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Improved Water Use of the Maize Soil–Root–Shoot System under the Integrated Effects of Organic Manure and Plant Density

Li-Chao Wei [1], Hua-Ping Zhang [1], Xiao-Lin Wang [1,*] and Sui-Qi Zhang [2]

[1] College of Life Sciences, Yulin University, Yulin 719000, China
[2] State Key Laboratory of Soil Erosion and Dry Land Farming on the Loess Plateau, Northwest Agriculture and Forestry University, Xianyang 712100, China
* Correspondence: wangxl8304@163.com; Tel.: +86-151-2997-8707

Abstract: On the Loess Plateau of China, water shortage and serious soil erosion are the key factors that restrict local agricultural development, especially in terms of crop yield. In order to expound the effect of treatment with organic manure in root growth, water transpiration and evaporation, biomass allocation and grain yield and *WUE* (water use efficiency), we took maize (Zheng Dan 958) sown for four years with three replicates at three densities. The results show that the highest rate of maize grain yield increase with organic manure is about 9.99% for a density of 90,000 plants/ha; at the same time, *ET* (evapotranspiration) and *WUE* also achieved marked increments, which the highest values of 415.47 mm with a density of 75,000 plants/ha and 7.92% with a density of 90,000 plants/ha, respectively. The results also demonstrate the obvious effect of organic manure in enhancing root growth and in the maximization of water transpiration and evaporation, and water use plays a vital and valuable role in biomass allocation. The results also serve as orientation for methods to increase maize yield and a reference for other crops in the relation of water and manure to their growth.

Keywords: water use efficiency; dryland agriculture; organic manure application

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1. Introduction

In the northwest dryland region of China, water scarcity and uneven rainfall are the main constraints to crop production and water use efficiency (*WUE*) [1,2], and water movement through the soil–plant–atmosphere system is considered to be one of the most important factors affecting crop grain production [3]. On the Loess Plateau of China, higher food production and *WUE* can be achieved through chemical fertilizer input, selection of deep root cultivars and appropriate plant density [4]. However, long-term excessive use of chemical fertilizer, high plant density and plastic film mulching are currently responsible for soil degradation and yield and *WUE* stagnation [5,6], and further severe and negative influences have appeared during the last several years [5,7–9].

Actions to produce more gains and high *WUE* with lower environmental cost include reducing chemical fertilizer input, or combining their use with organic manure can be an alternative way but more field approval is required [9]. Organic manure not only improves soil water permeability but also soil water holding capacity and thereby water availability [7,10], improving soil structure with higher contents of organic matter, greater enrichment of nutrients and lower bulk density [11,12]. From the long-term use of manure, all of these can lead to higher soil porosity, hydraulic conductivity and aggregate stability, which benefit crop root development and to root water movement [13]. Water movement to and from roots depends on the hydraulic conductivity of soil and crop roots [14], and water uptake by plant roots is one of the main processes for controlling water balance inside and outside the plant and is vital for agro-ecosystem management [15], and water supply to the root and shoot is determined by the hydraulic resistance of the root [16].

Dardanelli, Ritchie [17] reported that the distribution and depth of the root system is closely correlated with the capability of crop roots to extract soil water. Root length density [18,19] and the depth of the most densely rooted soil layer are more important for coping with the shortage of soil water and nutrients. Water uptake partitioning over depth is highly correlated with root mass or length per unit volume of soil [14,15]. Changes in environmental water conditions will affect the water physiological characteristics of plants, including water consumption by transpiration, water potential and photosynthesis [20,21].

Many studies based on the simplified soil–root–leaf water system have not provided a foundation of knowledge that is sufficient for our understanding of the complex process of crop water uptake, especially in dryland farms with diversiform fertilizer practices. According to Guan, Al-Kaisi [22], the root system serves as a bridge between the impacts of agricultural practices on soil, shoot function and harvested yield. An essential function of the root system is uptake of water from the soil and its transport to the shoot [23–25], and root hydraulic conductivity (*Lpr*) of the plant, as an indicator of root system function, is important in contributing to balancing the various demands of the shoot for water [24].

Stem sap flow measurement (heat balance) is an important technique for the study of plant water balances and represents a commonly used technique to monitor the sole transpiration term at the scale of a single plant [26–28], and sap flow in individual stems show strong positive relationships with net radiation and leaf area [29–32]. Thermoelectric balance methods for measuring sap flow in plants are frequently applied in studies of plant water relations [33] and to estimate plant transpiration, and *ET* represents the combination of water use from soil evaporation and transpiration from the plant [34–36]. Three water measurement positions at different organs are used, leaf parameters, stem sap flow velocity and root hydraulic conductivity, to upscale the *ET* from the soil to plant leaf, and incorporating the canopy structure and the relationships between sunlit and shaded leaves was proposed [37,38]. Field experimental data have so far been seldom available for examining the effects of root distribution and pattern on both root water uptake and soil water status [15,39].

Scientific data on these aspects are currently very crucial for addressing the mechanisms responsible for the interaction among fertilizer management, maize root water uptake and *WUE* in field experiments. Our objectives were (1) to collect data through investigating maize root–leaf development under organic manure and (2) to identify the relationship between maize growth and water uptake of the soil–root–leaf system. On the one hand, manure input can increase soil nutrition, but not all of soil intrinsic nutrition is absorbable, and the use of manure is based on the guarantee of obtaining nutrients for plants. On the other hand, manure may play a role in releasing some nutrients in the soil that cannot be directly absorbed, and this paper can be used for determining directions of follow-up research.

2. Materials and Methods

2.1. Field Experimental Sites

The field experiments were conducted from 2011 to 2014 at the Chang Wu Agroecological Experimental Station (35°12′30″ N, 107°40′30″ E, altitude 1200 m) Chinese Academy of Sciences, located in the south–central region of the Loess Plateau, which is an arid and semi-arid area of northwestern China (Figure 1). The soil is classified as Cumuli-Ustic Isohumosols (Heilu soil) whose construction is uniform and loose with a soil bulk density of 1.30 g/cm^{3}and pH = 8.3. The topsoil organic matter, total nitrogen, available phosphorus and available potassium contents are 10.4 g/kg, 0.6 g/kg, 3.0 mg/kg and 129.0 mg/kg, respectively, measured at a soil depth of 0–20 cm.

The climate at the experiment site is temperate semi-humid and semi-arid monsoonal, with a mean annual temperature of 9.1 °C and a mean annual precipitation of 584.6 mm. Approximately 60% of the precipitation occurs from June to September. During the maize developmental period (from April to September), 70% of the precipitation occurs from July to September, the period in which maize needs the most rain resource. Meanwhile, the temperature increases from April, reaching a peak point (22.5 °C) in July or August in each of the three growing seasons, and then gradually decreases (Figure 2).

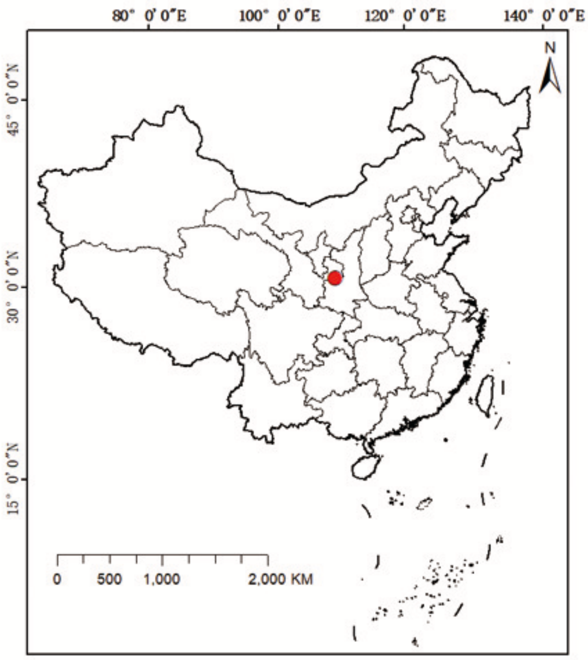

Figure 1. Location of Chang Wu Agroecological Experimental Station. The red dot shows the location of the experimental site in China.

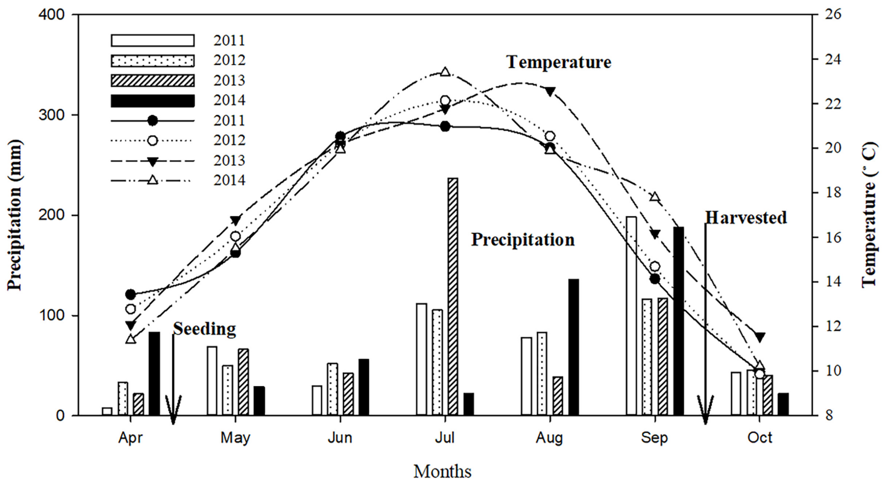

Figure 2. Dynamic change in monthly temperature and precipitation in four continuous growing seasons.

2.2. Experimental Design and Plot Arrangement

The experiments were replicated three times in a random block design. The maize cultivar (Zheng Dan 958) was sown on the 24th of April and harvested on the 15th of September in the four growing seasons (2011–2014). The plots were designed as 5 m wide × 6 m long. The maize was cultivated at three densities (60,000, 75,000 and 90,000 plants/ha) and wide–narrow row spacing (80 cm plastic film mulch; 40 cm row ledge). The content of effective inorganic components in the dry matter of manure is as follows: total C—362.1 g· kg^{-1}, total N—20.3 g· kg^{-1}, total P—18.2 mg· kg^{-1} and total K—8.5 mg· kg^{-1}. Plastic film mulch ensures the water and temperature are appropriate for seed emergence. Fertilization was conducted with combined chemical fertilizer and organic manure under three densities, and no manure application represents the control, as shown in Table 1. All of the experiments received the top application at the V6 stage with 90 kg/ha N. Precipitation and temperature during the growth period were recorded and shown in Figure 2.

Table 1. The experiments design and fertilizer practices.

Treatments	Plant Density (plants/ha)	Basic Fertilizer				Top Application N at V6 Stage (kg/ha)
		N (kg/ha)	P_2O_5 (kg/ha)	K_2O (kg/ha)	Manure (t/ha)	
T1	60,000	135	112.5	112.5	0	90
T2	60,000	135	112.5	112.5	52.5	90
T3	75,000	135	112.5	112.5	0	90
T4	75,000	135	112.5	112.5	52.5	90
T5	90,000	135	112.5	112.5	0	90
T6	90,000	135	112.5	112.5	52.5	90

2.3. Leaf Area Index (LAI) Measurement

The *LAI* in all of the experiments was measured using an *LAI* -2200 instrument (LI-COR Inc., Lincoln, NE, USA) at several main growth stages (V6 jointing stage, V10 tenth leaves, VT flowering stage, R2 kernel blistering, R3 kernel milking, R4 kernel dough, R6 physiological maturity). In addition, the LAI was measured three times in the center of the test region on a fair-weather afternoon.

2.4. Root Length Density (RLD) and Root Hydraulic Conductivity (Lpr) Measured

The roots were sampled using a root corer to minimize damage to the plots and examine the root distribution in detail at physiological maturity. The soil cores (9 cm in diameter and 9 cm in length) were collected at 10 cm intervals to a maximum depth of 100 cm to determine the vertical root distribution. The soil cores were positioned between the rows and washed in plastic baskets packed with spun yarn. The root lengths were measured using a scanner (Epson Perfection V700, Seiko Epson Crop, Suwa, Japan) and analyzed using WinRHIZO (Regent Instrument Inc., Quebec, QC, Canada) [40]. Then, the root samples were dried to a constant weight at 80 °C, and the total root dry weight (*RDW*) was calculated.

The root hydraulic conductivity (*Lpr*) from V12 to R4 of individual plants was measured using a high-pressure flow meter (HPFM, Dynamax Inc., Houston, TX, USA). At least three individual plants with similar morphological characteristics were selected, and their stems were cut at a height of 15–20 cm above the surface ground before measurements were conducted. Importantly, the stem sections were beveled before being installed in the vacuum spiral chamber that was linked to the HPFM via a plastic pipe and through which the water flowed to the stem section. All of the HPFM parts were under a vacuum at the beginning of the conductivity measurements. The HPFM was connected to a nitrogenous tank and a computer with HPFM analysis software. During the conductivity measurements, the water moved to the roots through the stem section, the pressure increased from 0 to 500 kPa, and the computer recorded the changes in the water flow and air pressure. We calculated the *Lpr* values based on the measured water flow and air pressure data to verify the variation in *Lpr* with competition under mixed cultivation.

2.5. Stem Sap Flow Measurement

Crop transpiration rates were measured using sap flow sensors. Three stem flow gauges (models SGB 16, SGB19 and SGB25, Flow 32-1K; Dynamax Inc., Houston, TX, USA) were used with the energy balance method to measure sap flow in the maize stems [41–43]. When the plants were 160–180 cm high with a stem diameter of 16–25 mm, three plants were selected for sap flow measurements. The flow sensors were installed on their stems at a height of 25–30 cm above the ground at pre-flowering stage when the plants were fully developed. After installation, the probes were sealed with silicon foam to prevent rain water intrusion and shielded with aluminum foil to avoid external thermal influences. Probe signals were read at 30 s intervals and recorded as 10 min averages on CR1000 data logger (Campbell scientific, Logan, UT, USA). The data were downloaded weekly from 15th of July (flowering stage) to 20th of September (at harvest) for analysis.

2.6. Evapotranspiration (ET) and Water Use Efficiency (WUE) Calculated

Soil moisture was gravimetrically recovered from sowing (24th of April) to maturity (15th of September) in three growing seasons, soil samples were collected at 10 cm intervals over a depth of 0–100 cm and at 20 cm intervals over a depth of 100–200 cm, and accumulated evapotranspiration (*ET*) was calculated using the water balance equation:

$$ET(\text{mm}) = (P + I + C) - (R + D) - \Delta SWS, \quad (1)$$

where P is precipitation, I is irrigation, and C is the upward flux into the root zone. R is the surface runoff, D is downward drainage out of the root zone, and Δ *SWS* is the change in stored soil water in the soil profile. Runoff was never observed, as the experimental field was flat. The groundwater table is very deep (about 80–90 m), so C was assumed to be negligible. There was no heavy rain or water logging events during the growing season, so deep drainage was assumed to be insignificant, and the plots were no irrigated, consequently *ET* can be reduced to:

$$ET(\text{mm}) = P - \Delta SWS \quad (2)$$

Changes in soil water content in the soil profile (Δ *SWS* in mm) were calculated as the difference in soil water content from sowing to maturity. To investigate the root:shoot ratio, we collected firstly shoot samples at maturity. Three adjacent plants of similar size were harvested from each plot. The aboveground portion (separated as stem and leaves) was inactivated for 1 h at 105 °C and dried to a constant weight at 80 °C to determine the shoot biomass (*BDW*) and leaf dry weight (*LDW*), combined to give the *RDW*, and we calculated root:shoot ratio as:

$$RSR = RDW/BDW \quad (3)$$

Water use efficiency (*WUE*) was calculated based on the following equation:

$$WUE(\text{kg/mm/ha}) = Y/ET \quad (4)$$

where Y is the grain yield per unit area [44].

2.7. Data Analysis and Statistics

SPSS Statistics 17.0 was used to assess the main effects of organic manure on maize growth, grain yield and *WUE*. Single maize plants with and without organic manure treatments were compared using a least significant difference (LSD) test at $p < 0.05$ in SPSS. The figures created using Sigma Plot 12.0 and ArcGIS 10.8.

3. Results

3.1. Soil Water Content at Harvest Stage

The water content of soil at different depths was measured by sampling in the growing area during harvest period and plotted as shown in Figure 3. It can easily be seen that above about 50 cm of soil layer, which can also be understood as the cultivated layer, the soil moisture content shows a large difference based on the variable with or without the use of organic fertilizer, and the soil water content is about 1.5–3.0% higher with use of organic manure than without. Therefore, organic fertilizer can effectively increase the soil moisture content and play an important part in maintaining moisture.

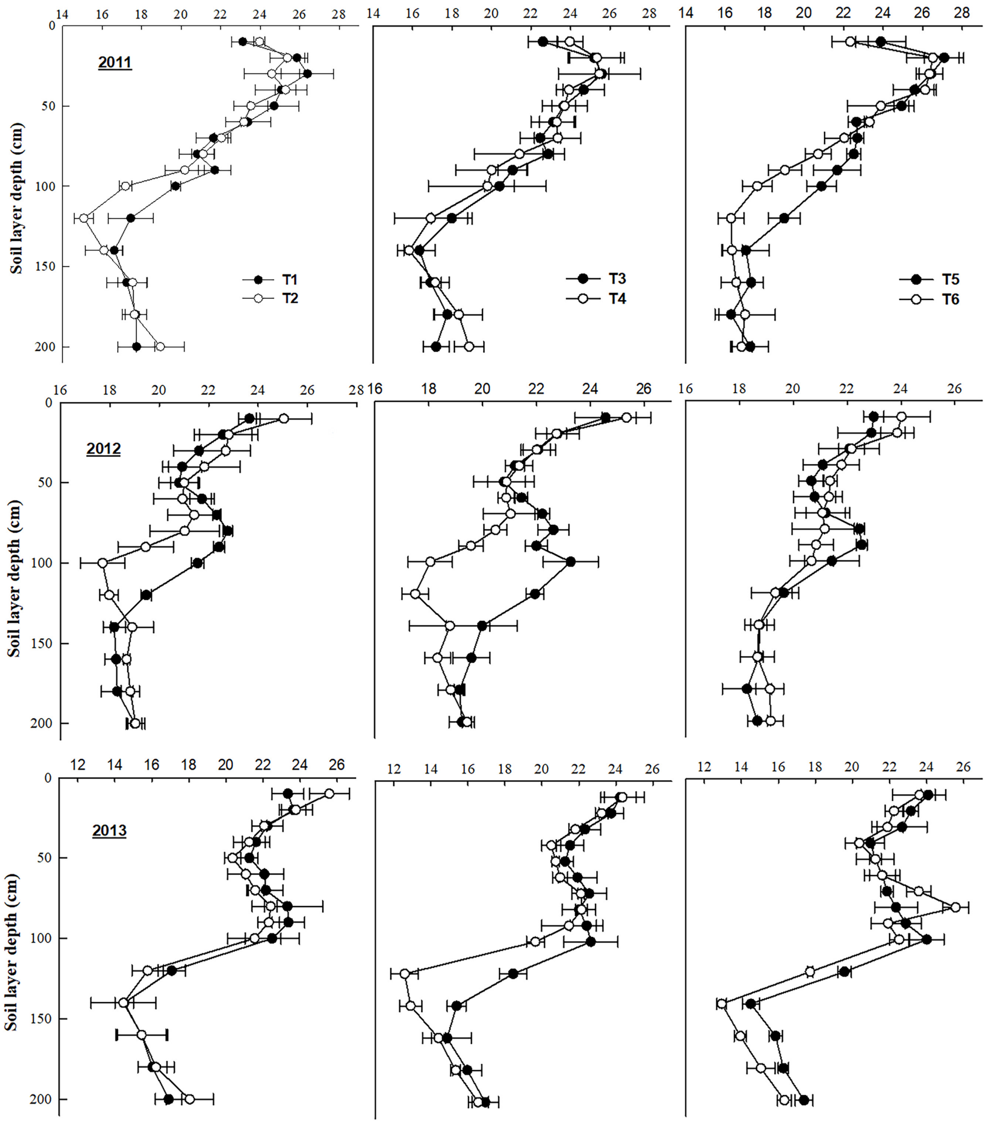

Figure 3. Different effects of organic manure on soil water content on profile.

3.2. Root Length Density (RLD)

The means of *RLD* in three years are presented in Figure 4, and *RLD* increased significantly under organic manure, but the rates of increase decreases as the density is increased. Significantly higher *RLD* always occurred in the 0–50 cm soil layer under three planting densities, and below the 50 cm soil layer, *RLD* showed insignificant differences between conditions with and without organic manure. The most significant data affected by organic manure are shown in b-3, which is about 4 cm·cm^{-3} higher than that without organic manure. The remaining five sets of data all show that the *RLD* with organic manure is about 1–3 cm·cm^{-3} higher.

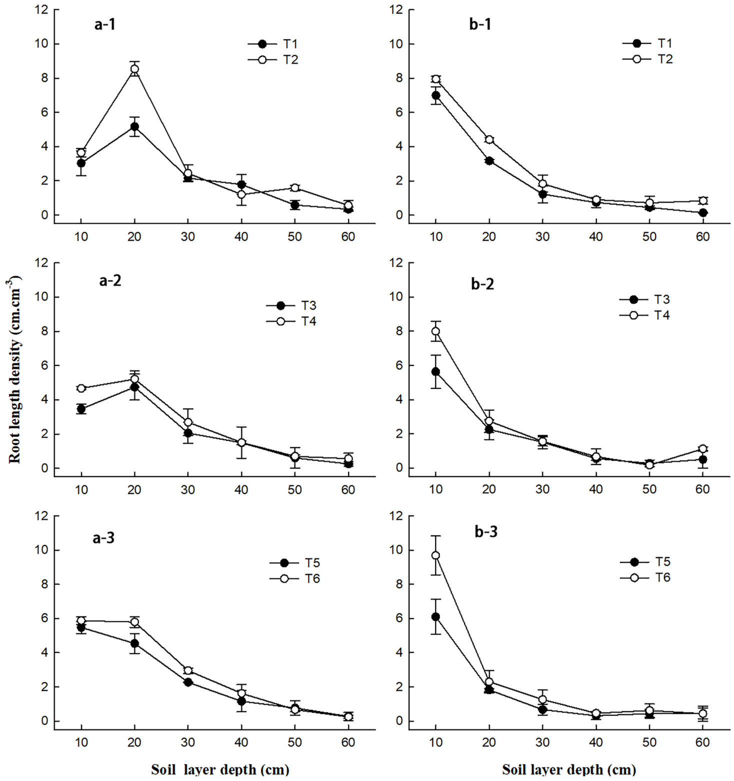

Figure 4. *RLD* under the effects of organic manure and planting densities. In this figure, (**a-1**) represents planting at a density of 60,000 plants/ha in 2011, (**a-2**) represents "75,000 plants/ha in 2011", (**a-3**) represents "90,000 plants/ha in 2011" , (**b-1**) means "60,000 plants/ha in 2012", (**b-2**) means "75,000 plants/ha in 2012", (**b-3**) means "90,000 plants/ha in 2012".

3.3. Root Hydraulic Conductivity (*Lpr*)

Lpr was enhanced under organic manure application in sustainable years (Figure 5), especially under lower planting density, with the development of maize into the reproductive period, and *Lpr* significantly improved under organic manure at the stage of V12 to R1, and the most remarkable improvement is at c-R1, higher by about $3{\cdot}10^{-8}{\cdot}s^{-1}{\cdot}cm^{-2}$, then gradually decreases with no significant difference. In conclusion, when maize growth enters the grain filling stage, the difference in *Lpr* between maize plants with and without organic manure is gradually diminished.

3.4. Stem Sap Flow Rate (*SFR*)

Leaf transpiration is calculated from the daily *SFR*, and our results show that *SFR* is improved and efficiently adjusted, as evidence of the great daily transpiration of leaves under the integrated effects of organic manure and density (Figure 6). With organic manure involved, *SFR* increased slightly and reaches a peak point at R2 or R4 with maize development, and *SFR* maintains a higher level compared with when no organic manure is applied, and *SFR* generally decreases with the progression of maize grain filling with chemical fertilizer only. *SFR* of single maize plants also increased with higher planting density and was the highest at R2 with the data mostly at around 150 $mg{\cdot}h^{-1}$.

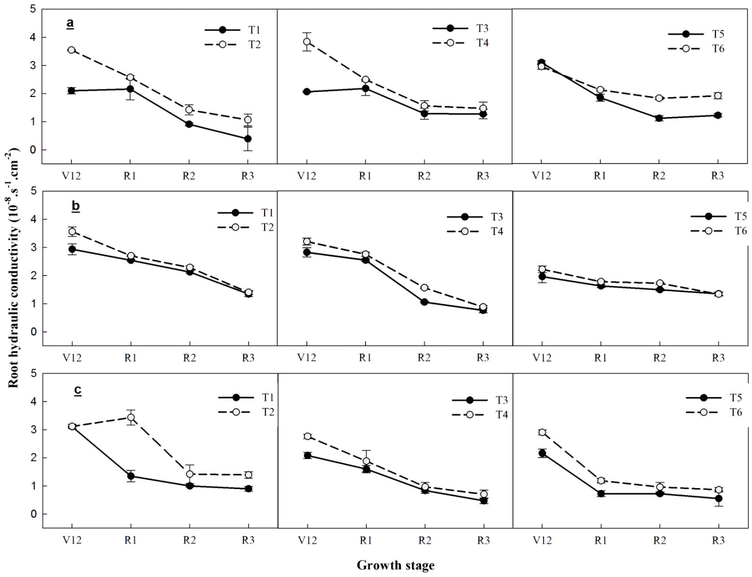

Figure 5. *Lpr* changes under organic manure in different planting stages . In this figure, V12, R1, R2 and R3 are different growth stages. V12 means the stage when the first leaf and second leaf are visible, R1 means that a silk is visible, R2 means that silks have darkened and are beginning to dry out, R3 means the silks have dried out. Letter (**a**) means the year 2011, (**b**) means the year 2012 and (**c**) means the year 2013.

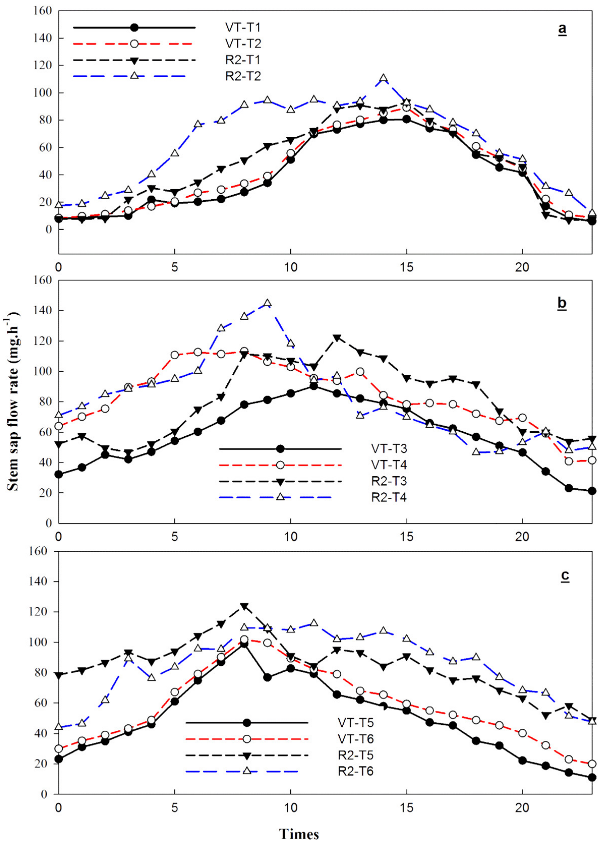

Figure 6. Daily changes in stem sap flow velocity at reproductive period under organic manure in three different planting densities. In this figure, letter (**a**) means the year 2011, (**b**) means the year 2012 and (**c**) means the year 2013.

3.5. Relationship between Leaf Area Index (*LAI*) and Transpiration

LAI increased with higher planting density and significantly improved under organic manure application. According to the main stages of *LAI*, the highest value occurred at VT with 4.42, 5.81 and 6.72 m^2/m^{-2} in three densities of 60, 75 and 90 thousand plants per hm^2 (Figure 7) and was higher than that of the non-manure treatments. Importantly, the green period of leaves was lengthened, which is favorable for leaf water transpiration, light interception and photosynthesis. Referring to maize leaf transpiration (Figure 8), it was significantly improved under the effect of organic manure and significantly decreases with increased planting density, especially with 60 thousand plants per hm^2, and the differences became more pronounced with the progression of maize grain filling.

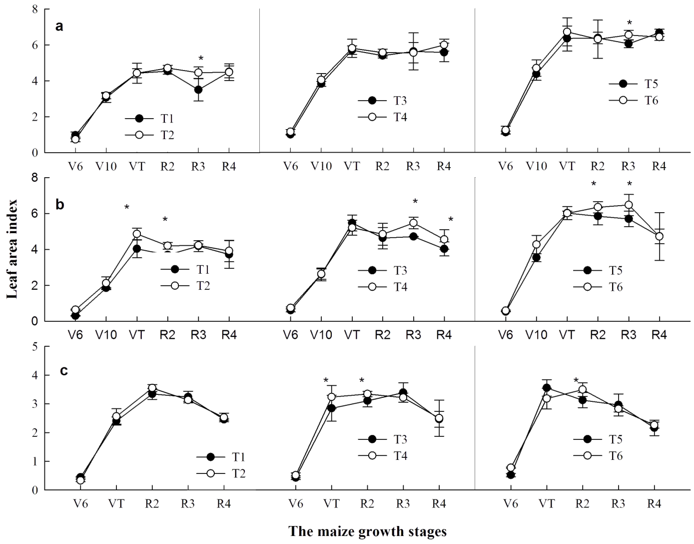

Figure 7. Change in *LAI* from V6 to R4 (maize growing stage) under integrated effect of organic manure and planting densities.In this figure, letter (**a**) means the year 2011, (**b**) means the year 2012 and (**c**) means the year 2013, * means significant difference at $p < 0.05$.

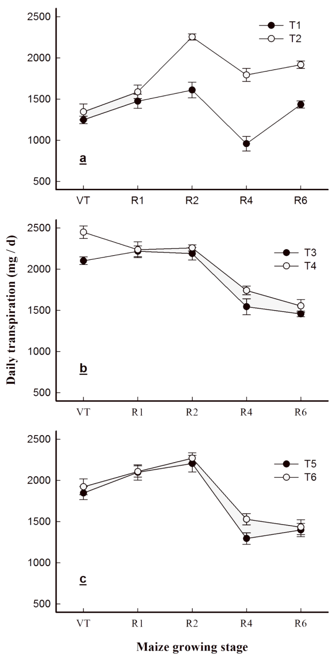

Figure 8. Change in daily transpiration from VT to R6 (maize growing stage) under integrated effect of organic manure and planting densities. In the two figures above, letter (**a**) means the year 2011, (**b**) means the year 2012 and (**c**) means the year 2013.

3.6. Biomass Allocation Related with Evaporanspiration (*ET*)

Total dry weight (*BDW*) was measured at maturity stage. Biomass sample was separated into roots, leaves and stems for calculating *LDW* and *RSR*. *BDW* increased under organic manure application by 12%, 6% and 12% in the three different density groups (Table 2). However, with increased sowing density, *BDW* significantly decreases along the gradient of the three densities. Meanwhile, *LDW* was improved under organic manure but also decreased with increased density (Table 3). Organic manure improved shoot biomass accumulation, combined with the root biomass, represented as *RSR*, which increased when organic manure was included, so organic manure is found to generally improve shoot growth through adjusting the root development and distribution in the soil layer.

Table 2. Effects of organic and density on the BDW, LDW and RSR at maturity stage.

Treatments	BDW (g)	LDW (g)	RSR (g)
T1	355.31ab	49.90a	0.07ab
T2	398.38a	46.26ab	0.06b
T3	327.68c	39.15c	0.07ab
T4	347.89b	41.22bc	0.07ab
T5	285.24d	38.08c	0.08a
T6	319.24cd	40.40c	0.08a

The values followed by different letters (a, b, c and d) within a row indicate significant difference between conditions with and without organic manure at $p < 0.05$, n = 3.

Table 3. Correlation among the measured indicators of BDW, RSR, LDW and ET.

Indicators	BDW (g)	RSR (g)	LDW (g)	ET (mm)
BDW	1			
RSR	0.72 *	1		
LDW	0.88 **	0.69 *	1	
ET	0.44	0.53	0.80 *	1

* Significant difference at $p < 0.05$; ** Significant difference at $p < 0.01$; *BDW*, total dry weight; *LDW*, leaf dry weight; *RSR*, root to shoot ratio; *ET*, evapotranspiration.

3.7. Grain Yield Increase Rate, *ET* and *WUE* Improve Stably and Sustainably

Grain yield always appeared higher under organic manure compared with non-manure and significantly increased with higher sowing density (Table 4). When organic manure was applied in continuous years, grain yield increased sustainably as seen in the 3-year mean of 13.78, 14.26 and 15.27 t/hm^2 in T2, T4 and T6. The rate of increase in yield and *WUE* in T2 significantly improved, and that of T4 and T6 were stable compared with non-manure treatment. Referring to the sustainable rate of yield and *WUE* increase, T2, T4 and T6 presented more efficient improvement due to organic manure stimulation. *WUE* in the treatments with chemical fertilizer only showed negative effects on the increase rate at T1 and T5.

ET of the whole season increased with the seasonal precipitation and was higher in $T_{2,4,6}$ than in $T_{1,3,5}$, especially for lower planting densities. Combined grain yield with *ET*, *WUE* was calculated and increased when organic manure was used. The highest *WUE* in the three seasons was 35.31, 39.40 and 35.68 kg/mm in T6, T6 and T4, respectively, and the mean of three seasons confirmed that the combination of organic manure and planting density potentially improved *WUE* .

Table 4. Grain yield increase rate, *ET* and *WUE* affected by organic manure and three densities.

Treatments	Grain Yield Increasing Rate (%)					ET (mm)					WUE (%)				
	2011	2012	2013	2014	Mean	2011	2012	2013	2014	Mean	2011	2012	2013	2014	Mean
T1	–	–	–	–	–	364.48a	372.11a	456.75a	412.41a	401.44a	–	–	–	–	–
T2	5.30	6.39	24.75	0.78	**9.31**	362.03a	380.49a	490.60a	420.36a	413.37a	6.01	5.02	16.17	1.95	**7.29**
T3	–	–	–	–	–	359.76a	379.94a	452.15a	418.47a	402.58a	–	–	–	–	–
T4	11.78	1.42	7.83	4.78	**6.45**	353.88a	386.93a	480.87a	440.21a	415.47a	7.40	1.71	5.56	0.43	**5.43**
T5	–	–	–	–	–	361.42a	359.49a	485.63a	410.23a	404.19a	–	–	–	–	–
T6	7.86	16.34	6.81	8.94	**9.99**	357.73a	377.59a	483.31a	423.14a	410.44a	8.97	9.75	7.36	5.59	**7.92**

The values followed by same letter "a" within a row indicate there is no significant difference between conditions with and without organic manure at $p < 0.05$.

3.8. Correlation of Analysis between RLD, BDW, LDW, RSR and ET

The results of correlation analysis based on the means of three growing seasons (Figure 3) show that *RLD* correlated closely with the biomass dry weight (*BDW*, $R^2 = 0.67$ *, $p < 0.05$), leaf dry weight (*LDW* , $R^2 = 0.37$), root:shoot ratio (*RSR*, $R^2 = 0.75$ *, $p < 0.05$) and evapotranspiration (*ET*, $R^2 = 0.88$ **, $p < 0.05$) (Tables 2 and 3). *RSR* directly reflects the root function of water and nutrient uptake such that *BDW*, *LDW* and *ET* show positive correlations with *RLD*. However, *RLD* increase resulted in a probable increase in root weight, so *RSR* presented a negative correlation with *RLD*.

4. Discussion

High plant densities result in thinner maize stems that increase the risk of lodging, which has a detrimental effect on yield [45]. The reduction in L_0 (normalized to root dry weight, L_0) was not correlated with the reduction in leaf area, and shading or cutting single leaves had a similar effect, and shoot topping (about 30% reduction in leaf area) reduced L_0 of maize by 50% to 60% [46]. The strong competition between lateral roots for nitrate causes increased LRBD (lateral root branching density) and decreased uptake per unit root length, and most genotypes have an LRBD that balances both in nutrient acquisition. LRBD merits additional investigation as a potential breeding target for greater nutrient acquisition [47,48]. It should be pointed out that on the one hand, the application of organic fertilizer increases the inorganic nutrition in the soil, and, on the other hand, organic fertilizer has strong sustainable fertility, and its impact on the soil is not limited to the current research. Only effective inorganic components such as effective N element in the soil can be directly absorbed and utilized by plants, but it is unknown whether organic fertilizer promotes the transformation of inorganic salts that cannot be directly absorbed into nutrients that can be directly absorbed. Exploration of this requires a deeper and longer-term experiment. In this study, organic fertilizer is not only used as a substance to improve soil properties and structure but also as an additional nutrient to ensure plant growth as a variable in the study.

Deeper-rooting cultivars and practices that improve effective rooting depth involve plant density and practices that reduce soil evaporation. Mulching and addition of organic fertilizers improve soil available water capacity and enhance responses to mineral fertilizers [4,49]. Organic manure is used benefit root system development [50,51]. In our research, the maize *Lpr* was enhanced and kept at a high level with years of sustainable organic manure application (Figure 5). Sufficient precipitation resulted in the great differences among the treatments with and without manure application. Root systems typically play a central role in maintaining whole-plant water balance and the plant water status in a changing water environment [40,52]. Soil water potential (*SWP*) is known to affect plant water status, even though observations demonstrate that *SWP* distribution around roots may limit plant water availability [53].

Prior to maize germination, the daily *ET* rates from bare soil were much higher than the daily water loss from the 0 to 90 cm of soil (Figure 3), there was upward movement from the profile, which was mostly balanced by total rainfall, *ET* loss, and a decrease in soil water storage [3,54] with maize growth. In this process, organic fertilizer provides rich inorganic ions for soil and plants, which promotes the growth and development of plant roots and greatly promotes the production and accumulation of plant harvested dry matter, which manifests as obvious improvements in *SFR* and dry matter after application of organic fertilizer (Table 4). However, it is still necessary to further study which ion or ion combination has the most significant effect on harvested dry matter accumulation and soil porosity maintenance in the operation of a series of ions in the northwest dryland region of China.

Variation in maize stem T_p involves both internal and external factors, and internal factors include canopy structure, stomata opening, stem and root hydraulic conductivity and hydraulic architecture characteristics, and external factors are environmental and include meteorology and soil moisture [41,55]. Upscaling from the plant (sap flow) to field scale has mainly been based on plant population and the size of plant stems [37]. This provides a direction and reference for comparisons in follow-up studies. Crop *ET* varies with the meteorological conditions and maize growth stages. The allocation of water to roots can account for the difference in *SWS* between the 0–1 and 1–2 m layers. Approximately 95% of the maize roots were distributed in the 0–0.6 m soil layer. Water uptake by roots substantially contributes to the depletion of water in the 0–1 m layer [56]. However, the 0–1 m soil layer contains the tillage layer, and its soil nutrient conditions and air permeability are two important factors that affect the subsequent harvesting of dry matter, and organic fertilizer has a positive effect on both. In the follow-up, the application amount of organic fertilizer can be studied in detail, so as to obtain a plan to increase the yield while consuming relatively little organic fertilizer and improving the actual production efficiency.

5. Conclusions

In this study, a large overlap study and three methods of treatments clearly showed that the maize yield and *WUE* under the treatments with manure was specifically higher than those without manure, and crop yield increase is extremely beneficial to the agricultural development of dryland. When maize density was 90,000 plants/ha, the highest grain yield increasing yield and the highest *WUE* are seen, which are respectively 9.99% and 7.92% on average, and it is also significant that the highest value of *ET* was found for 75,000 plants/ha. This study also points out that the effect of organic manure on boosting root growth, maximization of water transpiration and evaporation and water play quite an important role in biomass allocation. This serves as orientation on methods for increasing the maize yield. The results also provide a reference for selecting water and fertilizer management options for other crops.

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