weight. PAM had significant influence on the percentage of seedling emergence and total fresh weight. The interaction of FA and PAM had significant influence on the percentage of seedling emergence and total fresh weight ($p < 0.05$).

Table 5. Two-way ANOVA of the effects of CSL on the growth characteristics of *Artemisia ordosica* in 2016.

	FA		**PAM**		**FA × PAM**	
	F	**Sig.**	**F**	**Sig.**	**F**	**Sig.**
PSE	567.296	0.000	44.531	0.000	16.559	0.000
PLH of 2016	4.995	0.017	0.155	0.698	0.601	0.557
BD of 2016	11.164	0.000	1.315	0.264	0.087	0.917
TFW of 2016	31.067	0.000	7.278	0.013	5.429	0.013
TDW of 2016	32.960	0.000	4.136	0.055	3.508	0.048

Note: PSE: percentage of seedling emergence (%), PLH: plant height (cm), BD: basal diameter (mm), TFW: total fresh weight (g), TDW: total dry weight (g).

The influence of CSL on the emergence and growth properties of *Artemisia ordosica* was evaluated by principal component analysis: F5P1 > F5P2 > F10P1 > F10P2 > F15P1 > F15P2. It was clear that the CSL of F5P1 and F5P2 had changed soil pH and salt content slightly, and the negative influences brought by CSL on the growth of *Artemisia ordosica* were less than positive ones. The negative effects of the CSL in F10P1, F10P2, F15P1, and F15P2 were more significant, especially in 2016. With the deposition of organic matter in plant growth, the weathering of FA and leaching of precipitation, it could be expected that the soil pH and salinity levels would gradually decrease, and the physicochemical and biological properties of the CSL and its underlying soil also would change for the better [43]. Meanwhile, the changes in CSL affected the growth of *Artemisia ordosica* in turn. As compared with the control, in 2016, a fluctuant reduction of final plant height, basal diameter, leaf number, and total dry weight of *Artemisia ordosica* were found in CSL of 22.47%−34.85%, 5.59%−38.55%, 27.34%−80.09%, and 37.27%−82.01%, respectively. The final total fresh weight increased in CSL of F5P1 compared with CK. In 2017 and 2018, from the standpoint of significance, the positive effects in CSL of F5P1 were equal to/better than CK. Singh [44] also confirmed that 5%, 10%, 15%, and 20% FA addition reduced plant growth, biomass, and yield during early growth phases. Pandey [45] found that lower levels of FA in the soil caused enhancements of both growth and yield of *Cajanus cajan L.*, while adverse effects were observed at higher levels. Adriano [46] also found that establishment of turf was inhibited by the high concentration of soluble salt and boron in soil brought by FA, although FA significantly increased the water holding capacity of the soil and plant-available water. Mishra [22] analyzed the reasons for the increase in plant height and dry weight of corn and soybeans under 2 g/(m^2·day) and 4 g/(m^2·day) FA addition rates, finding that this was because of FA making up for the deficiency of boron in the soil. In contrast, the content of photosynthetic pigment and dry weight decreased under 8 g/(m^2·day) and 4 g/(m^2·day) FA addition rates, mainly because of the excessive absorption and accumulation of salt and boron in the soil by plants.

The use of inorganic-organic composite sand-fixing material CSL (FA + PAM) was more effective than the use of inorganic/organic sand-fixing material alone (FA/ PAM). Using FA and PAM to construct CSL had the advantages of convenient construction, low cost, short construction period, and remarkable effect. At the same time, the addition of FA also solved the problem of treating industry waste in northern China. Recent studies [33,34] showed that CSL had a certain structure and strength on the surface of the flow sand, and that CSL could effectively prevent sand dunes from wind erosion, control the sand's negative effects on the environment, and improve the productivity of sandy land in arid regions. Combining traditional chemical sand-fixing methods with a biological sand-fixing method is conducive to vegetation and ecological restoration, which could further provide new ideas for the development of desertification control.

Considering the harsh environment in desert areas, as well as the dynamic effects of CSL on *Artemisia ordosica* plant growth, further investigation using longer plant growth times and other sand-fixing plant types in the CSL, based on long-term field observation, is needed for better understanding of the influence of CSL on plant growth.

5. Conclusions

The CSL containing FA and PAM provided good growth conditions for *Artemisia ordosica* in arid regions, especially for plant height, basal diameter, total fresh weight, and total dry weight in F5P1 in 2017 and 2018. In terms of time series, accompanied by the gradual weakening inhibition effect of CSL on growth, the growth promotion effect became more significant. The role of CSL affecting the above actions was also analyzed using two-way ANOVA; the result showed that the FA, the PAM, and the interaction of FA and PAM, all had significant impacts on the percentage of seedling emergence and total fresh weight ($p < 0.05$).

The effects of CSL on the growth properties of *Artemisia ordosica* were evaluated by principal component analysis. The CSL with 5% FA and 0.006% PAM was recommended as an effective proportion for *Artemisia ordosica* growth, which could be used for desertification control and vegetation restoration in desert areas.

Author Contributions: J.N. designed the study, performed the experiments and wrote the manuscript. X.S. and Z.T. reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (NO 51379211).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gad, A.; Abdel-Samie, A.G. Study on desertification of irrigated arable lands in Egypt. II-Salinization. *Egypt. J. Soil Sci.* **2000**, *40*, 373–384.
2. Pye, N.; Middleton, N.J.; Thomas, D.S.G. World Atlas of Desertification. *Geogr. J.* **1994**, *160*, 210. [CrossRef]
3. Wang, T.; Zhu, Z.; Wu, W. Sandy desertification in the north of China. *Sci. China Ser. D Earth Sci.* **2002**, *45*, 23–34. [CrossRef]
4. Wang, T.; Wu, W.; Xue, X.; Sun, Q.; Chen, G. Study of spatial distribution of sandy desertification in North China in recent 10 years. *Sci. China Ser. D Earth Sci.* **2004**, *47*, 78–88. [CrossRef]
5. Zhao, H.-L.; Zhou, R.-L.; Zhang, T.-H.; Zhao, X.-Y. Effects of desertification on soil and crop growth properties in Horqin sandy cropland of Inner Mongolia, north China. *Soil Tillage Res.* **2006**, *87*, 175–185. [CrossRef]
6. Zhou, R.-L.; Li, Y.-Q.; Zhao, H.-L.; Drake, S. Desertification effects on C and N content of sandy soils under grassland in Horqin, northern China. *Geoderma* **2008**, *145*, 370–375. [CrossRef]
7. Zhao, H.-L.; He, Y.-H.; Zhou, R.-L.; Su, Y.-Z.; Li, Y.-Q.; Drake, S. Effects of desertification on soil organic C and N content in sandy farmland and grassland of Inner Mongolia. *Catena* **2009**, *77*, 187–191. [CrossRef]
8. Ibrahim, S.M.; El Salmawi, K.M.; Zahran, A.H. Synthesis of crosslinked superabsorbent carboxymethyl cellulose/acrylamide hy-drogels through electron-beam irradiation. *J. Appl. Polym. Sci.* **2007**, *104*, 2003–2008. [CrossRef]
9. Niu, J.; Yang, K.; Tang, Z.; Wang, Y. Relationships between Soil Crust Development and Soil Properties in the Desert Region of North China. *Sustainability* **2017**, *9*, 725. [CrossRef]
10. Pietrasiak, N.; Regus, J.U.; Johansen, J.R.; Lam, D.; Sachs, J.L.; Santiago, L.S. Biological soil crust community types differ in key ecological functions. *Soil Biol. Biochem.* **2013**, *65*, 168–171. [CrossRef]
11. Hawkes, C.V. Effects of biological soil crusts on seed germination of four endangered herbs in a xeric Florida shrubland during drought. *Plant Ecol.* **2004**, *170*, 121–134. [CrossRef]
12. Drahorad, S.; Felix-Henningsen, P.; Eckhardt, K.-U.; Leinweber, P. Spatial carbon and nitrogen distribution and organic matter characteristics of biological soil crusts in the Negev desert (Israel) along a rainfall gradient. *J. Arid. Environ.* **2013**, *94*, 18–26. [CrossRef]
13. Zhao, Y.; Zhu, Q.; Li, P.; Zhao, L.; Wang, L.; Zheng, X.; Ma, H. Effects of artificially cultivated biological soil crusts on soil nutrients and biological activities in the Loess Plateau. *J. Arid. Land* **2014**, *6*, 742–752. [CrossRef]
14. Wu, Y.W.; Rao, B.Q.; Liu, Y.D.; LI, G.B.; LI, D.H. Effects of different habitats on artificial crust development and surface soil nitrogen, phosphorus contents and enzymes activities. *Soils* **2013**, *45*, 52–59.
15. Pandey, V.C.; Singh, N. Impact of fly ash incorporation in soil systems. *Agric. Ecosyst. Environ.* **2010**, *136*, 16–27. [CrossRef]
16. Wigley, F.; Williamson, J. Modelling fly ash generation for pulverised coal combustion. *Prog. Energy Combust. Sci.* **1998**, *24*, 337–343. [CrossRef]
17. Jala, S.; Goyal, D. Fly ash as a soil ameliorant for improving crop production—A review. *Bioresour. Technol.* **2006**, *97*, 1136–1147. [CrossRef] [PubMed]
18. Cox, D.; Bezdicek, D.; Fauci, M. Effects of compost, coal ash, and straw amendments on restoring the quality of eroded Palouse soil. *Biol. Fertil. Soils* **2001**, *33*, 365–372. [CrossRef]
19. Riehl, A.; Elsass, F.; Duplay, J.; Huber, F.; Trautmann, M. Changes in soil properties in a fluvisol (calcaric) amended with coal fly ash. *Geoderma* **2010**, *155*, 67–74. [CrossRef]
20. Gangloff, W.J.; Ghodrati, M.; Sims, J.T.; Vasilas, B.L. Impact of Fly Ash Amendment and Incorporation Method on Hydraulic Properties of a Sandy Soil. *Water Air Soil Pollut.* **2000**, *119*, 231–245. [CrossRef]
21. Pathan, S.M.; Aylmore, L.A.G.; Colmer, T.D. Properties of several fly ash materials in relation to use as soil amendments. *J. Environ. Qual.* **2003**, *32*, 687–693. [CrossRef]
22. Mishra, L.; Shukla, K. Effects of fly ash deposition on growth, metabolism and dry matter production of maize and soybean. *Environ. Pollut. Ser. A Ecol. Biol.* **1986**, *42*, 1–13. [CrossRef]
23. Pathan, S.M.; Aylmore, L.A.G.; Colmer, T.D. Soil properties and turf growth on a sandy soil amended with fly ash. *Plant Soil* **2003**, *256*, 103–114. [CrossRef]
24. Gupta, D.K.; Rai, U.N.; Tripathi, R.D.; Inouhe, M. Impacts of fly-ash on soil and plant responses. *J. Plant Res.* **2002**, *115*, 401–409. [CrossRef]
25. Sepaskhah, A.; Shahabizad, V. Effects of water quality and PAM application rate on the control of soil erosion, water infiltration and runoff for different soil textures measured in a rainfall simulator. *Biosyst. Eng.* **2010**, *106*, 513–520. [CrossRef]
26. Armbrust, D.V. Effectiveness of polyacrylamide (PAM) for wind erosion control. *J. Soil Water Conservat.* **1999**, *54*, 557–559.
27. Yu, J.; Lei, T.W.; Shainberg, I.; Mamedov, A.I.; Levy, G.J. Infiltration and erosion in soils treated with dry PAM and gypsum. *Soil. Sci. Soc. Am. J.* **2003**, *67*, 630–636. [CrossRef]
28. Stern, R.; Van Der Merwe, A.J.; Laker, M.C.; Shainberg, I. Effect of soil surface treatments on runoff and wheat yields under irrigation. *Agronomy J.* **1992**, *84*, 114–119. [CrossRef]
29. Levy, G.; Ben-Hur, M.; Agassi, M. The effect of polyacrylamide on runoff, erosion, and cotton yield from fields irrigated with moving sprinkler systems. *Irrig. Sci.* **1991**, *12*, 55–60. [CrossRef]
30. Flanagan, D.C.; Chaudhari, K.; Norton, L.D. Polyacrylamide soil amendment effects on runoff and sediment yield on steep slopes: Part II. natural rainfall conditions. *Trans. ASAE* **2002**, *45*, 1339. [CrossRef]

31. Gomes, L.; Arrúe, J.L.; López, M.V.; Sterk, G.; Richard, D.; Gracia, R.; Sabre, M.; Gaudichet, A.; Frangi, J. Wind erosion in a semiarid agricultural area of Spain: The WELSONS project. *Catena* **2003**, *52*, 235–256. [CrossRef]
32. Yang, K.; Tang, Z. Effectiveness of Fly Ash and Polyacrylamide as a Sand-Fixing Agent for Wind Erosion Control. *Water Air Soil Pollut.* **2012**, *223*, 4065–4074. [CrossRef]
33. Wang, Y.; Yang, K.; Tang, Z.; Chen, C. The Effectiveness of the Consolidated Desert Surface by Mixing of Fly Ash and Polyacrylamide in Wind Erosion Control. *Water Air Soil Pollut.* **2016**, *227*, 429. [CrossRef]
34. Wang, Y.; Yang, K.; Tang, Z. In situ effect of combined utilization of fly ash and polyacrylamide on sand stabilization in North China. *Catena* **2019**, *172*, 170–178. [CrossRef]
35. Masto, R.E.; Chhonkar, P.K.; Singh, D.; Patra, A.K. Alternative soil quality indices for evaluating the effect of intensive cropping, fertilisation and manuring for 31 years in the semi-arid soils of India. *Environ. Monit. Assess.* **2007**, *136*, 419–435. [CrossRef] [PubMed]
36. Yemefack, M.; Jetten, V.; Rossiter, D. Developing a minimum data set for characterizing soil dynamics in shifting cultivation systems. *Soil Tillage Res.* **2006**, *86*, 84–98. [CrossRef]
37. Govaerts, B.; Sayre, K.D.; Deckers, J. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil Tillage Res.* **2006**, *87*, 163–174. [CrossRef]
38. Nadler, A.; Perfect, E.; Kay, B.D.K.; Kay, B.D. Effect of two polymers and water qualities on dry cohesive strength of three soil. *Soil Sci.* **1996**, *60*, 556–561.
39. Zheng, Y.; Xie, Z.; Gao, Y.; Jiang, L.; Shimizu, H.; Tobe, K. Germination responses ofCaragana korshinskiiKom. to light, temperature and water stress. *Ecol. Res.* **2004**, *19*, 553–558. [CrossRef]
40. Seiwa, K.; Watanabe, A.; Saitoh, T.; Kannu, H.; Akasaka, S. Effects of burying depth and seed size on seedling establishment of Japanese chestnuts, Castanea crenata. *For. Ecol. Manag.* **2002**, *164*, 149–156. [CrossRef]
41. Huang, Z.; Gutterman, Y. Comparison of germination strategies of Artemisia ordosica with its two congeners from deserts of China and Israel. *Acta Bot. Sin.* **2000**, *42*, 71–80.
42. Carlson, C.L.; Adriano, D.C. Environmental Impacts of Coal Combustion Residues. *J. Environ. Qual.* **1993**, *22*, 227–247. [CrossRef]
43. Haynes, R. Reclamation and revegetation of fly ash disposal sites—Challenges and research needs. *J. Environ. Manag.* **2009**, *90*, 43–53. [CrossRef] [PubMed]
44. Adriano, D.C.; Weber, J.T. Influence of Fly Ash on Soil Physical Properties and Turfgrass Establishment. *J. Environ. Qual.* **2001**, *30*, 596–601. [CrossRef]
45. Pandey, V.C.; Abhilash, P.; Upadhyay, R.N.; Tewari, D. Application of fly ash on the growth performance and translocation of toxic heavy metals within Cajanus cajan L.: Implication for safe utilization of fly ash for agricultural production. *J. Hazard. Mater.* **2009**, *166*, 255–259. [CrossRef]
46. Singh, A.; Sharma, R.K.; Agrawal, S.B. Effects of fly ash incorporation on heavy metal CSLumulation, growth and yield responses of Beta vulgaris plants. *Bioresour. Technol.* **2008**, *99*, 7200–7207. [CrossRef] [PubMed]