Water Use Efficiency and Nutrient Uptake of Maize As Affected By Organic And Inorganic Fertilizer

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Abstract

A sixty day greenhouse study was conducted to evaluate the water use efficiency of maize and the uptake of N, P and K. Twenty four pots containing 8.5 kg each of topsoil were treated with either poultry manure or urea and data taken from planted and non planted pots. Pots planted to maize were assessed for plant height, leaf number, dry matter yield, water loss (evapotranspiration), and the total plant water use over 60 days. Concurrently, water loss from non – planted pots was used to estimate evaporation. Maize fertilized with poultry manure showed significantly higher water use efficiency (54.6 g/ litre) over those fertilized with urea (48.7 g/litre). Consequently, crop growth rate was significantly higher in plants fertilized with poultry manure (5.94g/day) than those fertilized with urea (5g/day). There was significantly higher N and P uptake from poultry manure amended soil, but there was no difference in K uptake by plants fertilized with either poultry manure or urea.

Keywords: Evapotranspiration, Nutrient uptake, greenhouse, poultry manure, urea and maize

Introduction

Water Use Efficiency (WUE) is a reliable indicator of crop biomass production relative to water consumption, and it is a ratio between two physiological (transpiration and photosynthesis) or agronomic (yield and crop water use) entities (Blum, 2005). WUE is most efficient when optimum advantage is gained from the least amount of water available to the plant (Axel et al., 2005), and it may be evaluated in terms of the water use efficiency for biomass growth or the Harvest Index (Condon et al., 2002). Plants differ in their ability to utilise water, and WUE may vary from location to location. WUE may also vary due to soil conditions, agricultural practices including fertilization, and atmospheric factors. Generally, highest water use occurs at the point of highest biomass production (Cox et al., 2002).

WUE is highest under limited irrigation conditions such as during the dry season in the tropics (Kang et al., 2002). Soil structure and soil texture are also important factors which affect water use efficiency of plants, as crops on deep clay and peat soils tend to show highest water and nitrogen use efficiency and require relatively low
amounts of sub-irrigation water, while sandy soils require relatively high sub irrigation rates but an ineffective use of water and nitrogen resulting in a low biomass level (Kang et al., 2002). With increasing water scarcity in agriculture, there is a need to increase water use efficiency in crops (Lothar et al., 2005).

Nutrient uptake is the process by which plant roots take up nutrients present in soil solution, with such nutrients subsequently distributed to aerial portions of the plant (Havlin et al., 2005). This is affected mainly by environmental conditions, management practices, the concentration of nutrients and the form in which nutrients are present in the soil (Allen and David, 2007). Nutrient use efficiency is the ability of a plant to utilise soil available nutrients to result in measurable yield or yield parameters such as plant height, leaf development, dry matter and fruit / grain production (Hati et al., 2006). Research efforts to improve nutrient use efficiencies include increased stress tolerance of improved maize hybrids; improved production practices such as conservation tillage and planted population control; improved nutrient management with regard to form, placement and timing of fertilizer materials (Bhattacharya et al., 2008).

There is a direct relationship between water use, nutrient uptake and biomass yield in crops (Hobbie and Colpaert, 2004; Lucas et al., 2007). Water is a major factor in nutrient availability to plants as it is the vehicle through which nutrients move through soil to access plant roots for uptake (Rattan 2006). Maize has been found to have high water use efficiency when compared to other crops as well as being highly nutrient efficient because it produces high biomass in linear response to nutrient availability without excessive evapotranspiration (Ogola et al., 2002).

The objectives of the study were to:

i. Evaluate the amount of water being used up by maize plant for vegetative growth and also the amount of water lost through evaporation and evapotranspiration.

ii. To evaluate the effect of nutrient source (organic and inorganic) on water use by maize

iii. To determine the level of nitrogen (N), Phosphorus (P), and potassium (K) uptake of maize fertilized by poultry manure and urea.

Materials and Methods

Bulk topsoil was collected from the Eastern farm of Michael Okpara University of Agriculture, Umudike at a depth of 0-15cm and used in a greenhouse pot experiment between August and October, 2011. The base of each bucket was lined with 500g of charcoal to improve drainage, then 8.5kg of air dried soil was weighed into each bucket. The water content of the soil was brought to field capacity by adding 2.8kg of water to
each pot. The pots were placed on a raised concrete slab under a transparent rain shelter with a roof, to prevent excessive heating in direct sunlight. The moist soil was amended with either 30g of poultry manure before planting or 0.9g urea applied two weeks after germination of maize. Urea was not applied at planting to avoid volatilization or loss by leaching before maize plants became established. Applied urea was equivalent to 120kg N/ha, while poultry manure was equivalent to 140kg N/ha. The nutrient analysis of poultry manure and soil used in the greenhouse study is presented in Table 1.

<table>
<thead>
<tr>
<th>Source</th>
<th>pH (water)</th>
<th>Org.C. (%)</th>
<th>N (%)</th>
<th>P mg/kg</th>
<th>Ca cmol/kg</th>
<th>Mg cmol/kg</th>
<th>Na cmol/kg</th>
<th>K cmol/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry manure.</td>
<td>4.8</td>
<td>7.3</td>
<td>1.68</td>
<td>2.19</td>
<td>0.36</td>
<td>0.14</td>
<td>0.20</td>
<td>1.81</td>
</tr>
<tr>
<td>Soil</td>
<td>5.4</td>
<td>1.4</td>
<td>0.19</td>
<td>6.2</td>
<td>2.40</td>
<td>1.29</td>
<td>0.08</td>
<td>0.11</td>
</tr>
</tbody>
</table>

The control comprised of pots which were amended by either poultry manure or urea but not planted to maize, and these were used to estimate evaporation from the soil surface independently of plant transpiration. Four seeds were planted at 2cm depth in each pot and later thinned to 3 seedlings per pot. The different treatments were therefore poultry manure, planted (PMP); urea, planted (UP); poultry manure, not planted (PM NP) and urea, not planted (U NP). The design of the experiment was Completely Randomized Design (CRD) with six replications i.e. 2 amendments x 2 plant status x 6 replications = 24 pots. Maize (variety DMRESRY) was purchased from National Root Crop Research Institute Umudike (N.R.C.R.I), and poultry manure was collected from a deep litter poultry at Olokoro, near Umuahia. The manure was air dried and left on a greenhouse bench top to ‘cure’ for four weeks before it was used in the experiment.

At the onset of the experiment before germination of maize, each pot was weighed once per day. The amount of water lost during each measuring cycle was replaced bringing the pots back to their initial weight. After germination and as plant water use increased during the experiment, pots were weighed twice each day to ensure the amount of water lost during each measuring cycle did not exceed 300g (Kato et al., 2009). As the seedlings matured, the amount of water being added to the pots in each cycle increased from 200g to 300g. Total water use during the experiment was calculated by subtracting the cumulative water loss in non – planted (control) pots from that of pots with plants, corrected for the fresh weight increment of the plants during the experiment (Kato et al., 2009).
The experiment was terminated at 60 days (at tasselling), plants were divided into leaves and stems; dried to a constant weight at 70°C and weighed. The parameters measured in the study were water lost through evaporation (water loss from unplanted pots); water lost through evapotranspiration (water loss from planted pots) and water use by maize in the planted pots. Plant height (cm), number of leaves, stem thickness (cm), leaf area (m²), fresh weight and dry weight of plant were also measured. Water use efficiency (WUE) was calculated as

\[
\text{W.U.E} = \frac{\text{Total above ground dry matter produced}}{\text{Unit Soil water used over entire season}} \quad \text{(Singh et al., 2007)}.
\]

Crop Growth Rate per plant (CGR) was calculated as \( \frac{(\text{DMW})}{\text{DT}} \)

Where \( \text{DMW} = \) Average dry matter weight of 1 plant in grams and \( \text{DT} = \) total growth period (time in days) \( \text{(Fageria et al., 2006)} \)

Soil samples were analysed for pH in 1:2.5 soil to salt solution ratio, organic carbon was determined by Walkely- Black wet oxidation method (Black, 1965), total nitrogen by the Kjeldahl method (Black, 1965), available phosphorus by the Bray – 2 method (Bray and Kurtz, 1945), exchangeable acidity and exchangeable cations in ammonium acetate (Jackson, 1962). The N, P, and K concentration in maize was determined by acid digestion and nutrient uptake was calculated as nutrient concentration in leaf tissue x total dry matter yield. All data were subjected to ANOVA using GENSTAT Discovery 3 and where significant, means were compared using Least Significant Difference (LSD) test at 0.05 level of probability.

**Results and Discussion**

Plant parameters measured after sixty days show that poultry manure was very effective in promoting maize growth (Table 2). This confirms the potential of organic manures as viable alternative to inorganic fertilizers for maize production (Ojeniyi and Adeniyan, 1999). Results show that vegetative growth of maize plants which had been fertilized by poultry manure were significantly higher than those which had been fertilized with urea (Table 2), except leaf area which was not different.

The applied rate of urea equivalent to 80kg/ha may have been inadequate, considering that the soil used in the study had gone through a short fallow period following several years of cultivation. Up to 160kg/ha of nitrogen has been recommended for field grown maize in Nigeria (Ogola et al., 2002), but the
conservative rate of 80kg/ha was selected for the current study in order to minimize adverse conditions associated with pot experiments, one of which is an exaggeration of the effects of chemical fertilizers (Passioura, 2006).

Table 2 Mean plant parameters after 60 days of growth

<table>
<thead>
<tr>
<th>Measurement/ plant</th>
<th>Poultry manure</th>
<th>Urea</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of leaves</td>
<td>11.3</td>
<td>10.7</td>
</tr>
<tr>
<td>Plant height (cm)</td>
<td>57.1</td>
<td>49.5</td>
</tr>
<tr>
<td>Stem thickness (cm)</td>
<td>5.6</td>
<td>5.2</td>
</tr>
<tr>
<td>Leaf Area (m²)</td>
<td>186.2</td>
<td>124.9</td>
</tr>
<tr>
<td>Fresh weight (kg)</td>
<td>3.4</td>
<td>2.5</td>
</tr>
<tr>
<td>Dry weight (kg)</td>
<td>1.07</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Total above ground yield of maize plants relative to amount of water applied showed that water use by maize fertilized by poultry manure was 54.6 g/litre, significantly higher than the water use from urea application which was 48.7 g/litre (Table 3). This could have resulted in the higher growth observed in poultry manure fertilized plants compared to those treated with urea (Table 3). At 0.9 litres, transpiration in maize (ET – E) in poultry manure amended soil was lower than in urea-fertilized plants where it was 1.5 litres over 8 weeks of growth (Table 3). The ability of a plant to conserve moisture would also enhance their water use, translating into dry matter yield per unit of water applied (Beheshti and Fard, 2010). Poultry manure also resulted in significantly higher Crop Growth Rate of maize (5.94 g/plant/day) than urea (5.0 g/plant/day), while both CGR values confirm the high water use efficiency of maize in relation to biomass production (Ogola et al., 2002). Mean evapo-transpiration per week in pots treated with urea was higher than in pots treated with poultry manure (Figure 1).
This was largely due to high evaporation from urea treated soil, as urea has no mulching effect to reduce moisture loss from soil (Figure 2). In addition to that, urea is often lost from soil as ammonia gas, a process which involves moisture being given off. Conversely, non-planted pots treated with poultry manure lost less water due to evaporation (Figure 2). Manures are known for their mulching and aggregating ability which enhances the water holding capacity of soils, thus reducing water loss (Russel, 1995).
Table 3. Total Water use and water loss after 8 weeks of maize growth

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Initial soil weight/pot (kg)</th>
<th>Water added/pot litres</th>
<th>Fresh plant wt/pot (kg)</th>
<th>Final soil wt/pot (kg)</th>
<th>Water loss/pot e= (a+b)-(c+d)</th>
<th>Dry matter yield/pot kg</th>
<th>Water use g DM/litre</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM planted</td>
<td>8.5</td>
<td>19.6</td>
<td>3.4</td>
<td>11.2</td>
<td>13.5 (ET)</td>
<td>1.07</td>
<td>54.6</td>
</tr>
<tr>
<td>Urea planted</td>
<td>8.5</td>
<td>19.5</td>
<td>2.5</td>
<td>10.9</td>
<td>14.6 (ET)</td>
<td>0.9</td>
<td>48.7</td>
</tr>
<tr>
<td>PM non planted</td>
<td>8.5</td>
<td>14.9</td>
<td>0</td>
<td>10.8</td>
<td>12.6 (E)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Urea Non planted</td>
<td>8.5</td>
<td>15.8</td>
<td>0</td>
<td>10.2</td>
<td>13.1 (E)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

DM = dry matter; ET = evapotranspiration; E = evaporation
Nitrogen levels in poultry manure fertilized soil was significantly higher than in soils which had received urea, even in pots which had supported maize growth (Table 4). Manures are known to have the capacity for gradual release of nutrients to the soil (Ibeawuchi et al., 2010), minimizing loss by leaching or volatilization. In addition to supplying nitrogen, poultry manure also supplied phosphorus and potassium, being rich in those nutrients (Omotoso and Shittu, 2008).

Table 4. Soil N, P and K after 60 days of maize growth

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N (%)</th>
<th>P (mg/kg)</th>
<th>K (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM planted</td>
<td>1.2b</td>
<td>12.1b</td>
<td>0.04a</td>
</tr>
<tr>
<td>PM non-planted</td>
<td>1.6c</td>
<td>14.2b</td>
<td>0.26b</td>
</tr>
<tr>
<td>Urea planted</td>
<td>0.9a</td>
<td>5.9a</td>
<td>0.05a</td>
</tr>
<tr>
<td>Urea non-planted</td>
<td>1.1ab</td>
<td>6.9a</td>
<td>0.09a</td>
</tr>
</tbody>
</table>

Significance (≤ 0.05) LSD= 0.28 LSD=2.7 LSD= 0.10

PM- poultry manure
Maize uptake of nitrogen and phosphorus was significantly higher in maize plants which had been fertilized by poultry manure (Table 5).

Table 5. Plant tissue concentrations and uptake of N, P and K by maize after 60 days of growth

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N (%)</th>
<th>P (mg/kg)</th>
<th>K (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry manure</td>
<td>3.2</td>
<td>1.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Urea</td>
<td>2.1</td>
<td>0.6</td>
<td>1.2</td>
</tr>
<tr>
<td>Uptake = conc X yield</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poultry manure</td>
<td>3.42</td>
<td>1.61</td>
<td>1.50</td>
</tr>
<tr>
<td>Urea</td>
<td>1.89</td>
<td>0.54</td>
<td>1.08</td>
</tr>
</tbody>
</table>

Poultry manure is rich in phosphorus and this would account for the increased P uptake by maize. There was however no significant difference in potassium uptake (Table 5).

Conclusion

Water use measures the ability of plants to develop and produce yield under conditions of limiting moisture, and fertilizer type is one of the factors which affects water use by plants. This study indicates that organic fertilizer (poultry manure) enhanced water use efficiency of maize, with an added advantage in crop growth rate and nutrient uptake. Water use studies are essential for successful irrigated crop production, such as occurs in dry season farming in Nigeria. With increasing water scarcity in agriculture and the challenge of meeting national food requirements, there is a need to increase water use efficiency in crops through affordable and sustainable means such as organic manuring.

References


