

Effects of Different Water Harvesting on Soil Water, Growth and Yield of the Proso Millet (*Panicum miliaceum* L.) in a Semiarid Region of Northwest China

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Abstract

Field experiments were conducted to study the effects of different water harvesting on soil water, growth, yield and water use efficiency of the proso millet in a semiarid region of northwest China in 2010-2011. The experiment included five treatments: a flat plot with no mulching (NM) and four alternation ridge and furrow only the ridge mulched with white plastic film (PRFRH) systems. The cultivation system could increase soil water content of the furrow and maintained soil water content in ridges, there was better effect of water saving in P40, then P60 compared with NM. This system also promoted proso millet growth and yield development, P60 was higher agronomic characters compared with other treatments ($P < 0.05$). Proso millet yield and water use efficiency significantly increased by 73.87%-147.00% and 75.58%-185.54% compared with NM ($P < 0.05$), respectively. Evapotranspiration (ET) decreased by 3.93mm-101.40mm than NM. The best width of ridge: furrow was between 60 cm and 64 cm.

Keywords: proso millet, water harvesting, PRFRH system, semiarid region

1. Introduction

All the time, precipitation becomes an important limiting factor for crop production in semiarid regions of northwest China (He et al., 2007), this region has low rainfall, soil evaporation is high, and water use efficiency is low. Therefore, to maximize utilization of precipitation through rainfall collection and conservation techniques is necessary for agricultural practices.

In order to reduce evaporation and ensure the crop production of local people, conservation tillage has been used as a means of conserving soil and water resources to increase crop yield. However, the effectiveness of conservation tillage depends on soil type, climate, and land slope (Tolk et al., 1999; Lampurlanes et al., 2002; Zhang et al., 2009). Conservation tillage increased crop yield or got similar yields to conventional tillage according to 89% of studies, and decreased crop yields according to about 11% of studies (Xie et al., 2008). Therefore, conservation tillage should remain some uncertainties.

In arid and semiarid regions other field management practices, such as water harvesting, have been extensively applied for crop planting. The newest practices include alternating ridge and furrow, the ridge obtains water to furrow, and furrow is irrigated and planted (Moharrery & Shayannejad, 2009) for increasing crop yield. Lal et al. (1984) found that the use of a 'W'-shaped in situ rainfall harvesting system was effective for improving crop production in Brazil. Fisher (1995) reported that semi-permanent plastic mulching system left the plastic mulch in situ for a period of years, reused plastic mulching under the traditional mulching system, reduced plastic mulching cost, combined improved water management, decreased risk of soil erosion, and higher yields, which was the similar as alternating ridge and furrow with mulched ridges in plastic film. Gupta (1995) thought that the bare ridge and furrow method of rainwater harvesting significantly improved the growth of *Azadirachta indica*, *Tecomella undulata* and *Prosopis cineraria* trees in the Indian desert. Li et al. (2001) reported that the plastic mulched ridge and furrow rainfall harvesting (PRFRH) system improved water efficiency and increased corn

yield over the bare ridge and furrow harvesting (RFRH) system under semiarid conditions in northwest China. Wang et al. (2009) reported that the PRFRH system could be an optimal practice to improve runoff efficiency, rainwater harvesting and crop yield. The field micro-environment greatly distinguished the PRFRH system from the RFRH system.

Proso millet (*Panicum miliaceum* L.) is the main crop in the semiarid Loess region of northwest China. However, proso millet productivity in this area is often limited by drought stress (Pan et al., 2012). To increase the efficiency is the key to improve proso millet yield. Therefore, we designed four different water harvesting modes based on alternation ridge and furrow only the ridge mulched with white plastic film (PRFRH), the objectives of this study were to determine: (a) the effects of dry matter, leaf area and plant height in different treatments, (b) soil water storage and its distribution in soil profile would differ with various width of ridge: furrow, (c) proso millet yield and water use efficiency would also be affected.

2. Materials and Methods

2.1 Study Site Description

Field experiment to evaluate the possible benefits of plastic mulch options were conducted at Canghemao Experimental Station, Northwest A & F university, Fugu, Shaanxi province (39.09° N, 111.01° E and altitude 1000 m) in two seasons during 2010 and 2011. The climate is semiarid with annual mean precipitation of 366.2 mm, and rainfall is mainly between July and September. The mean annual temperature is 9.1°C with a maximum of 38.9°C and the minimum of -24°C. The average annual pan evaporation is 1092.2 mm. The average annual sunshine duration is 2890h with over 177 frost-free days. Soil type is loessial. Analysis of the top soil (0-20cm) obtained the following results: organic C, 19.32 g kg⁻¹; nitrate N, 1.2g kg⁻¹; available P, 6.4mg kg⁻¹; available K, 89mg kg⁻¹; ammonium N (NH₄⁺+NO₃⁻) 44.3mg g⁻¹ and soil bulk density is 1.50 g cm⁻³.

2.2 Experimental Design

In this study, five treatments were designed as follows: a flat plot with no mulching(NM), the width of ridges: furrow were 40cm:40cm(P40), 60cm:60cm(P60), 80cm:80cm(P80) and 100cm:100cm(P100), respectively. Only the ridges (10 cm high) mulched with white plastic film. A diagram showing the ridge and furrow system (P40) is presented in Figure 1. Furrows of P40, P60, P80, P100 were planted 2, 3, 4, 5 rows. P40, P60, P80, and P100 had four alternation ridges and furrows, their plot area were 3.2×5 m², 4.8×5 m², 6.4×5 m² and 8.0×5 m², respectively. The plot of NM was planted 8 rows, area was 3.2×5 m². All treatments were three replications that were arranged in a randomized block design. The entire experimental area was ploughed after all fertilizers (34.5 kg N ha⁻¹, 9.0 kg P₂O₅ ha⁻¹) were incorporated into the soil surface. P40-P100 had the ridge covered with 0.008 mm thick plastic film. The density was 5.0×10⁵ plants.ha⁻¹. Proso millet cultivar “Yumi 2” was planted on 11 June 2010, and reaped on 25 September 2010. The next year, it was planted on 12 June, and reaped on 23 September.

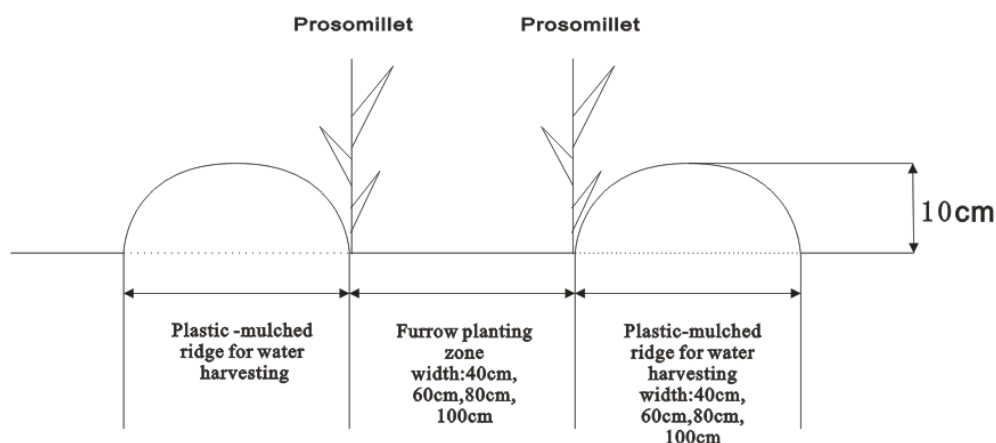


Figure 1. A diagram showing ridge and furrow water harvesting system with plastic mulches

2.3 Sampling and Measurements

Plants were sampled approximately monthly for leaf area and biomass determinations. Initially, five plants and

subsequently three plants were randomly sampled from each plot, located at least 1 m from plot edges and 0.5 m from previous sampling sites. All the leaves of the sampled plants in each treatment plot were collected and weighted. About 20 representative leaves were cut with a special hollow auger with an internal radius of 6 mm. The weight and area of the leaf wafers were then determined. The leaf area of all the sampled plants was estimated by the ratio between the weight of the 20 leaf wafers and that of all the sampled leaves (Hou et al., 2010). Then, total above ground biomass was determined gravimetrically after oven drying, at 105°C for 30 min initially and then at 65°C for 48 h.

The water content in the soil profile was determined at depth intervals of 20 cm, down to 100 cm. Measurements were made approximately every two weeks during the proso millet growing season and have continued since the start of the experiment. Soil water storage (SWS) in the profile was considered to be the total storage (0-100cm). Evapotranspiration (ET) (Zhang et al., 2011) was determined using the formula:

$$ET = P + SW_p - SW_h$$

P is the precipitation (mm) during the crop growth season and SW_p is the amount of soil water storage at planting (mm) based on the mean value from furrow and ridge and SW_h is the amount of soil moisture stored at harvesting (mm), without considering deep percolation and runoff. Water use efficiency (WUE) was calculated as grain yield (GY) in kg ha^{-1} divided by total water use in m (evaluated as ET in the present study):

$$WUE = GY/ET$$

Treatment means were compared using Duncan's method ($P < 0.05$) by SAS v6 software.

3. Results

3.1 Weather Conditions

Rainfall during the proso millet growing season was 274.0 mm in 2010, 165.7 mm in 2011, accounting for 102%, 62% of annual precipitation, respectively. Growing season in 2010 was more rainfall than that of 2011, rainfall distribution varied from June to September, more rainfall appeared in June, August and September 2010 than the same months of 2011, less rainfall in July 2010 than that of 2011 (Figure 2).

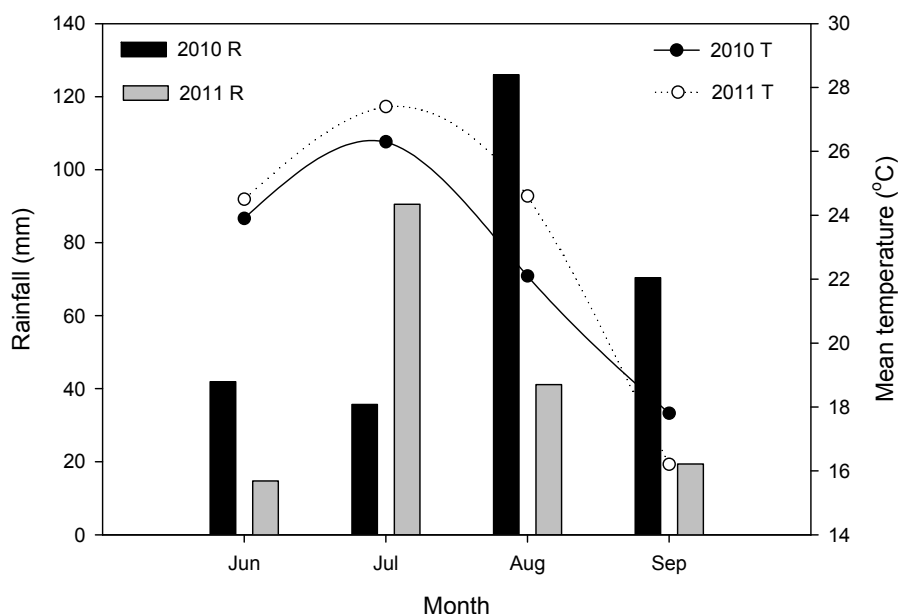


Figure 2. Distribution of monthly rainfall and mean temperature during proso millet growing seasons in 2010-2011

Air temperature also varied greatly between the two growing seasons (Figure 2). There were significantly higher temperature in June, July, August 2011 than those in 2010, and lower temperature in September 2011 than that in 2010. The differences in rainfall and air temperature during growing time might influence proso millet development and lead to yield change.

3.2 Aboveground Dry Matter, Leaf Area and Plant Height

Aboveground dry matter and leaf area per plant were measured when proso millet was at jointing in July and filling in August (Table 1). In 2010, all treatments had more dry matter, leaf area and plant height than those of NM, P60 was significantly ($P < 0.05$) higher than others in July and August. In 2011, every treatment had more dry matter, leaf area and plant height than those of NM, P60 was significantly ($P < 0.05$) higher than others. Dry matter, leaf area and plant height of all treatments in 2010 were higher than those of all treatments in 2011.

Table 1. Aboveground dry matter, leaf area and plant height per proso millet plants for rainfall harvesting treatments at two sampling dates during the 2010 growing season

Sampling date		Treatment				
		P100	P80	P60	P40	NM
July, 2010	Dry matter(g)	2.82b	3.00ab	3.67a	3.15a	2.01c
	Leaf area (m ²)	0.0405bc	0.0478b	0.0686a	0.0514b	0.0288c
	Plant height(cm)	41.13c	43.38bc	47.19a	44.30b	40.18c
August, 2010	Dry matter(g)	38.65c	45.23bc	52.05a	48.15b	28.75d
	Leaf area (m ²)	0.0757cd	0.1023bc	0.1548a	0.1136b	0.0599d
	Plant height(cm)	134.36c	144.92bc	149.70a	146.79ab	133.03d
July, 2011	Dry matter(g)	3.34c	3.67b	4.48a	4.08b	2.99c
	Leaf area (m ²)	0.0081b	0.0090a	0.0098a	0.0094a	0.0060c
	Plant height(cm)	23.34d	30.30c	33.93a	31.70b	22.23e
August, 2011	Dry matter(g)	10.96c	12.29b	17.39a	14.62b	8.94d
	Leaf area (m ²)	0.0095b	0.0096b	0.0117a	0.0114a	0.0070c
	Plant height(cm)	107.36d	109.87c	114.00a	112.87b	103.83d

Note: Same letter indicates no significant difference at $P < 0.05$ level. The same as below

3.3 Soil Water

The soil water storage (SWS) dynamics (0-100cm) showed different patterns in the two experimental seasons (Figure 3). In 2010, SWS was depleted within the proso millet growing seasons, with low values in July 25 and August 20. All treatments were higher SWS than NM, and P40 was higher SWS than others during this seasons. In 2011, SWS generally decreased up to proso millet mature period. In all treatments, P40 had higher SWS than others. However, there was no significantly difference in growing period.

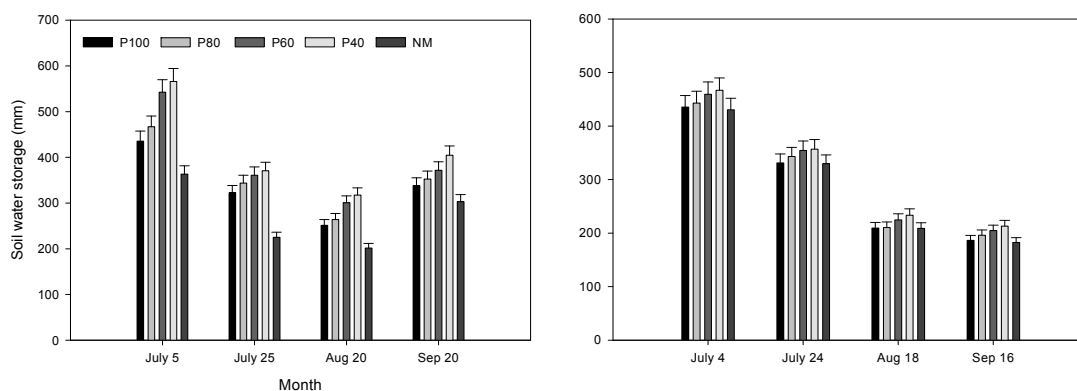


Figure 3. Change in soil water storage (0-100 cm) under NM, P100, P80, P60 and P40 treatments in two proso millet growing seasons: 2010 (left panel), 2011 (right panel)

The soil water content in the profile at harvest under all treatments reflected significantly depletion of soil water in deep soil layers, relative to those prior to planting in the first experimental season (Figure 4). The P40 and P60 treatments significantly increased the soil water content in the upper 60 cm soil layer compared with others. There was the same trend at the next growing seasons. In 80 cm-100 cm soil layer, P60 was lower soil water content than other treatments, then P40 in 2010, and there was the same trend in 2011. Between planting and harvesting, soil water content had significantly difference in both years, soil water was depleted apparently.

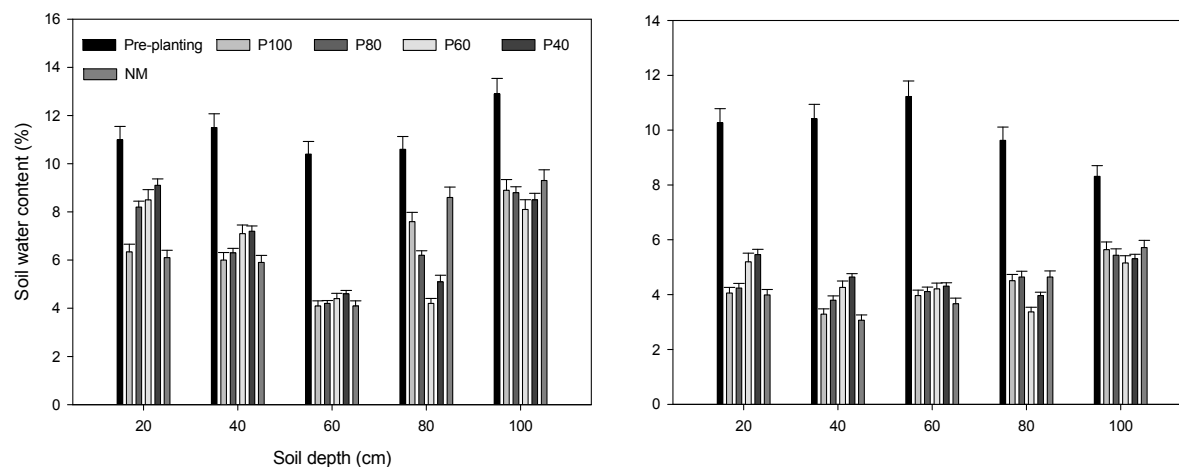


Figure 4. Soil water content (0-100 cm) at proso millet pre-planting and harvesting time under NM, P100, P80, P60 and P40 treatments in two proso millet growing seasons: 2010 (left panel), 2011 (right panel)

3.4 Proso Millet Yield and Water Use Efficiency

The proso millet yield of four treatments in 2010 was significantly ($P < 0.05$) higher than NM, yield of P60 was significantly ($P < 0.05$) higher than others. In 2011, tendency of proso millet yield was the same as the previous year (Table 2). The two years average yield among different treatments significantly increased by 73.87%-147.00% than NM. In 2010, ET was significantly lower compared with NM, decreased by 3.93 mm-101.4 mm. In both years, WUE significantly increased by 75.58%-185.54% than NM, WUE of the P60 was higher than others.

Table 2. Proso millet yield, ET and WUE in all treatments in 2010-2011

Treatments	2010			2011		
	Yield (kg ha ⁻¹)	ET (mm)	WUE (kg ha ⁻¹ mm ⁻¹)	Yield (kg ha ⁻¹)	ET (mm)	WUE (kg ha ⁻¹ mm ⁻¹)
P40	5789.19b	403.46	14.35a	2220.95b	437.16	5.08b
P60	6294.05a	436.70	14.42a	2812.60a	445.46	6.31a
P80	5764.18b	455.77	12.65b	2220.95b	454.27	4.89b
P100	5188.02c	469.90	11.04b	2101.12c	463.75	4.53b
NM	2548.16d	504.86	5.05c	1208.46d	467.68	2.58c

In this experiment, it was assumed that treatment NM corresponded to a ridge width of 0 cm and all the data were analyzed regressively, indicating that the ridge width giving the highest yield was 64 cm in 2010 and 63 cm in 2011 (Figure 5). The ridge widths giving the highest WUE were 61 cm in 2010 and 60 cm in 2011 (Figure 6). These statistics implied that a ridge width between 60 cm and 64 cm was best for the proso millet yield and water use efficiency in this cultivation system.

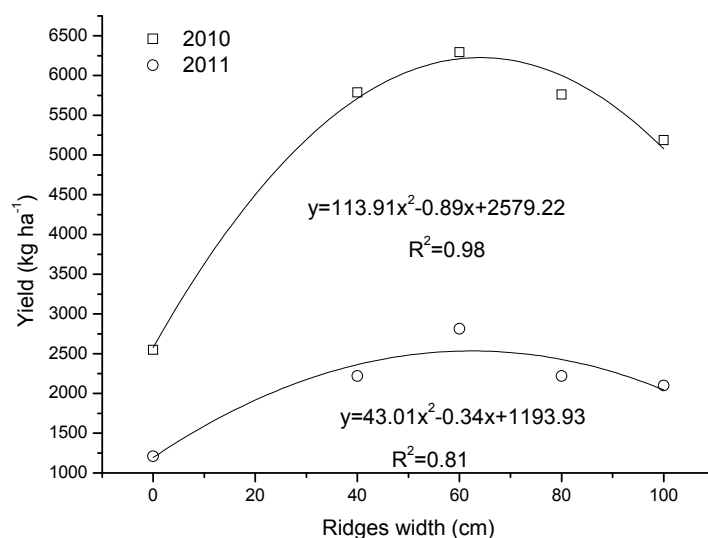


Figure 5. Yield of proso millet as a function of ridge width in P40, P60, P80, P100 and NM in 2010-2011

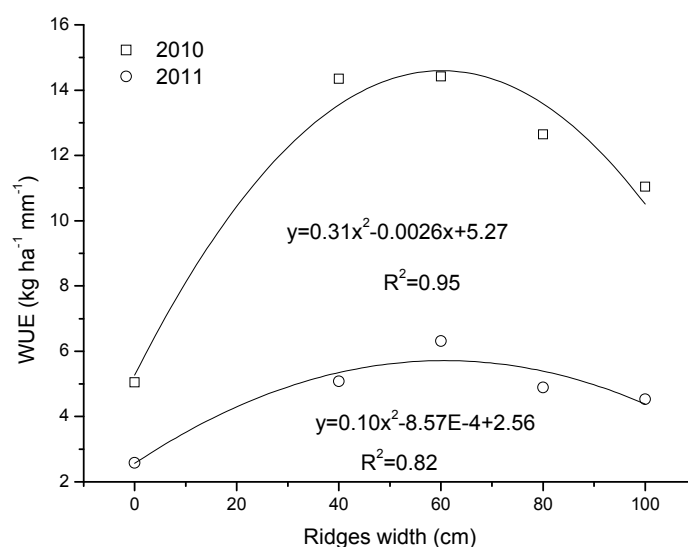


Figure 6. WUE of proso millet as a function of ridge width in P40, P60, P80, P100 and NM in 2010-2011

4. Discussion

Water harvesting based on alternating ridges and furrow with only the ridges mulched with white plastic film (PRFRH). Ridges mulched with plastic film collected rainfall to supply the water demand by the crop, it can improve plant growth and crop yield (Hou et al., 2010). This cultivation system was applied on potato (Wang et al., 2005; Yuan et al., 2003), maize (Zhang et al., 2011), wheat (Zhang et al., 2009), alfalfa (Yu et al., 2006; Li et al., 2007). However, for the moment, this cultivation system was not applied on proso millet in semiarid regions.

Proso millet roots can enter into 120cm soil layers (Saseendran et al., 2009), and soil water storage and content had difference in different growth stages among treatments. SWS of treatments had difference during two seasons, SWS of all treatments decreased firstly, then increased in 2010; In 2011, SWS of all treatments decreased all the time, every treatment had also difference in different growth stages, however, SWS variation of treatments were not difference in the same stage (Figure 3). The reason might be that rainfall distributed unevenly

in different growth stages (Figure 2), and root growth was influenced by different PRFRHs. Saving water of P40 was more better than others, that showed that the narrower of ridge and furrow width, the better effect of saving water, but its plant height and yield were lower than P60, the reason might be that P40 had advantage in topsoil (0-60cm) water saving, disadvantage of improving roots growth, low side row yield, and little use in other depth (60-100cm) between pre-planting and harvesting, but P60 might improve roots growth, increase roots to enter into soil depth, make use of limited rainfall effectively, enhance water use efficiency, obtain large side and middle row yield, and use soil water in all measured depth (Figure 4), also likely rainfall vertical infiltration under the P40 was weaker, and limited rainfall evaporation was easy relatively for large planting rowlength of the P40. Relevant results still needed to research further.

The observed variations in leaf area, dry matter, plant height during the two experimental seasons under the P60 were higher than others in the present research. In 2010, plant height, leaf area, dry matter and yield had more development compared with those of 2011, the reason might be that rainfall was significantly difference in both years (Figure 2), and ambient temperature was higher in 2011 than that of 2010 during two growing seasons, which likely led to more soil water evaporation. P60 treatment showed more advantage in yield, dry matter compared with other treatments in both years for large leaf area to enhance accumulation of photosynthesis matter.

It was well known that the yield was the product of water use efficiency multiplied by water use (Zhang et al., 2007). In order to improve crop yield, water use efficiency should be increased. The furrow and ridge system with film-mulched ridge should increase water use efficiency and yield because of water harvesting and control of evaporation from the topsoil (Deng et al., 2006; Zhou et al., 2009). Hou et al (2010) reported that water use efficiency of the potato increased by 197%-258%, and yield increased by 176%-237% compared with NM under the PRFRH system. Zhang et al (2011) reported that water use efficiency of spring-sown maize increased by 17%, and yield increased by 19% compared with NM under the PRFRH system. In present research, proso millet used was a drought-resistance crop, which had been planted for many years in this region. The proso millet in all treatments were allowed to fully mature, yield of proso millet increased by 73.87%-147.00%, and water use efficiency increased by 75.58%-185.54% compared with NM under the PRFRH system, the results showed that the PRFRH system was suited for proso millet planting. However, water use efficiency of treatments was low except P60, these showed that there was a optimal ridge and furrow width on the proso millet under the PRFRH system. Therefore, in order to obtain the optimal ridge and furrow width, regression method was used. The ridge widths giving the highest yield and water use efficiency were 63 cm, 64 cm in 2010, and 61cm, 60cm in 2011, respectively, and furrow width was the same as ridge width.

5. Conclusion

This cultivation system significantly increased soil water content of the furrow, and promoted proso millet growth and yield development. Water harvesting from plastic film on ridges supplied water to proso millet of the furrow, and the plastic film on ridges inhibited soil water evaporation, which improved water use efficiency and increased proso millet yield. Although, rainfall amount and distribution had large difference in two years, the optimal ridge and furrow mode was similar for two years: a ridge : furrow width was 60 cm-64 cm.

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