

Dry matter accumulation and nitrogen concentration in forage and grain maize in dryland areas under different soil amendments

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Abstract. Soil amendment plays significant role in improving soil fertility and increasing crop productivity in rain-fed agriculture. Understanding the grain yield associated with dry matter and N concentration is essential for improving maize production. A 3– year field study was conducted to determine dry matter accumulation, nitrogen concentration and grain yield of forage and grain maize under different soil amendments 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. Results showed that dry matter accumulation and nitrogen concentration in the swine manure in combination with chemical fertilized (SC) crops was significantly higher (by $\approx 60\%$ and 39%) than no amendment (NA) which therefore translated into increased grain yield $\approx 74\%$. The SC treatment also improved leaf area index and chlorophyll content ($P < 0.05$) by approximately 34% to 32% compared to NA, which supported the above results. The nitrogen concentration in the leaf was higher at jointing and lower at maturity. Grain yield positively correlated with dry matter accumulation and nitrogen concentration at jointing, flowering and milk stage. Dry matter accumulation and grain yield also increased in the sole swine manure (SM) and maize stover (MS) treatments, but to lesser extent than SC. Based on the improvement of dry matter accumulation, nitrogen concentration and grain yield, swine manure in combination with chemical fertilizer appears to be a better fertilization option under dryland cropping systems.

Key words: Biomass production, Nitrogen content, Rain-fed, Yield.

INTRODUCTION

Agroecosystem productivity is often constrained by a low availability of water and nutrients (Rasouli et al., 2014), and the challenge is serious in many arid and semiarid regions of the world, such as the Western Loess Plateau of China (Hou et al., 2012). The semiarid Loess Plateau of China is a home to an estimated population upwards of 108 million, of which more than 70% are reported to be living and working in agricultural areas (Wang & Li, 2010; Xu-Zhe et al., 2012). Cropping on the Loess Plateau is

dependent on natural precipitation. However, precipitation is relatively scarce in these areas, with high variation among years, and uneven spatial and temporal distributions (He et al., 2014). Soil moisture shortages commonly occur as a result of limited rainfall and strong evaporation in the semiarid region of China (Wang et al., 2015). Continuous loss of soil organic matter, associated with traditional methods of soil cultivation (Yin & Yin, 2010), often accelerates soil erosion processes and decline of soil fertility. However, many crops residues and livestock are produced in this region (Huang et al., 2008). Organic amendment has therefore gained interest amongst farmers at the Northwestern China. This is practiced widely as a measure to mitigate impacts on soil, and also for water conservation purposes (Huang et al., 2008).

Maize (*Zea mays* L.) is one of the most popular grain crops in the semiarid Loess Plateau region of northwestern China. In the last 50 years, maize yields in northern China have improved rapidly with mean growth rate of 5.3% (Zhen et al., 2006). The cropland dedicated to growing corn is bound to continue increasing due to the high demand for feed (Hu & Zimmer, 2013). This rapid increase in productivity has been mainly dependent on chemical fertilizer application, especially N (Guo et al., 2010). The higher crop yields have come under scrutiny because of the amendment levels needed to produce such yields and because of the perception and reality of the potential environmental impacts of those inputs. Optimizing soil and crop management to improve the crop productivity and yield stability of dryland agriculture is crucial to ensuring future food security (Lele, 2010). Management practices that consider the use of organic amendments are mentioned in several studies (Diacono & Montemurro, 2010; Cui et al., 2014) as an effective means to maintain soil water holding capacity, organic carbon and overall fertility levels when this technology is used in crop production. Liu et al. (2011) reported increases in dry matter accumulation and nitrogen concentration when fertilizer was applied in dry areas. The return of maize stover to soil has been long practiced in many parts in the Western Loess Plateau as a sustainable approach to improve soil water conservation and soil fertility (Huang et al., 2008). The use of maize stover as a soil amendment is currently challenged by the increased alternative demand for animal feed and fuel for heating and cooking (Lal, 2007). In the Western Loess Plateau of northwestern China, maize and swine production is the main crop–livestock integrated system practiced by small–scale farmers. The use of swine manure in crop production has declined since the 1980s due to increased use of inorganic fertilizers (Ju et al., 2005). Although great efforts have been made in the assessment of fertilization effects on crop yield in the region, few have focused on relationships between crop yields and nitrogen concentration under different soil amendment (Han et al., 2005; Liang et al., 2009).

Agronomic practices may play an important role in the concentration of secondary metabolites in plants (Selma et al., 2010). Maize grain yield increase is largely dependent on the improvement of nitrogen and dry matter accumulation. Rational application of organic manure has been shown to improve dry matter accumulation (Wang et al., 2009) and grain yield (Yang et al., 2015). However, there is speculation whether increase in dry matter accumulation is largely dependent on the improvement of dry matter accumulation at early growth season stage or at silking (Tollenaar & Lee, 2006; Ciampitti & Vyn, 2012). Identification of a specific period of crop development, regarded as critical for yield establishment, could indicate appropriate agronomic practices for maximizing crop yield. Therefore, an understanding of the relationships between grain yield and dry matter accumulation and nitrogen concentration at the early

growth stage and late growth stage is essential for improving management practices to further increase forage and grain maize yield. Therefore, this 3-yr field study was conducted to determine (1) the effect of soil amendment on grain yield, dry matter accumulation and nitrogen concentration, and (2) the response of grain yield to dry matter accumulation and N concentration at different growth stages.

MATERIALS AND METHODS

Experimental site

The field experiment was conducted over a period of three years (2014–2016) at the Dingxi Experimental Station (35°28'N, 104°44'E, elevation: 1,971 m above sea level) located in the Anding County (Gansu Province) in NW China. The aeolian soil in that region is locally known as Huangmian (Chinese Soil Taxonomy Cooperative Research Group, 1995), which equates to a *Calcaric Cambisol* in the FAO soil classification (1990), and has a sandy loam texture ($\geq 50\%$ sand). This soil has moderately low fertility, slightly alkaline pH (≈ 8.3), soil organic carbon $\leq 7.65 \text{ g kg}^{-1}$ and Olsen P $\leq 13.3 \text{ mg kg}^{-1}$, representing the major cropping soil in the district (Zhu et al., 1983). Long-term annual precipitation at the experimental site averages 391 mm, and ranges from 246 mm to 564 mm, as recorded in 1986 and 2003, respectively. Approximately, 60% of the rainfall occurs between July and September. Daily maximum air temperatures can reach up to 38 °C in July while minimum air temperatures can drop to negative 22 °C in January. The experimental site had been under long term cropping using conventional tillage practices. Fig. 1 shows in crop season rainfall recorded at the site for 2014 (280 mm), 2015 (274 mm) and 2016 (227 mm).

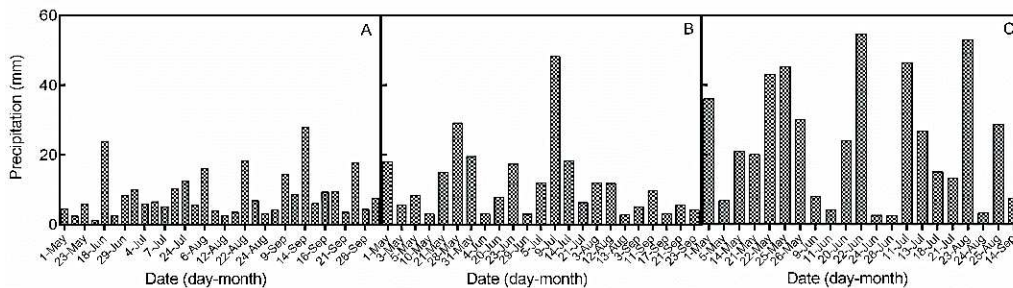


Figure 1. Daily rainfall records for the 2014 (A), 2015 (B) and 2016 (C) cropping seasons.

Experimental design

The experiment utilized a randomized complete block design with four treatments and three replications. The treatments were: No amendment (NA), which was used as control, dry swine manure (SM): 10 t ha⁻¹, maize stover (MS): 27 t ha⁻¹, swine manure + chemical fertilizer (SC): 5 t ha⁻¹ of swine manure + 100 kg ha⁻¹ of N as urea + 75 kg ha⁻¹ of P₂O₅ respectively. Table 1 provides detailed nutrient composition of swine manure and maize stover. Treatments applied were at the same input. Maize stover from the previous crop was collected, air dried, shredded, weighed and returned to the field plots. Dry swine manure was obtained from a local swine farm, stored for 2 months, and spread on the land surface and incorporated by ploughing within 3 days of application. Representative manure was sampled at the time of application for nutrient analysis. Urea

and maize stover were broadcasted and incorporated into the top 20 cm soil layer with shallow conventional tillage. The experimental design comprised 15 plots (plot dimensions: 3 m by 14.2 m), with alternate wide and narrow ridges (0.7 m and 0.4 m wide). Crops were sown with a hand held dibbler in furrows between the narrow and wide ridges. After the soil was covered with film, holes (about 20 cm apart) were made using a handheld device through the film in furrows to help collect and channel water from ridges to the rooting zone. All plots were mulched every two years with plastic film at sowing to increase soil temperature and speed up germination, and also to reduce evaporative losses. Plastic film mulching is regarded as an innovative technology for boosting maize productivity in arid environments (Gan et al., 2013). Colorless plastic film (polyethylene film 0.008–mm thick and 80 cm wide, made by Lanzhou Green Garden Corporation of China, Lanzhou), was laid by hand over the plot where the width of plastic film covering the plot surface was 60 cm wide. The crop before the experiment was established was potatoes (*Solanum tuberosum* L.). The experiment was initiated in 2012, however, this article reports the experimental data for the 2014, 2015 and 2016 cropping seasons.

Table 1. Chemical composition of maize straw and swine manure used in the study

Amendment	Organic C (%)	N	P	K	Ca	Mg
Maize stover	47.5	0.74	0.38	0.45	0.55	0.74
Swine manure	39.94	2.2	1.7	1.9	2.7	0.5

Values are means (n = 3).

Sowing and field management

The experiment and the treatments were imposed on the same plots each year of the study. Maize (*Zea mays* L., cv. Funong 821) was sown in late April at a row spacing of 0.55 m with 0.35 m between plants and thus a density of 52,000 plants ha⁻¹; the crop was harvested in late September to early–October each year. Roundup® (glyphosate, 10% v/v) was used for weed control during fallow after harvesting as per product guidelines. During the growing season, weeds were removed by hand. All agronomic management except for nutrient applications, which were dependent on treatments, were equal for all plots.

Crop measurements and analyses

Leaf area index

Five maize plants were sampled from each plot using the ‘S’ type method described by Yin et al. (2016). Sampling was conducted at jointing (60 days after sowing (DAS)), flowering (90 DAS), milking (120 DAS) and maturity (153 DAS) stages, respectively, based on Ritchie et al. (1997). Leaf area index (LAI) was determined using Eq. (1) described in Yin et al. (2016):

$$LAI = 0.75 \cdot P \cdot \sum_{i=1}^n (ai \times bi) \quad (1)$$

where LAI is leaf area index; P is planting density (plants ha⁻¹); ai is leaf length; bi is the greatest leaf width, and 0.75 is the compensation coefficient of maize.

Chlorophyll content

Chlorophyll content (Chl) of fully developed leaves was determined at jointing, flowering and milking stages using a portable chlorophyll meter (SPAD Model 502, Minolta Camera Co. Osaka, Japan). Measurements were conducted from 9:00 am to 12:00 noon on ten fully expanded leaves per plot.

Dry matter accumulation

Three plants were randomly chosen from each treatment plot, and cut to ground level for dry matter accumulation at jointing, flowering, milking and maturity stages. The plants were divided into various parts and fresh weight of these was taken using an electronic balance in the Dingxi experimental laboratory. Plant materials were then put in large brown envelopes and oven dried at 80 °C for 48 hours to a constant weight. The dried plant materials were ground for chemical analysis.

Grain yield

At physiological maturity, maize plants were manually harvested from an area of 13.2 m² (4 m × 3.3 m) per plot. Plants were threshed and grains weighed and converted to grain yield, and reported in kg per hectare.

Determination of nitrogen content

Leaf nitrogen content was assessed at jointing, flowering, milking and maturity stages whereas nitrogen content in the grain was assessed at maturity. The leaf and grain were ground to pass through a 1mm sieve and stored in plastic vials at room temperature until quality analyses were conducted. The C:N analyzer (elementar vario macro cube, Hanau–Germany) was used for the determination of nitrogen concentration.

Data analysis

The data were statistically analyzed with analysis of variance (ANOVA) at $P < 0.05$ using Statistical Package for the Social Sciences 22.0 (IBM Corporation, Chicago, IL, USA). The differences between the means were determined using least significant difference (LSD) at $P < 0.05$. The data analyzed were pooled for bivariate correlation analysis (two-tailed) using Pearson correlation coefficient.

RESULTS AND DISCUSSION

Leaf area index

Results of leaf area index are presented in Fig. 2. The LAI increased with crop growth and then decreased at maturity in all treatments over the study period. Significant differences ($P < 0.05$) were recorded among treatments at certain stages of measurement. The average LAI increased in the order SC > SM > MS > NA during the study period. Application of swine manure in combination with chemical fertilizer in 2014 enhanced LAI by 9%, 11% and 35% compared to SM, MS and NA respectively. In addition, SC, SM and MS treatments significantly increased LAI by 30%, 23% and 40% in 2015 and by 36%, 35% and 49% in 2016 respectively compared to NA. Differences in leaf area index can affect the spatial distribution of the crop's canopy and

the micro–environment around the plant, which in turn plays a significant role in the photosynthetic efficiency of crops (Fageria & Baligar, 2005). A suitable leaf area index is a major sign of high crop yield, as it is important in the relationship between sink and source of crops, and balance in the development of crop organs. Studies involving crop leaf area index, may provide scientific basis for achieving high yield by regulating crop physiological characters. Our results demonstrated that the use of swine manure in combination with chemical fertilizer would allow for increased photosynthesis and consequently greater yields. This study would, therefore, provide theoretical basis for higher yield in crop production.

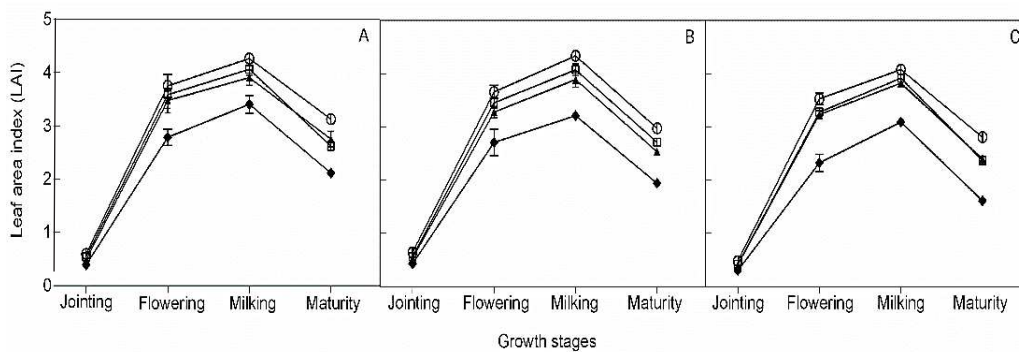


Figure 2. Leaf area index measured at jointing, flowering, milking and maturity in 2014 (A), 2015 (B) and 2016 (C) respectively. Symbols are: (■) No amendment (NA); (□) swine manure (SM); (▲) maize stover (MS) and (○) swine manure in combination with chemical fertilizer (SC).

Leaf chlorophyll content

Leaf chlorophyll content exhibited significant differences ($P < 0.05$) in all the stages of sampling depending on treatment (Fig. 3). Application of swine manure combined with chemical fertilizer boosted chlorophyll content by 32%, 10% and 11% compared to NA, SM and MS respectively. To a lesser extent, SM and MS treatment increased chlorophyll content compared to NA. Chlorophyll is a vital pigment for absorbing, transferring and transforming in photosynthesis (Yao et al., 2007). Changes in chlorophyll content are indicative of water stress and crop phenological status. The higher chlorophyll content is in accord with the findings of Aspasia et al. (2010) who reported higher leaf chlorophyll content under combined application of organic and inorganic fertilizer. This is a significant finding since leaf greenness is an important plant biophysical parameter that determines plant physiological status (Gitelson et al., 2003) and thus relates to canopy photosynthetic capacity of plants (Suyker et al., 2005) and consequently improved yield.

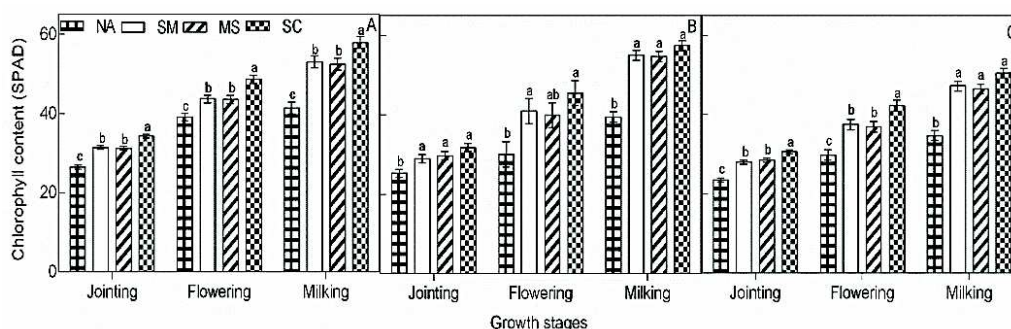


Figure 3. Chlorophyll content (SPAD) of maize measured in 2014 (A), 2015 (B) and 2016 (C) at jointing, flowering and milking. Means comparison was done using least significant difference ($P < 0.05$). Symbols are: No amendment (NA); swine manure (SM); maize stover (MS) and swine manure in combination with chemical fertilizer (SC). Bars with different letters in the same growth stage and year denote significance at $P < 0.05$. Error bars denote the standard error of means.

Dry matter accumulation

Dry matter accumulation under different soil amendment is presented in Fig. 4. Dry matter accumulation (DMA) averaged across years and treatments was $9.20 \text{ g plant}^{-1}$ at jointing, $211.18 \text{ g plant}^{-1}$ at flowering, 287.91 at milking and $437.71 \text{ g plant}^{-1}$ at maturity. This resulted in 2195% increase from jointing to flowering, 36% increase from flowering to milking and 52% from milking to maturity. The three amendment treatments had higher average DMA in 2014 ($283.2 \text{ g plant}^{-1}$), 2015 ($255.3 \text{ g plant}^{-1}$) and 2016 ($205.5 \text{ g plant}^{-1}$) compared to NA (213.8 , 176.2 and $130.1 \text{ g plant}^{-1}$ in 2014, 2015 and 2016 respectively). Across growth stages, SC increased dry matter accumulation by 13% and 25% in 2014, 12% and 23% in 2015, and 16% and 30% in 2016 compared to SM and MS treatments respectively. Swine manure in combination with chemical fertilizer (SC) had a positive effect on crop growth and development with an increase in dry matter accumulation. Our results agrees with the findings of Kibunja et al. (2010) who found that a combination of organic and inorganic nutrient source gave a higher total dry matter of maize. A number of mechanisms have been ascribed to the increased dry matter accumulation when organic manure is applied in combination with chemical fertilizer. In this study, increased dry matter accumulation in swine manure in combination with chemical fertilizer could be attributed to the improved leaf area growth and chlorophyll content. Fageria & Baligar (2005) reported increased dry matter production with greater leaf growth. The results reported here demonstrate that swine manure combined with chemical fertilizer could be useful in a sustainable agricultural system which has an important role in increasing the productivity and stability of yield in rain-fed agricultural areas.

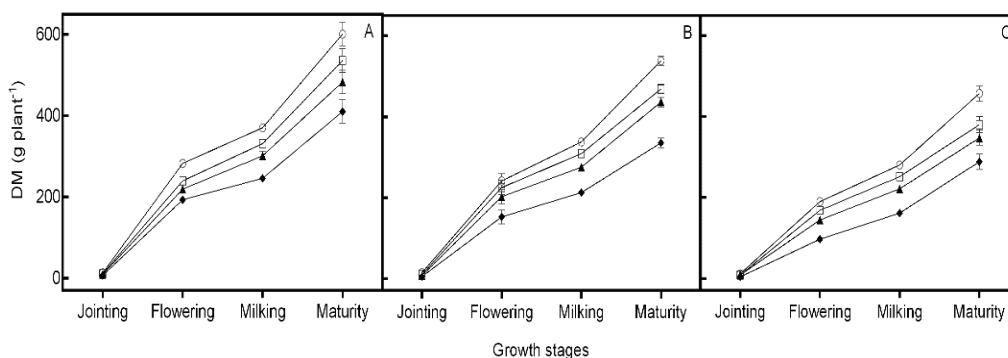


Figure 4. Dry matter accumulation curves for different soil amendment recorded at different growth stages in 2014 (A), 2015 (B) and 2016 (C). Vertical bars denote the standard error of means. Symbols are: (◆) No amendment (NA); (□)swine manure(SM); (▲) maize stover (MS), and (○) swine manure in combination with chemical fertilizer(SC).

Grain yield and yield component

Analysis of variance indicated that, the treatments had significant effect ($P < 0.05$) on grain yield and yield components, whereas year has significant effect at $P < 0.05$, for all characters except kernel weight (Table 2). There was no significant interaction between treatment and year for grain yield and yield components. Generally, higher grain yields were observed in the amended treatments relative to the control. Swine manure in combination with chemical fertilizer (SC) increased grain yield by approximately 69%, 14% and 12% on average compared to NA, SM and MS respectively. Similarly, ear number, kernel number per ear and 1,000 kernel weight increased with the application of amendments compared to non-amended soils. A similar trend was observed between the yield components and the grain yield. Results of correlation analysis showed EN, KN and KW had significant positive effect ($P < 0.05$) on grain yield of maize (Table 3). Swine manure in combination with chemical fertilizer averagely increased EN, KN and KW by 36%, 26% and 42%, respectively. Among the amendment treatment, SC increased EN, KN and KW by 17% and 13%, 6% and 7%, and 15% and 13% compared to SM and MS respectively. The significant effect of cropping year on grain yield and some yield components might due to the different intensity and timing of rainfall in different year. Variations in rainfall amount and distribution reduced soil water availability to crops which influenced photosynthesis and grain yield (Li et al., 2002).

Appropriate application of organic manure has been shown to improve grain yield (Yang et al., 2015) and dry matter accumulation (Wang et al., 2009). Comparing the soil amendment treatments, application of swine manure, especially in combination with chemical fertilizer consistently increased yield components and grain yield. The increased grain yield with SC in particular may be related to increased transport of carbohydrate. Kibunja et al. (2010) as well as Pan et al. (2009) found that a combination of organic and inorganic nutrient sources resulted in increased maize yield. Authors attributed the results to enhanced crop growth via improved leaf area index and greater transport of carbohydrate to grain from leaves, stems and sheaths. We found a positive correlation between grain yield and dry matter at all the growth stages. This finding

indicate that grain yield improvement depends greatly on dry matter accumulation. Shearman et al. (2005) as well as Álvaro et al. (2008) postulated that grain yield was mainly associated with the pre-anthesis assimilate contribution to grain filling and greater dry matter translocation efficiency. The results showed that application of swine manure in combination with chemical fertilizer is especially effective to increase crop yield in Northwest agricultural regions such as the Western Loess Plateau of China, where water shortage and nutrient deficiency are the two main obstacles threatening maize production.

Table 2. Maize grain yield (GY, kg ha⁻¹), ear number per 10 m² (EN), kernel number per ear (KN), and 1,000 kernel weight (KW) for different soil amendment in 2014, 2015 and 2016

Treatment	Days after sowing (DAS)											
	GY			EN			KN			KW		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
NA	5,322	4,594	3,459	88	71	63	409	343	351	226	251	235
SM	7,888	6,732	5,641	104	74	81	474	440	396	299	299	280
MS	7,550	7,433	5,768	104	83	81	457	445	398	305	301	286
SC	8,900	8,209	6,156	113	91	98	488	475	431	339	332	339
LSD (0.05)	398	479	491	6	7	12	33	56	53	36	20	30
Sources												
Amendment (A)	***			**			**			***		
Year (Y)	***			***			**			ns		
A x Y	ns			ns			ns			ns		

Table 3. Correlation coefficients between Grain yield (GY), ear number per 10 m² (EN), kernel number per ear (KN), 1,000 kernel weight (KW), dry matter and leaf nitrogen content at Jointing (60 DAS), flowering (90 DAS) and milking (120 DAS)

Variable	EN	KN	KW	Dry matter			Leaf nitrogen content		
				60	90	120	60	90	120
GY	.960*	.996**	.982*	0.927 ns	0.941 ns	0.947*	.968*	.997**	.988*

Non-significant (ns), Significant (*) at $P < 0.05$, and Significant (**) at $P < 0.01$.

Leaf and grain nitrogen concentration

Treatment had significant effect on nitrogen content in the leaf over the three study years, whereas year had effect at 90 and 120 DAS at $P < 0.05$ (Table 4). There was significant interaction between treatment and year in affecting nitrogen content in the leaf, with one exception (120 DAS). Significant ($P < 0.05$) differences in nitrogen concentration between amended crops and the control were observed at all the stages studied (Table 4). The SC treatment exhibited the highest nitrogen concentration at all the stages sampled, whereas NA had the lowest nitrogen concentration over the study period. On average, nitrogen concentration of amended treated crop was up to 33% higher than that of the control. Among the amendment treatments, SC increased nitrogen concentration by 1% and 3% on average at jointing, 8% and 9% at flowering, 6% and 8% at milking, and 18% and 25% at maturity compared to SM and MS treatments respectively.

Table 4. Nitrogen concentration (%) in leaves at 60, 90, 120 and 153 days after sowing (DAS) for different soil amendment in 2014, 2015, and 2016

Treatment	Days after sowing (DAS)											
	60			90			120			153		
	2014	2015	2016	2014	2015	2016	2014	2015	2016	2014	2015	2016
NA	2.52	2.40	2.20	1.66	1.53	1.53	1.10	1.16	1.12	0.71	0.66	0.73
SM	2.85	2.89	2.93	2.30	2.15	1.85	1.65	1.69	1.49	1.05	0.92	0.97
MS	2.85	2.88	2.79	2.24	2.14	1.87	1.66	1.71	1.34	1.10	0.94	0.72
SC	2.89	3.07	2.78	2.35	2.40	2.07	1.73	1.80	1.57	1.15	1.18	1.14
LSD (0.05)	0.09	0.11	0.08	0.05	0.10	0.15	0.07	0.08	2.76	0.05	0.10	0.15
Sources												
Amendment (A)	**			***			**			**		
Year (Y)	ns			**			*			ns		
A x Y	**			*			ns			*		

** Significant at $P < 0.01$; ***Significant at $P < 0.001$; ns, not significant.

There were significant differences between amended crops and the control in grain nitrogen concentration (Fig. 5). Application of SC increased nitrogen content in grain yield by 20% in 2014, 20% in 2015 and 26% in 2016 compared to NA. Application of SM and MS also significantly increased grain nitrogen content compared with NA, but to a lesser extent relative to SC.

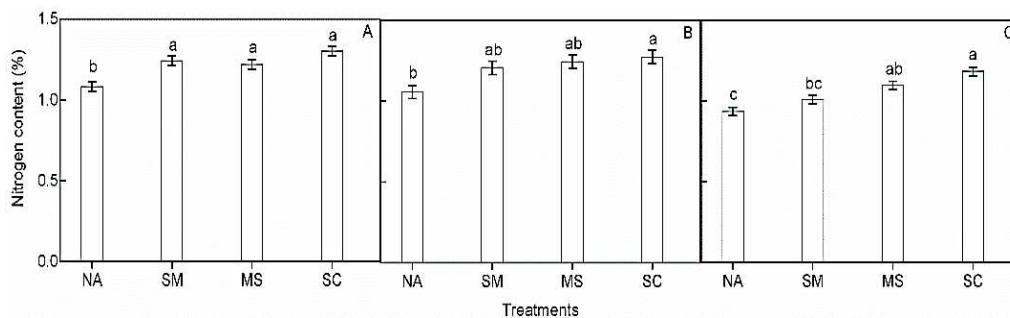


Figure 5. Grain nitrogen concentrations in 2014(A), 2015 (B) and 2016 (C). Means comparison was done using least significant difference ($P < 0.05$). Symbols are: (♦) No amendment (NA); (□)swine manure(SM); (▲) maize stover (MS), and (○) swine manure in combination with chemical fertilizer(SC). Bars with different letters in the same year denote significance at $P < 0.05$. Error bars denote the standard error of means.

The general decrease of N concentration in the leaves with maturity observed in this study is in agreement with Charles-Edwards et al. (1987) as well as Fageria & Baligar (2005) who reported that plant nitrogen concentration decreased in accordance with increasing growth stage. Higher N content in the leaf and grain achieved under swine manure, particularly swine manure in combination with chemical fertilizer (SC), suggests enhanced plant growth and quality of plant material as indicated by its leaf area and dry matter accumulation. This is a significant finding because the quality and quantity of plant materials produced impacts plant carbon pool and sequestration of carbon (West & Post, 2002) and digestibility when used as feed. Grain yield correlated

positively with N concentration at all growth stages with milkng having the greatest effect (Table 3).

CONCLUSION

The main conclusions derived from this work are:

- Application of swine manure in combination with chemical fertilizer had a beneficial effect on leaf area index and leaf chlorophyll content which translated into higher dry matter accumulation and nitrogen content.
- Increased dry matter accumulation when swine manure was applied in combination with chemical fertilizer translated into higher yield components and consequently grain yield.
- The results reported in this study were consistent with positive correlations observed between grain yield, ear number, kernel number, kernel weight, dry matter accumulation and nitrogen content. This confirmed that the grain yield of the crop is sensitive to changes in dry matter accumulation, yield components and nitrogen content in the leaf, and that small stresses on these traits can result in significant impacts on grain yield.
- This set of results offer new insights into beneficial use of swine manure as a soil conditioner, particularly when applied with chemical fertilizer. The results particularly contribute to our understanding of dry matter accumulation and nitrogen concentration at different growth stages and consequently grain yield response. From this, there appears to be potential for further development of management practices involving use of swine manure in crop production under semiarid environments.

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