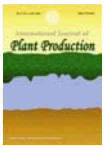

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Effect of different cultivation methods on germination and growth of *Puccinellia tenuiflora*

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Abstract

The effects of drip irrigation and different cultivation methods on seed germination and growth of *Puccinellia tenuiflora* in saline-sodic soils were investigated in field experiments during 2008-2010 in the Songnen Plain, China. Drip irrigation was applied to waste saline-sodic *P. tenuiflora* grasslands for both flat and ridge cultivation methods. Drip irrigation affected the distributions of electrical conductivity of saturated-soil extract (ECe) and pH of the saline-sodic soil. After cropping under drip irrigation for two years, the ECe and pH had decreased greatly in the root zone on both the flat and ridge lands, and enabled *P. tenuiflora* seeds to germinate and grow rapidly. In addition, the plant height, number and length of spikes, coverage and aboveground biomass were all higher on the flat than on ridge land, but the differences of the two cultivation methods were not obvious. Compared to ridge planting, the flat planting method was more convenient, and flat cultivation and drip irrigation may be appropriate for restoration of saline-sodic grasslands.

Keywords: Saline-sodic soils; Planting methods; *Puccinellia tenuiflora*; Grassland restoration.

Introduction

The Songnen Plain, located between 42° 30′-51° 20′ N and 121° 40′-128° 30′ E, covers an area of about 17.0×10^6 ha in the central part of northeastern

China (Deng et al., 2006; Chi and Wang, 2010). Songnen grassland is one of the main districts in which Chinese saline-sodic soil concentrates the topographical features and climatic conditions of the area result in very unique soil alkalization and salinization process (Kulakov et al., 1997; Qiu et al., 2003; Shi and Guo, 2006). *Puccinellia tenuiflora* is a native perennial grass that is widespread on saline-sodic low-lying grasslands in the Songnen Plain (Wang, 2001), and can tolerate highly alkaline soil (Gao et al., 1996; Li and Zheng, 1997). However, in recent years soil salinization of these grasslands has become serious due to overgrazing and they have rapidly degenerated, with many seeds unable to emerge under natural conditions (Zheng and Li, 1993).

Puccinellia tenuiflora is very tolerant to saline and alkaline conditions, but highly saline and alkaline conditions inhibit its seed germination (Su et al., 2004). Despite this, the conditions required for seed germination and seedling growth of *P. tenuiflora* are easily achieved under irrigated conditions (Wang, 2004; Eslami et al., 2010). In addition, tillage has a major impact on the distribution of weed seeds in the soil (Yenish et al., 1992; Lutman et al., 2002; Gürsoy et al., 2011; Celik et al., 2011), and disturbance can encourage revegetation of perennial grasslands (Wisheu and Keddy, 1991; Milberg, 1993; Luzuriaga et al., 2005). Therefore, appropriate cultivation and irrigation methods could help to recover the saline-sodic *P. tenuiflora* grassland.

The germination of *P. tenuiflora* requires 7-10 d of sustained high soil moisture and the absence of direct sunlight (Su et al., 2004). Drip irrigation can supply sustainable water and leach salt, and can supply water at low discharge rates and high frequencies over an extended period, thus minimizing the salinity levels in the soil water by leaching of salts (Keller and Bliesner, 1990). Because of the point-source nature of drip irrigation, the salts will be pushed toward the fringes of the wetted area with water, resulting in formation of a desalinized zone in close proximity to the emitter (Goldberg et al., 1976; Kang, 1998). Many studies have shown that drip irrigation is an important method for improving saline land (Jiao et al., 2006; Wan et al., 2007; Chen et al., 2009; Kang et al., 2010).

The objectives of the present study were (1) to find the effects of different cultivation patterns on *P. tenuiflora* germination and growth, and (2) to find an optimal mode for rapidly and conveniently recovery of saline-sodic grassland.

Materials and Methods

Experimental site

The field experiments were carried out from 2008 to 2010 at the Da'an Sodic Land Experiment Station in China. The station (45^{o} 35′ 58″-45^{o} 36′ 28″ N, 123^{o} 50′ 27″-123^{o} 51′ 31″ E) is in the western part of the Songnen Plain, northeast China. The area is characterized by a combination of temperate, semi-humid and semi-arid monsoon climates. The annual average temperature is 3-5 ^{o}C, and the annual average precipitation is 413.7 mm, 70-80% of which occurs during July-September. The average evaporation in this region is 1791.6 mm. Seasonal drought is frequent in spring and autumn, with drought occurring 90% of the time in spring. These conditions have resulted in salts accumulating throughout the soil profile. The groundwater level varies within depths of 1-3 m annually. The experimental field was saline wasteland next to artificial *P. tenuiflora* grassland that was planted six years previously, so there were many *P. tenuiflora* seeds buried in the litter and the experimental soil. The physical and chemical properties of the soil in the experimental land are shown in Table 1.

Table 1. Physical and chemical properties of tested soil.

Soil layers (cm)	Soil mechanical composition (%)			pH	EC_e (dS m^{-1})	SAR $(mmol_c\ L^{-1})^{1/2}$
	<0.002 mm	0.002-0.05 mm	0.05-2 mm			
0-10	16.07	50.60	33.33	9.79	15.25	11.00
10-20	16.40	55.33	28.27	9.77	13.56	6.85
20-30	8.87	47.73	43.40	9.82	13.20	11.94
30-40	19.22	57.93	22.85	9.88	12.02	14.57
40-60	25.41	57.78	16.82	9.86	11.39	10.16
60-80	16.85	45.30	37.85	9.69	8.60	10.16
80-100	25.56	57.79	16.65	9.62	5.16	6.50
100-120	34.53	49.55	15.92	9.42	3.69	6.85

Soil samples were measured by the saturated-soil extract, water samples were obtained using a centrifuge, and the water extract was measured for ECe, pH, Na^{+}, Ca^{2+} and Mg^{2+}, the sodium adsorption ratio (SAR) $(mmol_c\ L^{-1})^{1/2}$ was calculated as: $SAR = Na^{+} / \sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}$.

Experimental design

A field experiment was started in September 2008, with two different planting patterns: flat and ridge. All experimental fields were shallow ploughed with a rotary tiller pulled with a tractor, and then leveled or ridged respectively. Both treatments were replicated three times, and a total of six experimental plots (each 4.8×4 m) were used. The drip tubes in each plot were 4 m long, the distance between two drip tubes was 0.8 m, and the emitters were placed at 0.2 m intervals. A white polyethylene film was placed over each drip tube. Each treatment plot was equipped with an independent gravity-type irrigation system. The irrigation system consisted of a plastic barrel (400 L) used as a water source, 18 drip tubes (6 tubes per plot), a ball valve installed under the bottom of the barrel to control irrigation and an outlet 1.2 m above the ground surface. The soil matric potential (SMP) immediately beneath the 20 cm depth emitters was controlled at -20 kPa for both the flat and ridge treatments according to results of earlier research (Liu et al., 2012). Two vacuum tensiometers were installed at a depth of 0.2 m under drip emitters for each treatment to determine the SMP on both flat and ridge land; irrigation was started when SMP fell below the target value. Each application of irrigation water was 3.5 mm before tillering stage and 7 mm after tillering, according to the water requirements of plants during different growth stages (Su et al., 2004). The tensiometers were observed three times daily (at 7:00, 14:00 and 18:00 h).

Agronomic practices

The fertilization proportions of nitrogen, phosphorus and potassium were 4:1:1 as occurs in the artificial planting grassland (Oliver et al., 2005). During the *P. tenuiflora* growth stage topdressing applied to fields was 112 kg ha^{-1} urea, 28 kg ha^{-1} phosphate and 28 kg ha^{-1} potassium dihydrogen phosphate in 2009; and 188 kg ha^{-1} urea, 47 kg ha^{-1} phosphate and 47 kg ha^{-1} potassium dihydrogen phosphate in 2010. The total amount of fertilizer applied to both treatment groups was the same.

The first irrigation was on 20 September 2008. The initial irrigation amount was 21 mm, after which 3.5 mm was applied daily from 21 September to 1 October. On 10 October 2008, 21 mm of winter irrigation was applied. Prior to applying the SMP treatment, all plots were irrigated with the same amount of water to maintain uniform growth. During May-September 2009 and 2010, the irrigation was controlled by the tensiometers. The total irrigation amount was 100 mm in 2009 and 235 mm in 2010 on the flat land, and 96 mm in 2009 and 214 mm in 2010 on the ridge land.

Observations and equipment

Puccinellia tenuiflora emergence and growth

The emergence of *P. tenuiflora* was determined after it was complete, using a quadrat of 0.4×0.4 m on randomly selected parts of each plot of both flat and ridge lands. Additionally, 1 m^2 quadrats were randomly selected and fixed in each plot of all treatments to determine height, number and length of spikes at 30 d intervals during the growth period. Another 1 m^2 area was randomly selected and sampled in each plot for aboveground biomass at the end of the growth period. The coverage of *P. tenuiflora* was measured using a plant canopy analyzer (LAI-2000, LI-COR, USA).

Soil ECe and pH

Soil samples were obtained from each plot using an auger (2.0 cm in diameter, 15 cm in height) on 20 September 2008, 20 September 2009 and 25 September 2010. All soil samples were air-dried and sieved through a 2 mm sieve, and the electrical conductivity of saturated-soil extract (ECe) and pH determined using a conductivity meter (DDS-11A, REX, Shanghai, China) and a pH meter (PHS-3C, REX). Distilled water was added to a 50 g soil sample while stirring with a spatula until it reached the criteria for saturation according to guidelines in the USDA Handbook 60 (USDA, 1954). Saturated pastes were allowed to stand for 16 h, after which a water sample was obtained using a centrifuge.

Results and Discussion

Distribution of ECe in soil profiles

On the experimental land before cultivation, a mass of salts had accumulated on the soil surface and in the surface layer (ECe>15 dS m^{-1}). However, drip irrigation clearly influenced the distribution of ECe for different cultivation methods (Figure 1). After the first drip irrigation of 21 mm, the ECe decreased greatly on both the flat and ridge lands. In the 0-40 cm soil layers, there was ECe<6 dS/m for both flat and ridge planting methods. According to Su et al. (2004), these conditions were suitable for *P. tenuiflora* germination. The ECe was reduced on both the flat and ridge lands after using drip irrigation for one year, especially for the 0-20 cm soil layer, where ECe < 12 dS/m. The low salinity area on the ridge land was larger than that for the flat land, consistent with findings of Guan et al. (2010). After two years of drip irrigation, ECe had further decreased and the size of the low salt area had expanded, with average ECe in the root zone of < 10 dS m^{-1}. According to Su et al. (2004), *P. tenuiflora* can tolerate a salt content of 1.2%, so drip irrigation provided suitable conditions for *P. tenuiflora* growth on both the flat and ridge lands.

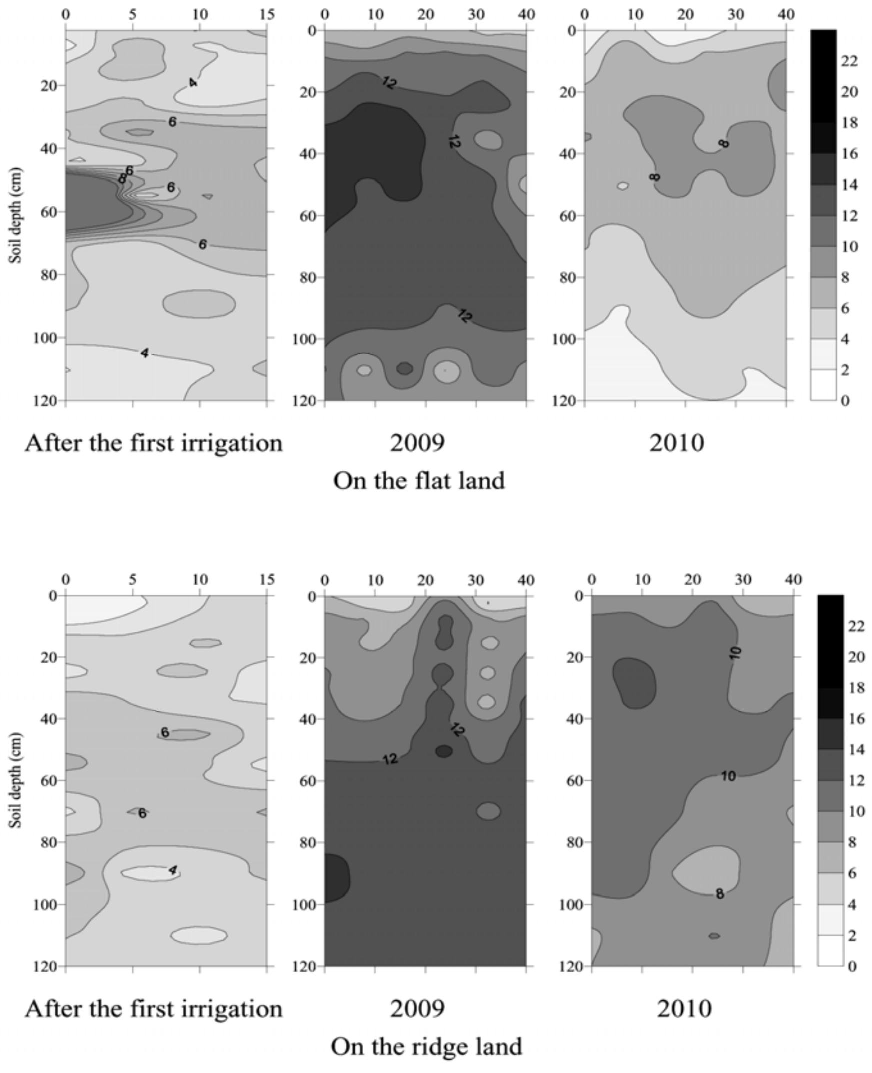

Figure 1. Distribution of ECe for different cultivation methods.

Distribution of pH in soil profiles

Before cultivation, pH was 9.8 in the surface layer for the experimental land. After the first drip irrigation of 21 mm, the distribution of pH was similar to that of ECe (Figure 2), with pH decreasing greatly after the first irrigation, especially in the 0-40 cm soil layer; pH was around 9.6 for both flat and ridge methods. After one year of drip irrigation, a low pH zone appeared on the ridge land in the 0-5 cm soil layer; the pH on the flat land also decreased, but to a lesser degree than for the ridge land. After using drip irrigation for two years, the pH on both the flat and ridge lands decreased significantly, and was close to 9.7 in the 0-40 cm soil layer. The pH was a little lower for ridge compared to flat land, but the difference was not obvious. *Puccinellia tenuiflora* can tolerate pH 10 (Su et al., 2004), and so should survive pH 9.7 on the flat and ridge lands.

The effect on P. tenuiflora growth

Puccinellia tenuiflora emergence

The emergence *P. tenuiflora* was between 27 September and 2 October 2008. The distribution of the seedlings was uniform, and the average emergence numbers in a 1 m^2 quadrat were 256 and 287 on the ridge and flat land, respectively-both close to the level in the artificial *P. tenuiflora* grassland of the Hexi corridor inland saline area with 301 plants/m^2 (Shen et al., 1994). The flat planting land had greater emergence than the ridge, because the seeds were closer to the soil surface and more easily emerged; however, seeds were ploughed in deeper when ridged (Gruber et al., 2010).

Puccinellia tenuiflora height

At the beginning of the experiment in 2009, the *P. tenuiflora* height was low and uniform for both treatments: average height 16.42 and 15.31 cm on the flat and ridge lands, respectively. The *P. tenuiflora* height during the growth period in 2009 and 2010 is shown in Figure 3. The vigorous growth period of *P. tenuiflora* was in May-June, during this period the height increased greatly, and ceased after August and remained stable. The height of

P. tenuiflora on flat land was a little greater than on ridge land in the same growth period. After two years of the experiment, the average height was 76.2 and 71.6 cm on the flat and ridge land, respectively-both higher than the average of 71.2 cm on the six-year-old artificially planted *P. tenuiflora* grassland nearby.

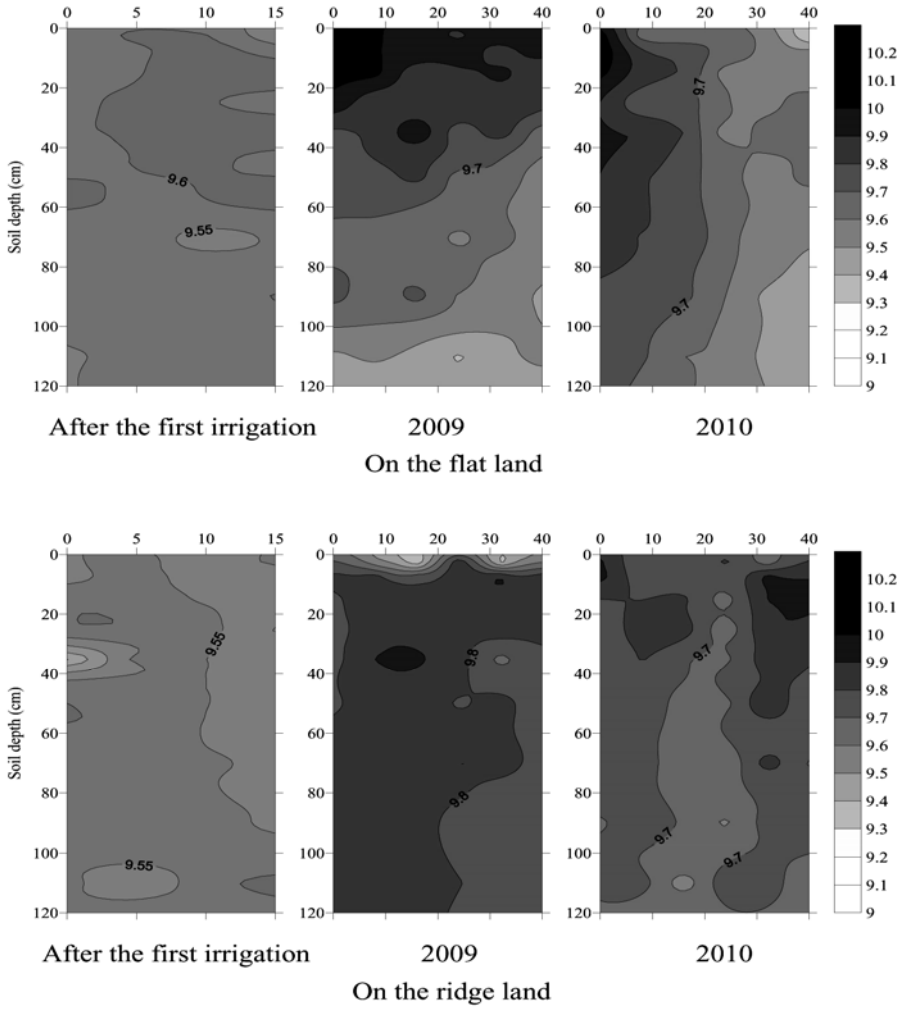

Figure 2. Distribution of pH for different cultivation methods.

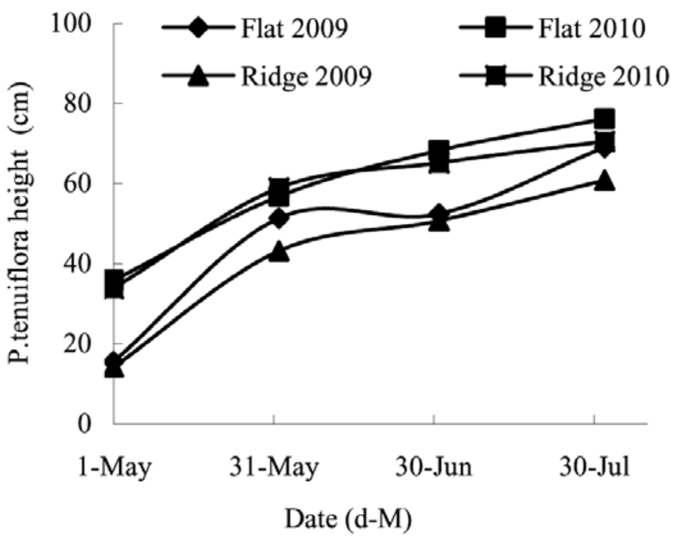

Figure 3. Height of *P. tenuiflora* during the growth period.

Spike number and length

In 2009, the heading stage started in early June, and during this period the spike number was few (Figure 4) and the spike length was small (Figure 5) on both flat and ridge lands. The vigorous heading time was from mid-June to mid-July; in late June, spike number and length were almost stable. Spike number and length were greater in 2010 than in 2009.

Coverage and aboveground biomass

During the two years' experiment, the growth of *P. tenuiflora* was very rapid, and the aboveground biomass and coverage rapidly increased (Table 2). The aboveground biomass on the flat and ridge lands were both close to the level of the artificial *P. tenuiflora* grassland of the Hexi corridor inland saline area, where the aboveground biomass was 1173 kg/ha (Shen et al., 1994). The coverage of the artificial *P. tenuiflora* grassland near the experimental site was 85%, and the average coverage of both flat and ridge land were close to these values; and were both higher than that for the second year of the artificial *P. tenuiflora* grassland, where coverage was 73% (Shen et al., 1994).

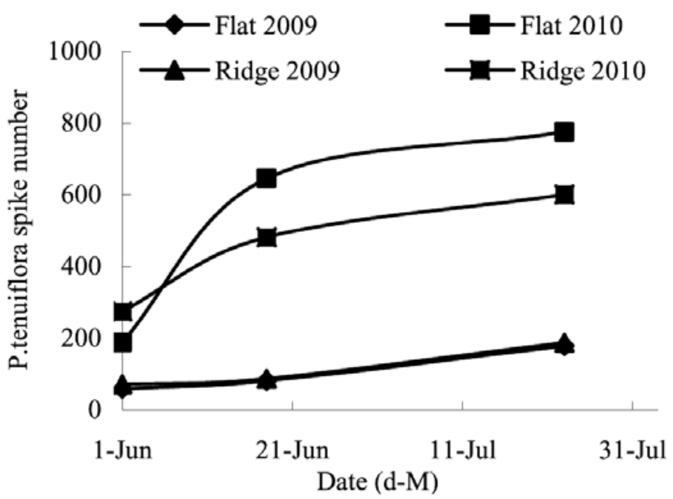

Figure 4. Spike number of *P. tenuiflora* during the growth period.

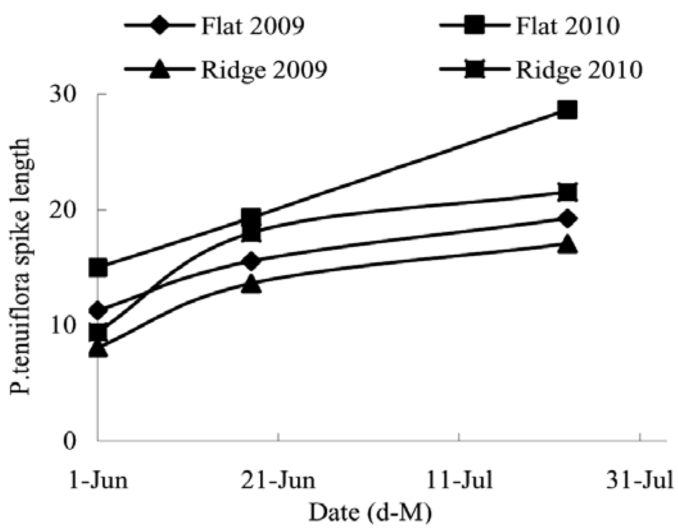

Figure 5. Spike length of *P. tenuiflora* during the growth period.

Table 2. Aboveground biomass and coverage of different treatments.

Treatment	Aboveground biomass (kg ha^{-1})		Coverage (%)	
	2009	2010	2009	2010
Flat	532.44	1078.67	84	90
Ridge	381.04	924.06	81	88

Conclusion

Both the flat and ridge cultivation methods greatly influenced the emergence and growth of *P. tenuiflora* in saline-sodic soils. During the growth period of *P. tenuiflora*, the height, spike number and length, coverage and aboveground biomass were also greatly influenced by drip irrigation and different cultivation methods. The growth on flat land was slightly better than ridge land. Based on the results, it is recommended that drip irrigation be used for restoration of the saline-sodic *P. tenuiflora* grasslands. Indeed, both the flat and ridge planting methods enabled the germination and emergence of *P. tenuiflora* seeds, and their rapid growth on the saline wasteland. Compared to ridge cultivation, flat cultivation was more convenient and the growth of *P. tenuiflora* was better, and it could be used in conjunction with drip irrigation to restore saline-sodic grasslands. The saline-sodic grassland was established after 2 years drip irrigation, further researches without irrigation are still continued in our study to know can the grass keep on growing under the rainfed condition.

Acknowledgements

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