SOIL WATER STORAGE, LEAF PHOTOSYNTHESIS AND GRAIN YIELD OF MAIZE (*Zea mays* L.) AS AFFECTED BY DIFFERENT SOIL AMENDMENTS

[1,2,4]*S. Lamptey, [1,3,5]S. Yeboah, [1,2]L. Li and [1,3]R. Zhang

[1] *Gansu Provincial Key Lab of Arid Land Crop Science, Lanzhou 730070, China*
[2] *College of Agronomy, Gansu Agricultural University, Lanzhou 730070, China*
[3] *College of Resources and Environmental Sciences, Gansu Agricultural University, Lanzhou 730070, China*
[4] *University for Development Studies, P.O. Box TL 1882, Tamale–Ghana*
[5] *CSIR–Crops Research Institute, P.O. Box 3785, Kumasi, Ghana*
***Corresponding author**: naalamp2009@yahoo.com

Abstract
Water scarcity and soil fertility are two critical factors limiting maize production over most semi-arid regions of the world. Photosynthesis as a sensitive physiological parameter of plant metabolism and development reflect plant response to changes in environmental factors. It is unclear whether soil amendments can sustainably address these issues. A three-year study was conducted to investigate the effects of soil amendments on soil water storage, photosynthetic activities and grain yield of dual-purpose maize in the Western Loess Plateau of China. The experiment was conducted using a randomized complete block design with four treatments and three replicates per treatment. The treatments were: no–amendment (NA), swine manure (SM), maize stover (MS), and swine manure in combination with chemical fertilizer (SC). Results showed that, compared to NA, SC significantly increased soil water storage within the 0–110 cm depth at flowering, milking and maturity stages. Swine manure in combination with chemical fertilizer (SC) increased stomatal conductance (gs), photosynthetic rate (PN) and transpiration rate (E) by 46%, 48% and 51%, respectively, which translated into increased crop biomass and grain yield (≈74%) and water use efficiency (≈68%) compared to NA. We conclude that for increased soil water storage and maize grain yield in the semi-arid Loess Plateau, swine manure in combination with chemical fertilizer could be considered.

Keywords
Soil amendment; Soil respiration; Carbon emission efficiency; Maize

Introduction

The Western Loess Plateau of northwest China is one of the most important rain-fed grain cropping regions in China (Liu et al., 2006), providing food security and employment for a population greater than its 34 million residents (Zhao et al., 2012). The area is one of the most severely eroded areas in China coupled with limited precipitation and high evaporation results in low crop yield (Liu et al., 2009). Crop intensification coupled with unbalanced fertilization has resulted to soil quality degradation and decline in corn yield (Liang et al., 2009). For intensive sustainable crop production, a management practice that reduces the use of agricultural chemicals is required (Bilalis et al., 2009). The integrated soil fertility management (ISFM) is currently promoted as a management approach that optimizes the use of all available resources within each target environment (Kimani et al., 2003). Talgre et al. (2012) suggested the application of organic materials as an effective way to improve soil fertility and enhance soil moisture holding capacity. Song et al. (2010) reported higher soil water content from chemical fertilizer plus organic amendment.

Photosynthesis is a sensitive physiological parameter of plant metabolism and development that reflect plant response to changes in environmental factors. Photosynthetic efficiency in crops is associated with soil water and nutrient availability. Soil water content limits plant photosynthesis which accounts for the majority of variation in biomass production and therefore yield (Takai et al., 2010). Decreased soil water content causes a reduction in stomata conductance and net photosynthesis resulting in poor plant growth (Reynolds et al., 2000). Fertilizers applied to crops can be used to synthesize the components of the photosynthetic apparatus (Sugiharto et al., 1990) and the absence of fertilizers in crop production can directly disturb photosynthetic activities and also restrict partitioning of assimilates (Kanai et al., 2011). There is the need for nutrient supply to improve soil water storage and photosynthetic activities. The objectives of this study were to: (i) evaluate the influence of different soil amendment on soil water storage, and (ii) determine the photosynthetic response of maize to soil amendment in the semiarid Loess Plateau.

Materials and Methods

Experimental site

The field experiment was conducted at the Dingxi Experimental Station (35°28'N, 104°44'E and elevation 1971m), Anding County, Gansu Province, northwest China for three consecutive years. The site has a *Huangmian* soil (Chinese Soil Taxonomy Cooperative Research Group, 1995), aligning with a *Calcaric Cambisols* in the FAO soil map of the world (FAO, 1990). It is a sandy-loam with low fertility, soil organic carbon below 7.63 g kg^{-1} and Olsen P below 13.3 mg kg^{-1} representing the major cropping soil in the district (Xianmo et al., 1983). The long-term annual rainfall at the experimental site averages 391 mm ranging from 246 mm in 1986 to 564 mm in 2003 with about 54% received between July and September. Daily maximum temperatures can reach up to 38°C in July while minimum temperatures can drop to negative 22°C in January. The experimental site has a long history of continuous cropping using conventional tillage practice.

Experimental Design and Treatment Description

The experiment was conducted in a randomized complete block design with three replicates and four treatments. The treatments were: No amendment (NA), swine manure (SM), maize stover (MS) and swine manure in combination with chemical fertilizer (SC). The experiment was established in 2013; however, this article reports the experimental data for the 2014, 2015, and 2016 cropping seasons. The same plot was used for the three years. Detailed chemical composition of maize stover and swine manure is presented in (Table1) whilst detailed treatment description is presented in (Table2). The SM, MS, and SC are considered as "amendment treatments" in this paper. The rates of application for all the amendments were based on the N rate; 200 kg ha^{-1}. There were twelve plots, each measured 42.6 m^2 (14.2 m length and 3 m width). All other agronomic considerations were kept constant for all treatments.

Measurement and methods for calculating indices

Most of the data in this study were collected at the maize growth stages [seedling stage (nine or more leaves unfolded), flowering (tips of stigmata visible; pollen shed may begin), milking stage (middle kernels milky, yellowish, white), and physiological maturity (black layer visible, fully ripe; kernels hard and shiny)] according to the standardized maize development stage system (Ritchie et al., 1997).

Soil water storage

Soil water content was measured at flowering, milking and physiological maturity stage at six depths (0–5, 5–10, 10–30, 30–50, 50–80 and 80–110 cm. The gravimetric soil water content in the 0–5 and 5–10 cm depth interval was determined using the oven-drying method described by Jia et al. (2012). Gravimetric water content (0–5 and 5–10 cm) was multiplied by soil bulk density (1.25 $\pm$ 0.042 g cm^{-3}) to obtain the volumetric water content, which is expressed in cm^3/cm^3. Trime-Pico IPH (Precise Soil Moisture Measurement, IMKO Micromodultechnik GmbH, Ettlingen, Germany) was used to measure volumetric soil water content in 10–110 cm depth. Subsequently, soil water storage (0–110 cm) was estimated from the volumetric soil water content by multiplying this value by the soil layer depth.

Leaf area index

For calculations of LAI, five maize plants were sampled from each plot using the "S" type method described by Yin et al. (2016). Sampling was conducted at seedling, flowering, milking and maturity stage. Leaf area index (LAI) was determined using Equation 1 as described by Yin et al. (2016):

$$LAI = 0.75 \times P \times \sum_{i=1}^{n} (a_i \times b_i) \quad (1)$$

Where: P is planting density (plants ha^{-1}), a_i is leaf length, and b_i is the greatest leaf width, and 0.75 is the compensation coefficient of maize.

Chlorophyll content

Chlorophyll content (Chl) of uppermost fully developed leaves was determined at seedling, flowering, and milking stage using a portable chlorophyll–meter (SPAD Model 502, Minolta Camera Co. Osaka, Japan). Measurements were conducted from 9:00 to 12:00 h on ten (10) leaves per plot, concurrently with measurement of photosynthetic parameters.

Leaf water potential

Measurements of leaf water potential (ψw) was conducted with a pressure chamber (Decagon, model WP4C Potentiometer) on the first fully expanded leaf and near the leaves used for measurements of the photosynthetic parameters described below. Water potential was measured in 2015 and 2016 cropping season at seedling, flowering and milking stage between 06:00 and 09:00 h to minimize adverse effects of evaporative losses on ψw readings. Water potential was measured on three leaves per plot.

Measurement of leaf photosynthetic parameters

Stomatal conductance (gs), transpiration rate (E), net assimilation rate (PN), intercellular CO_2 concentration (Ci), ambient CO_2 concentration (Ca), air relative humidity (RH), and leaf-to-air vapour pressure deficit (VPD) were measured under natural light at flowering and milking stage. The measurements were done on cloudless days every two hours from 08:00-18:00 h using a Portable Gas exchange Fluorescent System (GFS-3000, Heinz Walz GmbH. Eichenring. Germany). The conditions in the gas exchange device were set as follows: flow rate of air through the chamber (750 μmol/s), Impeller (7), Area (8 cm^2), Parbot (12 μmol^{-2}.s^{-1}), Partop (2 μmol^{-2}s^{-1}), T leaf (15.89°C), T cuv (16°C) and T amb 12.89°C. Three readings were randomly taken on three plants per plot on fully expanded flag leaf (each measurement took one minute thirty seconds within which it gives three readings per leaf). All measurements were performed on the middle portions of the flag leaf exposed to full sunlight, approximately halfway along the length of the leaf. Measurement was done at flowering and milking stages and the diurnal (08:00-18:00 h) were averaged and presented. Stomatal limitation was calculated using the formulae: Ls = 1 - Ci/Ca (Yin et al., 2006).

Grain yield

At physiological maturity, an area of 13.2 m^2 (4 m $\times$ 3 m) of each plot was demarcated and the maize cobs were hand-harvested. Physiological maturity was determined by the

Table 1. Chemical composition of maize straw and swine manure used in 2014, 2015 and 2016

Amendment	Total C (g/kg)	N	P	K	Ca	Mg
			——— % -			
Maize stover	399.7	0.7	0.4	0.5	0.6	0.7
Swine manure	212.5	2.2	1.7	1.9	2.7	0.5

Values are means (n=3)

Table 2. Detailed treatment description of soil amendment experiment

Code	Treatment	Rate	Detailed description
NA	No amendment	Zero-amendment	No amendment in all the years
SM	Swine manure	10 t ha^{-1}	Solid swine manure was obtain from a local swine farm, stored for 2 months, and spread on the land surface and incorporated by ploughing within 3 days of application
MS	Maize straw	28.5 t ha^{-1}	Maize stover from the previous crop was collected, air-dried shredded, weighed and returned to the field plots
SC	Swine manure+c hemical fertilizer	5 t ha^{-1} of swine manure + 100 kg ha^{-1} of N	Swine manure was applied using the same protocol as described under SM. Nitrogen (Urea) and Phosphorus fertilizers were broadcasted at sowing

calendar method (using crop phenology) and physical observation (black layer visible, fully ripe; kernels hard and shiny) according to the standardized maize development stage system (Ritchie et al., 1997). The grains were shelled, weighed and the grain yield (kg ha^{-1}) for each treatment was extrapolated.

Statistical analyses

Statistical analyses were undertaken with the Statistical Package for the Social Sciences 22.0 (IBM Corporation, Chicago, IL, USA) with the treatment as the fixed effect and year as random effect. The data from each replicate was averaged across all diurnal sample times and growth stages before statistical analysis to obtain the average values of the photosynthetic activity. Differences between the means were determined using the Tukey's HSD (Honestly Significant Difference) test. All statistical significances were declared at the probability level of 5%

Results

Daily precipitation

Daily precipitation for 2014, 2015 and 2016 cropping season is shown in (Figure 1). The cumulative for 2014 (280 mm) growing season was slightly higher than that of 2015 (274 mm) and 2016 (227 mm). Highest precipitation was observed between July to September in 2014, 2015 and 2016 cropping seasons. The precipitation in 2014 was well distributed compared to 2015 and 2016.

Soil water storage (SWS) measured at flowering (Table 3), milking (Table 4) and harvest (Table 5) stage increased with

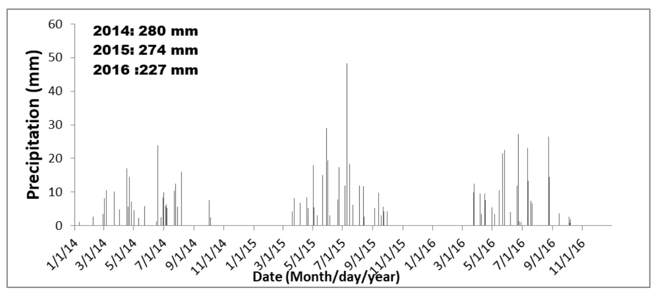

Figure 1. Daily precipitation in 2014, 2015 and 2016

increasing soil depth irrespective of the treatment. Treatments recorded no significant differences in most cases; however, interactions between year and treatment were significant ($P<0.05$) at flowering, milking and harvest stages. At the flowering stage, soil water storage increased within the 0–5 and 5–10 cm depth for the plot that received no amendment. Across the 0–110 cm depth, SC significantly increased SWS by 9.5% and 12.6% in 2014 and 2015, respectively, compared to NA (Table 3). Soil water storage at milking and harvest stages followed similar trend as flowering stage with SC recording the highest SWS in the 0–110 cm depth compared to NA.

Leaf Area Index

Result of leaf area index (LAI) is presented in (Figure 2); LAI increased with maturity as LAI was lowest at the seedling stage whilst milking stage had the highest, but decreased afterwards. The treatments recorded significant differences in

Table 3. Effect of different soil amendment on soil water storage (mm) (0–110 cm) at flowering stage

Year	Treatment	0-5	5-10	10-30	30-50	50-80	80-110	Mean
		............Soil depth (cm)........................						
2014	NA	10.1^a	10.7^a	41.9^{ab}	41.7^a	68.4^b	63.3^c	40.2^c
	SM	9.1^b	9.6^b	38.7^c	42.9^a	60.5^c	65.2^{bc}	38.6^{bc}
	MS	9.6^{ab}	9.9^{ab}	40.3^{bc}	44.9^a	69.3^{ab}	69.7^b	41.5^b
	SC	9.7^{ab}	9.7^b	43.5^a	44.6^a	73.7^a	77.6^a	40.0^a
2015	NA	7.1^a	7.8^a	30.1^b	28.9^b	52.0^b	53.8^b	30.16^c
	SM	5.8^b	5.5^d	31.1^{ab}	33.1^a	55.1^{ab}	57.1^{ab}	32.2^b
	MS	6.7^a	6.6^c	30.2^b	31.4^{ab}	57.7^a	60.5^a	32.2^{ab}
	SC	6.7^a	6.9^b	33.4^a	34.1^a	58.0^a	59.3^a	33.9^a
2016	NA	5.9^a	5.8^a	20.6^a	24.6^a	42.4^a	40.7^a	24.1^a
	SM	5.1^b	5.9^a	23.3^a	25.5^a	34.7^b	40.1^a	23.2^a
	MS	5.0^b	5.8^a	22.5^a	24.3^a	37.7^{ab}	43.8^a	23.9^a
	SC	5.9^a	5.6^a	21.8^a	23.1^a	35.3^{ab}	43.4^a	23.3^a
	Sources of variation							
	Treatment (T)	**	ns	ns	ns	ns	*	
	Year (Y)	***	***	***	***	***	***	
	T * Y	*	***	***	**	***	***	

*, ** and *** indicate significant difference at P<0.05, P<0.01 and P<0.001, respectively

Table 4. Effect of different soil amendment on soil water storage (mm) (0–110 cm) at milking stage

Year	Treatment	0-5	5-10	10-30	30-50	50-80	80-110	Mean
		............Soil depth (cm)........................						
2014	NA	10.2^a	9.7^a	39.7^a	31.9^b	55.2^b	54.2^b	33.3^b
	SM	8.3^b	9.6^a	35.6^b	35.0^{ab}	59.0^{ab}	60.9^{ab}	34.8^{ab}
	MS	8.6^b	9.3^a	34.0^b	37.4^a	64.9^a	62.1^{ab}	36.1^{ab}
	SC	9.6^a	10.3^a	40.3^a	33.6^{ab}	62.5^a	63.3^a	36.6^a
2015	NA	10.0^a	11.6^a	38.0^a	26.4^c	40.0^a	39.4^b	27.6^b
	SM	8.0^b	9.8^b	32.8^b	28.2^{bc}	46.6^a	48.7^a	29.0^{ab}
	MS	7.6^b	8.6^c	32.6^b	31.9^a	47.8^a	42.0^b	28.4^{ab}
	SC	9.4^a	8.6^c	34.9^b	29.7^{ab}	49.7^a	50.8^a	30.5^a
2016	NA	5.9^b	5.3^b	23.8^b	24.8^a	47.5^a	45.7^a	25.4^{ab}
	SM	5.0^b	5.2^b	21.6^b	23.4^a	48.6^a	47.0^a	25.1^b
	MS	4.9^b	5.4^b	21.6^b	23.4^a	46.5^a	45.2^a	24.6^b
	SC	6.2^a	6.6^a	27.0^a	23.9^a	48.8^a	47.5^a	26.6^a
	Sources of variation							
	Treatment (T)	*	ns	*	ns	ns	*	
	Year (Y)	***	**	***	***	***	***	
	T * Y	***	***	**	**	*	**	

*, ** and *** indicate significant difference at P<0.05, P<0.01 and P<0.001, respectively

Table 5. Effect of different soil amendment on soil water storage (mm) (0–110 cm) at harvest

Year	Treatment	0-5	5-10	10-30	30-50	50-80	80-110	Mean
		...........Soil depth (cm)........................						
2014	NA	11.0^{b}	11.4^{b}	42.2^{b}	38.5^{a}	40.7^{b}	52.7^{a}	32.7^{c}
	SM	11.7^{b}	11.0^{b}	49.0^{a}	40.2^{a}	47.2^{ab}	45.8^{a}	34.2^{b}
	MS	11.5^{b}	11.6^{b}	42.5^{b}	35.2^{b}	52.0^{a}	50.4^{ab}	33.9^{c}
	SC	13.0^{a}	13.0^{a}	48.8^{a}	39.0^{a}	52.1^{a}	48.3^{ab}	35.2^{c}
2015	NA	8.2^{c}	8.5^{c}	28.8^{b}	25.3^{b}	43.5^{bc}	40.4^{c}	25.8^{c}
	SM	10.2^{b}	9.1^{b}	29.7^{a}	25.7^{a}	41.3^{ab}	43.1^{b}	26.7^{bc}
	MS	8.9^{c}	8.6^{bc}	29.0^{b}	25.9^{b}	45.8^{b}	45.3^{b}	27.2^{b}
	SC	11.2^{a}	11.3^{a}	36.8^{a}	32.5^{a}	55.9^{a}	50.4^{a}	33.0^{a}
2016	NA	7.3^{a}	7.4^{a}	28.9^{a}	27.2^{a}	45.0^{a}	44.7^{a}	26.6^{a}
	SM	6.1^{b}	6.4^{b}	22.9^{b}	27.5^{a}	45.0^{a}	46.4^{a}	25.7^{a}
	MS	5.9^{b}	6.3^{b}	21.3^{b}	27.8^{a}	48.1^{a}	46.9^{a}	26.2^{a}
	SC	5.6^{b}	5.9^{b}	21.5^{b}	27.5^{a}	49.2^{a}	46.7^{a}	25.9^{a}
	Sources of variation							
	Treatment (T)	ns	ns	ns	ns	*	ns	
	Year (Y)	**	**	**	**	ns	ns	
	T * Y	***	***	***	***	***	***	

*, ** and *** indicate significant difference at P<0.05, P<0.01 and P<0.001, respectively

LAI at all the stages in 2014, 2015 and 2016. Averagely, NA recorded the least whereas among the amendment treatments, SC recorded 9 and 11% higher LAI compared with SM and MS, respectively in 2014. Swine manure in combination with chemical fertilizer (SC), SM and MS significantly increased LAI by 30, 23 and 40% in 2015 and by 36, 35 and 49% in 2016, respectively compared to NA.

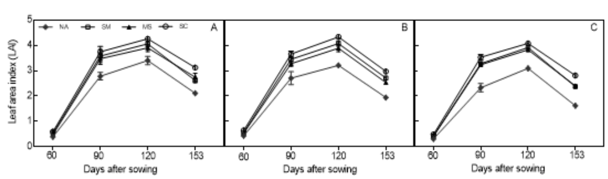

Figure 2. Leaf area index (LAI) measured at seedling, flowering, milking and harvest stage in 2014 (A), 2015 (B) and 2016 (C) respectively.

Chlorophyll content

Leaf chlorophyll content (Chl) exhibited significant differences (P<0.05) among treatments at seedling, flowering and milking stages (Figure 3) with NA recording the least. No amendment recorded average chlorophyll content of 36 in 2014 whereas amended treatments recorded between 42 to 46. Swine manure in combination with chemical fertilizer (SC) increased chlorophyll content by 32, 10 and 11% compared with NA, SM and MS respectively. Chlorophyll content increased with maturity.

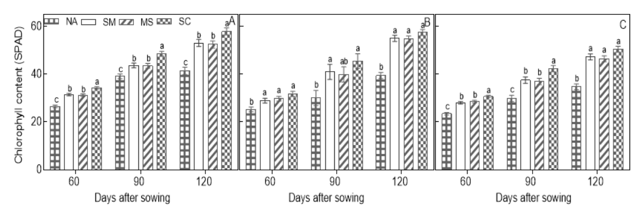

Figure 3. Chlorophyll content (SPAD) of maize measured under soil amendment in 2014 (A), 2015 (B) and 2016 (C) at 60, 90 and 120 DAS. Bars with different letters in the same year are significantly different at (P<0.05).

Leaf water potential

Results on leaf water potential at seedling, flowering and milking stages in 2015 and 2016 is presented in figure 4. Soil amendments significantly influenced water potential at all the growth stages. Amendment treatments increased water potential by 12 and 9% compared with NA in 2015 and 2016, respectively. Among the amendment treatments, SC increased water potential by 8 and 4% compared with SM and MS, respectively.

Photosynthetic activities under soil amendment

Analysis of variance on stomatal conductance (gs), net assimilation rate (PN), transpiration rate (E), intercellular CO_2 concentration (Ci), and stomatal limitation (Ls) is presented in Table 6. There was no significant (P<0.05) amendment by year interactions on stomatal conductance (gs), net assimilation rate (PN), transpiration rate (E), intercellular CO_2

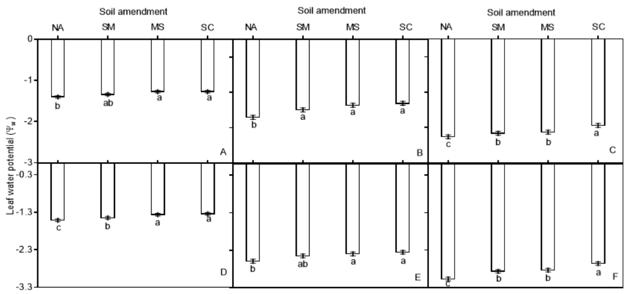

Figure 4. Leaf water potential (ψw) of maize measured under soil amendment in 2015 (A, B and C) and 2016 (D, E and F) at seedling, flowering and milking stages, respectively. Bars with different letters in the same year are significantly different at (P<0.05).

concentration (Ci) and stomatal limitation (Ls). There were, however, significant (P<0.05).year effects on gs, PN, E, Ci and LS (Table 6). The average gs, PN, E, Ci and LS values presented in table 7 are means averaged across all diurnal sample times and growth stages for a given year. No amendment treatment recorded lower gs, PN, E and higher Ci and Ls compared with the amendment treatments. On average, swine manure in combination with chemical fertilizer (SC) recorded a significant higher gs, PN and E values (168.18 mol (H_2O) m^{-2} s^{-1}, 19.43 μmol m^{-2} s^{-1}, 3.78 mmol (H_2O) m^{-2} s^{-1}) compared with NA (115.34 mol (H_2O) m^{-2} s^{-1}, 13.14 μmol m^{-2} s^{-1}, 2.51 mmol (H_2O) m^{-2} s^{-1}). This resulted in 46, 48, and 51% increase in gs, PN and E, respectively. Swine manure in combination with chemical fertilizer (SC) also decreased Ci and Ls by 19 and 31%, respectively compared with NA.

Table 6. Analysis of variance of nitrogen rate, time, year and their interaction on stomatal conductance (gs, mmol (H_2O) m^{-2} s^{-1}), net assimilation rate (PN, μmol m^{-2} s^{-1}), transpiration rate (E, mmol (H_2O) m^{-2} s^{-1}), intercellular CO_2 concentration (Ci, μmol (CO_2) mol^{-1}) and stomatal limitation (LS) in maize under different soil amendment

Sources of variation	gs	PN	E	Ci	Ls
Treatment (T)	***	***	***	***	***
Year (Y)	***	***	***	***	***
T * Y	ns	ns	ns	ns	ns

Grain and biomass yield

The biomass and grain yield decreased with increasing years. Overall, there were significant differences (P<0.05) in total biomass and grain yield depending on the treatment, which was observed in all the years (Table 8). Averagely, swine manure in combination with chemical fertilizer (SC) had greater biomass yield (17108 kg ha^{-1}), followed by SM (15433 kg ha^{-1}), MS (14736 kg ha^{-1}) and NA (10736 kg ha^{-1}). This resulted in SC significantly increasing biomass yield by 59%, 11% and 16% compared with NA, SM and MS, respectively. Swine manure (SM) significantly increased biomass yield by ≈ 5% compared with MS. Similarly, SC significantly increased grain yield by approximately 70, 14 and 12% compared with NA, SM and MS, respectively. Analysis of variance showed that treatments and year had significant effect on biomass and grain yield. However, their interaction did not influence biomass and grain yield at P<0.05 (Table 8).

Water use efficiency

Grain and biomass water use efficiency for treatment and year exhibited significant differences however; their interactions were not significant (Table 9). The amendment treatment recorded significantly higher grain water use efficiency compared to NA. Among the amendment treatments, grain water use efficiency showed no significance (Table 10). Grain and biomass water use efficiency increased in the trend 2016 >2014 >2015.

Discussion

Improving soil water storage is particularly important in the Western Loess plateau where water deficit and low soil fertility are the two main abiotic stresses hindering crop production. In the current study, the soil amendment treatments increased soil water storage within the 0–110 cm depth, particularly in the SC treatment. This clearly demonstrates the potential of SC to increase soil water storage in rainfed maize fields. The possible mechanism for the increased could be that, application of swine manure in combination with chemical fertilizer may have improved soil physical (Abdollahi et al., 2014), chemical (Reddy and Crohn, 2014), and biological (Hu et al., 2014) conditions. The improved soil properties increased infiltration of rain water into the soil and enhanced soil water retention. Rong et al. (2001) reported that combined application of organic and inorganic fertilizer increased soil moisture and soil fertility. In this current study, the application of chemical fertilizer in combination with organic fertilizer may have provided a synergistic effect that enhanced soil water storage (Gentile et al., 2009). The lesser soil water storage in NA treatment is contrary to the results of Song et al. (2010) who reported increased soil water storage under no soil amendment compared to combination of chemical and organic amendment.

Leaf area index (LAI) is an important agronomic parameter which reflects crop growth and predicts crop yield. Lower LAI recorded by NA may be attributed to the reduced available water resulting in reduced leaf growth rate. The higher LAI produced by SC treatment compared to NA could be attributed to increased water storage resulting in increased leaf growth rate. Emam et al. (2010) reported significant responses of leaf area to water stress conditions. Differences in leaf area can affect plant spatial distribution and the microenvironment within a population (Giunta et al., 2008), which plays a decisive role in the photosynthetic efficiency and light energy distribution of crops (Boedhram et al., 2001).

In the current study, the amendment treatment, SC in par-

Table 7. The data represent an averaged across all diurnal sample times and growth stages of each replicate prior to statistical analysis.

Year	Treatment	gs	PN	E	Ci	Ls
2014	NA	131.95^{c}	16.92^{b}	2.79^{c}	332.58^{a}	0.19^{a}
	SM	166.38^{b}	21.32^{ab}	3.45^{bc}	299.13^{bc}	0.15^{c}
	MS	170.52^{b}	20.70^{ab}	3.59^{ab}	311.29^{b}	0.17^{b}
	SC	191.21^{a}	24.14^{a}	4.14^{a}	287.18^{c}	0.15^{c}
2015	NA	111.58^{c}	13.77^{b}	2.47^{c}	359.58^{a}	0.22^{a}
	SM	137.90^{b}	17.01^{ab}	3.17^{b}	320.78^{bc}	0.17^{bc}
	MS	144.43^{b}	17.24^{ab}	3.30^{b}	332.65^{ab}	0.19^{ab}
	SC	165.80^{a}	20.13^{a}	3.80^{a}	297.84^{c}	0.16^{c}
2016	NA	102.59^{c}	8.72^{b}	2.27^{c}	362.10^{c}	0.22^{a}
	SM	121.57^{b}	12.28^{a}	2.98^{b}	331.49^{b}	0.19^{c}
	MS	131.64^{b}	11.28^{ab}	2.98^{b}	337.30^{b}	0.21^{b}
	SC	147.42^{a}	13.74^{a}	3.39^{a}	304.84^{c}	0.18^{c}

Stomatal conductance (gs, mol (H_2O) m^{-2} s^{-1}), net assimilation rate (PN, μmol m^{-2} s^{-1}), transpiration rate (E, mmol (H_2O) m^{-2} s^{-1}), intercellular CO_2 concentration (Ci, μmol (CO_2) mol^{-1}) and stomatal limitation (LS) in maize under different soil amendment.

Table 8. Biomass and grain yield (kg ha^{-1}) of maize under soil amendment

Treatment	Biomass yield			Grain yield		
	2014	2015	2016	2014	2015	2016
NA	13012^{c}	12098^{c}	7098^{c}	5322^{c}	4594^{c}	3459^{b}
SM	18061^{b}	17133^{a}	11104^{b}	7888^{b}	6732^{b}	5641^{a}
MS	16687^{b}	16240^{b}	11282^{b}	7550^{b}	7433^{ab}	5768^{a}
SC	19440^{a}	18763^{a}	13123^{a}	8900^{a}	8209^{a}	6156^{a}

Table 9. Analysis of variance on Biomass yield, grain yield, WUE_g and WUE_b

Sources of variation	Biomass yield	Grain yield	WUE_g	WUE_b
Treatment (T)	**	***	**	**
Year (Y)	***	***	*	***
T * Y	ns	ns	ns	ns

Table 10. Grain and biomass water use efficiency under soil amendments

Treatment	WUE_g			WUE_b		
	2014	2015	2016	2014	2015	2016
NA	20.07^{b}	14.26^{c}	15.61^{b}	59.89^{b}	46.86^{c}	31.93^{b}
SM	28.61^{a}	20.85^{b}	25.03^{a}	84.89^{ab}	70.59^{ab}	49.24^{a}
MS	27.48^{a}	24.35^{ab}	25.29^{a}	80.07^{ab}	64.26^{b}	49.32^{a}
SC	31.68^{a}	27.60^{a}	24.65^{a}	97.06^{a}	82.14^{a}	52.38^{a}

ticular increased leaf photosynthetic activities. Efthimiadou et al. (2010) reported higher photosynthetic rate and stomatal conductance under combined application of organic and inorganic fertilizer treatment. Greater photosynthetic activity in SC treatment may be attributed to increased soil water storage which enhanced uptake of soil water, resulting to improved plant water status, water potential, and LAI. Increased photosynthetic activities under amendment treatments had a positive effect on crop growth and development with an increase in dry matter accumulation. Dry matter production is affected by resource availability (Echarte and Andrade, 2003) which influences crop yield (Echarte and Andrade, 2003). A number of mechanisms have been ascribed to the increased dry matter accumulation when organic manure is applied in combination with chemical fertilizer. An improvement in soil conditions could make plant roots extend deeper in the environment of adequate nutrient supply. The increased grain yield with SC in particular may be related to increase transport of dry matter from leaves, stems and sheath to grains. Moreover, the increased soil water storage in SC optimized, chlorophyll content, LAI and plant photosynthetic efficiency. This promoted the accumulation of dry matter and, consequently, increased grain yield than in the no amendment treatment. This could be as a result of direct relationship between water use and crop yield (Cernusak et al., 2007).

Conclusion

Our study demonstrate the influence of, swine manure, maize stover and swine manure in combination with chemical fertilizer on soil water storage, plant physiological parameters and yield of maize. The highest soil water storage was achieved under swine manure in combination with chemical fertilizer at flowering, milking and harvest stage. This enhanced crop physiological activities with a consequential increase in biomass and grain yield. For sustainable improvement in maize yield in the Western Loess Plateau, swine manure in combination with chemical fertilizer is recommended. A combined use of organic materials with inorganic fertilizer may not only maintain improve yield but also reduce dependence on inorganic fertilizer on agricultural lands and the associated environmental risk.

Acknowledgments

This research received financial support from the National Basic Research Program of China (973 Program-2012CB72290–2), the National Science and Technology Planning (Project no. 2015BAD22B04–03), the Program of Science and Technology for Circulation Agriculture (Project no. 2012BAD14B05) and the National Natural Science Foundation of China (Grants no. 31460337 and 31660373).

References

Abdollahi, L., Schjønning, P., Elmholt, S., and Munkholm, L. J. (2014). The effects of organic matter application and intensive tillage and traffic on soil structure formation and stability. *Soil and Tillage Research*, 136:28–37.

Bilalis, D., Karkanis, A., Efthimiadou, A., Konstantas, A., and Triantafyllidis, V. (2009). Effects of irrigation system and green manure on yield and nicotine content of Virginia (flue-cured) Organic tobacco (Nicotiana tabaccum), under Mediterranean conditions. *Industrial Crops and Products*, 29(2-3):388–394.

Boedhram, N., Arkebauer, T. J., and Batchelor, W. D. (2001). Season-long characterization of vertical distribution of leaf area in corn. *Agronomy Journal*, 93(6):1235–1242.

Cernusak, L. A., Aranda, J., Marshall, J. D., and Winter, K. (2007). Large variation in whole-plant water-use efficiency among tropical tree species. *New Phytologist*, 173(2):294–305.

Echarte, L. and Andrade, F. H. (2003). Harvest index stability of Argentinean maize hybrids released between 1965 and 1993. *Field Crops Research*, 82(1):1–12.

Efthimiadou, A., Bilalis, D., Karkanis, A., Froud-Williams, B., et al. (2010). Combined organic/inorganic fertilization enhance soil quality and increased yield, photosynthesis and sustainability of sweet maize crop. *Australian Journal of Crop Science*, 4(9):722.

Emam, Y., Shekoofa, A., Salehi, F., and Jalali, A. H. (2010). Water stress effects on two common bean cultivars with contrasting growth habits. *Am.-Eurasian J. Agric. Environ. Sci*, 9:495–499.

FAO (1990). Soil map of the world: revised legend. World Soil Resources Report 60. Food and Agriculture Organization of the United Nations, Rome.

Gentile, R., Vanlauwe, B., Van Kessel, C., and Six, J. (2009). Managing N availability and losses by combining fertilizer-N with different quality residues in Kenya. *Agriculture, Ecosystems & Environment*, 131(3-4):308–314.

Giunta, F., Motzo, R., and Pruneddu, G. (2008). Has long-term selection for yield in durum wheat also induced changes in leaf and canopy traits? *Field Crops Research*, 106(1):68–76.

Hu, W., Jiao, Z., Wu, F., Liu, Y., Dong, M., Ma, X., Fan, T., An, L., and Feng, H. (2014). Long-term effects of fertilizer on soil enzymatic activity of wheat field soil in Loess Plateau, China. *Ecotoxicology*, 23(10):2069–2080.

Jia, D., Dai, X., and He, M. (2012). Polymerization of glutenin during grain development and quality expression in winter wheat in response to irrigation levels. *Crop science*, 52(4):1816–1827.

Kanai, S., Moghaieb, R. E., El-Shemy, H. A., Panigrahi, R., Mohapatra, P. K., Ito, J., Nguyen, N. T., Saneoka, H., and Fujita, K. (2011). Potassium deficiency affects water status and photosynthetic rate of the vegetative sink in green house tomato prior to its effects on source activity. *Plant Science*, 180(2):368–374.

Kimani, S. K., Kimenye, L. N., Odera, M. M., Esilaba, A. O., Gachengo, C., and Vanlauwe, B. (2003). Integrated Soil Fertility Mangement (ISFM): Farm stratification and use of organic nutrient sources with modest amount of mineral fertilizers to enhance maize production in central Kenya. 1st Annual project report to Rockefeller Foundation Grant.

Liang, A., Yang, X., Zhang, X., McLaughlin, N., Shen, Y., and Li, W. (2009). Soil organic carbon changes in particle-size fractions following cultivation of Black soils in China. *Soil and Tillage Research*, 105(1):21–26.

Liu, C. A., Jin, S. L., Zhou, L. M., Jia, Y., Li, F. M., Xiong, Y. C., and Li, X. G. (2009). Effects of plastic film mulch and tillage on maize productivity and soil parameters. *European Journal of Agronomy*, 31(4):241–249.

Liu, X.-z., Wei, X.-h., and Su, Q. (2006). Research on soil and water conservation integrated measures of restoration and reconstruction of ecological environment in Loess Plateau. *Journal of Shandong Agricultural University (Natural Science Edition)*, 4:23.

Reddy, N. and Crohn, D. M. (2014). Effects of soil salinity and carbon availability from organic amendments on nitrous oxide emissions. *Geoderma*, 235:363–371.

Reynolds, M. P., Van Ginkel, M., and Ribaut, J.-M. (2000). Avenues for genetic modification of radiation use efficiency in wheat. *Journal of Experimental Botany*, 51(1):459–473.

Ritchie, S. W., Hanway, J. J., and Benson, G. O. (1997). How a corn plants develops. Spec. Publ. 48. Iowa State Univ. Coop. Ext. Serv., Ames.

Rong, X.-m., Jiang, J.-r., Zhu, H.-m., Liu, Q., Zhang, F.-q., Liu, J.-m., and Yue, Z.-h. (2001). Effects of application of inorganic fertilizer in combination with organic fertilizer to red upland soil. *Journal-Hunan Agricultural University*, 27(6):453–456.

Song, C. Y., Zhang, X. Y., Liu, X. B., Sui, Y. Y., and Li, Z. L. (2010). Impact of long term fertilization on soil water content in Haploborolls. *Plant, Soil and Environment*, 56(9):408–411.

Sugiharto, B., Miyata, K., Nakamoto, H., Sasakawa, H., and Sugiyama, T. (1990). Regulation of expression of carbon-assimilating enzymes by nitrogen in maize leaf. *Plant Physiology*, 92(4):963–969.

Takai, T., Kondo, M., Yano, M., and Yamamoto, T. (2010). A quantitative trait locus for chlorophyll content and its association with leaf photosynthesis in rice. *Rice*, 3(2-3):172–180.

Talgre, L., Lauringson, E., Roostalu, H., Astover, A., and Makke, A. (2012). Green manure as a nutrient source for succeeding crops. *Plant, Soil and Environment*, 58(6):275–281.

Xianmo, Z., Yushan, L., Xianglin, P., and Shuguang, Z. (1983). Soils of the loess region in China. *Geoderma*, 29(3):237–255.

Yin, C. Y., Berninger, F., and Li, C. Y. (2006). Photosynthetic responses of *Populus przewalski* subjected to drought stress. *Photosynthetica*, 44(1):62–68.

Yin, W., Chai, Q., Guo, Y., Feng, F., Zhao, C., Yu, A., and Hu, F. (2016). Analysis of leaf area index dynamic and grain yield components of intercropped wheat and maize under straw mulch combined with reduced tillage in arid environments. *J. Agric. Sci*, 8(4):26–42.

Zhao, X.-Z., Li, F.-M., Mo, F., Yue, D.-X., Zhang, H.-J., Turner, N. C., Zhou, H., Wang, R., Wu, S., Xiong, Y.-C., et al. (2012). Integrated conservation solutions for the endangered Loess Plateau of northwest China. *Pak. J. Bot*, 44:77–83.