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Nitrogen and phosphorus leaching and vegetative growth of maize as affected by organic manure application

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Abstract

Maize production in Asia is rapidly increasing. For its sustainable production, the effects of raw and dry manure application on soil water dynamics, nutrient leaching, and plant growth were investigated. Nitrogen (N) and phosphorus (P) concentrations in the percolated water below a 110-cm depth of field-lysimeter columns were analyzed to quantify leaching. Soil water, soil temperature, and plant growth were routinely monitored. The manure application practices increased soil water content by 0.008–0.025 cm^3 cm^{-3} throughout the vegetative period by reducing bulk density and reduced the daytime temperature range by 0.4–1.2°C. The average leaching concentrations of total N increased from 2.6 to 4.7 mg N L^{-1} and available P decreased from 0.12 to 0.04 mg P L^{-1} between 63 and 93 DAS (day after sowing), respectively. The manure treatments did not increase nutrient leaching load at 63 DAS, but at 93 DAS the N load was increased by 219–324 g ha^{-1} and P load by 2.0–3.1 g ha^{-1} compared with the control treatment. The dry manure released a larger amount of N (30.7%) and P (3.2%) in the leachates than the raw manure. The dry and raw manure treatment produced 14.5 and 5 cm taller plants, respectively than the control treatment. Manure application with a slight modification in nutrient management can avoid the nutrient leaching problem.

Keywords: Dry manure, maize root growth, raw manure, soil temperature, soil water conservation.

Introduction

A major challenge for sustainable agriculture is to continue supplying the ever-increasing food demand without deteriorating environmental quality. Agriculture is a major non-point source of nitrogen (N) and phosphorus (P) loss to the environment (Amin et al., 2018). Even in the relatively well-managed Chesapeake Bay catchment in the USA, agricultural land releases 34% of total N and 50% of total P load of the catchment outlet, for instance (CBP, 2016). The nutrient that leached below root zone soils can join shallow aquifers and then pollute nearby surface water through surface water-groundwater interactions, and cause eutrophication of aquatic ecosystems (Norring and Jørgensen, 2009). Nutrients joining groundwater can appear in pumping wells that supply water to households or industries (Giacomoni et al., 2014). Appropriate incorporation of conservation practices can reduce nutrient losses from agricultural fields. Among major crops, maize cultivation exerts comparatively higher nutrient leaching (Amin et al., 2018).

To meet the national food and feed demand, maize production is rapidly increasing in many Asian countries (FAO, 2018). Maize is a dry season crop grown after monsoon season when soil water content starts to deplete steadily because of continuous rainless days. Therefore, the effective use of residual water in the root zone is crucial, especially in the water-scarce areas (Rahman et al., 2015; Huhmann et al., 2017). Organic manure application can help use the residual soil water effectively (Amin et al., 2014; Xia et al., 2017; Eze et al., 2020). A number of studies assessed the effects of these practices on soil water reserve and

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plant growth; however, scientists are still working to explicate these issues (Du et al., 2020; Eze et al., 2020; Jjagwe et al., 2020). Dry or compost animal manure is usually applied to crop fields, but relatively fresh manure may end up in agricultural fields due to storage limitations. How the application of different types of animal manure affects N and P leaching in maize fields is still somewhat unclear (Sainju, 2017; Amin et al., 2018).

Animal manure application increases soil water retention in and around the manure-application slit (Amin et al., 2014; Xia et al., 2017) and improves soil properties (Admas et al., 2015). Land application is a profitable option to handle the huge amount of wastes generated from the expanding animal industries in developing countries (ILMM policy, 2015). However, N and P can slowly mineralize from organic manure and be available for leaching to shallow groundwater during and between the main crop seasons (Amin et al., 2014; Sainju, 2017; Xia et al., 2017; Amin et al., 2018). The overall effects of these practices on agroecology need to be assessed before large-scale implementation in a region. We hypothesized that a better soil water reserve under different types of organic manure application can enhance nutrient transport and leaching in the soil. This study was, therefore, conducted with three specific objectives: (i) to quantify the effectiveness of two manure types on soil water content and soil temperature; (ii) to investigate the impact of the organic manures on N and P leaching; and (iii) to evaluate the impacts of the organic manures on the vegetative growth of maize.

Material and Methods

Study site

A field lysimeter at the Field Irrigation Lab, Bangladesh Agricultural University, Mymensingh, Bangladesh (24°55´ to 25°55´ N and 90°10´ to 90°30´ E at 18 m above the mean sea level) was used for this experiment. The study location is situated in the Old Brahmaputra Alluvial Floodplain having non-calcareous dark gray floodplain soil. The local climate is sub-tropic with summer-dominant rainfall mostly concentrated over April to October, but November to March is dry (Ali et al., 2007). Daily weather data were collected from an on-site weather station. Rainfall started after a month of sowing and then had an increasing frequency in the later part of the experiment (Figure 1). The wind speed increased, whereas sunshine hour decreased due to frequent cloud formation in the later part. The daily mean temperature during the study period ranged from 20 to 32.4°C, and the mean relative humidity fluctuated between 57 and 95% during the growing period (Figure 1).

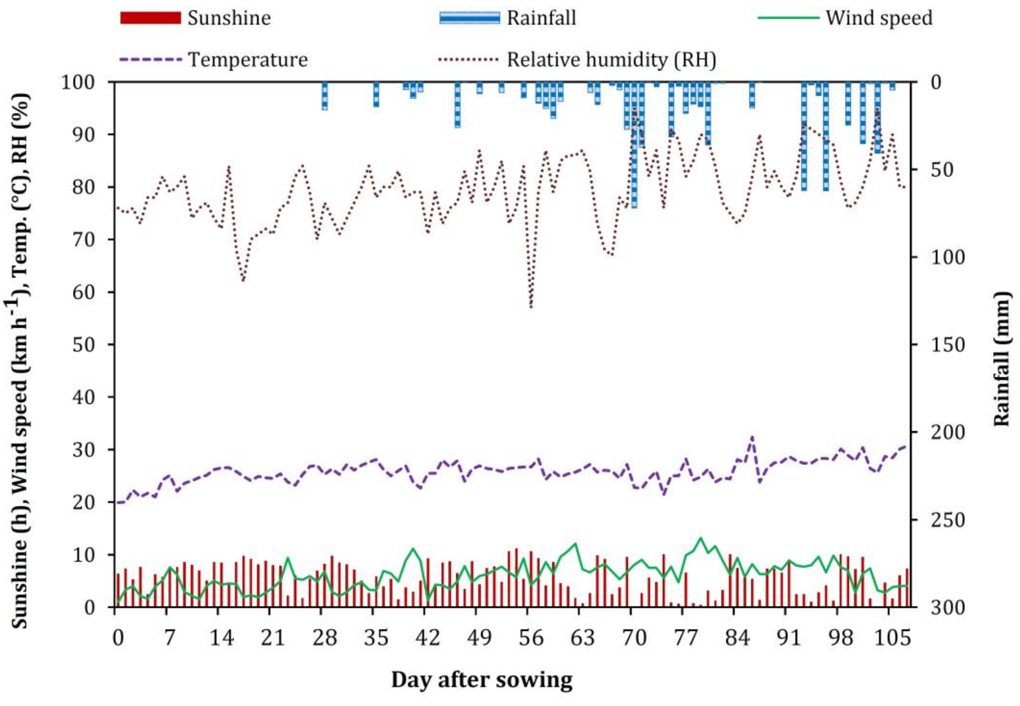

Figure 1. Daily mean temperature, rainfall, sunshine hours, wind speed, and relative humidity during the study period

Lysimeter

The dimension of each soil column of the lysimeter is 1.2 m × 1.2 m × 1.1 m (Figure 2). A 1-m buffer zone separated the columns from each other. A perforated pipe covered with envelope materials was built-in at the bottom of the soil column to collect percolated water and leachate samples. This lysimeter is suitable to measure evapotranspiration, crop-water requirement, water percolation, and chemical leaching in the soil profile (Xue et al., 2013). A test before the experiment confirmed that each of the soil columns was hydraulically isolated from the surrounding soil. Locally available perennial grass was grown in the previous three years so that the soil columns represent local field conditions. Soil samples collected from the lysimeter columns were analyzed for some selected physicochemical properties. The soil was silt loam (sand 42%, silt 49%, and clay 10%) with pH 6.49, electrical conductivity of 131.6 µS cm^{-1}, organic matter of 1.1%, bulk density of 1.33 g cm^{-3}, field capacity of 38.2%. The soil was low in nutrient content, i.e., TN (0.63 g kg^{-1}), P (0.15 ppm) and K (12.6 ppm).

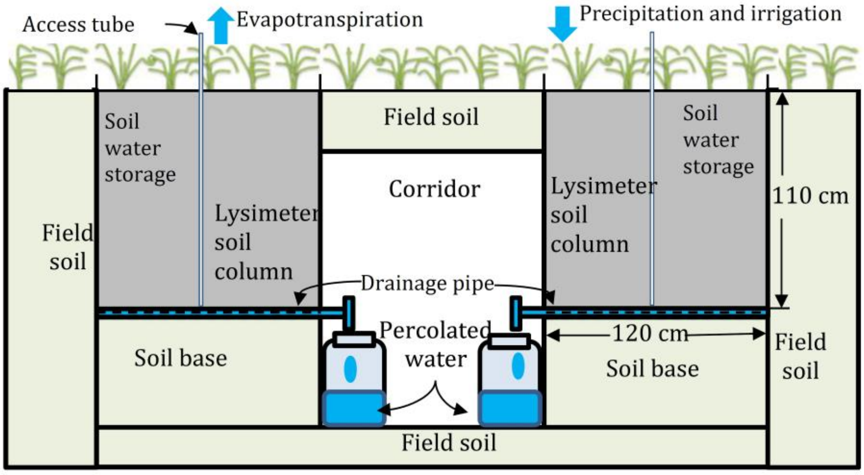

Figure 2. Cross-sectional view of a soil column in the lysimeter

Manure treatments

The effects of manure application on the soil water and temperature dynamics, nutrient leaching, and vegetative growth of maize were investigated. The following manure application treatments with three replications of each were established: (i) no-manure (manure not applied), (ii) raw manure (one-week-old cow dung applied at 110 t ha^{-1}), and (iii) dry manure (cow manure stored in an open pit for six months applied at 60 t ha^{-1}). The raw manure had 16.8% dry matter (3.0±0.3 kg N t^{-1}, 0.7±0.06 kg P t^{-1}, 2.5±0.22 kg K t^{-1}) and the dry manure had 30.8% dry matter (5.0±0.6 kg N t^{-1}, 1.5±0.16 kg P t^{-1}, 2.3±0.19 kg K t^{-1}); as a result, both treatments received an equal amount of manure dry matter and N. Land was prepared before the surface application of the manure and then the manure was mixed with the top 15-cm soil.

Agronomic management

Inorganic fertilizer was applied according to the recommended dose (FRG, 2012): phosphorus (110 kg P ha^{-1}) as triple superphosphate, potassium (120 kg K ha^{-1}) as muriate of potash, sulfur as gypsum (15 kg ha^{-1}), and zinc as zinc sulfate (5 kg ha^{-1}) only once before sowing. Nitrogen as urea was applied thrice (total 240 kg N ha^{-1}); one basal before sowing and two side-dresses at 35 and 60 days after sowing (DAS). On 18 February 2018, seeds of hybrid maize variety Kaveri-3696 were sown 20 cm apart with a row-to-row distance of 60 cm. The plots received no irrigation. Other agronomic requirements of the plants were provided equally.

Vegetative growth

The shoot length of randomly selected 50% plants from each plot was measured at 30, 60, and 107 DAS. Root length of maize plants was measured at 30 DAS. Surrounding soil (20 cm × 20 cm × 20 cm) having the plant roots was collected very carefully and the roots were gently rinsed in the laboratory to wash away the soil before measuring the length. The fresh weight and air-dried weight of the root and shoot of each plant were recorded. The full-matured maize plants were harvested on June 06, 2018 (107 DAS).

Soil and water sampling

Soil water content at 5, 15, and 30 cm below the ground surface was measured at 10–15-day interval. Soil thermometers set at 15-cm depth in the plots gave soil temperature record. Soil water content and soil temperature were measured during the first two months after the sowing. After that period, crop canopy was fully established and soil surface was fully covered, and thereby the differences in soil temperature under different treatments became insignificant. Plastic water containers were used to collect leachate from each soil column of the lysimeter (Figure 2). Rainfall events at 63 and 93 DAS produced adequate leachate samples to be chemically analyzed. The total leachate volume of each column was recorded. The leachate samples were immediately taken for the analysis of total N and available P concentration.

Sample analysis

The oven drying method (105°C for at least 24 hours to reach a constant weight) was used to determine soil water content. Soil organic carbon content was analyzed using the wet oxidation method and cation exchange capacity by the sodium saturation method (Black, 1965). Exchangeable K was extracted with 1.0 N NH_4OAc (pH 7) solution and then a flame photometer was used to determine the extractable K (Black, 1965). Total N (TN) was estimated by the Micro-Kjeldahl method (Bremner and Mulvaney, 1982) where samples were digested with 30% H_2O_2, conc. H_2SO_4 and catalyst mixture of K_2SO_4: $CuSO_4$:$5H_2O$: Se=100:10:1. Nitrogen in the digest was measured by distillation with 40% NaOH followed by titration of the distillate trapped water in H_3BO_3 with 0.01N H_2SO_4. The samples were shaken with 0.5M $NaHCO_3$ solution at pH 8.5 to extract available P, and then P was measured by developing a blue color using $SnCl_2$ reduction of phosphomolybdate complex solution. The absorbance of the complex was measured at 600 nm wavelength in a spectrophotometer and available P was calibrated with a standard P curve.

Data analysis

The experimental data were analyzed by one-way Analysis of Variance by using MS Excel 2016. The differences between the treatment-means were tested with the Least Significant Difference (LSD) value at a significance level of 0.05.

Results and Discussion

Soil water and soil temperature

The dry manure treatment had higher soil water contents than the no-manure treatment, and dry manure outperformed raw manure in increasing soil water availability (Figure 3a). Celik et al. (2004) also observed higher soil water availability due to higher porosity and hydraulic conductivity induced by dry manure application compared with raw manure application. The raw manure constituents were possibly redistributed better in the soil because of the higher water content in it, as suggested by Amin et al. (2014). Nahar et al. (2006) reported that fresh manure loosened soil aggregates by increasing microbial activities more than the composted dry manure. The loose aggregates can facilitate soil water transport through its pore spaces (Amin et al., 2016). Manure application increased soil organic matter from 1.1 to 1.4–1.9% and electrical conductivity from 132 to 156–206 µS cm^{-1} but reduced bulk density from 1.33 to 1.25 g cm^{-3} in the topsoil. The saturated soil water content (45.9 ± 2.4%) observed in the manure-treated soils was considerably higher than that in the un-amended soils (40.8 ± 1.8%). Wortmann and Shapiro (2008) reported that manure organic matter increased total porosity and infiltration capacity, thereby increasing water-holding capacity. The decreasing soil water content between 28 and 38 DAS indicates that total evapotranspiration during this vegetative growth period under this warm and dry weather was higher than the total rainfall (Figure 3a).

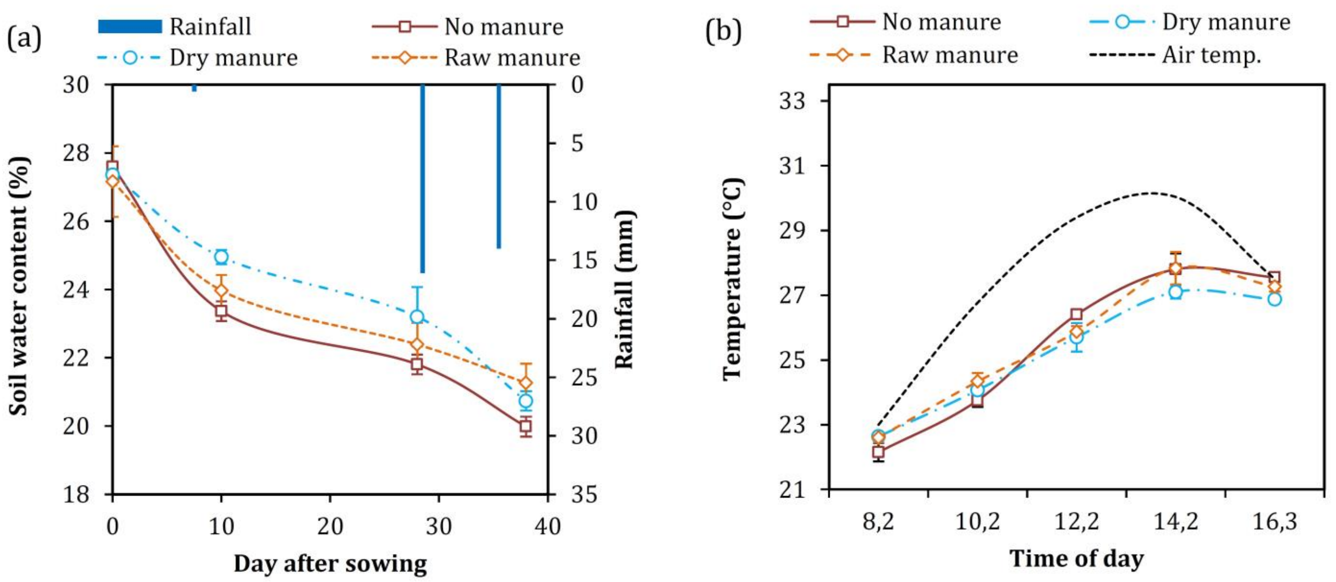

Figure 3. Temporal changes of soil water content at 15-cm depth (a) and daytime soil temperature fluctuation at 24 days after sowing (b) for different manure applications (error bars show standard errors)

The manure treatments had a slightly higher soil temperature than that of the no-manure in the morning but had a lower temperature in the afternoon at 24 DAS (Figure 3b). Organic matter in the applied-manure can reduce the thermal conductivity of the topsoil due to the increased soil porosity and reduced bulk density as suggested by Adekiya et al. (2016). Manure application reduced the daily temperature range by increasing the daily minimum temperature and reducing the daily maximum temperature (Figure 3b). Agbede et al. (2017) stated that manure application raised the minimum temperature and reduced the maximum temperature of a day. Reduction of daily temperature range can create a suitable soil environment for plant growth in places with a long diurnal temperature range.

Nitrogen leaching

At the first leaching event, the dry manure treatment released the highest amount of total N (191 g N ha^{-1}), but the difference was not significant (Figure 4a). At 93 DAS, the dry manure and raw manure treatments exerted a similar amount of total N leaching, and the amount was higher than that in the no-manure treatment (Figure 4b). The average leaching concentration of N under the manure treatments was 2.8 mg N L^{-1} at the first event and 5.8 mg N L^{-1} at the second event. At the latter event, the combined effect of rainfall and N mineralization from the land-applied manure released a higher amount of N. Asadu and Igboka (2014) obtained higher N leaching from the plots receiving manures compared with those receiving no-manure. The increased leaching of N in the manure treatments was attributed to the manure-borne N. Plants could not fully make use of the mineralized N, so the unused mineral N in soil subsequently started to leach.

The dry manure released a larger amount of N (30.7%) in the leachates than the raw manure. It is attributed to the steadier mineralization of N in soils amended with the compost-like dry manure. In contrast, straws present in the raw manure can increase N-immobilization (Lehrsch and Kincaid, 2007). The residual N content after maize harvesting was still higher in the manure-treated soils (0.77–0.97 g N kg^{-1}) than that in the non-manure treatment (0.63 g N kg^{-1}). Sanni (2016) observed an increase in available N in soils treated with the amendments that had slower nutrient release rates compared with the amendments with faster nutrient release rates.

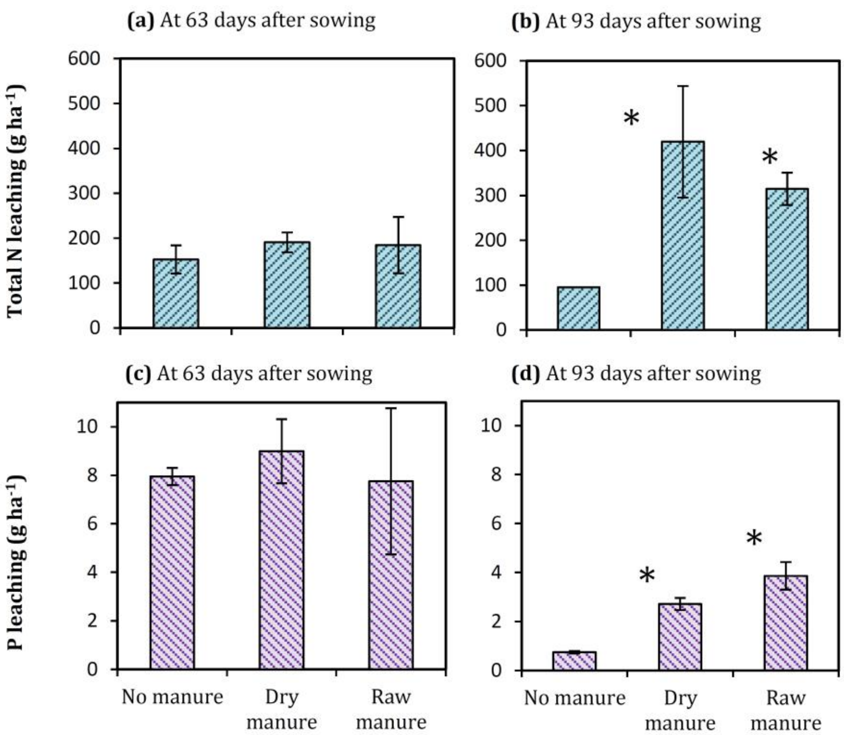

Figure 4. Leaching of total nitrogen (a and b) and available phosphorus (c and d) for rain events at 63 and 93 days after sowing for different manure application (* sign indicates significantly different compared to the control treatment at 5% significance level)

Phosphorus leaching

At 63 DAS, the difference in P leaching for no-manure and manure application was not significant (Figure 4c). At 93 DAS, the manure-treated plots released a higher amount of P compared with the control plots (Figure 4d). This finding agrees with the results of Chardon et al. (2007), who observed that land application of manure gradually increased P concentration in leachates. Phosphorus slowly mineralized from the land-applied manure, and then it started to leach, as stated by Eghball et al. (2002). The gradual increase in rainfall frequency and intensity augmented the vertical flux of water, which assisted the downward movement of P in the soil (Xue et al., 2013). The raw manure treatment released a higher amount of P than the dry manure treatment at 93 DAS. Ksheem et al. (2015) also found that raw manure released more water-soluble P in leachates than dry manure.

The N leaching rate was much higher than the P leaching because the NO_3-N form of N is more mobile in the soil. Moreover, the N application rate was more than double of P application rate. The average leaching concentration of total N increased from 2.6 mg N L^{-1} at 63 DAS to 4.7 mg N L^{-1} at 93 DAS, whereas available P leaching decreased from 0.12 mg P L^{-1} to 0.04 mg P L^{-1} between these two events. Leaching of N usually increases gradually up to a certain duration after field application because NO_3-N accumulates slowly through nitrification depending on the soil condition and subsequently starts to leach (Amin et al., 2014). In contrast, P is immobile in bulk soils and consequently often takes a preferential flow path to move (Williams et al., 2018). However, the effects of the manure treatments on the N and P leaching were almost the same, i.e., the treatments did not increase the leaching at the first event but had higher leaching at the second event.

Vegetative growth

Both the manure treatments enhanced plant growth, but the dry manure treatment outperformed the raw manure treatment (Table 1). This result agrees with De Boer (2008), who found an increased maize yield for dry manure application compared with raw manure application. Water content and crop-available nutrient in the topsoil were relatively higher for the dry manure treatment than that for the raw manure treatment. The end-of-season total N content in soil was 0.97 ± 0.02 g kg^{-1} for the dry manure treatment and 0.77 ± 0.01 g kg^{-1} for the raw manure treatment. Lehrsch and Kincaid (2007) found up to 17% more N uptake in compost-amended soils than that in manure-amended plots. The dry manure used in the study was more decomposed than the raw manure. Aziz et al. (2010) also observed that dry manure application improved plant growth and shoot weight compared with raw manure application. Saunders et al. (2012) found better forage production and N use efficiency for compost slurry application compared with the raw slurry application. However, Eghball et al. (2002) and Loria et al. (2007) found similar positive effects of compost and raw cattle or swine manure on maize yield and soil characteristics.

Table 1. Vegetative growth of maize for different manure types

Treatment	At 30 days after sowing (DAS)			Shoot length at 60 DAS (cm)	Shoot length at 107 DAS (cm)
	Shoot length (cm)	Root-shoot length ratio	Root-shoot mass ratio		
No-manure	50.3^{c}	0.22^{a}	0.13^{c}	161.6^{b}	190.7^{b}
Dry manure	69.7^{a}	0.19^{b}	0.20^{a}	187.3^{a}	205.2^{a}
Raw manure	59.9^{b}	0.22^{a}	0.15^{b}	164.5^{b}	195.7^{ab}

*Values with different letters (a, b, and c) are significantly different at 5% significance level.

The no-manure and raw manure treatments had a higher root-shoot length ratio than that of the dry manure treatment (Table 1). The raw manure treatment had a higher root length than the dry manure treatment probably because the nutrient in the raw manure redistributed more into the deeper soil. The raw manure had a larger liquid fraction than the dry manure, which could have facilitated the redistribution of manure-borne nutrients in the soil. Amin et al. (2014) found higher redistribution of manure-borne constituents in soil when the water content in manure was higher. Lynch (2013) reported that a better development of root foraging into deep soil strata occurred when N became available in the subsoil. The low soil water and nutrient availability in the topsoil under the no-manure treatment presumably increased the root length compared with that in the dry manure treatment (Table 1). Sharp et al. (2004) suggested that water stress condition exerts pressure on roots to spread more to search for water and nutrient into the soil to check crop failure. However, the dry manure treatment produced the highest root-shoot mass ratio followed by the raw manure treatment.

Conclusion

Manure application effectively conserved soil water throughout the vegetative stage of maize. Manure application raised the daily minimum temperature and reduced the daily maximum temperature. The average total N content in leachates was 2.6 mg N L^{-1} at 63 DAS and 4.7 mg N L^{-1} at 93 DAS, and the values for available P were 0.12 and 0.04 mg P L^{-1} at 63 and 93 DAS, respectively. These practices did not increase nutrient leaching at the first leaching event but released a higher amount of nutrient in the leachates at the second event than the control treatment. The manure treatments gave longer shoots due to the increased soil water availability and thus augmented crop uptake of nutrients. A nutrient management plan should be in place to avoid the leaching problem before any large-scale implementation of these practices.

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