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Effect of Manure Management on the Temporal Variations of Dryland Soil Moisture and Water Use Efficiency of Maize

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ABSTRACT

Degraded soils in Northwest China are mostly nonproductive due to imbalanced nutrient and inadequate water supply. The effects of manure application at three different rates (7.5, 15.0, and 22.5 t ha^{-1}) combined with chemical fertilizers on soil water and Water-Use Efficiency in maize [compared with chemical fertilizers (control)], under semi-arid conditions in dark Loessial soil and over a period of four years were studied to provide scientific support for water management. High manure application significantly reduced soil water evaporation throughout the fallow period as compared with control. It significantly increased soil water storage capacity at the big trumpet growth stage of the crop, and with the fertilization application years continued ($P< 0.05$). Manure application improved soil water holding capacity at the tasseling and grain filling stages. It decreased evapotranspiration at the jointing–big trumpet and tasseling–grain filling stages. It as well improved Water-Use Efficiency by 16.67 to 295.42% at the jointing–big trumpet stage *vs.* 9.38-68.96% at the tasseling-grain filling stage and 8.51 to 36.58% for the whole growth period of the crop maize. With a continuation of the fertilizer application years, water-use efficiency at the tasseling-grain filling stage was significantly improved with increasing manure application rates ($P< 0.05$). Medium and High Manure application rates significantly increased water-use efficiency at the big trumpet–tasseling and grain filling-maturity stages as compared with control ($P< 0.05$). With manure application years continued, soil nutrient was no longer the major factor limiting the crop's water-use efficiency. The most promising manure application rate adopted to improve water-use efficiency was recorded as 15.0 t ha^{-1}.

Keywords: Dry land, Farmyard manure, Soil water storage, Water use efficiency.

INTRODUCTION

Soil water shortage is a main factor limiting the development of rural economies by hindering of agricultural productivity especially in arid and semi-arid regions of the world. Northwest China is a vast semi-arid region with an average annual precipitation of ranging from 300 to 600 mm (Li and Xiao, 1992). Rainfall distribution is temporally uneven, with 60 to 70% of the rainfall falling during July-September, and soil water evaporation high in Loess Plateau region of Northwest China (Li *et al*., 2000). More than 90% of the cropland in this area is non-irrigated. As the second main crop in the Loess Plateau, maize is conventionally cultivated after a single annual crop yearly produced.

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This is, followed by an approximately seven month fallow. During the fallow period water is stored in the soil to be later used up by the subsequent maize crop. However, the conventional practice of having the soil water to be replenished only during the fallow period results in very low fallow efficiency (ratio of soil stored water to rainfall during the fallow period) (Latta and O'Leary, 2003; Shangguan *et al.*, 2002). In addition, the infiltration depth is shallower in high fertilization than low fertilization (Huang *et al.,* 2002). Therefore, the conventional practice does not appear to be a sustainable management option in the long-run.

To deal with the limitation of the scare water *vs.* a high demand for substantial crop yield, the practice of improving crop water productivity will be a responding solution to the problems (Zhang *et al*., 2003). Of all the farming practices, rational organic manure application is among the most important measures to bring about increase in grain yield (Fan *et al.,* 2005a; Patil and Sheelavantar, 2006), improve soil water storage (Zougmoré *et al.*, 2004) and promote water-use efficiency (grain yield per unit of seasonal evapotranspiration, in kg ha^{-1} mm^{-1}) (Adamtey *et al.,* 2010; Hati *et al.*, 2006; Patil and Sheelavantar, 2006), and as well meet the aspirations towards sustainable crop production, required to meet the food demands of the region's growing population. Affholder (1995) reported that application of manure raised a crop's water demand without substantially increasing the water supply of the soil. The soil dried faster at the end of the crop cycle where manure was applied than when not. Tadayon *et al*. (2012) and Miranzadeh *et al*. (2011) demonstrated that application of chemical fertilizers promoted water productivity as well as water-use efficiency. The important role of fertilization to optimize the use of deposited water in the root zone has been highlighted (Lu *et al.,* 1998). Farmyard manure combined with inorganic fertilizers play important roles in a better penetration of (Hati *et al.,* 2006) and subsequently firm and deep establishment of crop roots *(Li et al.,* 2010), helping the plant to extract water from deeper soil layers and to help maintain high relative plant water content under a soil moisture stress condition, which is quite common in rain-fed farming (Hati *et al.*, 2006). Additionally, such an integration is regarded as a fundamental approach in improving efficient water-use in crop production (Mohanty *et al.,* 2007). In semi-arid areas, production is mainly dependent upon rainfall while water shortage, along with low nutrient availability and low water–use efficiency being the main factors limiting the growth of crops in these areas (Li *et al*., 2001; Zhang *et al*., 1998).

Hence, the present study was undertaken to investigate the effects of three rates of farmyard manure (each combined with a same level of chemical fertilizer) on soil moisture and water-use efficiency of the crop maize and at different growth stages in a semi-arid agro-ecosystem.

MATERIALS AND METHODS

Site Description and Experimental Design

A four-year field experiment was conducted on maize grown on dark loessial soil (sand 26.83%, silt 41.91%, and clay 21.03%) between years 2007 and 2010 at the Ganjing Research Station of the Northwest A&F University, Heyang, Shaanxi China (35° 24′N, 110° 17′E; 850 m altitude). The mean annual temperature is recorded as 9.0–10.0°C. The experimental site was characterized by low and erratic rainfalls with droughts occurring at different stages of maize's growth. The long-term mean annual rainfall at the site was 571.9 mm and the mean annual evaporation rate 1,832.8 mm. Most of the rainfall fell from July to September. In the years from 2007 to 2010, the rainfall occurring during the maize growing period amounted to 398.3, 350.8, 379.1, and 390.7 mm, respectively. Based upon analysis of soil samples taken from the experimental area in October 2006, the top 20.0 cm of soil was of

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the following characteristics: pH 8.14, soil organic carbon 8.25 g kg^{-1}, total nitrogen (N) 0.80 g kg^{-1}, total phosphorus (P) 0.53 g kg^{-1}, total potassium (K) 8.39 g kg^{-1}, available N 46.5 mg kg^{-1}, available P 9.0 mg kg^{-1}, and finally available K equaling 106.2 mg kg^{-1}.

The field experiment was established upon a completely randomized block design of four treatments in three replicates. A 4×6 m plot was made use of. The four treatments considered were as follows: (i) application of chemical fertilizers (CK); (ii) application of manure at a low rate of 7.5 t ha^{-1} in combination with chemical fertilizers (LM);(iii)application of manure at a medium rate of 15.0 t ha^{-1} in combination with chemical fertilizers (MM); (iv) and finally an application of manure at a high rate of 22.5 t ha^{-1} in combination with chemical fertilizers (HM). The N and P contents of the chemical fertilizers utilized were 255 and 90 kg ha^{-1}, respectively. The N and P fertilizers were separately applied as the main fertilizers before sowing of the crop, and at rates of, 102 and 90 kg ha^{-1}, respectively. Additional N fertilizer was applied at a rate of 153 kg ha^{-1} at the stage when the crop bore a spear-shaped tip (late July). The chicken manure used, contained 12.59 g N kg^{-1}, 6.36 g P kg^{-1}, and 13.44 g of K kg^{-1}. The manure was applied (in each experimental year) following maize harvest at the end of September. The seed used was of the variety Shendan 16. as for each of the experimental years, maize was planted at a rate of 49,500 plants ha^{-1} at mid-April and harvested in mid-September. No irrigation was applied in any of the experimental years.

Sampling and Analysis Methods

Soil water content was determined gravimetrically (oven drying method, w/w) down to a depth of 200 cm and at 20 cm increments before sowing of the seed and at different growth stages of the maize crop. Three locations in each plot were randomly taken to determine soil water content. Soil bulk density was determined according to Robertson *et al.* (1999).

Soil water storage (S_W) was estimated through:

$$Sw = hdb\% \times 10 \qquad (1)$$

where S_W (mm) stands for the average values of soil water content; h (cm), soil layer depth; d (g cm^{-3}), soil bulk density in different soil layers and $b\%$ the percentage of soil moisture content by weight. S_W was calculated at 0-20 cm depth of soil profile, while the S_W used in calculating evapotranspiration rate being found out for the 0-200 cm soil profile.

Evapotranspiration (ET, mm) was calculated through the following equation:

$$ET = P - D - R - \Delta S - E_i \qquad (2)$$

where P (mm) stands for precipitation, R (mm) for surface runoff, D (mm) represents the downward drainage out of the root-zone (where the crop root is spread out), ΔS (mm) the change occurring in soil water storage and E_i (mm) standing for evaporation from the intercepted rainfall. Throughout the present study, D was ignored because the groundwater contribution from a water table of 50 m below the ground surface, and as well the drainage out of the root-zone needed not to be considered in this area. Surface runoff was taken as zero because the topography was flat, and E_i was neglected because it was constant and constituted a very negligible proportion of the water balance, as compared with the other items (Zhang *et al.,* 2007). ΔS could be either positive or negative. Therefore, evapotranspiration was determined through precipitation and the change in soil water storage according to:

$$ET = P - \Delta S \qquad (3)$$

Water Use Efficiency (*WUE*) was defined as:

$$WUE = Y / ET \qquad (4)$$

where *WUE* represents Water Use Efficiency for the crop's biomass yield (kg ha^{-1} mm^{-1}), Y (kg ha^{-1}) indicating the biomass yield for the crop maize, and ET (mm) standing for evapotranspiration.

Dry matter was determined at different growth stages of the crop. All the five samples of maize were firstly dried in an

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oven at 105°C for 1 hour and then dried up at 75°C to constant weight. Five maize plants were collected from each plot and used (and thus, destroyed) for each measurement at any of the different growth stages of the crop.

Statistical Analysis

Analysis of Variance (ANOVA) was performed using the program SAS 6.2 in Windows. The significance of treatment effects was determined using *F*-test. Multiple comparisons of means were performed employing Duncan's Multiple Range Test (Duncan, 1955) at $P \leq 0.05$ level.

RESULTS

Rainfall and Evapotranspiration

As shown in Table 1, there occurred an abundance of rainfall in 2010 while low one in 2008 during the maize growing period and during the three experimental years. Rainfall was mostly concentrated mostly at jointing–big trumpet and tasseling–maturity growth stages of the crop. Grain filling–maturity stage of the crop received the lowest rainfall with 45.8 mm in 2008 which was about half the level of either 2009 or 2010. The tasseling–grain filling stage received the lowest rainfall of 30.9 mm among the different growth stage of maize in 2009 which was about one fourth of that in either 2008 or 2010. Jointing–big trumpet growth stage of maize received the lowest rainfall of 37.2 mm among the different growth stages of maize in 2010 which was about one third of that in 2008 and 2009. The above figures indicate that the distribution of rainfall at different growth stages of the crop greatly vary for each year.

As observed from Table 2, evapotranspiration rates following manure application were slightly higher than those treatments CK at sowing–jointing stages of the crop maize. At jointing–big trumpet stage, the main evapotranspiration occurred through evaporation from soil surface. LM treatment slightly decreased evapotranspiration as compared with CK., while MM and HM treatments resulted in significantly lower evapotranspiration rates as compared with either CK or LM treatments at jointing–big trumpet growth stage of the crop ($P< 0.05$). During the years from 2008 to 2010 respectively, MM treatment caused a decrease of evapotranspiration by 27.41, 10.38, and 48.81% as compared with CK and by 25.37, 4.63, and 48.36% as compared with LM, and while HM treatment decreasing evapotranspiration rate by 27.50, 13.34, and 49.15% as compared with CK and by 25.46, 7.78, and 48.71% when compared with LM at jointing–big trumpet growing stage of the maize crop. The above figures indicate that manure application could restrain evapotranspiration (dominated by water evaporation from soil surface) and the effect of restraining evapotranspiration is more pronounced with an increase in manure application rates. Since the main evapotranspiration occurred as evaporation from soil surface at jointing–big trumpet stage of maize, a decrease of evapotranspiration at this growth stage of maize could retain and save soil water to be used by the crop at its later periods of growth. This would bring

Table 1 Rainfall at different growth stages of maize from 2008 to 2010.

Years	Rainfall (mm)					
	Sowing-jointing stage	Jointing-big trumpet stage	Big trump-tasseling stage	Tasseling-grain filling stage	Grain filling-maturity stage	Whole growth stage
2008	57.7	96.9	27.0	123.4	45.8	350.8
2009	71.5	111.8	46.6	30.9	118.3	379.1
2010	75.9	37.2	92.4	114.0	102.8	422.3

Table 2. Effect of organic manure management on evapotranspiration at different growth stages of the crop maize [a].

Years	Treatments	Evapotranspiration (mm)				
		Sowing-jointing stage	Jointing-big trumpet stage	Big trumpet-tasseling stage	Tasseling-grain filling stage	Grain filling-maturity stage
2008	Control	79.73a	96.50a	23.94c	151.52a	52.21c
	Low manure	79.90a	93.86a	28.17b	126.61c	75.75b
	Medium manure	80.41a	70.05b	28.32b	150.02a	77.38b
	High manure	81.69a	69.96b	29.80a	132.64b	92.17a
2009	Control	36.45a	146.68a	74.72c	38.90a	106.77c
	Low manure	37.00a	137.84a	88.67b	24.94d	116.82b
	Medium manure	37.72a	131.46b	90.02b	28.11b	123.91a
	High manure	38.70a	127.11b	96.31a	26.14c	126.28a
2010	Control	58.96a	58.47a	89.13c	124.83a	42.21d
	Low manure	59.71a	57.96a	93.18b	106.09c	58.95c
	Medium manure	60.18a	29.93b	94.69a	123.71a	70.33b
	High manure	60.48a	29.73b	98.03a	113.14b	77.72a

[a] Values in the same year and same column followed by different letters indicate significant differences (Duncan P< 0.05).

about practical significance on maize growth.

Manure treatments significantly increased evapotranspiration as compared with CK at big trumpet–tasseling stage of the crop maize (P< 0.05). In other words, LM, MM and HM treatments respectively increased evapotranspiration by 17.67, 18.30 and 24.48% during 2008, and 18.67, 20.4 and 28.89% during 2009, whilst 4.54, 6.24 and 9.99% during 2010. Evapotranspiration rates for HM treatment were 5.79, 8.62 and 5.20% higher than those for LM during the years from 2008 to 2010 respectively, and 5.23 and 6.99% higher than those for with MM during the years 2008 and 2009 respectively. This was slightly higher than that of MM in 2010 and when at the big trumpet–tasseling growth stage of maize.

The main part of evapotranspiration rate at tasseling–grain filling stage of maize comes from crop evapotranspiration. Manure treatments decreased evapotranspiration as compared with CK treatment at tasseling–grain filling stage of maize, i.e. LM and HM treatments decreased evapotranspiration by 16.44 and 12.46% in 2008, and by 35.89 and 32.80% in 2009, and also by 15.01 and 9.36% in 2010. This indicates that manure application can reduce a crop's invalid water consumption. The highest evapotranspiration was recorded for MM treatment followed by HM and LM at tasseling–grain filling growth stages of maize, i.e. in the years from 2008 to 2010 respectively. LM treatment decreased evapotranspiration by 4.55, 4.59 and 6.23% as compared with HM, and 15.60, 11.28 and 14.24% as compared with MM, and while HM treatment decreasing it by 11.59, 7.01 and 8.54% as compared with MM.

Evapotranspiration figures with manure application were significantly higher than those for CK treatment at grain filling–maturity stage (P< 0.05), i.e. LM, MM and HM treatments respectively increased it by 45.09, 48.21 and 76.54% in 2008, and while 9.41, 16.05 and 18.27% for 2009, and as well 39.66, 66.62 and 84.13% for year 2010.

It can be seen from the above, that manure application could improve evapotranspiration and more feasibly facilitate the economized use of limited soil water.

Soil Water Storage

The change of soil water storage in different treatments varied at different growth stages of maize during the three experimental years (Table 3). Before sowing of the seeds, soil water storage for HM treatment was slightly higher than that for CK, in 2008, while it was significantly higher than those for CK in 2009 and 2010 ($P< 0.05$), (6.14 and 5.62% respectively). The above indicated that HM treatment significantly increased soil water content with continuity in the fertilization years ($P< 0.05$). Manure treatments caused increase in soil water storage at jointing stage, but not so significantly.

Compared with CK, the LM and MM treatments significantly decreased soil water storage at the crop's big trumpet stage and for years 2008 and 2009 ($P< 0.05$), while in year 2010 LM treatment slightly increased it. MM treatment had increased it by 5.97%. The above indicated that organic manure application could cause sufficient utilization of soil water storage when there was a considerable level of rainfall (96.9 and 111.8 mm in 2008 and 2009 respectively). Moreover organic manure application could retain soil water content during lower rainfall years (37.2 mm in 2010). With continuity in fertilization years, HM treatment could significantly increase soil water storage at the crop's big trumpet stage as compared with CK ($P< 0.05$) and by 7.15 and 11.45% for years 2009 and 2010 respectively. HM treatment resulted in14.03, 19.68, and 10.58% higher soil water storage than LM and 10.12, 14.45, and 5.18% higher soil water storage than MM at big trumpet stage of maize's growth within the years from 2008 to 2010 respectively. This indicated that increasing manure application rates could improve soil water condition at the big trumpet stage of maize's growth.

Soil water storage when accompanied by manure treatments was significantly higher than that of CK at tasseling stage of maize ($P< 0.05$), i.e. in the years from 2008–2010 respectively. LM treatment increased it by 5.27, 5.32 and 6.67%, and while MM treatment by 9.76, 13.19 and 11.18%, and HM by 7.09, 6.30 and 9.52%. The above indicated that manure application could improve soil water condition at the tasseling stage of maize's growth. There was no significant difference observed in soil water storage among manure treatments at the tasseling stage of maize.

Manure treatments resulted in higher soil water storage than CK treatment at grain filling stage of maize, i.e. within the respective years from 2008 to 2010. LM treatment increased storage by 9.95, 8.90 and 7.43%, and MM treatment by 7.82, 5.11 and 5.54%. The above indicated that manure application could improve soil water

Table 3. Effect of organic manure management on surface soil water storage at different growth stages of maize[a].

Years	Treatments	Soil water storage (mm)					
		Sowing	Jointing stage	Big trumpet stage	Tasseling stage	Grain filling stage	Maturity stage
2008	Control	39.88a	38.69a	41.72a	35.13b	45.41b	41.42a
	Low manure	39.96a	39.31a	37.21b	36.98a	49.93a	41.13a
	Medium manure	39.99a	39.75a	38.53b	38.56a	48.96a	40.98a
	High manure	41.39a	40.58a	42.43a	37.62a	47.42ab	39.75a
2009	Control	38.43b	44.21a	26.16b	25.55b	27.41b	48.85a
	Low manure	39.41ab	44.60a	23.42c	26.91a	29.85a	48.71a
	Medium manure	39.97ab	44.87a	24.49c	28.92a	28.81a	48.58a
	High manure	40.79a	45.28a	28.03a	27.16a	27.58ab	47.76a
2010	Control	38.42b	43.82a	29.17c	36.12b	46.02b	51.12a
	Low manure	38.68b	44.13a	29.40c	38.53a	49.44a	50.16a
	Medium manure	39.39ab	44.82a	30.91b	40.16a	48.57a	49.40a
	High manure	40.58a	45.52a	32.51a	39.56a	47.92ab	49.05a

[a] Values in the same year and same column followed by different letters indicate significant differences (Duncan $P< 0.05$).

condition at grain filling stage. There was no significant difference observed in soil water storage among different manure treatments at grain filling stage, and no significant difference among different treatments at maturity stage of the crop either.

Water-use Efficiency

Manure application improved water – use efficiency at different growth stages of the maize crop in varying degrees (Table 4). At jointing–big trumpet stage, water–use efficiency for manure treated soil was significantly higher than that of CK ($P< 0.05$), i.e. LM treatment increased it by 16.67, 23.61, 51.94% while MM treatment increasing it by 74.31, 39.00, 246.13% and HM by 95.36, 63.97, 295.42% during the years from 2008 to 2010 respectively. The above indicated that manure application could significantly increase water–use efficiency at jointing–big trumpet stage of the crop maize ($P< 0.05$). Water–use efficiency significantly increased with increasing manure application rates at jointing –big trumpet stage of maize ($P< 0.05$), i.e. within the respective years from 2008 to 2010, MM treatment increased WUE by 49.41, 12.45, and 127.81% more than LM. HM treatment increased it by 67.45, 31.84, and 160.25% more than LM while, HM by 12.08, 17.25, and 14.24% more than MM. The results finally indicated that increasing manure application rates could significantly increase water–use efficiency at jointing–big trumpet stage of the crop maize ($P< 0.05$).

Water–use efficiency for HM treatment was 6.81, 7.49 and 7.42% higher than that for CK at big trumpet – tasseling stage of maize for the years from 2008 to 2010 respectively ($P< 0.05$). MM treatment resulted in 4.80 and 6.31% higher water – use efficiency than CK at big trumpet–tasseling stage of maize in 2008 and 2009 respectively.

Manure treatments significantly increased water–use efficiency compared with CK at tasseling– grain filling stage of the crop maize ($P< 0.05$), i.e. LM treatment increased it by 9.38, 46.22 and 13.24%, and MM treatment by 9.66, 56.40 and 19.10%, and while HM by 28.78, 68.96 and 25.16% for the years from 2008 to 2010 respectively. Water–use efficiency increased with increasing manure application rates at tasseling–grain filling stage of the crop maize, i.e. HM application resulted in 17.74,

Table 4. Effect of organic manure management on water-use efficiency at different growth stages of maize[a].

Years	Treatments	Water-use efficiency (kg ha^{-1} mm^{-1})				
		Sowing-jointing stage	Jointing-big trumpet stage	Big trumpet-tasseling stage	Tasseling-grain filling stage	Grain filling-maturity stage
2008	Control	0.80a	7.98d	156.93c	24.84d	45.56a
	Low manure	0.82a	9.31c	158.32bc	27.17c	45.66a
	Medium manure	0.83a	13.91b	164.47ab	27.24bc	46.75a
	High manure	0.84a	15.59a	167.61a	31.99a	47.17a
2009	Control	1.92a	5.59d	45.82b	99.22d	24.71b
	Low manure	1.94a	6.91c	47.49ab	145.08c	25.07ab
	Medium manure	1.96a	7.77b	48.71a	155.18b	25.26ab
	High manure	1.97a	9.11a	49.25a	167.64a	26.28a
2010	Control	1.23a	11.36d	41.89b	30.05d	40.36b
	Low manure	1.25a	17.26c	42.01b	34.03c	42.02ab
	Medium manure	1.26a	39.32b	43.73ab	35.79b	43.04a
	High manure	1.27a	44.92a	45.00a	37.61a	43.11a

[a] Values in the same year and same column followed by different letters indicate significant differences (Duncan $P< 0.05$).

15.55 and 10.52% higher water–use efficiency than LM, and 17.44, 8..03 and 5.09% higher than MM in the years from 2008 to 2010 respectively. MM treatment increased WUE by 6.96% in 2009 and by 5.17% in 2010 more than LM ($P < 0.05$). The results indicated that increasing manure application rates could significantly increase water–use efficiency at tasseling–grain filling stage of maize if accompanied by a continued increasing of the fertilization years ($P < 0.05$).

At grain filling – maturity stage of the crop, and compared with CK, MM treatment increased water–use efficiency by 6.64% in 2010 ($P < 0.05$), while HM treatment increasing it by 6.35% in 2009 and by 6.81% in 2010 ($P < 0.05$). The results indicated that MM and HM treatments could significantly increase water–use efficiency at grain filling–maturity stage of maize and with a continuation of the fertilization years ($P < 0.05$).

Manure application could significantly increase water–use efficiency within whole growth period of maize ($P < 0.05$) (Figure 1), i.e. compared with CK, LM treatment increased water–use efficiency by 14.49, 8.51 and 10.91%, while MM treatment increasing it by 24.20, 17.77 and 27.63%, and HM treatment by 36.58, 23.18 and 33.31% within the years from 2008 to 2010 respectively. Compared with LM treatment, MM treatment increased water–use efficiency by 8.48, 8.53 and 15.07%, while HM treatment increasing it by 19.30, 13.52 and 20.19% during the years from 2008 to 2010 respectively. Water–use efficiency with HM treatment was 9.97% higher than that with MM in 2008, while in years 2009 and 2010 it was only slightly higher than that of MM. The results finally indicated that with a continuation of the fertilization years there was no significant difference observed in water–use efficiency between MM and HM treatments and soil conditions were no longer the major determining factors for an improvement in water use efficiency.

DISSCUSION

Rainfall pattern affects soil water storage in a way that during dry years the soil water storage level is lower in the organic plots in comparison with the plots supplied with mineral fertilizer (Zougmoré *et al.,* 2004). In the present study, the decrease in soil water storage at big trumpet growth stage of maize in

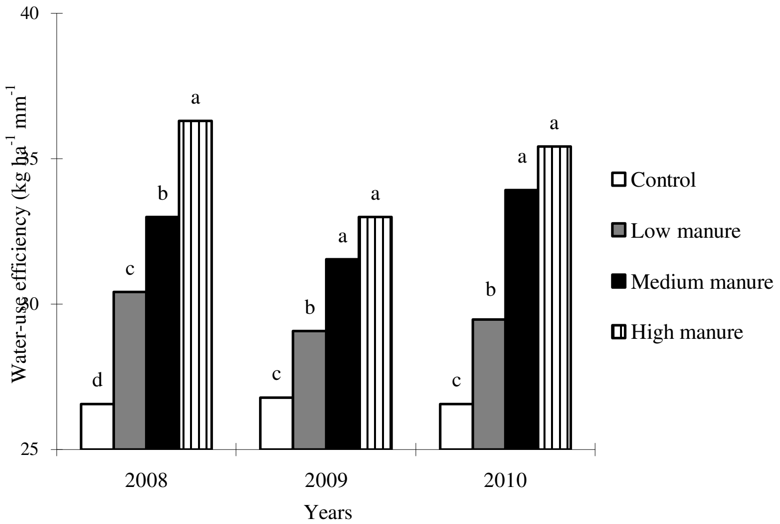

Figure 1. Effects of organic manure management on water-use efficiency during the whole growth stages of the crop maize. As for the same years, different letters above the bars mean significant differences (Duncan, $P < 0.05$).

LM and MM treatments as compared with CK and for years 2008 and 2009 may be due to the high level of rainfall (96.9 and 111.8mm) fallen these years. The lower soil nutrients in control resulted in a lower utilization of rainfall. In contrast, the increase of soil water storage at big trumpet stage within LM and MM treatments as compared with CK and in 2010 may be attributed to the lower rainfall (37.2 mm) and the better soil water-holding capacity the cases of LM and MM treatments. These results indicate that when there was a large pour of rainfall, organic manure application could cause sufficient utilization of soil water storage, and when there were lower rainfalls the organic manure application could retain water in the soil. The increase in soil water storage at big trumpet stage with increase in manure application during 2008-2010 indicated that the increase in manure application could strengthen soil water-holding capacity at this stage of crop's growth.

The decrease in evapotranspiration at jointing-big trumpet stage in manure treatments was because evaporation was the main factor affecting evapotranspiration at jointing-big trumpet growth stage of maize (Cai *et al.,* 2011), and the organic manure application could help reduce water evaporation (Zougmoré *et al.*, 2004). The significant increase in evapotranspiration at big trumpet–tasseling stage in manure applied treatments was because this factor was the main one affecting evapotranspiration at the big trumpet–tasseling stage (Cai *et al.*, 2011). Higher water-holding capacity, along with reduced water evaporation (Tolk *et al.,* 1997) resulted in increased soil water storage (Table 2), benefiting plant growth (Wang *et al.,* 2010). Evapotranspiration at big trumpet–tasseling stage was significantly higher in HM than for MM during years 2008 and 2009, while in 2010 there was no significant increase observed .This may be attributed to the beneficial effect of continuous application of higher rates of organic manure on improving soil physical (Ferreras *et al.,* 2006; Hati *et al.,* 2007; Rose, 1991) and chemical (Fan *et al.*, 2005a; Plaza *et al.,* 2005; Schjonning *et al.,* 1994) conditions resulting in a higher water-holding capacity in the soil profile (Bauer and Black, 1994; Diaz-Zorita *et al.,* 1999; Zougmoré *et al.,* 2004).

At tasseling-grain filling growth stage of the crop, manure treatments decreased evapotranspiration as compared with CK. HM treatment decreased evapotranspiration more than MM treatment did. These may be due to the decrease in invalid water consumption with manure application and as well high rate of manure application (Wang *et al.,* 2010). However, LM treatment significantly decreased evapotranspiration as compared with MM and HM treatments. This may be because of the decrease in invalid water consumption (Wang *et al.,* 2010) and lower dry matter accumulation (Li *et al.*, 2010) resulting in lower water requirement.

The significant increase in evapotranspiration at grain filling-maturity stage of maize in manure applied treatments was because grain filling-maturity was the important stage for the formation of final crop yield (Wang *et al.*, 1997). Manure applied maize grew vigorously (Fatondji *et al.*, 2006), calling for a higher water consumption to transfer the needed nutrients, accumulated in stems and leaves, to the grain.

Throughout the experiment, it was observed that the combined use of chemical fertilizers and organic manure enhanced water-use efficiency. The result is in accordance with Fan *et al.*'s (2005b), who found that a combination of chemical fertilizers and organic material resulted in the most efficient use of water. In the present study, water-use efficiency during the whole growth period of maize increased significantly with higher manure application rates. This might be because increased manure application rate enhances soil nutrient uptake (Clark *et al.,* 1998; Schjonning *et al.*, 1994) extending roots deeper (in plants grown with adequate nutrient supply) than when grown in nutrient deficient conditions (Payne *et al.*, 1995). Increased root proliferation increases the volume of soil colonized, thereby reducing the probability of plant growth being restricted by intermittent periods of drought and while increasing the potential for more efficient water use (Brown, 1971).

MM treatment significantly increased water-use efficiency at the big trumpet-tasseling stage of maize as compared with CKduring years 2008 and 2009, while in 2010 there was only a slight increase observed. This may be due to the higher rainfall (Table 1) at big trumpet-tasseling stage of the crop in 2010, which made soil moisture no longer the main factor limiting maize growth in the CK treatment.

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COCLUSIONS

Manure application or increasing the application rate could reduce invalid crop water consumption, make reasonable use of soil water and improve water-use efficiency at different growth stages of a crop (maize). Manure application could increase soil water storage by 5.27-13.19% at tasseling stage of maize, enhance water-use efficiency by 8.51-36.58% in whole growth period of maize and decrease evapotranspiration by 4.54-28.89% and 9.41-84.13% at big trumpet-tasseling and grain filling-maturity stages of the crop respectively, Organic manure application could make sufficient utilization of soil water storage when rainfall was more abundant, while its application could retain soil water when rainfall low. With increase in fertilization years, soil nutrient conditions were no longer the major factors limiting the increase of water use efficiency. A rational manure application rate to improve water use efficiency amounted to 15.0 t ha^{-1}.

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تأثیر مدیریت افزایش کود آلی به خاک بر تغییرات رطوبت خاک و استفاده مطلوب از آب (WUE) در زراعت ذرت دیم

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چکیده

خاکهای فرسودهٔ شمال غرب چین اغلب به علت عدم توازن مواد غذائی و کمبود آب غیر حاصلخیزند. تأثیر افزایش کود حیوانی در سه سطح (۷/۵ و ۱۵ و ۲۲/۵ تن در هکتار) در ترکیب با کود شیمیائی بر روی رطوبت خاک و بازده آبی Water Use efficiency (WUE) در مورد ذرت دیم (در قیاس با کود شیمیایی به عنوان کنترل) در شرایط آب و هوائی نیمه خشک و در خاکهای تیرهٔ لائوسی (Liessial) به مدت چهار سال مورد مطالعه قرار گرفت. که مبنای علمی برای مدیریت آب پایه‌گزاری شود. کاربرد در سطح بالای کود حیوانی باعث کاهش تبخیر آب (در قیاس با کنترل) در مدت زمانی شد که خاک به صورت آیش باقی گذاشته شده بود. این امر سبب شده بود که ظرفیت ذخیره آب در خاک برای مرحلهٔ رشد سریع گیاه (big trumpet stage) و با ادامه‌دار شدن مدت زمان کوددهی بطور معنی‌داری (P<0/05) افزایش یابد. افزایش کود حیوانی به خاک باعث بالا رفتن ظرفیت نگهداری آب در خاک برای مراحل پیدایش گلهای نر (Tasseling) و پر شدن دانه (Grain filling) شد. این امر همچنین سبب کاهش تبخیر و تعرق در هر یک از مرحله‌های گره‌زائی رشد سریع گیاه و پیدایش گلهای نر و پر شدن دانه گردید. بهبود در بازده استفاده از آب در هریک از مراحل رشد گیاه به شرح زیر مشاهده شد: ۱.گره‌زائی –رشد سریع گیاه به میزان ۱۶/۶۷ تا ۲۹۵/۴۲ درصد. ۲. پیدایش گلهای نر ۳. پر شدن دانه به میزان ۹/۳۸ تا ۶۸/۹۶ درصد. و نهایتاً ۸/۵۱ تا ۳۶/۵۸ درصد در خلال تمامی دورهٔ رشد گیاه با ادامهٔ سالهای کوددهی و همچنین افزایش میزان کود، بازده استفاده از آب (WUE) به طور معنی‌داری (P< ۰/۰۵) (در مراحل پیدایش گلهای نر– پر شدن دانه) ارتقاء پیدا کرد. کاربرد کود در سطح متوسط و به میزان زیاد کود آلی بازده استفاده از آب را (مراحل رشد سریع گیاه– پیدایش گلهای نر و پر شدن دانه– رسیدن دانه) به طور معنی‌داری (P< ۰/۰۵) افزایش داد. با این ترتیب و با افزایش میزان و مدت زمان افزایش کود آلی به خاک مشکلی (از نظر مواد مغذی موجود در خاک) در جهت افزایش بازده استفاده از آب وجود نداشت و مناسبترین میزان افزایش کود ۱۵ تن در هکتار برآورد شد.

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