Research article

Site-specific Soil Conservation Approaches in Desertification-prone Areas in the Inner Mongolia Region, China

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Abstract Desertification is still a severe problem in the Inner Mongolia region of China, despite the country's efforts to stop land degradation. The authors carried out periodic field surveys for over a decade in different desertification-prone arid lands of Northern China. Based on a series of experiments and analyses, this paper proposes locally-tailored technologies that can ensure greater participation, and lead to more effective, sustainable measures to combat desertification in the area. Specifically, the potential of both cotton and coal ash as water-holding materials was experimented with sandy soil. From the results, an amount of 0.5% (by weight) cotton and 3% (by weight) alkali-treated coal ash (named artificial zeolite) mixed with sandy soil could ensure water retention in the soil and so facilitate upland crops growing in arid environments. The results also showed that, if mixed individually with the soil, both of these materials demonstrated constant positive effect as water-holding materials. However, dual application (both the items mixed together with soil) did not show constant positive effect. In addition, to diversify the potential uses of coal ash, the effects of artificial zeolite as a particle film sprayed over plant-leaves were also tested. The results showed that cotton plants with a particle film that were grown in sandy soil tended to transpire less water than those plants without a particle film on their leaves. Finally, since the properties of applied forms of coal ash (i.e. the artificial zeolite) differ based on the processing methods (alkali treatment) used, proper selection of the type of artificial zeolite could further diversify its potential uses, for example as a salinity mitigator in arid soil.

Keywords desertification, site-specific, water-holding material, arid land, sustainability

INTRODUCTION

Afforestation has been the most popular measure used to combat desertification in many arid land areas of the world as well as in the Inner Mongolia region in China, which is experiencing severe desertification. Afforestation plays a very significant role in desertification control, but planting trees is not the only measure against desertification. Instead, when only the planting of trees is considered and no measures are considered regarding farmland to enhance the per area unit output, the prevention of desertification fails in many cases (Fan and Zhou, 2001). Massive man-made forests that include plants, such as poplar, larches, pines, birches, oaks, elms, lindens, and willows, have been established in the Inner Mongolia region to prevent desertification; however, the illegal cutting down of plants, i.e., deforestation, occurs frequently in the region (Liu, 2014). Despite different land conservation and restoration efforts undertaken by the Chinese communes based on ideological motivation and regulatory steps, the reality is that the encroaching rate of desertification due to deforestation exceeds the status of prevention (Cao, 2008). Such a situation emphasizes the necessity of revising the basic strategies for participation in land conservation. In other words, site-specific sustainable soil conservation approaches could encourage the mitigation of the desertification syndrome in the Inner Mongolia region. This study thus investigated the potential natural resources in north China that could feasibly be used as a tool(s) to combat desertification in a sustainable way. We identified the cotton plant as an alternative/complementary plant in the Inner Mongolia region because China is the largest producer of cotton in the world and because domestic production is mainly concentrated in the northwest Xinjiang region (Xinjiang Uyghur Autonomous region), which is a neighbor province of Inner Mongolia. The climate and ecology of the Xinjiang and Inner Mongolia regions are very similar. Unlike other quick growing forest plants in Inner Mongolia, such as poplars and pines, perennial cotton plants have little value as an alternative fuel or precious wood, and are less likely to be the target of illegal wood-cutters. At the same time, cotton has a high potential to be a cash crop. Therefore, to introduce and to grow the cotton plant in Inner Mongolia would not be a difficult task from eco-environmental and socio-economic standpoints; however, since the existing status of the production, marketing, and distribution channels of cotton products (cotton wool and fibers) are concentrated in the Xinjiang region, and because the people in the Inner Mongolia region are not accustomed to growing cotton as upland crops, to make the cotton a cash crop in the Inner Mongolia region, problems associated with certain factors, such as extension, marketing, and price-fixing, would arise at the initial stage because of the imbalance in the demand-supply of the products in the locality. Therefore, the authors also attempted to diversify the usage of cotton products in the region. Due to its nature and properties, cotton wool is an organic substance and has good water-holding capacity. Therefore, wasted and/or un-used portions of cotton wool can be used as an organic water-holding material in sandy soil.

In addition, the Inner Mongolia region is an important coal production base with more than a quarter of the world's coal reserves located in the province, which produces millions of tons of coal fly ash as a by-product every year. Coal ash or fly ash, usually refers to ash/residue produced during combustion of coal, is the largest quantity of industrial waste residues in China (Tang et al., 2013). To find out effective/recycle use(s) of this product is a big issue in that region. The Chinese government has initiated some steps to recycle it as an alternative raw material for concrete and cement materials (Yi et al., 2012). In this regard, we attempted to use this waste material as a soil improver, which could facilitate plant growth in the sandy soil. Accordingly, we experimented with coal ash's nature as a water-holding material not by applying it to farmland soil in its original form but in the form of an artificial zeolite (alkali treated coal ash) because the latter has superior physico-chemical properties than in its original form (Henmi, 1997).

This paper aims for and focuses on the identification of the site-specific problems related to soil conservation in the Inner Mongolia region as well as the sustainable measures that involve introducing locally originated water holding materials by using cotton plants/wools and alkali-treated coal ash (waste) based on basic experiments and investigations. In addition, to diversify the uses and the application of cotton and coal ash in the region, other potential uses of the materials were investigated.

METHODOLOGY

Study Sites

Inner Mongolia is the third largest province (an autonomous region) in China, and it has a temperate continental monsoon climate with a sharp rainfall gradient from 50 mm to 450 mm in the west and northeast parts, respectively, while the evaporation capacity is above 1200 mm in most areas of this region. Most of the rainfall occurs in the summer season (May to September). The region is characterized by a diverse ecosystem, including vast forests and agricultural lands as well as the world's largest temperate grasslands and extensive sandy lands and deserts (Bai et al., 2004). Land degradation/desertification caused by deforestation and over-grazing has been severe. Between 1980 and 2000, Inner Mongolia's population increased by 26%, from 18.76×10^6 to 23.72×10^6. The most affected degraded grassland area in the region is the Xilingol League (a prefecture level division of Inner Mongolia) where the population increased by 19%, livestock increased 177%, and the grassland productivity decreased by 30% within the period of 1980 to 2000 (Zhen et al., 2014). The authors carried out field surveys periodically in different parts of the Inner Mongolia region from 2000 to 2009. The surveyed sites included grasslands and agricultural lands at five different administrative areas named Xilinhot County, Erenhot County, Zhenglan Banner (a county level division of Inner Mongolia), Abag Banner, and Sonid Right Banner of the aforesaid Xilingol League along with one more site at Wuchuan County in Hohhot City (a prefecture level city). All of these sites were prominent for desertification. The Xilingol area in particular, located in central Inner Mongolia, had been a fertile prairie in northern China, but desertification and sand storms have increased in the past decades. Fig. 1 shows the locations of the surveyed sites at Xilingol League and Hohhot city, while Table 1 presents the major soil and vegetation types in the grassland-dominated study sites.

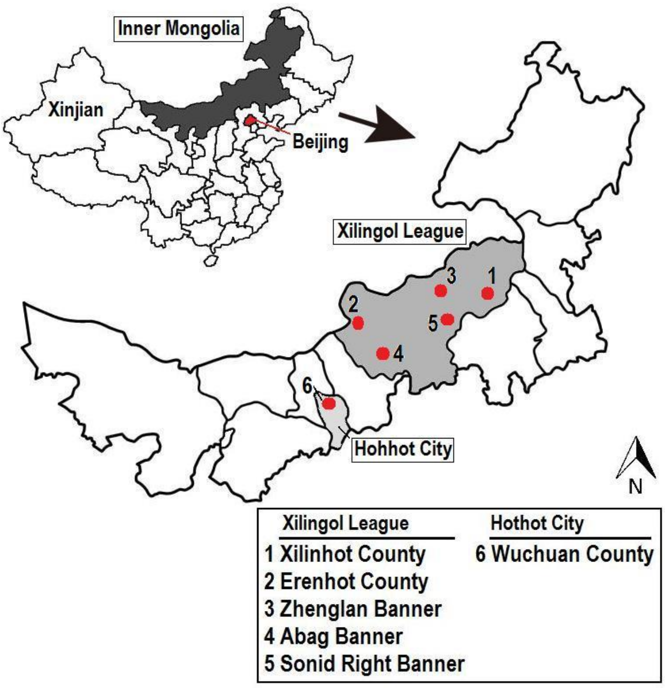

Fig. 1 Study sites at Xilingol League in Inner Mongolia region, China

Table 1 Major soil and vegetation types in the study sites of Inner Mongolia region

Study site	Soil type	Vegetation type	Dominant species
Xilinhot County	Chestnut	Typical steppe	*Stipa* species, *Cleistogenes* species
Erenhot County	Brown	Desert steppe	*Stipa* species
Zhenglan Banner	Chestnut	Typical steppe	*Stipa* species
Abag Banner	Chestnut	Typical steppe	*Artemisia* species, *Stipa* species
Sonid Right Banner	Brown	Desert steppe	*Artemisia* species, *Stipa* species
Wuchuan County	Chestnut	Desert steppe	*Stipa* species, *Artemisia* species

Materials and Methods

Cotton and coal ash as water-holding materials: A series of indoor and outdoor experiments were carried out by mixing cotton and alkali-treated coal ash (named artificial zeolite, henceforth AZ) with soils (sandy and loamy soils). The indoor experiments were carried out inside an artificial climate chamber (Fig. 2), whereas the outdoor experiments were conducted in farmland (Fig. 3). Both of these establishments are located within the campus of the College of Bioresource Sciences, Nihon University, Japan.

For the indoor experiments, seedlings of Chinese cabbage (*Brassica chinensis* L.) were used as test plants and grown in pots filled with river sand that is used for gardening purposes. Pieces of torn cotton wool were added at three different weight ratios (0.1%, 0.3%, and 0.5%), while Na-type artificial zeolite (Maeda Corporation, Japan) was added to the soil (sand) at the weight ratio of 3%. A total of 25 pots that included five replications of each item of the controls (non-treated), cotton-mixed (0.1%, 0.3% and 0.5%), and AZ-treated soils, were used to cultivate the test plants. The same doses of chemical fertilizer (N:P:K=8:8:6) and water were used to facilitate the natural growing of the plants. The soil moisture was measured by using a W.E.T sensor (DIK-691A; Daiki Rika Kogyo Co., Ltd.) coupled with a time-domain reflectometer, while the physiology of the shoot-part of each plant (shoot length and number of leaves) was measured periodically throughout the growing period. In addition, the pF values at each condition of the soil and plant weights (dry weights) were also measured.

On the other hand, for the outdoor experiments, cotton plants (*Gossypium hirsutum* L.) were grown in four adjacent plots (each with a dimension of 180cm length×30cm width) with the same soil texture (Andosol, also known as Kanto loam); however, the treatments of the soil in each plot were different, namely, the control (non-treated), the 0.5% (by weight) cotton-mixed soil, the 3% (by weight) AZ-mixed soil, and the cotton plus AZ-mixed soil. In the outdoor field, Ca-type AZ was used, and the same amount (g) of 0.5% cotton and AZ (g) was mixed in the dual application plot. To measure the periodic in-situ soil moisture and the pF, soil-moisture sensors (ECH2O-10; Decagon Devices, Inc.) attached to a data logger (Em5b; AINEX Co., Ltd.) and tensiometers (Daiki-8331; Daiki Rika Kogyo Co., Ltd.) were installed at each plot, respectively. The W.E.T sensor (DIK-691A; Daiki Rika Kogyo Co., Ltd.) was also used to cross check the recorded soil moisture values. Periodic measurements of the physiology of the plant-shoots (shoot length and number of leaves) as well as the biomass (dry weight, fresh weight) of the plant bodies were also carried out.

Coal ash as a particle film on plant-leaves: Inside a glass house (Fig. 4), a total of 24 cotton plants (*Gossypium hirsutum* L.) were grown in cultivation pots filled with two different textured soils (12 plants of each soil), namely, sand and Andosol/Kanto loam. A small amount of Ca-type AZ (Chubu Electric Power Co., Inc., Japan) with the pH value adjusted to 7 was mixed with water and sprayed over the foliage sections in equal numbers of the 6 young cotton plants (6 replications) from each soil type. The remaining 6 plants from each group (soil type) received no foliar-spray. After drying-up, the dust-like particle film created partial blockage to the stomata at the upper leaf surface. The plants were then grown by applying the usual doses of compound fertilizer (N:P:K=8:8:6). The parameters related to the plant growth, such as shoot length, number of leaves, stem-diameter, leaf-temperature, and leaf area as well as the daily transpiration rate were measured periodically. In addition, at the latter half of the growing stage, a 10-day long dry-down experiment was carried out on the plants by applying water equal to the 80% of their daily transpiration amounts. To identify the status between the transpiration and the available water for plant growth, this watering scheme followed a similar procedure as described by Sinclair and Ludlow (1986). Finally, the dry weights of the plants were measured.

Other potential uses of cotton and coal ash: Salinity is also an issue in many arid lands and in some areas of our study sites as well. To investigate the potential of coal fly ash and cotton as salinity mitigators, a number of experiments (Kaneuchi et al., 2008; Roy et al. 2009; Nishimura and Roy, 2010) have been carried out by applying AZ and waste cotton materials to different types of soil with different protocols. This paper will present an experiment in which a small amount of Ca-type AZ

Fig. 2 Experiments inside the artificial climate chamber

Fig. 3 Experimental plots with cotton-plants growing in different conditions

Fig. 4 Experiments inside the glass house with a particle film sprayed over cotton plants

Fig. 5 Experiments of artificial zeolite and cotton gauze as salinity mitigators

Table 2 Major physico-chemical properties of artificial zeolites (AZ) and soils used in the experiments

Type	Particle size	EC (dSm^{-1})	pH (H_20)	Exchangeable cation cmol(+) kg^{-1}				CEC cmol(+) kg^{-1}
				Na	K	Ca	Mg	
Sand	0.2～2 mm	0.12	6.9	0.8	0.1	0.5	0.1	6.5
Andosol	0.02～2 mm	0.33	6.2	0.3	2.9	2.6	0.6	18.7
Ca type AZ	5～100 μm	1.60	9.8*	122.0	15.3	151.0	1.9	260.8
Na type AZ	5～100 μm	1.10	11.2	160.0	11.4	111.0	0.2	210.0

*Note: * Except the pH adjusted to 7 for f_A zeolite during particle film spray*

(named f_A zeolite, Maeda Corporation, Japan) was applied to the top surface of artificially-prepared (by 5% sodium chloride solution) saline soil (Andosol/Kanto loam) filled in 8 Wagner pots (Fig. 5). The treatments in every two pots were different. Of the 8 pots, two had 5mm thin AZ-layers applied directly to the top of the soil, while the same amount of AZ was sealed in between the double-fold cotton gauze pockets in two other pots. Five-fold cotton gauzes were laid over the surface soil in two pots, and two remaining pots were kept under no-treatment (control) conditions. The pots with moist saline soil were placed in an artificial glass chamber (relative humidity: 60%, average temp: 25°C) for 30 days. The soil samples from the upper layers were collected, and the concentrations of specific ions (Na^+ and Ca^{++}) in the soil samples were investigated by using an

Atomic Absorption Spectrophotometer (AA-6800; Shimadzu Corporation, Japan). Also, the electrical conductivity of the soil samples was measured by using an EC meter (B-173; Horiba, Japan).

Table 2 presents the major physico-chemical properties of artificial zeolite (AZ) and farmland soil (Andosol/Kanto loam) used in the different experiments.

Statistical Analysis

All data were statistically analyzed using MiniTab statistical software. Particularly; mean, standard deviation, and percentage were determined using descriptive statistics. Mean of treatments were compared by One-way ANOVA (Analysis of Variance) at 0.50 significance level.

RESULTS AND DISCUSSION

Cotton and coal ash as water-holding materials: Fig. 6 and 7 show the variations in the average physiological growth (shoot length) and the soil moisture content under each condition (treatment) throughout the growing period carried out for the indoor experiments. As can be observed from the figures, while the AZ-treated soil had the highest soil moisture content accounting for an average of 3-5% higher than the other pots, the plant-growths (shoot lengths) were better in the order of 0.5% cotton-treated, 0.3% cotton-treated, and AZ-treated soil. Fig. 8 illustrates the pF-soil moisture curve in each treatment from which it was found that regarding the effective pF range to grow plants (pF=1.8

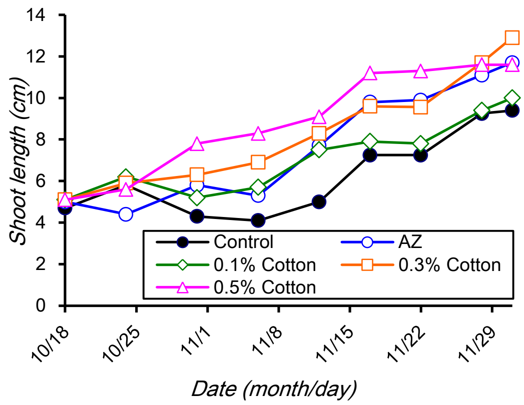

Fig. 6 Variations in the shoot length (*B. chinensis*) at different treatments of soil (indoor)

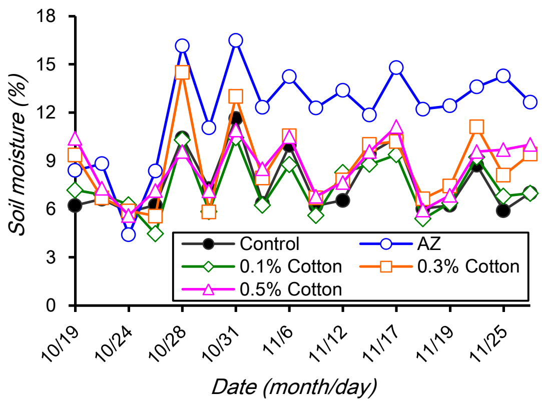

Fig. 7 Variations in the soil moisture content at different treatments of soil (indoor)

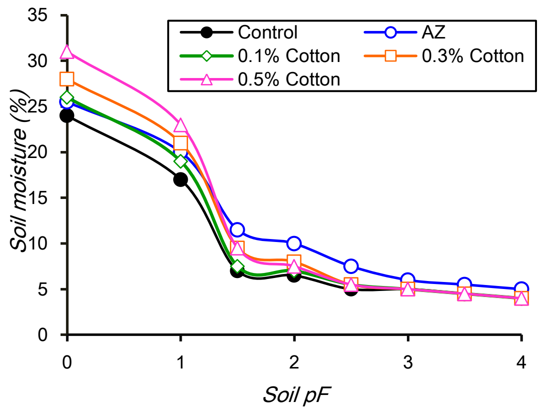

Fig. 8 Soil moisture retention curves at different treatments of soil (indoor)

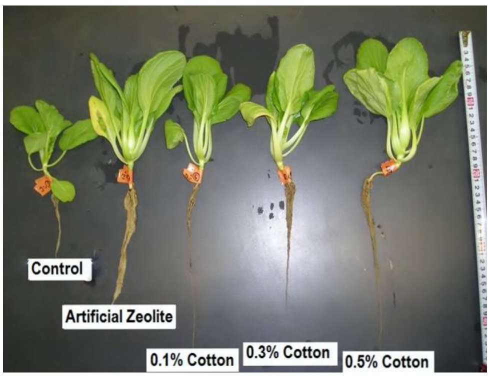

Fig. 9 Plant growth at different treatments of soil (indoor)

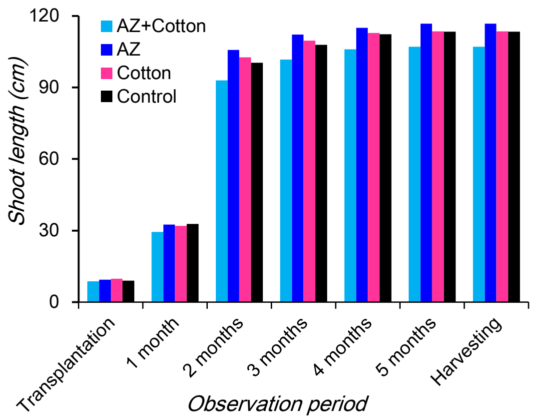

Fig. 10 Variations in the shoot length (*G. hirsutum*) at different treatments of soil (outdoor)

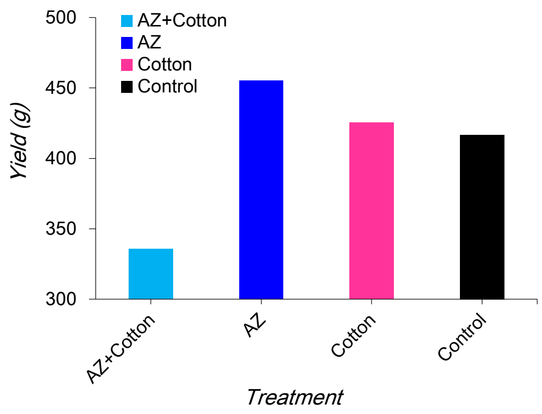

Fig. 11 Variations in the yields of cotton balls at different treatments of soil (outdoor)

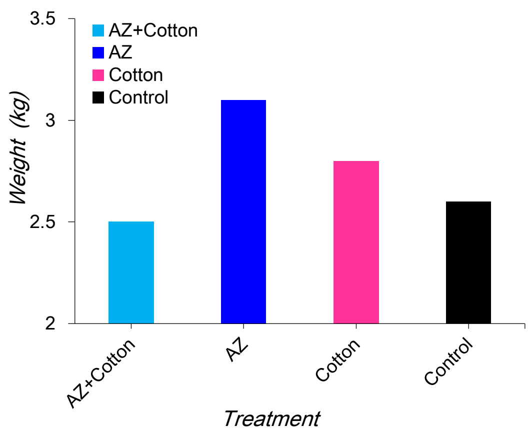

Fig. 12 Variations in the dry weights of plants at different treatments of soil (outdoor)

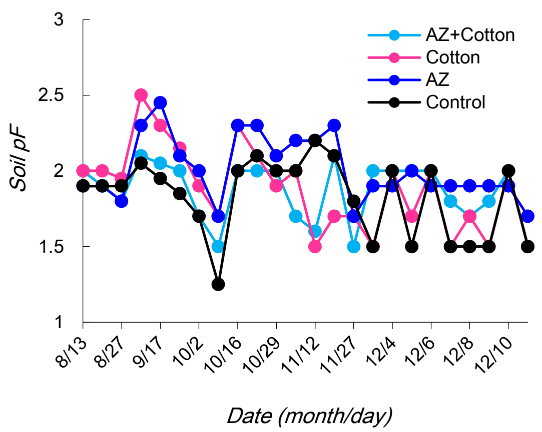

Fig. 13 Variations in the soil pF values at different treatments of soil (outdoor)

to 3.0), the AZ-treated soil followed by the 0.5% and 0.3% cotton-mixed soils had better soil moisture capacity. In addition, considering other measured parameters, such as the plant weight and the number of leaves, the AZ-treated soil and the 0.5% cotton-mixed soil were found to be the most suitable treatments among all of the treatments when using them as water-holding materials for the soil. Fig. 9 shows the average growing conditions of the plants under each condition.

Fig. 10, 11 and 12 show the average variations in the representative physiological parameters, including the shoot length, yield (weights of cotton balls), and dry weight of the plant bodies (shoot plus root), for cotton plants grown in outdoor plots. From the figures, it can be seen that AZ and cotton wool mixed independently with soil favored the cotton growth/production; however, when these materials were mixed together and applied jointly to the soil, the growth/production trailed behind the control (no-treatment) condition. A similar tendency was also found for other measured parameters (number of leaves, biomass). The specific problems related to the dual application of AZ and cotton wool that may be caused by poor function are: slaked finer *particles of soil/AZ blocked* pores of the cotton wool, the formation of a type of a *soil* crust, reduced infiltration and water movement through the *soil*, and the hampered growth/yield of the plants. Fig. 13 shows the periodic variations in the soil pF values with each treatment. While the pF values in all of the plots ranged from 1.25 to 2.5 (within the range suitable for plant growth; pF =1.8 to 3.0), the cotton-treated plot showed the most stable values that ranged from pF= 1.5 to 2.5 followed by the AZ-treated plot with pF values that ranged from pF= 1.3 to 3.0 throughout the growing period. On the other hand, unlike the indoor experimental results, the soil moisture content did not show distinct differences among the treatments in the outdoor experiments.

Coal ash as a particle film: Variations in the transpiration rate of the plants grown with and without a particle film in both types of soil (sand and Andosol) are presented in Fig. 14, while Fig. 15 and Fig. 16 present the variation in the shoot lengths and the dry weights of the plant bodies. From the figures (Fig. 15 and Fig. 16), it can be observed that the plants with a particle film sprayed over the leaves had slightly higher average growths than the plants with no particle film in both types of soils. A similar tendency was also found in cases of other physiological parameters (number of leaves, stem-diameter, and leaf area); however, in the case of the daily transpiration rate, the tendency varied in the soil types both before and after the dry-down period (Fig. 14). To identify the specific effect of each treatment on the transpiration, the normalized transpiration rates (daily relative transpiration rates normalized against the plant growth) for each treatment were plotted against the fractions of transpired soil water (the ratio of daily transpired soil water to the water at field capacity) following the Sinclair and Ludlow (1986) method (Fig. 17). From the difference/degree of inclination between the two approximate straight regression lines of the same soil with and without a particle film, the results show that cotton plants with a particle film that were grown in sand transpired less water than the plants without a particle film on their leaves.

Uses of cotton and coal ash as potential salinity mitigators: Variations in the average ion-concentrations (Na^+ and Ca^{++}) at the top surface soil in the pots with different treatments are presented in Fig. 18, while the average EC concentrations are presented in Fig. 19. The results show that the AZ application (direct application and inside cotton gauze packets) reduced the concentration of Na-ion in the topsoil; however, the Ca-ion concentrations also reduced slightly in comparison with the control and cotton gauze treatments (Fig. 18). The reason is that the type of artificial zeolite used in the experiment (Ca type) was not saturated by specific exchangeable ions (Ca^{++}) and was part of Ca-ion thus transmitted from the topsoil to the finer AZ particles. The variation in the average EC values at the end of the experiment as shown in Fig. 19 also supports the tendency found in the case of changes in the Na-ion concentration in the topsoil. Therefore, it can be said that AZ has a great potential to be used as a salinity mitigator; however, depending on the properties of AZ, such as the type/method of alkali used to process the coal ash, the extent of salinity mitigation will vary. Moreover, the salinity mitigation capacity can be maximized while using AZ in cotton packets.

CONCLUSION

The experiments carried out in this study focuses on different potential uses of cotton and coal ash as soil improvers by using them as soil water holding materials, as transpiration reducers by using them as foliar particle film materials, and as salinity mitigators by using them as salt absorbents in arid land soil (sandy and loamy). The results show that mixing small amounts of these items (artificial zeolite: 3% by weight; cotton wool: 0.5% by weight) with soil (sandy and loamy types) could facilitate plant growth in arid land soils (sandy and loamy). In addition, if used as a particle film, pH-adjusted (to 7.0) coal ash (artificial zeolite) can sustain plant growth with less transpiration, and this anti-transpiration capacity maximizes in sandy soil in comparison with loamy soil. Moreover, based on the type/processing of the materials, utilizing the higher cation exchange capacity (CEC) of artificial zeolite, specific ions responsible for salinization (Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-) can be removed from soil (loamy), and this salinity mitigation capacity maximizes if it is used in packs made of cotton gauze. These experimental findings demonstrate the diversified potential uses of cotton and coal ash in an arid land environment. In other words, potential and proper uses of two locally tailored items to combat desertification in the Inner Mongolia region are identified from this study.

The sustainable conservation of natural resources, such as soil and water, of an area incorporates many bio-physical and socio-cultural interdisciplinary actions regardless of being a developing or

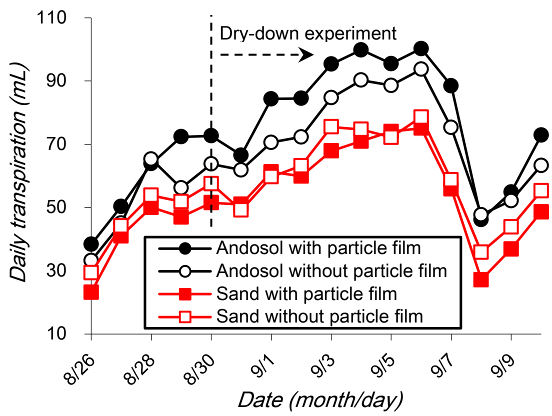

Fig. 14 Variations in the transpiration rate by plants with and without a particle film

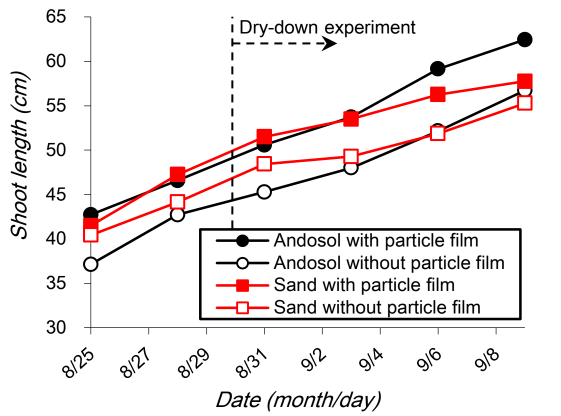

Fig. 15 Variations in the shoot length of plants with and without a particle film

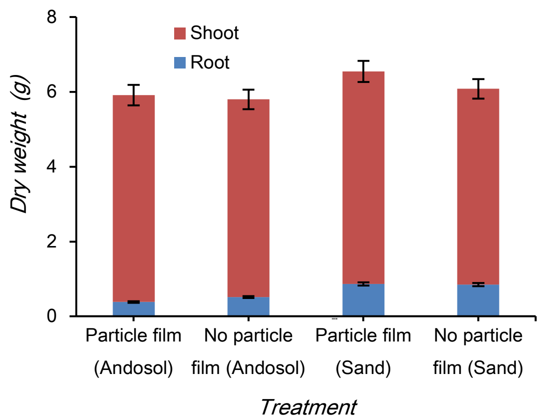

Fig. 16 Variations in the dry weights of plants with and without a particle film

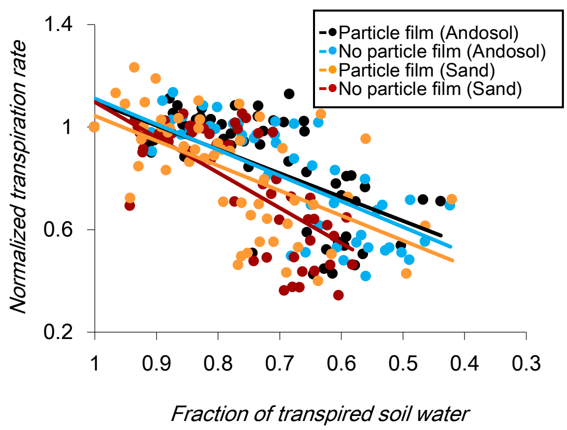

Fig. 17 Variations in the transpired amount of soil water during the dry-down experiment

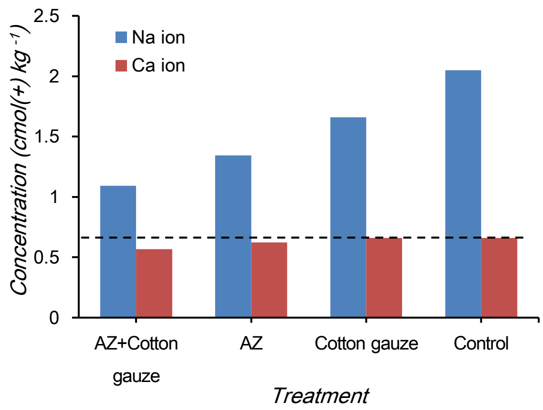

Fig. 18 Variations in the average ion-concentration at surface soil with different treatments

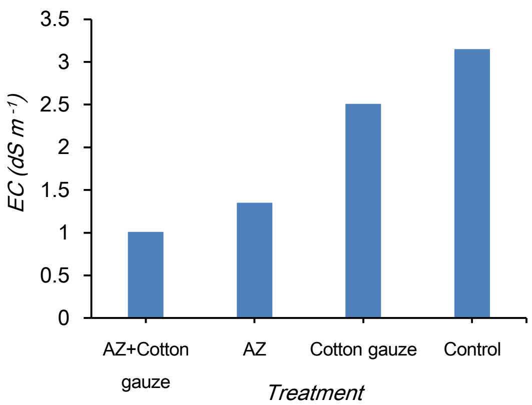

Fig. 19 Variation in the average EC values at surface soil with different treatments

developed country. From the case studies in the study sites, it is not easy to conclude that eco-environmental and natural resource problem(s) are always easier to manage in a specific area because it depends on the facts and the circumstances of each case. As stated in the methodology section, we carried out a number of preparatory experiments to set and to determine the most suitable ratios among the concerned parameters (e.g., soil, water, cotton, coal ash, and vegetation) in our study area, which was the Inner Mongolia region. Some of the study sites as well as other potential resources in this particular region (studies are currently being conducted) are not included in this paper; however, the results and the analyses discussed in this paper outline that the locally available/waste materials, specifically cotton and coal ash in our study, have a great potential to be used as soil improvers that facilitate plant growth and thus combat desertification in a site-specific and sustainable way. To achieve the best results, carrying out outdoor experiments in the study fields and convincing the local people to accept the extension of our technologies would be more effective from the perspective of field-application. Also, follow-ups and feasibility surveys at the initial stage (if accepted by the local people) would be necessary.

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