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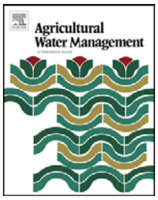

Effect of N-enriched co-compost on transpiration efficiency and water-use efficiency of maize (*Zea mays* L.) under controlled irrigation

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ABSTRACT

Population growth, urban expansion and economic development are increasing competition for water use between agriculture and other users. In addition, the high rate of soil degradation and declining soil moisture in the Sub-Saharan African Region have called for several crop production management and irrigation options to improve soil fertility, reduce water use by crops and produce 'more crops per drop of water'. Notwithstanding this, considerable variations exist in the literature on water-use efficiency, WUE_{cwu} (economic yield per water used) for maize (*Zea mays* L.) across climates and soil management practices. Different views have been expressed on the effect of different rates of nitrogen (N) application on transpiration efficiency, TE (biomass produced per unit of water transpired). The objectives of the study were to assess the effect of different rates of N-enriched municipal waste co-compost and its derivatives on TE, WUE_{cwu} and yield of maize (*Z. mays* L.) in comparison to inorganic fertiliser. The greenhouse pot experiment was conducted in Accra, Ghana on a sandy loam soil (*Ferric Lixisol*) using a split plot design. The main plot treatments were soil (S), dewatered faecal sludge (DFS), municipal solid waste compost (C), co-compost from municipal solid waste and dewatered faecal sludge (Co), compost enriched with $(NH_4)_2SO_4$ (EC), co-compost enriched with $(NH_4)_2SO_4$ (ECO), $(NH_4)_2SO_4$ and NPK15–15–15 + $(NH_4)_2SO_4$. The sub-plot treatments were different rates of application of nitrogen fertiliser applied at the rate of 91, 150 and 210 kg N ha^{-1} respectively. Maize cv. *Abelehii* was grown in a poly bag filled with 15 kg soil. Eight plants per treatment were selected randomly and used for the collection of data on growth parameters forth-nightly. At physiological maturity two plants per treatment were also selected randomly from each treatment plot for yield data. The results showed that TE of maize (*Z. mays*) varied for the different treatments and these are 6.9 Pa in soil (S) alone to 8.6 Pa in ECO. Increase in N application rate increased TE at the vegetative phase for fast nutrient releasing fertilisers (DFS, ECO, EC, NPK + $(NH_4)_2SO_4$, $(NH_4)_2SO_4$) and at the reproductive phase for slow nutrient releasing fertilisers (C and CO). Water-use efficiency increased significantly as rate of N application increased. Treatment ECO improved crop WUE_{cwu} and was 11% and 4 times higher than that for NPK + $(NH_4)_2SO_4$ or soil alone; and 18–36% higher than those for DFS and CO. Treatment ECO used less amount of water to produce dry matter yield (DMY) and grain yield (GY) that was 5.2% and 12.6%, respectively, higher than NPK + $(NH_4)_2SO_4$. Similarly, the DMY and GY for ECO was 8.9–18.5% and 23.4–34.7%, respectively, higher than DFS and CO. High nutrient (N and K) uptake, TE, and low leaf senescence accounts for 83% of the variations in DMY whereas WUE_{cwu} accounts for 99% of the variations in GY. Thus, the study concluded that different sources of fertiliser increased TE and WUE_{cwu} of maize differently as N application rate increases.

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1. Introduction

In Ghana, loss of soil organic matter, plant nutrients, low water infiltration and water holding capacity of soils, are some of the factors that have rendered the soil unproductive (FAO-RAF, 2000). Despite the release of several high yielding maize (*Z. mays* L.) varieties to small-holder farmers and its high adoption rate, maize production levels in sub-Saharan Africa remains low (Kalonga, 2002). Water availability and cost is a limiting factor in crop production in Accra and other urban areas of Ghana. There is increased use of low quality water like untreated waste water from drains to meet crop water demand and use. This practice raised concerns because the waste water has been reported to contaminate food crops (Amoah et al., 2005). High inter-annual variability and erratic rainfall distribution in space and time, coupled with water loss through runoff, soil evaporation, drainage below the root zone, and decline in soil fertility status are some of the factors that account for low water-use efficiency and crop production (Mando, 1997). Several soil and water conservation technologies including tillage, stone walls, stone bunds, earthing bunds and dykes have been used to improve soil water infiltration, storage and availability (FAO-RAF, 2000; Zougmoré et al., 2004). However, sometimes, these technologies are difficult to adapt to the socio-economic and environmental conditions and needs of the beneficiaries (FAO-RAF, 2000). There is the need to develop technologies that optimise the use of the limited water and soil resources to achieve sustainable crop production (if pests and diseases are well controlled).

Application of organic manure and/or compost has been shown to improve the soil organic matter content (Adani et al., 2007; Soumare et al., 2003), water infiltration and retention (Agassi et al., 2004; Bationo et al., 1998) and the available water content of soils by 58–86% (Celik et al., 2004). Application of municipal solid waste compost increased available water in the root zone (mainly due to reduction in evaporation) and increase the yields of wheat crops from 1190 kg ha^{-1} in the control to 1520 kg ha^{-1} (Agassi et al., 2004). Compost application improved soil water storage in the sorghum rooting zone (0–80 cm) especially when combined with stone rows, grass strips (Bationo et al., 1998) and when rainfall was well distributed over the period (Zougmoré et al., 2004). The addition of 30% rice straw compost significantly increased plant dry biomass, fruit quality, yield and water-use efficiency of tomato (Ibrahim Ali et al., 2006).

Water-use efficiency (WUE) is defined as the yield of plant product (grain, silage, forage, tuber or other plant product of concern) produced per unit of water used (Power, 1983). However, in maize, sunflower, and wheat because the ratio 'commercial yield/biomass' varies significantly in response to water deficit (Fereres and Soriano, 2007; Katerji et al., 2008), the marketable yield is more interesting and represent liable economic value which is important in determining irrigation cost (Zairi et al., 2001). Therefore, Agronomists defined the ratio of economic yield to cumulative plant water use to produce the yield as physiological or agronomic water-use efficiency, $\mathrm{WUE_{cwu}}$ (de Barros et al., 2007; Gregory, 2004; Howell, 2001; Katerji et al., 2008). And the ratio of biomass produced per unit of water transpired as transpiration efficiency, TE (Brück et al., 2001; Kemanian et al., 2005; Xin et al., 2008).

There is sparse information about the effects of specific nutrient sources or nitrogen fertiliser on $\mathrm{WUE_{CWU}}$ and TE. Besides, considerable variations exit in the literature on $\mathrm{WUE_{CWU}}$ for maize (*Z. mays* L.) across climates and soil management practices (Ben Nouna et al., 2000; Dagdelen et al., 2006; Fageria and Baligar, 2005; Fernandez et al., 1996; Karam et al., 2003; Katerji et al., 1996; Ting-Hui et al., 2006). Similarly, different views have been expressed on the effect of different rates of N application on TE. Cooper et al. (1987) and Corak et al. (1991) reported an increase in TE as N application increased. Walker and Richards (1985) reported that improved soil fertility increased TE only if the soil nutrient levels were low. On the other hand, Goudriaan and Van Keulen (1979), Ogola et al. (2002) found no effect of N levels on TE of maize (*Z. mays* L.). In the above the authors use different fertiliser sources and that may account for the different observations. Information on the effects of different fertiliser sources such as inorganic fertilisers or co-compost and its derivatives on TE, $\mathrm{WUE_{cwu}}$ and yield of maize (*Z. mays* L.) as N application rate increases is paramount. It will increase the interest in the use of municipal waste compost which is vital for its efficient management and use in crop production especially in urban and peri-urban areas of developing countries. The study hypothesised that (i) different sources of fertiliser affect TE and $\mathrm{WUE_{cwu}}$ of maize differently as N application rate increases; (ii) the use of enriched municipal waste co-compost will increase maize yield per unit of water consumed as compared to inorganic fertiliser; (iii) improved transpiration efficiency, water-use efficiency and nutrient uptake account for good plant growth and yield in enriched co-compost medium. The objectives of the study were to assess the effect of different rates of N-enriched municipal waste co-compost and its derivatives on TE, $\mathrm{WUE_{cwu}}$ and yield of maize (*Z. mays* L.) in comparison to inorganic fertiliser.

Table 1
Long-term monthly and growing season climatic data of experimental area[a] (1998–2007).

Years	Month	T_{max} (°C)	T_{min} (°C)	T_{avg} (°C)	R (mm)	RH (%)		PET (mm)	VPD (Pa)
						6:00 h	15:00 h		
1998–2007	October	31.5	23.6	27.5	79.7	93.5	69.9	97.1	–
	November	32.6	24.2	28.4	42.6	93.2	67.5	107.8	–
	December	33.0	24.1	28.6	29.7	93.4	65.8	117.9	–
	January	33.2	23.0	28.1	25.7	87.7	57.7	139.9	–
	February	34.1	24.4	29.2	9.8	90.3	59.1	140.1	–
	March	33.7	24.6	29.2	68.5	90.2	62.3	129.3	–
2006	November	33.6	24.3	–	6.6	93	66	108.0	870[b]
	December	33.9	24.5	–	4.8	94	60	118.1	925[b]
									955[b]
2007	January	34.4	20.6	–	0.0	77	44	164.3	1030[b]
									1870[b]

Ghana Meteorological Agency. Legon, Accra.

[a] T_{max} (maximum temperature), T_{min} (minimum temperature), T_{avg} (average temperature), R (total rainfall), RH (relative humidity), PET (potential evapotranspiration, VPD (vapour pressure deficit).

[b] Fortnightly data.

Table 2
Treatment used in the study.

Treatment	Label
Soil alone	Soil
Dewatered faecal sludge	DFS
Municipal solid waste compost	C
Municipal solid waste and dewatered faecal sludge co-compost	CO
Municipal solid waste compost enriched with ammonium sulphate fertiliser	EC
Municipal solid waste and dewatered faecal sludge co-compost enriched with ammonium sulphate fertiliser	ECO
Ammonium sulphate fertiliser	$(NH_4)_2SO_4$
NPK (15–15–15) + ammonium sulphate fertiliser	NPK + $(NH_4)_2SO_4$

Table 3
Physical and chemical characteristics of sandy loam soil used for greenhouse pot experiment.

Parameters			
Bulk density		$g\ (cm^3)^{-1}$	1.57
Texture	Sand	$g\ kg^{-1}$	600.15
	Clay	$g\ kg^{-1}$	270.50
	Silt	$g\ kg^{-1}$	120.35
pH 1:1 H_2O			5.10
pH 1:2 KCl			4.10
EC		$mS\ m^{-1}$	5.0
Total N		$g\ kg^{-1}$	0.9
Ammonium-N		$g\ kg^{-1}$	0.002
Nitrate-N		$g\ kg^{-1}$	0.016
Total C		$g\ kg^{-1}$	9.0
C/N			10.00

2. Materials and methods

2.1. Study area

The greenhouse pot experiment was conducted at the University of Ghana, College of Agriculture and Consumer Science, Crop Science Department Research Farm in Accra (Lat. 05° 39″ N; Long. 00° 09″ W). The site is about 77 m above sea level and is characterized by an average monthly maximum temperature of 34 °C over the growing period (10-year average), and a minimum temperature of 24 °C with a relative humidity of 94–58%, and a rainfall of about 36 mm (Table 1) (GMS, 2009).

2.2. Experimental design and treatment

The experiment was a split plot design with the treatments arranged in a randomized fashion. The treatments in (Table 2) served as the main plots and the different rates of application based on N content (i.e. 91 kg N ha^{-1}, 150 kg N ha^{-1} and 210 kg N ha^{-1}) served as the sub-plots. Each experimental plot consisted of 26 poly bags of dimension 43.2 cm × 35.6 cm and spaced at a distance of 30 cm × 80 cm and replicated three times.

2.3. Soil characteristic and treatments

A sandy loam soil (Table 3), classified as *Ferric Lixisol* (FAO, 1998b) was taken from 0 to 15 cm layer and used for the study. Some chemical characteristics of the treatments used for the experiment are shown in (Table 4). The soil texture was determined by the hydrometer method (Bouyoucos, 1962), pH was determined in co-compost–water slurry with a ratio of 1:5, v/v (TMECC, 2002) and soil–water slurry with a ratio 1:1, v/v (Black et al., 1965). Inorganic N (NH_4^+-N and NO_3^--N) were determined from 40-ml aliquots of 2 M KCl extracts by steam distillation (Okalebo et al., 2002) using Tecator Kjeltec System 1002 Distilling Unit. Total N was determined by the Kjeldahl method (Okalebo et al., 2002). Total carbon (C) content of soils and treatments was determined by dry combustion using Carbon and Sulphur Analyser Eltra CS 500. Organic carbon was determined by the wet oxidation method (Walkley and Black, 1934) and the organic matter content of soil was estimated by multiplying the organic carbon by a factor of 1.724. Total P was determined by acid digestion and available P by Bray 1 method (Okalebo et al., 2002). The P content of both the digest and the extract was measured colorimetrically using spectrophotometer (model Perkin Elmer Lambda 45). Total K was also determined after digestion with Ternary mixture (20 ml $HClO_4$:500 ml HNO_3:50 ml H_2SO_4) using flame photometer (model Jenway PFP7).

Maize cv. *Abelehii* was grown between 3rd November 2006 and 1st March 2007. Each poly bag was filled with 15 kg sandy loamy soil, *Ferric Lixisol*, which has been sieved through 5 mm mesh size. Three seeds per poly bag were sown and thinned to one seedling, 5 days after emergence. Through out the growing period the moisture content of the soil was adjusted to 60% field capacity using Time Domain Reflectometer (TDR 300). To prevent runoff and soil water evaporation, tap water (pH, 7) was gently added to the soil in each poly bag and the surface was immediately covered with black polythene sheet. Weeds were removed with hands and spraying against stem borers was done whenever necessary.

2.4. Crop water use, crop water consumption rate, transpiration rate and crop water demand

Crop water use is the water used by the crop for growth and cooling purposes and was determined by summing up the water stored in the plant and the amount of water transpired (Eq. (3) and (4)). The water stored in the plant was determined by finding the difference between the fresh and the dry weight of the harvested maize plant. Crop water use per day was calculated as the ratio of the cumulative water used up to the sampling period to number of days within the period. Crop water consumption rate was calculated according to Zhang et al. (2008) as the ratio of cumulative water used or consumed to total leaf area at specific time periods.

The ratio of ET:ETc (actual evapotranspiration:evapotranspiration under standard conditions when no limitations were placed on crop growth or evapotranspiration from soil moisture and salinity stress, crop density, pests and diseases, weed infestation or low fertility) was used to determine how maize crop water

Table 4
Some chemical characteristics of different compost materials used for the experiment.

Treatment	pH (1:5 H_2O)	EC ($\mu S\ cm^{-1}$) (×10)	N (%)	NH_4^+-N ($mg\ kg^{-1}$)	NO_3^- -N ($mg\ kg^{-1}$)	Total P (%)	Avail P ($\mu g\ g^{-1}$)	Total K (%)	Total carbon (%)	C/N
C	8.0 ± 0.03	0.61 ± 0.16	1.22 ± 0.09	149 ± 4.37	79 ± 2.82	1.80 ± 0.17	3619.5 ± 50.71	0.79 ± 0.10	8.50 ± 0.87	7.2
CO	7.8 ± 0.03	0.43 ± 0.52	1.35 ± 0.02	223 ± 6.67	218 ± 2.27	1.60 ± 0.10	2392.0 ± 52.57	1.90 ± 0.12	10.23 ± 0.50	7.6
ECO	7.6 ± 0.01	25.60 ± 1.37	3.10 ± 0.07	12878 ± 963.63	214 ± 24.58	1.14 ± 0.02	2777.0 ± 33.06	1.40 ± 0.06	9.70 ± 0.01	3.1
EC	7.4 ± 0.00	31.80 ± 1.62	2.92 ± 0.21	11728 ± 251.24	219 ± 22.31	0.42 ± 0.04	1994.0 ± 49.70	2.66 ± 0.18	6.38 ± 0.92	2.3
DFS	6.0 ± 0.01	n. a.	2.06 ± 0.24	208 ± 20.64	453 ± 18.71	2.44 ± 0.09	3782.0 ± 40.00	0.47 ± 0.01	7.09 ± 0.29	3.4

Compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), dewatered faecal sludge (DFS).

demand was satisfied in the various treatments (Zougmoré et al., 2004). The ETc was determined by the crop coefficient approach whereby the effect of the various weather conditions were incorporated into PET and the crop characteristics into k_c coefficient:

$$\mathrm{ET_c} = k_c \times \mathrm{PET} \tag{1}$$

where k_c is single crop coefficient (maize k_c is 0.35) (FAO, 1998a), PET is the potential evapotranspiration obtained from a nearby meteorological station. Transpiration: the water transpired or "lost" to the atmosphere from stomata was calculated from the root zone water balance equation (Hillel, 1980). The water balance equation may be expressed as:

$$(\Delta S + \Delta V) = (P + I + U) - (R + D + E + T) \tag{2}$$

where ΔS in mm is change in root zone soil moisture storage (which was zero in our case because the crop was grown at a moisture content of 60% field capacity), ΔV in mm is increment of water incorporated in the plants; P is precipitation (which was zero because the crop was grown in a greenhouse), I in mm is irrigation, U is upward capillary flow into the root zone (which was zero in our case because crops were grown in poly bags and also at 60% field capacity); R is runoff (which was zero in our case because watering was carefully controlled); D is downward drainage out of the root zone (was zero in our case because no water drain out of the poly bags at 60% field capacity); E is direct evaporation from soil surface (in this experiment it was assumed to be zero because thick black polythene sheets were used to cover the soil surface in the pots); T is transpiration.

Thus if ΔS, P, U, R, D and E are zero then Eq. (2) can be written as

$$\Delta V = I - T \tag{3}$$

$$\text{Transpiration (mm) was estimated as, } T = I - \Delta V \tag{4}$$

Transpiration rate (mm day^{-1}) expresses the amount of water transpired or lost from cropped surface per day.

2.5. Transpiration efficiency and water-use efficiency

Transpiration efficiency (kg m^{-3}), TE, was determined according to Kemanian et al. (2005) as plant biomass produced per the amount of water transpired at specific growth stages (6th and 8th) week corresponding to vegetative and reproductive stages. Transpiration efficiency depends on crop characteristics and on the environment in which crops develop. For a species the transpiration efficiency is uniform over a range of climates when differences in vapour pressure deficit (VPD) are accounted for. The normalised TE for the maize crop was obtained by regressing the rate of dry matter accumulation against the ratio of T/VPD (Kemanian et al., 2005; Walker, 1986). The VPD data (i.e. the difference between the amount of moisture in the air and the moisture at saturation) for the period of plant growth was collected from a nearby weather station (Table 1). Water-use efficiency ($\mathrm{WUE_{cwu}}$) was determined according to Howell (2001) by dividing the economic yield (i.e. maize grain at a moisture content of 13%) by the cumulative water use.

2.6. Growth and yield data

Eight plants per treatment were used for agronomic data collection. The chlorophyll content of the fifth leaf (from the base of the selected plants) was measured at three different points, i.e. from the middle towards the tip of the leaf blade using Chlorophyll Meter (model, Minolta SPAD-502) and the mean recorded. Leaf area was measured using Leaf Area Meter (model CI-202, CID INC). Leaf area index (LAI) was calculated as the total leaf area per plant divided by the ground area in the poly bags. Percent leaf senescence was determined on the 9th week by counting the number of senescent leaves and expressing it as a percentage over the total number of leaves per plant. Two plants were selected randomly from each treatment plot, and oven dried at 70 °C for 72 h and the dry weight taken. Eight plants per treatment plot were randomly harvested at physiological maturity and the grains dried to 13% moisture content and the weight taken. The mean grain yield was expressed as kg plant^{-1}. The harvest index was calculated by expressing the grain yield (GY) over the final total dry matter yield (TDM). The root volume was estimated by the water displacement method after the roots were carefully removed from the soil and washed with water. This paper used mean data of growth parameters, yield and nutrient uptake across treatments.

2.7. Plant nutrient analysis

Dried plant samples were ground into fine powder in a mill and 0.1 g of each plant sample was analysed in the laboratory. Total nitrogen (N), phosphorus (P) and potassium (K) were determined according to the method described earlier by Okalebo et al. (2002). Nutrient uptake was calculated as:

$$\text{Nutrient uptake} = \frac{\text{nutrient content} \times \text{sample dry weight}}{100} \tag{5}$$

2.8. Statistical analysis

Data collected were subjected to analysis of variance (ANOVA) and means separated by Duncan multiple range test or Least significant difference at 5%. Simple linear regression was used in excel to determine the correlation between leaf senescence and transpiration efficiency; water-use efficiency and grain yield. GenStat release 9.2 was used to determine the relationship between root volume and crop water use. Similarly, the relationships between growth parameters (i.e. leaf area index (LAI), leaf senescence (LS), leaf chlorophyll content (LC), dry matter and grain yield, water-use efficiency, transpiration efficiency, and nutrient uptake were established using stepwise multiple regression procedure in StatView version 5.0.1 (SAS Institute, 1998). The partial F-ratio criteria for entering and removing variables were such that the F-to-remove variables were set at 3.996 and F-to-enter was set at 4.000.

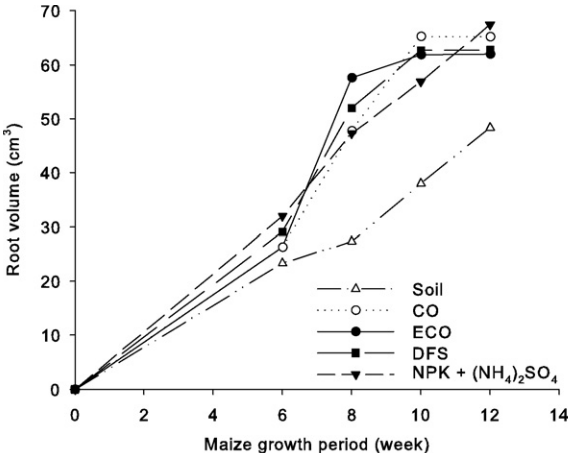

Fig. 1. Effect of co-compost, enriched co-compost and inorganic fertilisers on maize root volume grown under greenhouse at 60% field capacity.

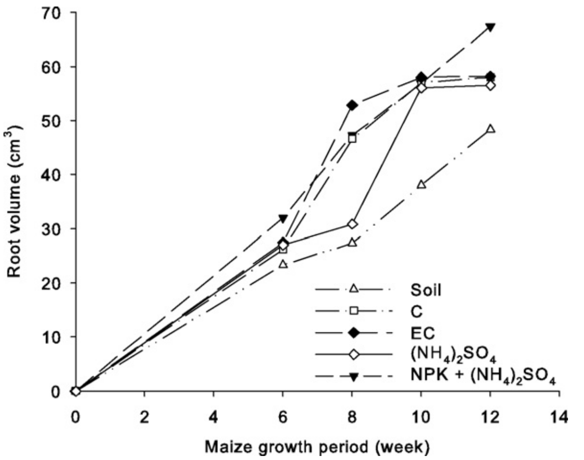

Fig. 2. Effect of compost, enriched compost and inorganic fertilisers on maize root volume grown under greenhouse at 60% field capacity.

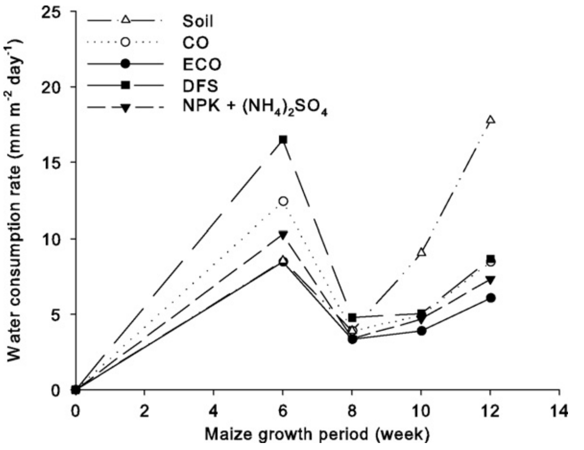

Fig. 3. Changes in water consumption rate per day of maize crop as affected by co-compost, enriched co-compost and inorganic fertiliser grown under greenhouse at 60% field capacity.

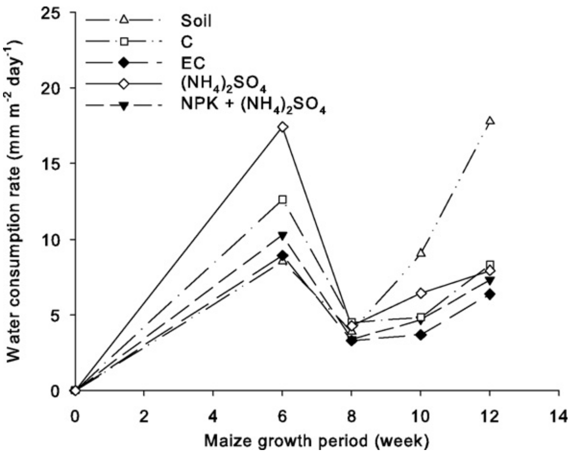

Fig. 4. Changes in water consumption rate per day of maize crop as affected by compost, enriched compost and inorganic fertiliser grown under greenhouse at 60% field capacity.

3. Results

3.1. Sources of fertiliser and effect on crop water use, crop water demand, transpiration rate and water consumption rate

There was no significant difference between the N application rates for any particular treatment; therefore results in this section are presented as averages across treatments. Maize crops from inorganic fertiliser or compost and its related treatments showed larger root volume as compared to soil alone (Figs. 1 and 2). There was a relationship between root volume and crop water use and this was dependent on growth stage of the maize crop (Table 5). At the initial stages of plant growth (vegetative phase), there was a weak correlation coefficient ($r = 0.13$) between crop water use and root volume. However, at the reproductive phase, the relationship became stronger in the 8th week ($r = 0.73$) through to the 10th week ($r = 0.82$) and thereafter decreased at maturity, i.e. in the 12th week ($r = 0.40$) (Table 5).

Table 5
Correlation between root volumes of maize plant (*Zea mays* L.) and water use at 6th–12th week.

Week	Correlation coefficient (r)
6	0.13
8	0.73[*]
10	0.82[*]
12	0.41

[*] $P \leq 0.05$.

Cumulative water use of maize crop was highest in EC and lowest in soil alone (Table 6). Results showed that there were differences in the cumulative crop water use among compost and its derivatives. In addition, cumulative crop water use in EC was significantly higher than in DFS, C, or $(NH_4)_2SO_4$ (Table 6). No significant difference was observed in cumulative crop water use between EC, CO, ECO and NPK + $(NH_4)_2SO_4$. Crop water use per day from the 4th to the 10th week decreased in the following order: DFS > CO > C > EC > ECO > NPK + $(NH_4)_2SO_4$. The trend however changed from the tenth to the 12th week onwards, with EC, ECO, CO and NPK + $(NH_4)_2SO_4$ recording higher crop water use per day (data not provided). No significant difference was also observed in crop water use per day among compost related treatments in the eighth to 10th week (Table 6). Water consumption per day of the maize crop from emergence to the 6th week fluctuated and no significant difference was observed among treatments (Figs. 3 and 4). Water consumption per day was higher in crops grown on soil alone (3.75–17.44 mm m^{-2} day^{-1}), DFS (4.03–8.42 mm m^{-2} day^{-1}) CO (3.26–8.24 mm m^{-2} day^{-1}) and C (3.77–8.08 mm m^{-2} day^{-1}). Lowest water consumption per day was observed in maize crops grown in ECO (2.86–5.96 mm m^{-2} day^{-1}) followed by EC (2.78–6.22 mm m^{-2} day^{-1}) and NPK + $(NH_4)_2SO_4$ (2.88–7.17 mm m^{-2} day^{-1}). Crop water demand satisfaction in compost and its derivatives was significantly higher than that of inorganic fertiliser or soil alone (Table 6). Furthermore, results showed that no significant difference was observed in the crop water demand satisfaction for treatments DFS, C, CO, DFS, EC and ECO in the 8th week. But significant differences were observed in the 10th week for treatments DFS, C, CO and EC or ECO. The amount of water transpired per day by the maize crops on treatments containing compost and its derivatives was significantly higher than those grown on treatments containing inorganic fertilisers and soil alone (Table 6).

3.2. Sources of fertiliser and effect on transpiration efficiency and water-use efficiency of maize crop

Transpiration efficiency (TE) at the 6th week after planting was generally higher than the 8th week (Table 7). At the 6th week (vegetative phase), results showed that, TE increased with increasing rate of N application in DFS, EC, ECO, $(NH_4)_2SO_4$ and NPK + $(NH_4)_2SO_4$. However, in treatments C and CO, TE increased from 91 to 150 kg N ha^{-1}, but decreased at the higher rate of 210 kg

Table 6
Effect of compost, its derivatives, or inorganic fertiliser on maize water use, transpiration rate and crop water demand satisfaction.

Treatment	Cumulative water use (mm plant^{-1})	Crop water use (mm plant^{-1} day^{-1})		Transpiration (mm plant^{-1} day^{-1})		Plant water demand satisfaction	
		8th week	10th week	8th week	10th week	8th week	10th week
Soil	201.90 c	1.20 c	2.37 c	1.18 d	2.35 c	0.300 d	0.397 f
DFS	207.43 b	1.30 a	2.45 a	1.27 a	2.41 a	0.314 ab	0.408 a
C	207.39 b	1.28 a	2.44 a	1.25 b	2.40 a	0.312b	0.407 b
CO	209.38 ab	1.30 a	2.45 a	1.26 ab	2.41 a	0.314 ab	0.408 a
EC	210.70 a	1.27 a	2.43 a	1.23 bc	2.38 ab	0.309 bc	0.403 c
ECO	208.50 ab	1.27 a	2.43 a	1.23 bc	2.38 ab	0.308 bc	0.403 c
$(NH_4)_2SO_4$	207.80 b	1.23 b	2.39 b	1.21 c	2.35 c	0.305 cd	0.399 d
NPK + $(NH_4)_2SO_4$	208.65 ab	1.23 b	2.40 b	1.21 c	2.36 c	0.302 d	0.398 e

Dewatered faecal sludge (DFS), compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), NPK (15:15:15).

Table 7
Effect of rates of compost, its derivatives, and inorganic fertiliser on transpiration efficiency of maize (kg m^{-3}).

Treatment	Vegetative phase (6th weeks) (kg N ha^{-1})				Silking–tasseling (8th weeks) (kg N ha^{-1})			
	0	91	150	210	0	91	150	210
Soil	7.30	–	–	–	6.01	–	–	–
DFS	–	8.14	8.55	9.20	–	8.36	9.54	8.40
C	–	7.19	8.42	7.95	–	6.52	7.95	8.58
CO	–	7.76	9.44	7.37	–	7.45	7.43	8.46
EC	–	8.07	8.19	8.42	–	7.32	8.64	9.20
ECO	–	8.62	9.39	10.17	–	8.80	8.72	8.21
$(NH_4)_2SO_4$	–	9.41	9.10	10.98	–	6.82	6.43	6.81
NPK + $(NH_4)_2SO_4$	–	8.49	9.67	10.67	–	8.24	7.70	7.94
LSD treatment			2.39*				1.76*	
LSD levels			1.00*				0.99*	
LSD treat × levels			3.22*				2.80*	

Dewatered faecal sludge (DFS), compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), NPK (15:15:15).
* $P \leq 0.05$.

N ha^{-1}. Conversely, treatments C and CO, showed an increase in TE with increasing N application at the 8th week (i.e. reproductive phase). The TE of treatments DFS, ECO, $(NH_4)_2SO_4$ and NPK + $(NH_4)_2SO_4$ at the reproductive phase did not show any regular pattern as N application rate increased. A linear relationship with a negative intercept was obtained between the rate of dry matter accumulation and the ratio of transpiration to vapour pressure deficit, VPD (Figs. 5 and 6). Transpiration efficiency (slope) varied according to the type of treatment applied. The highest TE of 8.6 Pascal (Pa) was observed in crops treated with ECO, while crops from soil alone showed the lowest TE of 6.9 Pa.

The result of a stepwise multiple regression of TE (a dependent variable) against the following independent variables (leaf area index (LAI), leaf senescence (LS), leaf chlorophyll content (LC), water-use efficiency (WUE) and nutrient (N, P, K) uptake) included only potassium (K) in the model with an adjusted $R^2 = 0.18$ and this was significant at ($P \leq 0.0001$). The model eliminated LAI, LS, LC, WUE, N and P. The regression equation for the relationship between TE and the variable in the model is shown as:

$$\mathrm{TE} = 1.56 \times \mathrm{K} + 5.08 \tag{6}$$

where TE = transpiration efficiency; K = potassium.

A negative and strong correlation was observed between leaf senescence and TE ($r = -0.78$).

The water-use efficiency (WUE_{CWU}) increased with N application rate. Maize crops that received 210 kg N ha^{-1} showed the highest and significant increased in WUE_{CWU} compared to those that received 150 kg N ha^{-1}, except for treatments EC, ECO and

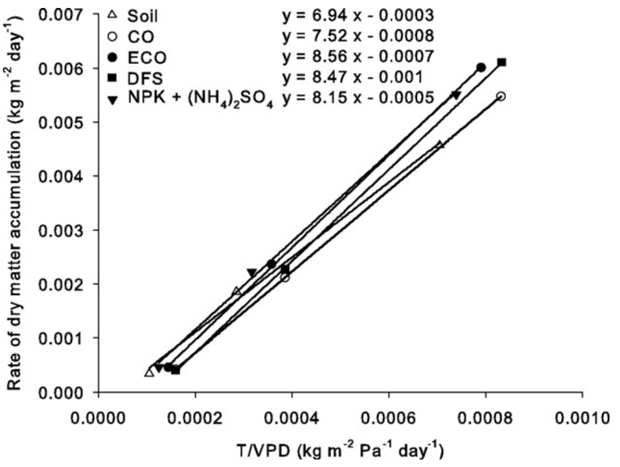

Fig. 5. Effect of co-compost, enriched co-compost and inorganic fertilisers on rate of dry matter production of maize per day versus transpiration/vapour pressure deficit.

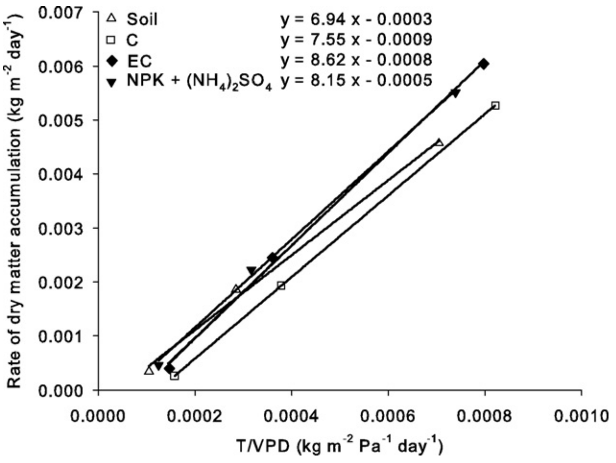

Fig. 6. Effect of compost, enriched compost and inorganic fertiliser on rate of dry matter production of maize per day versus transpiration/vapour pressure deficit.

Table 8
Effect of rate of application of compost, its derivatives, and inorganic fertiliser on maize water-use efficiency (kg m^{-3}).

Treatment	0	91	150	210
	(kg N ha^{-1})			
Soil	0.12	–	–	–
DFS	–	0.33	0.42	0.46
C	–	0.35	0.39	0.44
CO	–	0.33	0.35	0.40
EC	–	0.44	0.49	0.51
ECO	–	0.48	0.48	0.51
$(NH_4)_2SO_4$	–	0.33	0.35	0.42
NPK + $(NH_4)_2SO_4$	–	0.40	0.45	0.46
LSD treatment			0.09***	
LSD rate			0.03***	
LSD treat × rate			0.11*	

Dewatered faecal sludge (DFS), compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), NPK (15:15:15).
* $P \leq 0.05$.
*** $P \leq 0.001$.

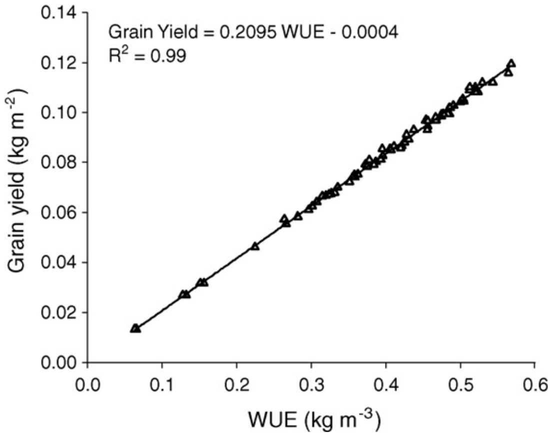

Fig. 7. Relationship between water-use efficiency and grain yield of maize grown in a pot under greenhouse at 60% field capacity.

NPK + $(NH_4)_2SO_4$ (Table 8). Water-use efficiency of maize crop at 150 kg N ha^{-1} was significantly higher than those at 91 kg N ha^{-1} except CO,ECO and $(NH_4)_2SO_4$. Water-use efficiency of maize crop from ECO was 11% and 4 times higher than crops from NPK + $(NH_4)_2SO_4$ or soil alone respectively. Also, the WUE_{CWU} of maize crop from ECO was 18% and 36% higher than DFS and CO respectively. Similarly, WUE_{CWU} of maize crop from EC was 19% higher than C. The result of a stepwise multiple regression of WUE_{CWU} (dependent variable) against growth parameters including root volume (RV), transpiration efficiency (TE), nutrient (N, P, K) uptake and soil organic matter (SOM) gave an adjusted $R^2 = 0.96$ which was significant at ($P \leq 0.0001$). Leaf senescence (LS), harvest index (HI), TE, N and K were included in the model whereas LAI, LC, RV, SOM and P were out of the model. The regression equation of the variables in the model is shown as:

$$WUE_{CWU} = -0.001 \times LS + 0.005 \times TE + 1.046 \times HI + 0.147 \times N + 0.24 \times K - 0.086 \quad (7)$$

where WUE_{CWU} = water-use efficiency; LS = leaf senescence; TE = transpiration efficiency; HI = harvest index; N = nitrogen; K = potassium.

3.3. Sources of fertiliser and effect on growth parameters, dry matter yield, grain yield and nutrient uptake

The leaf area index of crops from treatments ECO and EC was higher and significantly different ($P \leq 0.05$) from NPK + $(NH_4)_2SO_4$, C, CO and DFS. Although the N contents of the treatments were about the same, there were differences in the chlorophyll contents of the leaves. Chlorophyll content of crops from ECO and EC was significantly ($P \leq 0.05$) higher than the other compost treatments and NPK + $(NH_4)_2SO_4$. However, results showed that no significant difference was observed in the harvest index among the treatments except soil alone. The percentage leaf senescence was affected by the different treatments. A higher and significant percentage of the senesced leaves was observed under soil only compared to the other treatments (Table 9). Among the treatments, the least percentage of senesced leaves was observed in treatments EC and ECO and was significantly ($P \leq 0.05$) different from the inorganic fertiliser and the other compost related treatments. Total dry matter and grain yield from ECO and EC treated crops were significantly ($P \leq 0.05$) higher than all the treatments except NPK + $(NH_4)_2SO_4$.

The result of a stepwise multiple regression of dry matter yield (dependent variable) against the following independent variables: leaf area index (LAI), leaf chlorophyll content (LC), leaf senescence (LS), transpiration efficiency (TE), water-use efficiency (WUE_{cwu}), nitrogen (N), phosphorus (P), and potassium (K) gave an adjusted $R^2 = 0.83$ and this was significant at ($P \leq 0.0001$). Leaf senescence, TE, N and K were included in the model whilst LAI, LC, WUE and P were out of the model. The regression equation for the relationship between DMY and those parameters in the model is shown as:

$$DMY = -0.35 \times LS + 1.00 \times TE + 23.00 \times N + 4.93 \times K + 39.04 \quad (8)$$

where DMY = dry matter yield; TE = transpiration efficiency; N = nitrogen; K = potassium.

Table 9
Effect of compost, its derivatives, and inorganic fertiliser on growth parameters, dry matter and grain yield.

Treatment	Leaf area index[a]	Leaf chlorophyll content[c]	Harvest index[c]	Leaf senescence[b] (%)	Total dry matter yield[c] (g plant^{-1})	Grain yield[c] (g plant^{-1})
Soil	1.60 e	29.15 d	0.13 b	50 a	41.69 d	5.74 c
DFS	3.47 d	38.93 c	0.29 a	31 b	65.03 c	19.90 b
C	3.57 d	38.57 c	0.30 a	29 b	62.58 c	19.38 b
CO	3.49 d	38.04 c	0.27 a	33 b	70.48 c	18.23 b
EC	4.59 b	45.51 a	0.32 a	20 c	76.10 a	24.32 a
ECO	4.99 a	47.42 a	0.32 a	18 c	76.77 a	24.55 a
$(NH_4)_2SO_4$	3.68 d	41.34 b	0.29 a	29 b	64.21 c	18.33 b
NPK + $(NH_4)_2SO_4$	3.99 c	43.49 b	0.30 a	27 b	72.96 ab	21.80 ab

Dewatered faecal sludge (DFS), compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), NPK (15:15:15).
[a] Determined at 10th week.
[b] Determined at 9th week.
[c] Determined after harvest.
Values with different letters in a column are significantly different ($P \leq 0.05$) from each other.

Table 10
Effect of compost, its derivatives, inorganic fertiliser on soil organic matter and nutrient uptake of maize crop at final harvest.

Treatment	N	P	K	SOM (%)
	($mg\ plant^{-1}$)			
Soil	350.9 d	48.1 d	1057.5 c	0.8 d
DFS	572.9 bc	88.0 bc	1838.1 ba	1.0 c
C	537.5 bc	68.9 bc	1673.0 b	1.1 b
CO	573.3 bc	84.8 bc	1831.2 ba	1.2 b
EC	695.8 a	70.8 bc	1936.6 ba	1.2 b
ECO	665.2 ab	119.8 a	2173.4 a	1.3 a
$(NH_4)_2SO_4$	519.0 c	76.6 c	1315.5 c	0.8 d
NPK + $(NH_4)_2SO_4$	631.7 bc	98.2 b	2144.6 a	1.1 bc

Dewatered faecal sludge (DFS), compost (C), co-compost (CO), enriched compost (EC), enriched co-compost (ECO), NPK (15:15:15).
Values with different letters in a column are significantly different ($P \leq 0.05$) from each other.

There was a strong and positive linear relationship between WUE_{cwu} and grain yield (Fig. 7) with correlation coefficient of ($r = 0.99$).

Nitrogen (N) uptake by maize crops from EC and ECO treatments was significantly higher (695.75 and 665.19 $mg\ plant^{-1}$), than that in NPK + $(NH_4)_2SO_4$ (631.66 $mg\ plant^{-1}$) and the other compost treatments (Table 10). Phosphorus uptake by maize crops from ECO (119.78 $mg\ plant^{-1}$) was significantly ($P < 0.05$) higher than all the treatments. No significant difference was observed in the phosphorus uptake by crops from NPK + $(NH_4)_2SO_4$ and the other compost related treated plants. Potassium uptake by crops follow similar pattern like that of phosphorus. Potassium uptake was highest in crops from NPK + $(NH_4)_2SO_4$, ECO, and EC treated plots.

4. Discussion

Poor root development (Figs. 1 and 2), differences in growth rate as indicated by smaller leaf area index and dry matter production (Table 9) could account for the lower cumulative water use by maize crop (Table 6) from soil alone as compared to plants from inorganic fertiliser or compost related treatments. On the contrary, rapid growth (as indicated by higher root volume and dry matter yield) may explain the higher and significant amount of cumulative water used by crops from EC, CO, NPK + $(NH_4)_2SO_4$ and ECO as compared to DFS or C and $(NH_4)_2SO_4$. About 73–82% of the variations in crop water use at the vegetative stage and physiological maturity could be explained by root volume of the maize crops (Table 5). The nutrients supplied by the inorganic fertiliser or compost and its related treatments extended the roots and increased the volume. The higher the root volume the more the roots can ramify, exploit and absorb most of the available water. This may explain the increased correlation coefficient observed between crop water use and root volume from the initial stages of growth through the reproductive stage to physiological maturity. The nutrients expanded the leaf area which is likely to increase potential water use by transpiration. The high dry matter production also requires high crop water use for physiological activities such as transpiration, nutrient translocation and photosynthesis. This result agrees with Power (1983) who reported expansion of leaf area to markedly affect crop water use. Dagdelen et al. (2006) also reported that leaf area index and dry matter yields increase with increasing water use. Tanner and Sinclair (1983) Walker (1986) similarly, reported a strong positive correlation between dry matter accumulation and crop water use. Campbell et al. (1977), also reported that soil fertility status alters plant rooting pattern (rooting depth, rooting density, rate of root penetration), which markedly affects crop water use, particularly in a well-drained soil.

The higher crop water use per day and transpiration rate per day of maize crops in compost and its related treatments compared to crops that had received inorganic fertiliser (Table 6) could be attributed to enhanced water retention as a result of improved soil organic matter content, and differences in potassium (K) uptake (Table 10). Potassium uptake in NPK + $(NH_4)_2SO_4$ was 39% higher than $(NH_4)_2SO_4$. The high dependency of transpiration rate, 86%, on leaf area in $(NH_4)_2SO_4$ compared to 62% in NPK + $(NH_4)_2SO_4$ suggest the role of K. Brag (1972) as well as Peaslee and Moss (1968) reported high K content of plants to be correlated with low rate of transpiration. Bradbury and Malcolm (1977) similarly reported high potassium uptake to be associated with significant reduction in water loss per unit of height increment and shoot weight of Stika sprue (*Picea sitchensis*). As plant ages K content decreases and transpiration rate increases (Brag, 1972). This may explain the high crop water use per day and transpiration per day that were observed in the 12th week (data not provided). Alternatively, the low crop water use per day and transpiration per day of maize crop from soil alone may be attributed to poor growth and low dry matter yield.

The insignificant difference and fluctuation in water consumption rate (WCR) in the first-6 week (Figs. 3 and 4) could be attributed to low crop N demand, while the significant difference in WCR for crops from soil alone and the other treatments from the six to the 12th week could be attributed to differences in N demand. The fact that there was no significant difference in WCR among CO, ECO and NPK + $(NH_4)_2SO_4$ indicates that N amount rather than treatment effect was the most important factor in WCR.

The values for crop water demand satisfaction at the 8th and 10th weeks (Table 6) indicate that the water supplied to the crop was moderate (i.e. 60% FC). According to Zougmoré et al. (2004) the rate at which crop water demand is met is considered satisfactory when ET:ETc > 0.75, moderate when 0.3 < ET:ETc > 0.75 and deficient when ET:ETc < 0.3. The higher and significant difference that was revealed in crop water demand satisfaction under compost and its related treatment as compared to inorganic fertiliser treated soil indicate that compost media contain more available water than soil treated with inorganic fertiliser. This is because compost and its related treatments increased the organic matter content of the soil (Table 10) and this increased the soil available water-holding capacity. Power (1983) reported that plant available soil water (volume basis) increased by about 1.8 percentage-units for each percentage-unit increase in organic matter content for soils ranging in texture from sand to clay.

The decrease in transpiration efficiency, TE, observed in the 8th week (Table 7) compared to the 6th week could be attributed to the high percentage senescence and ageing of the lower leaves (Table 9). The aged lower leaves and the high senesced leaves are associated with reduced activities which are expected to cause a reduction in CO_2 assimilation. This may explain the negative strong correlation coefficient that was observed between leaf senescence and transpiration efficiency ($r = -0.78$). Koch and Estes (1975) reported a reduction in CO_2 assimilation as maize plant aged and attributed it to a reduction in the activities of the lower leaves. The increase in TE observed in DFS, EC, ECO, $(NH_4)_2SO_4$ and NPK + $(NH_4)_2SO_4$ at the vegetative phase and in C and CO at the reproductive phase as rate of N application increased could be attributed to the differences in nutrient release pattern and uptake. About 24–65% of the total N content of DFS, EC, ECO, $(NH_4)_2SO_4$ and NPK + $(NH_4)_2SO_4$ were released at the 6th week of incubation when compared to less than 7% in C and CO, in the 8th week (data not provided). Since about 71.7% of the total N of fertiliser supplied to crops is absorbed by the maize at the vegetative phase (Moll et al., 1982), the N requirement of the maize crops from treatments DFS, ECO, $(NH_4)_2SO_4$ and NPK + $(NH_4)_2SO_4$ might have been met already. This may explain why increased rates of N application did not show a corresponding increase in TE at the reproductive phase. On the other hand the slow N release for treatments C, and CO, might explain the increase in TE with increasing rate of N application at the reproductive phase to compensate for the inadequate N that might be obtained at the vegetative phase. These results leads one to conclude that depending on the type of N sources, increased rate of N application will increase TE at either the vegetative or reproductive phases. The result agrees with Cooper et al. (1987) and Corak et al. (1991) who reported an increase in TE as N application increased. Walker and Richards (1985) who reported that improved soil fertility increased TE only if the soil nutrient levels were low. However, the result disagrees with Goudriaan and Van Keulen (1979) and Ogola et al. (2002) who found no effect of N levels on TE of maize (*Z. mays* L.).

It is seen from the model (Eq. (6)) that 18% of the variations in TE can be accounted for by K uptake. A unit increase in K uptake increased TE by 1.56 kg m^{-3}. The low ($R^2 = 0.18$) value for K could be attributed to the entire K content of the plant that was used in the regression analysis. It would have been high if only the leaf K content was used. The strong correlation coefficient ($r = 0.91$) between K and N may explain the absence of N in the model. However, in the absence of K, N accounted for about 12% of the variations in TE. The same reason given above explains the low ($R^2 = 0.12$) value for N. Improvement in nutrient uptake explain the high TE observed at the vegetative phase in NPK + $(NH_4)_2SO_4$, S + $(NH_4)_2SO_4$, and ECO as compared to C, CO, DFS and soil (S) alone. Improved nutrient uptake (especially N and K) might have increased the photosynthetic capacity of the plant (Condon et al., 2002), consequently leading to increased biomass production (Table 9). The results agree with Zhang et al. (1998) who reported an increase in TE of wheat (*Triticum aestivum*) due to rapid growth as a result of N application. Lips et al. (1990) also reported an increase of TE of maize (*Z. mays*) as K uptake increased. The TE when VPD was corrected (6.9–8.6 Pa) was within the 5.5–9.7 Pa reported by Walker (1986) for field grown maize. The mean 7.9 Pa was within the mean range of 7.4 and 8.0 Pa reported for maize by Walker (1986), Tanner and Sinclair (1983). This result supports the view that for given specie, the TE is uniform over a range of climate when differences in VPD are accounted for.

The increase in water-use efficiency, WUE_{CWU} as rate of N application increased (Table 8) can be attributed to high nutrient (e.g. nitrogen and potassium) uptake, transpiration efficiency (TE), harvest index (HI) and low leaf senescence (LS). The same reason also account for the high WUE_{CWU} for crops from treatments ECO, EC and NPK + $(NH_4)_2SO_4$. The multiple regression result showed that LS, TE, HI, N and K significantly account for 96% of the variations in water-use efficiency (WUE_{cwu}). From the model (Eq. (7)), a unit decrease in LS can increase WUE by 0.001 kg m^{-3} keeping TE, HI, N and K constant. Alternatively, a unit increase in TE, HI, N or K can increase WUE by 0.005, 1.046, 0.147 and 0.240 kg m^{-3}, respectively, when any three of the variables are kept constant at a time. High nutrient uptake (especially N) increased leaf development (Tables 9 and 10) which consequently increased the photosynthetic capacity of the crops, hence the higher harvest index for ECO, EC and NPK + $(NH_4)_2SO_4$. Harvest index is a key component in improving WUE_{CWU} ($R^2 = 0.95$). This agrees with Xue et al. (2006) who reported increased WUE_{cwu} as harvest index increased under deficit irrigation. On the other hand, the very low nutrient uptake by the maize crop from soil alone might have caused a reduction in the biochemical capacity for photosynthesis and photosynthesis to take place in a higher ratio of stomata to biochemical conductance (Raven et al., 2004). At a very low N supply C_4 plants such as maize increased leakage of the bundle sheaths to carbon dioxide (CO_2)—a mechanism whereby WUE_{CWU} is decreased (Fravolini et al., 2002). These two factors may explain the low WUE_{CWU} for the maize crops from soil alone. The significant increase in WUE_{CWU} of maize crop as N level increased is in agreement with the results of Li et al. (1994) and Ting-Hui et al. (2006). Li et al. (1994) however assigned the increase in WUE_{CWU} to root growth and grain yield. The WUE_{CWU} values of 0.12–0.51 kg m^{-3} obtained in this experiment are within the range reported by Katerji et al. (2008) but lower than the range (0.82–2.16 kg m^{-3}) reported by Dagdelen et al. (2006), Katerji et al. (1996), Karam et al. (2003) and Fernandez et al. (1996). The differences in values can be attributed to differences in climate, soil texture, varietal differences, treatments (fertiliser and water regime) planting density, and medium of growth (pot or field).

The significant higher leaf area index for treatments ECO and EC compared to treatments NPK + $(NH_4)_2SO_4$,C, CO, DFS and soil alone can be attributed to higher soil moisture, nutrient supply and availability (Tables 4 and 9). Sivasankar et al. (1993) reported increased N supply to increase leaf area development. Muchow (1994) and Mburu et al. (1999) reported that water and nitrogen availability influence leaf area index. However, nitrogen or nutrient availability to crops is influenced by soil water supply (Kamoni et al., 2003; Novoa and Loomis, 1981; Power, 1983). The significant increase in leaf chlorophyll content for ECO, EC compared to inorganic fertilisers and other compost treatments could be attributed to differences in the nutrient uptake (especially, N). Sheshshayee et al. (2006) reported that increase in chlorophyll content of leaves accompanied N levels changes.

The harvest index reflects the partitioning of photosynthate between the grain and the vegetative plant. Improvement in harvest index emphasizes the importance of carbon allocation to grain development (Sinclair, 1998). The relatively higher harvest index of maize crops for treatments ECO and EC (Table 9) compared to NPK + $(NH_4)_2SO_4$, C, CO and DFS may be attributed to the high nitrogen uptake (Table 10). Sinclair (1998) reported high harvest index to be associated with high N levels in maize crops. The harvest index for the various treatments is within the range reported for maize by Hay and Gilbert (2001). The higher dry matter yield (DMY) for ECO, EC compared to NPK + $(NH_4)_2SO_4$ and the other compost related treatments can be attributed to their high nitrogen (N) and potassium (K) uptake, transpiration efficiency (TE), and low leaf senescence (LS). From the stepwise multiple regression result it can be seen that LS, TE, N and K significantly account for about 83% of the variations in DMY. The model (Eq. (8)) showed that, a unit decrease in LS can increase DMY by 0.35 g keeping the effect of TE, N and K constant. Alternatively, a unit increase in TE can increase DMY by 1.00 g, when LS, N and K are kept constant. Similarly, a unit increase in N or K can increase DMY by 23.02 g and 4.93 g, respectively, when either N or K in addition to LS and TE are kept constant. The strong correlation coefficients ($r = 0.71–0.95$) between LS, TE, N or K and LAI, LC, WUE or P may explain why LAI, LC, WUE and P were out of the model. In the absence of LS, TE, N or K in the model LC, WUE and P could explain 73% of the variations in DMY and this was significant at ($P < 0.0001$).

On the other hand, the high grain yield for treatments ECO, EC compared to NPK + $(NH_4)_2SO_4$ and the other compost related treatments can mainly be attributed to their high water-use efficiency (Table 8). Water-use efficiency significantly account for about 99% of the variations in grain yield (Fig. 7). An increase in a unit of WUE_{cwu} can lead to an increase in grain yield by 0.21 kg m^{-2}. Nitrogen influences WUE_{cwu} and is also required in proteins and nucleotides of developing seeds within a fairly specific concentration. There is a high dependence of seed yield on N supplied to crops ($R^2 = 0.94$). Therefore, the low grain yield for soil alone is due to reduced plant growth as a result of low nutrient (especially, N) supply and uptake.

The high N uptake for maize crops from treatments EC and ECO compared to NPK + $(NH_4)_2SO_4$, C, CO, and DFS can be attributed to the initial high organic matter, NH_4^+-N content, relatively low pH of treatments (Table 4), high available soil moisture (Table 6), high mineralization rate and per cent nitrogen recovery (data not provided). The high organic matter is expected to hold more water which is a key factor in nutrient uptake. Novoa and Loomis (1981) and Kamoni et al. (2003) reported improved crops N uptake to be associated with increased nutrient input and available soil water supply. Alternatively, reduction in soil inorganic P sorption capacity and sorption percentage may account for the high and significant P uptake for crops from ECO compared to NPK + $(NH_4)_2SO_4$ (Chen et al., 2001). Similarly, the humic organic acids from compost and its derivatives might combine with iron, aluminium or calcium in the soil to reduce P adsorption (Barrow, 1989), thus making more P available to crops from compost and its derivatives. The improvement in soil organic matter content for compost related treatments is due to their initial high organic matter content.

5. Conclusion

The hypothesis tested in this study has not been disproved. The different fertiliser sources showed different effect on transpiration efficiency (TE) and this was dependent on the growth stage of the plant. Increase in N application rate increased TE at the vegetative phase for fast nutrient releasing fertilisers (DFS, ECO, EC, NPK + $(NH_4)_2SO_4$, $(NH_4)_2SO_4$) and at the reproductive phase for slow nutrient releasing fertilisers (C and CO). The water-use efficiency (WUE_{cwu}) of maize crop increased with N application rate. N-enriched co-compost (ECO) improved crop WUE_{cwu} and was 11% and 4 times higher than that for NPK + $(NH_4)_2SO_4$ or soil alone; and 18–36% higher than those for DFS and CO. About 97% of the variations in WUE_{cwu} of maize crop for ECO, EC and NPK + $(NH_4)_2SO_4$ were mainly due to high nutrient uptake (N and K), TE, harvest index (HI) and low leaf senescence (LS). Treatment ECO used less amount of water to produce dry matter yield (DMY) and grain yield (GY) that was 5.2% and 12.6%, respectively, higher than NPK + $(NH_4)_2SO_4$. Similarly, the DMY and GY for ECO was 8.9–18.5% and 23.4–34.7%, respectively, higher than DFS and CO. High nutrient (N and K) uptake, TE, low LS accounts for 83% of the variations in DMY whereas WUE_{cwu} accounts for 99% of the variations in GY. Thus, the study concluded that different sources of fertiliser increased TE and WUE_{cwu} of maize differently as N application rate increases.

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