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Nutrients leaching in Briquetted NPK and Urea Super Granules and its effect on the performance of rice (*Oryza sativa L.*)

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ABSTRACT

Government policies in sub-Saharan Africa is geared towards intensification of rice production to reduce import. Intensification of production requires the use of inorganic fertilizers. Although the amount of nutrient lost through leaching has not been quantified to guide fertilizer use, briquetted formulations of chemical fertilizers are now being used to address nutrient leaching. This study is aimed at quantifying nutrients' loss in different formulations and how it influences growth and yield of rice. The field experiment was conducted using clay-filled 0.28 m diameter passive wick lysimeters to collect leachates for laboratory analysis. The treatments consisted of urea super granule (USG), granular urea, briquetted NPK, granular NPK in two split applications using NPK and SA, all applied at 57.5- 22.5-11.3 kg ha-1. An untreated control was also kept. For the urea and USG, TSP and Murriate of potash (MOP) were added to supply P and K. The treatments were arranged in completely randomized design. Four rice seedlings were transplanted per lysimeter. Data collected on growth and reproductive parameters as well as nutrient content of the leachates were subjected to analysis of variance using Genstat Edition 18. Urea-based fertilizers recorded higher tiller and panicle number than NPK-based fertilizers. Grain number was not affected by the treatments. The USG and briquetted NPK lost 5% of N applied while granular urea and NPK lost 15% of N applied within 8 weeks after application. Phosphorus was the least leached nutrient, less than 0.2 kg/ha, whilst Potassium recorded the highest nutrient loss (3.7- 9.2 kg/ha). The study recommends the use of USG and briquetted NPK to address nutrient leaching in rice fields.

Keywords: Leaching, Nutrient loss, Briquetted, NPK, USG, fertilizer, lysimeter

INTRODUCTION

Rice (Oryza sativa L.) is important cereal which serves as dietary staple for more than half the world's human population. It is critical to the lives of billions of people around the world, providing 21% of global human per capita energy and 15% of per capita protein (ODI, 2003). According to Statistical, Research and Information Directorate of MoFA (SRID/MoFA) (2017), 412, 814 Mt of milled rice was produced locally in 2016 and 697,391 Mt was imported during the same period. Per capita rice consumption in Ghana hovers around 35 kg/annum (SRID/MoFA, 2017).

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Low inherent soil fertility has been identified as a major cause of low rice yield in sub-Saharan Africa (USAID, 2011). The problem is compounded because farmers are not able to purchase fertilizer due to relatively high cost and therefore rely mostly on natural soil fertility. Moreover, under flooded conditions, most of the applied nutrients are lost through different path ways (Kokare *et al*., 2015). Deep placement of fertilizers may be more efficient and farmers can benefit more from this compared to broadcast method (Rahman *et al*., 2016). The use of briquetted fertilizer may help to reduce the loss of nutrients under flooded conditions. Farmers in Vietnam and Cambodia obtained 25% higher yields with deep placement of NPK briquettes over the broadcasting of fertilizer (IFDC, 2007). In Bangladesh, yield of rice was increased by 15-25 %, while expenditure on commercial fertilizer was decreased by 24-32 % when briquetted fertilizers were used as the source of plant nutrients. Deep placement of briquetted fertilizer has been reported to have environmental and economic benefits (IFPRI, 2009).

Rice yields recorded by small holder farmers in Ghana have been declining over the years due to a number of factors. Most important among the factors is the decline in soil nutrients. Various efforts have been made to address yield decline chief among them being the use of organic manure. Ibrahim (1985) is of the view that chemical fertilizer remains an attractive economic alternative to the use of organic fertilizer in rice cultivation. The challenge however has to do with making sure that the applied nutrients are available to the plant, whilst minimizing the loss of the nutrients through leaching and volatilisation. Regular granular fertilizers, though useful, have been proven to result in nutrients leaching beyond the reach of crops, especially in flooded lands. As a result, more of the fertilizer has to be applied in order to achieve the desired effect. Predotova *et al*. (2011) have reported N leaching of 2.2-7.3 kg/ha while Goenster *et al*. (2015) reported N losses of 53-45 kg/ha per year. Weimer *et al* (2019) also reported less than 1 kg N/ha in maize farms in Tamale in northern region of Ghana. Information on losses of nutrients on clayey soils used for rice production in Ghana is lacking. This study would provide information on N, P and K quantities that are leached out in soils when briquetted and granular fertiliser are used in stimulated rice field condition.

The study aimed to compare the effect of split application of granular NPK and urea with single application of briquetted form on growth and yield of rice. Secondly, it sought to compare nutrient losses in granular fertilizers with their corresponding briquetted ones during the vegetative stage.

MATERIALS AND METHODS

Experimental site

This research was carried out at the experimental field of the University for Development Studies, Tamale, Ghana. The experimental site is located on longitude 0o 58' 42'W and latitude 9o 25' 14' N with an altitude of 183 m above sea level. The area experiences a unimodal rainfall pattern ranging from 1000 mm to 1200 mm. Rainfall starts late April and reaches a peak in July to September; there is a sharp decline or absolutely no rain in November (SARI, 2007). The research spanned the period of April - October, 2017.

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Construction of lysimeter

The experiment involved the use of passive wick lysimeter (Plate 1) adapted from Siemens and Kaupenjohann (2004) and Werner *et al*. (2019). The passive wick lysimeters is made up of two chambers (buckets) placed on top of each other and sealed together with epoxy. The top chamber with inner diameter of 0.28 m and depth of 0.50 m was filled with clay soil leaving the top 6 cm as a receptacle for irrigated water and to prevent run-off water from entering the bucket. The second chamber with the same dimension as the top chamber was designed to collect leachates. The two chambers were connected to each other by means of a 0.4 m length glass fiber wick of 10 mm diameter used to create a hanging water column and draw water from the soil in the upper chamber into the lower chamber. A PVC pipe housing a rubber tube was connected to the second chamber. Holes of 0.6 m diameter and height of 1.2 m were dug and the lysimeters placed into them, the soils augured out were used to fill the sides of the bucket to make it firm in the soil. The buckets were grounded in an area where run-off water will not run over them. Water was added to the top 6 cm and it was ensured that water was most often up to a height of 4 cm till senescence. Leachates were drawn out of the second chamber through the tube using a vacuum pump of 40-kPa every two weeks on four occasions.

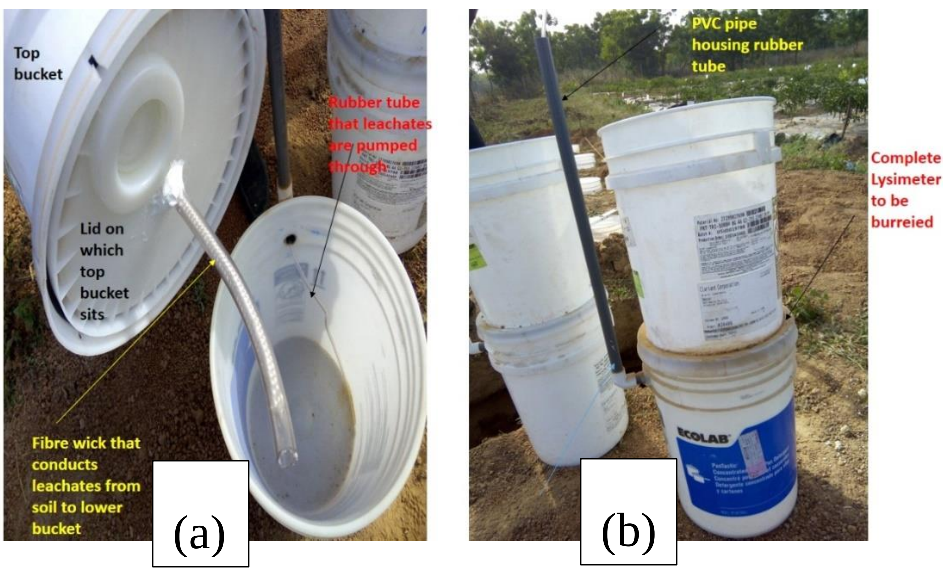

Plate 1: Lysimeter construction. Plate 1(a) shows the upper and lower buckets linked by fibre wick. Plate 1(b) shows the two buckets assembled together ready to be grounded.

Treatment and Experimental design

Urea super granule was applied to 4 plants by placing it in the midpoint of four plants in order to reduce fertilizer application. Triple Super Phosphate (TSP) and Muriate of Potash (MOP) were added to the USG to provide P and K respectively. The quantities of USG, TSP and MOP applied to four plants informed the 57.5- 22.5-11.3 kg ha-1 used for the other treatments in the study. The lysimeters were arranged in a complete randomized design with six replications. Rice variety Jasmine was nursed in buckets and transplanted three weeks after emergence. The treatments were

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applied 2 weeks after transplanting (WAT) and top dressing with sulphate of ammonia (SA), where required, was done at four weeks later. The treatments consisted of Urea Super Granule , Urea granular, Briquetted NPK, NPK (split application of nutrients in treatment 3 using granular NPK and SA), and Control (untreated control).

Plate 2: Briquetted NPK fertilizer

Data Collection

Growth and yield data collected were plant height at two weeks for eight weeks, shoot dry weight at harvest, tiller number at two-week intervals, panicle number and weight, and number of seeds per panicle.

The leachate was sampled every two weeks after the treatment application during the vegetative phase. The volume of the leachate was measured and a sample transported to the lab in an icebox. All samples were acidified (pH ~2) and stored in a fridge at 4 ºC until they were analysed. Analysis of NO_3-N was done photometrically following the methods of Cataldo *et al*. 1975, NH4-N as per Koroleff, 1976 and PO4 P according to Ohno and Zibilske 1991. Light absorption at the specific wavelengths was measured with an UV/VIS pectrophotometer (Pharo 300 Spectroquant, Merck GmbH, Darmstadt, Germany). The amount of K was determined by the flame emission photometric method.

Leachate analysis

The nutrients content of leachates measured in mg/l was converted to kg/ha using the formula applied by Werner *et al*. (2019). Leaching losses in kg/ha = concentration of the nutrient in leachate (mg/l) x the volume of leachate pumped out (l) x 0.162. The factor 0.162 was used to account for the area of the lysimeter (0.28 m in diameter).

Effective nitrogen loss during the period was computed by summing up the total nitrogen losses in nitrate and ammonium. Nitrogen loss from the untreated control was subtracted from the fertilizer

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treatments in order to cater for indigenous nitrogen in the soil. Effective nitrogen loss of the fertilizer treatment t was calculated as

: $\sum(NH4Nt + NO3\ Nt) - \sum(NH4Nc + NO3Nc)$

where $NH_4^+N_t$ is ammonium N lost in treatment t, NO_3^- -N_t is nitrate N lost in treatment t, $NH_4^+N_c$ is ammonium N lost in control treatment and NO_3^- -N_c is nitrate N lost in control treatment.

Data analysis

The data collected were subjected to analysis of variance (ANOVA) using Genstat Statistical Package software, Teaching and Learning version, 18th edition. All tests of significance were assessed using an alpha of 0.05 unless otherwise stated.

RESULTS

Plant height

The fertilizer and week interaction did not have significant interaction effect (P=0.358) on plant height however the main effect of the fertilizer treatment had significant effect on plant height (P=0.001). The plant height was fairly similar among the fertilizer treatments. The fertilizer treatments however, recorded significantly higher plant height than the untreated control (Figure 1).

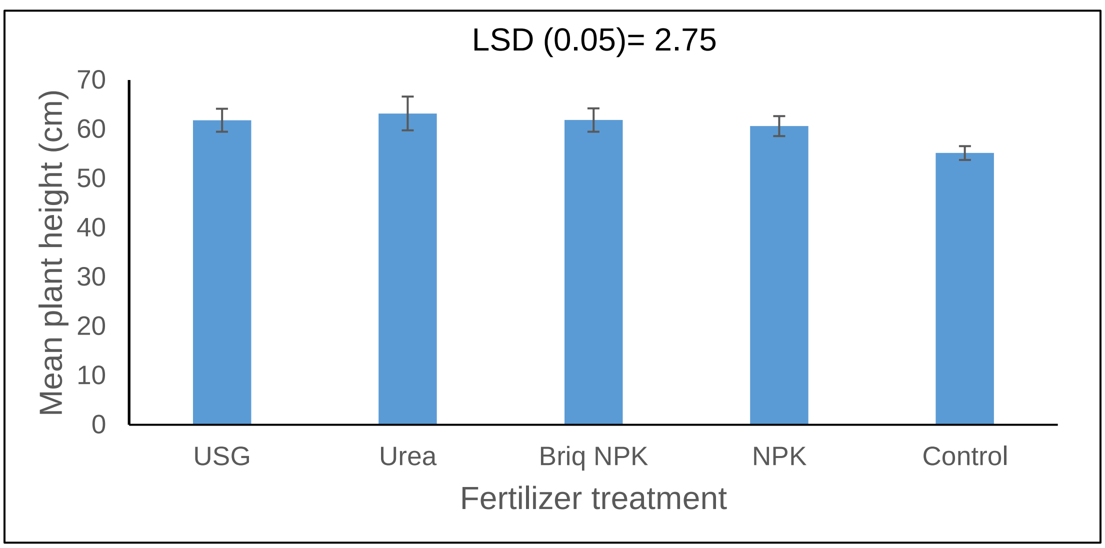

Figure 1: Effect of fertilizer treatments on plant height. Error bars represent standard error of means (SEM)

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Dry shoot weight

The fertilizer treatments had significant influence on dry shoot weight (P<0.001). The USG produced 14.8 % more shoot weight than the briquetted NPK, and it increased to 18.5 % when compared with NPK (Figure 2). The urea treatment also performed significantly better (15 %) than the NPK treatment. The briquetted treatments performed about 4% better than the granular applications though the differences were not significant. The untreated control produced the least dry shoot weight (Figure 2).

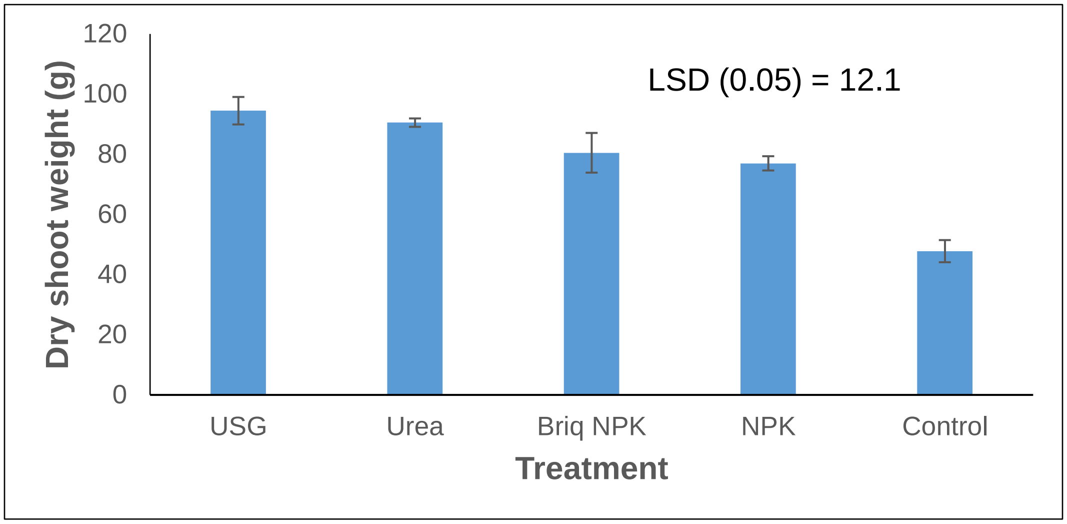

Figure 2: Effect of fertilizer treatment on dry shoot weight per lysimeter. Bars represent SEM

Tiller number

The fertilizer treatments were significantly different (P=0.047) at the three periods (4, 6 and 8 WAT) tiller numbers were counted. The urea treatment recorded significantly higher tiller number than all the other fertilizer treatments in the fourth week (Figure 3). In the later weeks, the USG induced more tiller number than the NPK-based fertilizer treatments (Figure 3). The differences in the briquetted and granular forms were not significant. The fertilizer application significantly increased tiller number over the untreated control (Figure 3).

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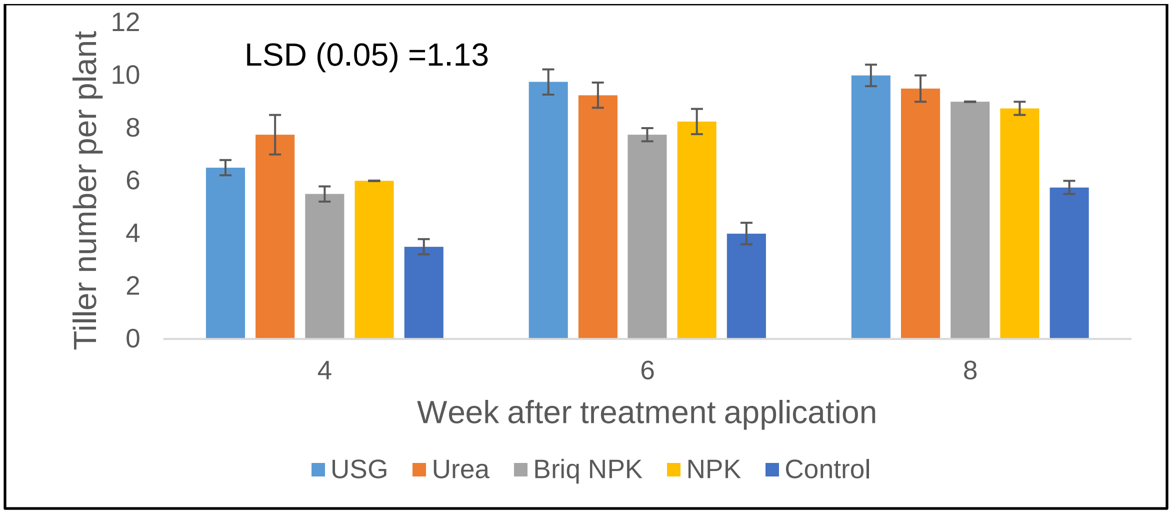

Figure 3: Effect of fertilizer treatment on tiller number. Error bars represent SEM

Panicle number and weight

The fertilizer treatments had significant influence on the number of panicles per plant (P<0.001). The urea super granule treatment produced significantly higher number of panicles than the NPK treatment. The fertilizer treatments significantly increased panicle number more than the untreated control (Figure 4). The briquetted NPK and USG induced more panicles than their granular forms though the difference was not significant. The fertilizer treatments had significant influence on panicle weight (P=0.004). The trend observed in panicle number was similar to what was observed in panicle weight (Figure 5).

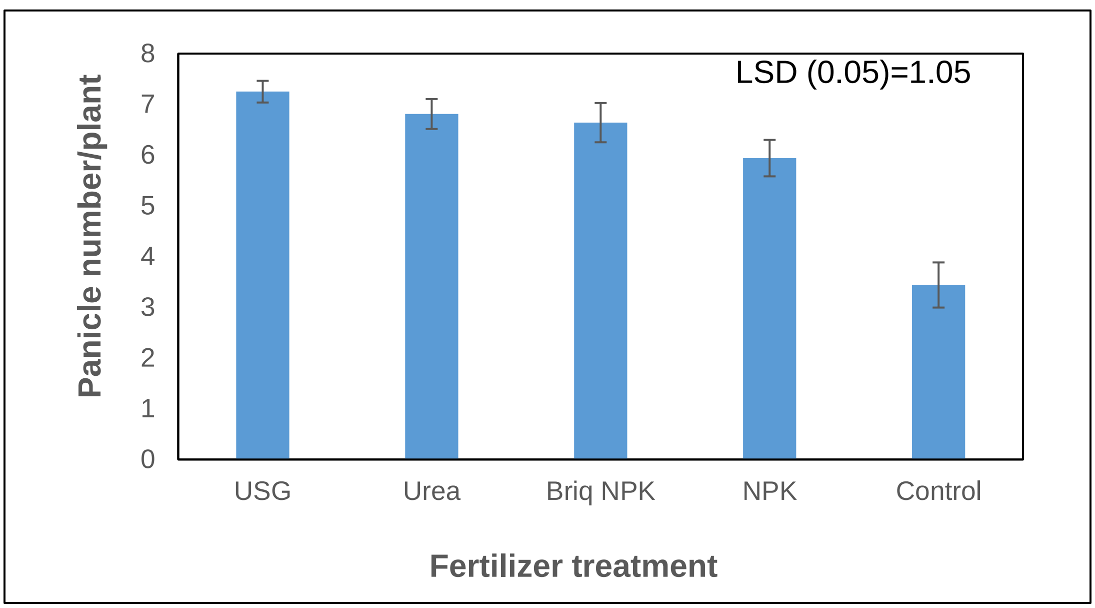

Figure 4: Effect of fertilizer treatment on panicle number per plant. Bars represent SEM.

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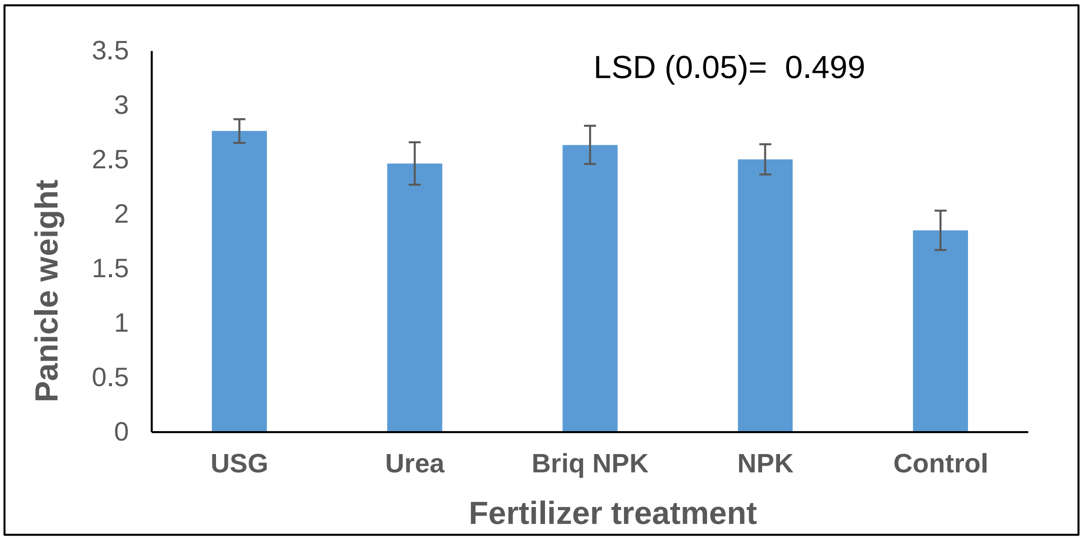

Figure 5: Effect of fertilizer treatment on panicle weight. Bars represent SEM.

Number of grains per panicle

The fertilizer treatments had no significant influence on the number of grains per panicle (P=0.099). However, all the treatments that received fertilizer produced more grains than the untreated control. The USG treatment produced 12 .8% more grains than the untreated control (Figure 6).

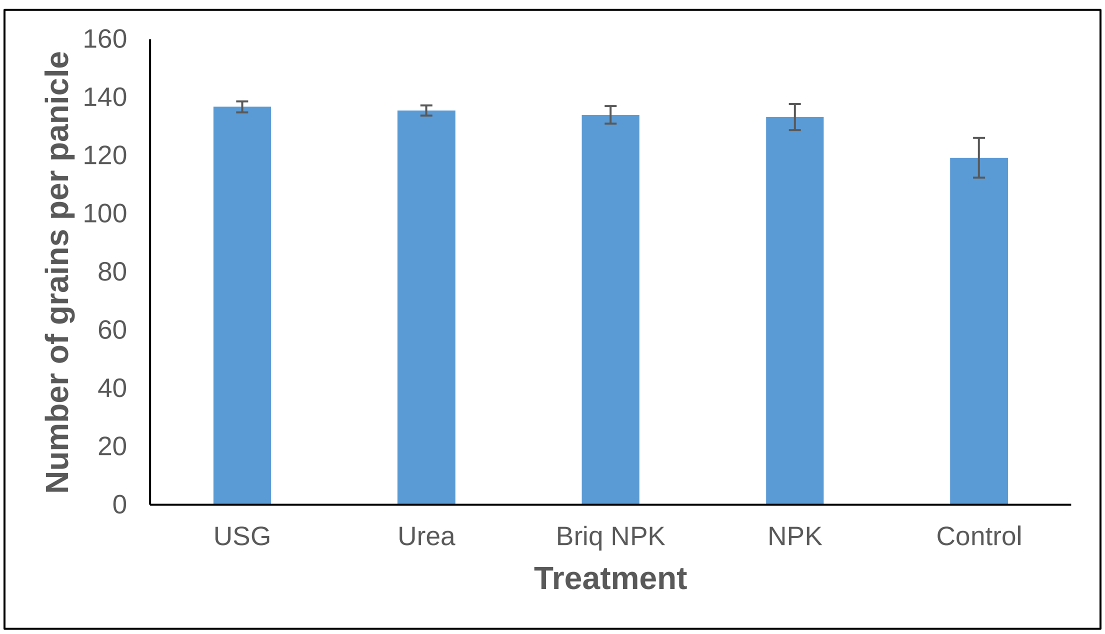

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Figure 6: Effect of fertilizer treatments on number of grains per panicle. Error bars represent SEM.

NH4 –N content in leachates

The fertilizer treatment and the weekly interaction had significant effect on the amount of NH4 –N leached from the soil (P= 0.018). Quantity of NH4 leached was significantly higher in the urea treatment during the first four weeks after application (Figure 7). By the sixth week losses from the soil through leaching in the urea treatment had fallen below the level of the granular NPK due to increases in NH4+ -N leaching as a result of sulphate ammonia top dressed to NPK treatment. The briquetted NPK and USG recorded NH4 quantities lower than that of the granular forms but the differences were not always significant. The untreated control recorded significantly lower NH4 leached in the first four weeks (Figure 7).

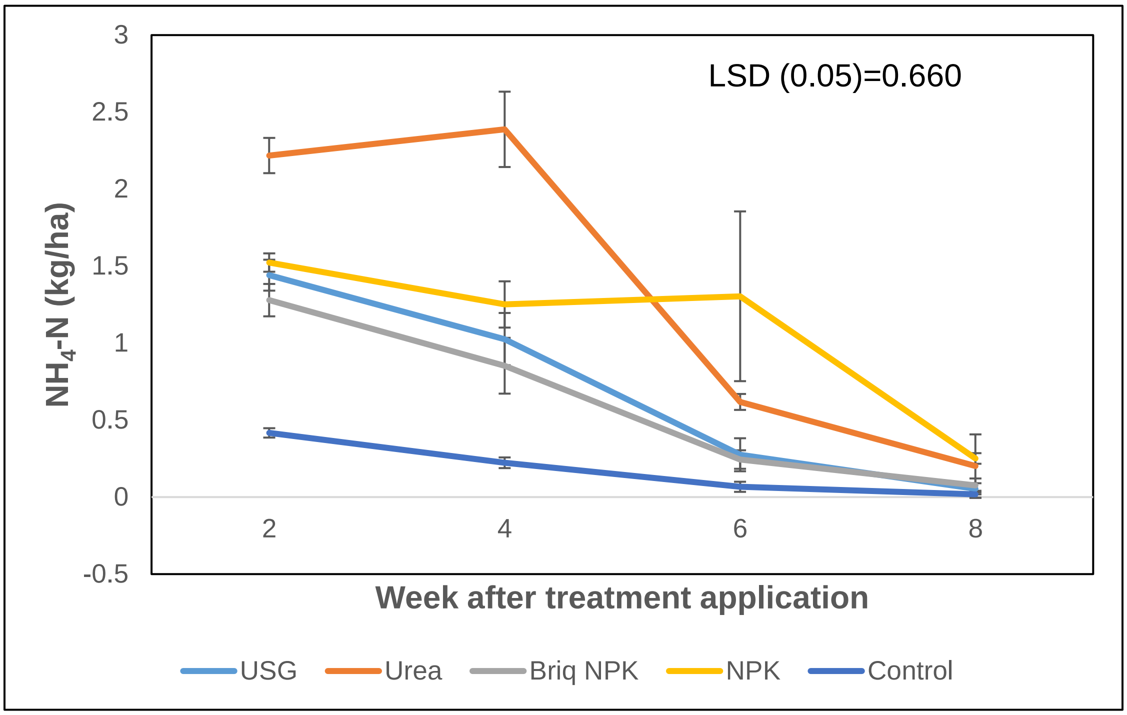

Figure 7: NH¬4 content of leachates collected from lysimeter. Error bars represent SEM

NO3 – N quantities in leachates.

The fertilizer treatment significantly influenced the amount of NO3 -N leached from the soil in the different weeks (P<0.001). In the first two weeks after treatment application, the NPK treatment recorded significantly higher NO3-N quantities than the other treatments (Figure 8). However, quantities in the NPK treatment declined and the amount in the urea significantly spiked higher than the rest of the treatments in the fourth week. The NO3-N quantities in the USG and the

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briquetted NPK treatments were lower than that of urea up to the sixth week. By the 8th week the quantities in all the treatments had declined to the level of the untreated control (Figure 8).

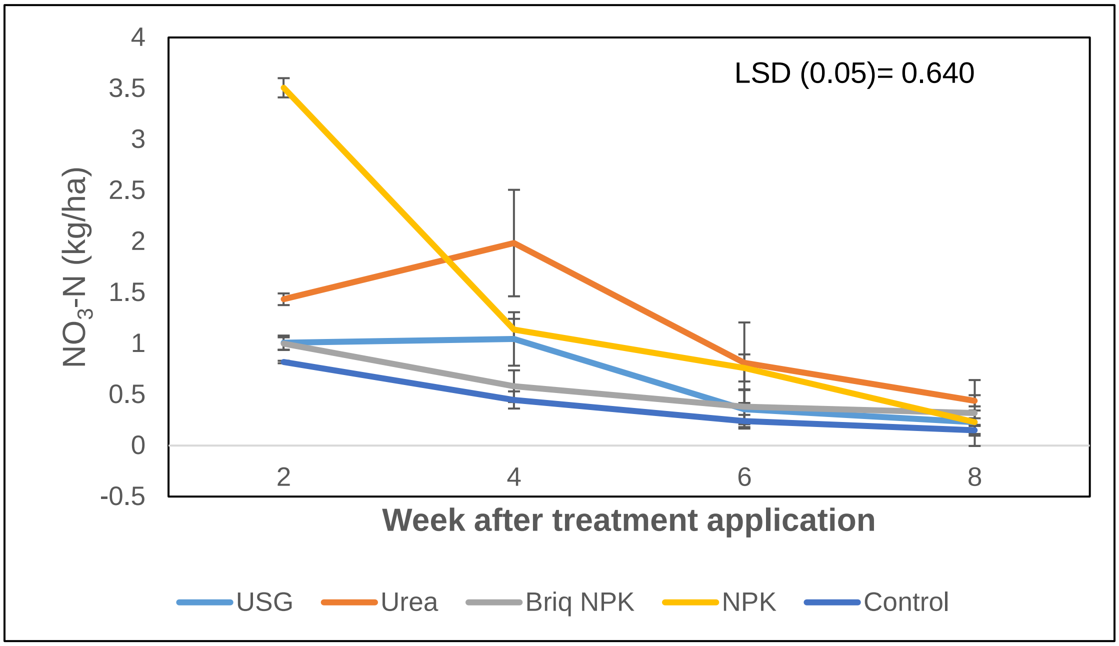

Figure 8: The NO3 content of leachates collected from lysimeter. Error bars represent SEM.

Effective nitrogen loss

Computed effective nitrogen loss for the eight weeks shows that the compacted fertilizers USG and briquetted NPK recorded lesser nitrogen amount when compared with the granular fertilizers (Figure 9). The nitrogen leached from the granular fertilizers, urea and NPK, were about double what were leached from the compacted form, the USG and the briquetted NPK.

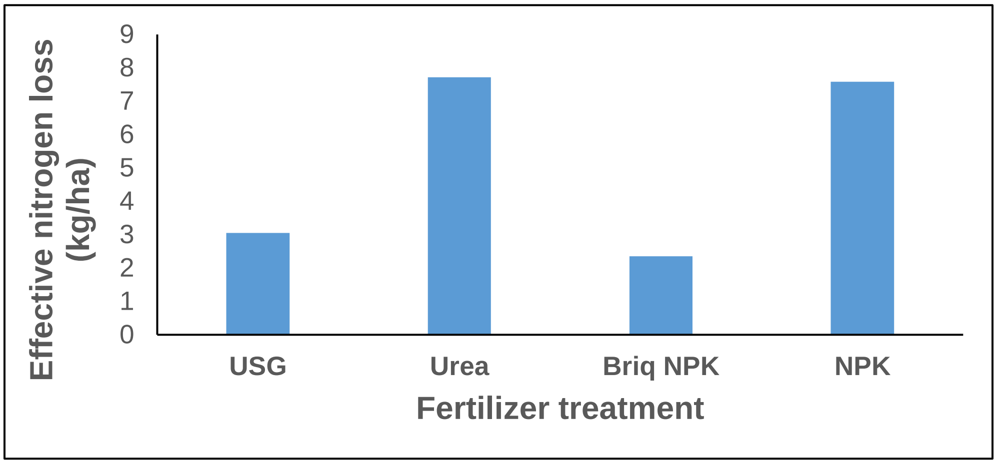

Figure 9: Effective total nitrogen loss through leaching for the eight weeks period

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P content of leachates

The treatment and the week interaction had significant effect on the amount of P leached from the soil (P= 0.05). At the second week after treatment application, the urea and the USG plots that were supplied with P in the form of TSP joined granular NPK treatment to leach more P than the briquetted NPK treatment (Figure 10). Leaching losses declined among the three treatments while that of the Briquetted NPK treatment increased at the fourth week. By the sixth week quantities of P in the fertilizer treatments had declined to the level of untreated control and remained constant till the eighth week (Figure 10).

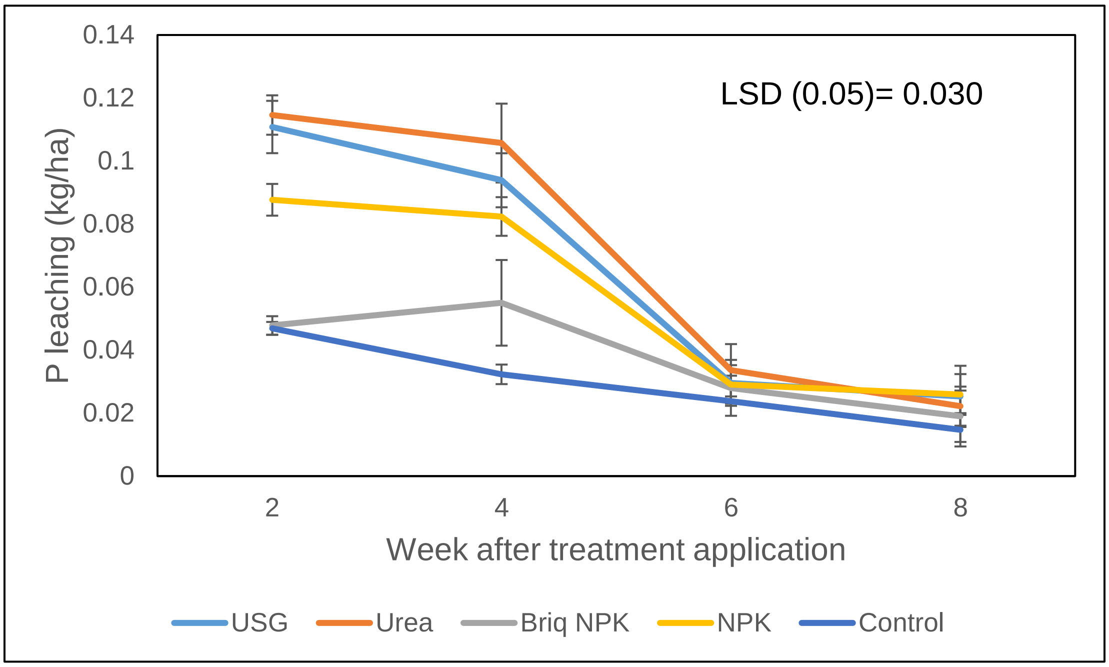

Figure 10: Phosphorus content of leachates collected from lysimeter. Error bars represent SEM.

K_2O content of leachates

The fertilizer treatments were significantly different in potassium that leached in the different weeks (P<0.001). The urea and its briquetted form, USG, that were applied in addition to Muriate of potash leached significantly higher potassium than even granular NPK treatment. Quantities of potassium increased significantly in the urea treatment more than the NPK and the briquetted NPK treatments in the fourth week. Losses through leaching in all the fertilizer treatments plummeted to the level of untreated control by the sixth week (Figure 11).

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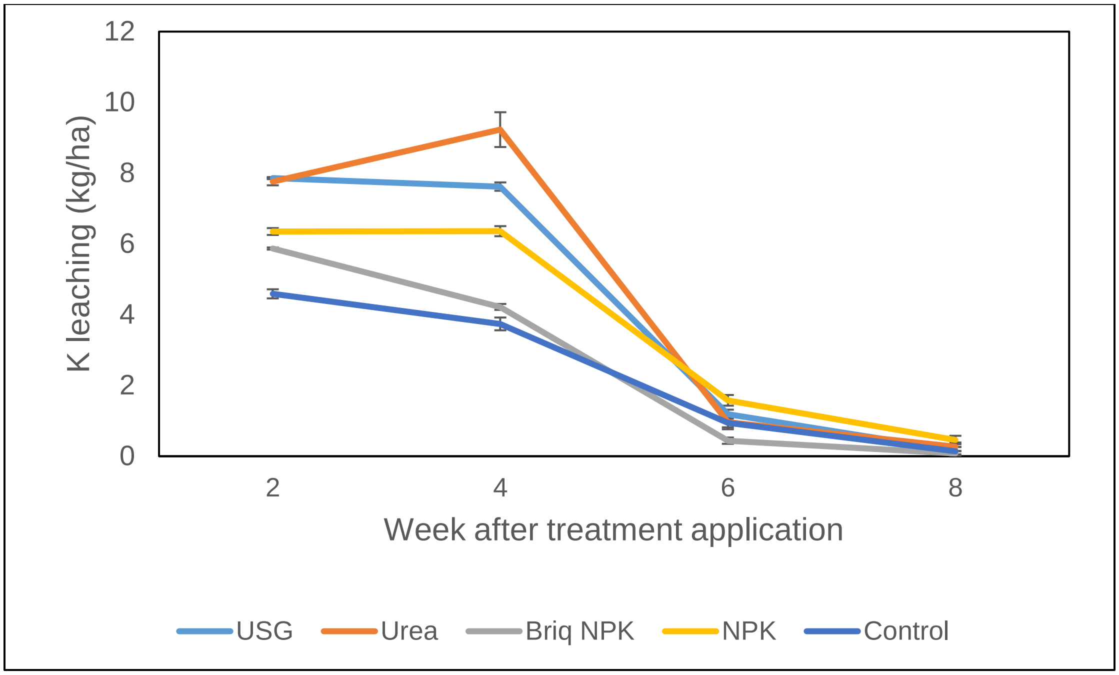

Figure 11: Potassium content of leachates collected from lysimeter. Error bars represent SEM

DISCUSSION

Crop growth and yield parameters

The fertilizer treatments were fairly the same in promoting vertical growth of the crop and the results showed that the fertilizer treatment promoted growth compared to the control. Sudhakar *et al*. (2016) submitted that plant dry weight is the most useful and reliable parameter to determine plant growth. In the case of dry shoot weight, the urea super granule promoted better growth than both NPK-based fertilizers. These two results show that while the two fertilizers type, urea and NPK, promoted growth the urea-based fertilizer were better than NPK-based fertilizer and the slow release of nitrogen by the urea super granules might have accounted for its dominance over granular NPK. Nitrogen requirement of rice for growth is demonstrated in the work of Khairunniza-Bejo *et al*. (2017) where N promoted growth parameters and yield of rice.

The urea-based fertilizer improved tiller production better than the NPK based fertilizers. Panicle number and weight also followed similar trend where the urea-based fertilizer treatments were better than the NPK-based fertilizer treatments though the difference was not significant. Urea is known to dissolve easily and N made available to the plant after contact with moisture within 48 hours of application YARA (2017). Cytokinin content in the nodes of tillers is enhanced by nitrogen and that helps to promote tillering (Liu *et al*., 2011). This might have accounted for the high performance of the urea-based fertilizers. Tahir *et al*. (2008) and Sakakibara *et al*. (2006) have reported that adequate supply of nitrogen promotes tillering. Lampayan *et al*. (2010) emphasized

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the importance of fertilizer application in panicle development. They reported higher panicle density when nitrogen fertilizer was applied at early vegetative period. The briquetted NPK and

USG released their nitrogen slowly and that made nitrogen available for uptake in the vegetative stage which promoted higher panicle development. In this study the grain number per panicle was not affected by the treatments even though the fertilizer treatments recorded more grains than the untreated control. This is in contrast to previous studies (Win, 2012; Islam *et al*., 2008) where fertilizer application had improved yield components like grain number per panicle.

Nutrients losses through leaching

Generally, nitrogen fertilizers are completely water soluble and a significant portion is lost through leaching. The N losses occur in the form of NO3- and NH4+. The results however showed that most of the N was leached in the form of NO3-. This finding is supported by (Vlek *et al*., 1980; Xing *et al*., 2000; Velu *et al*., 2001). They found that leaching loss of N occurs in the form of NO3-N and NH4+N from rice fields and the extent of NO3- losses is 90 % more than NH4+. In nutrient losses study in Tamale, Werner *et al*. (2019) observed that NO3- -N loss was higher than NH4+-N and losses in both were below 1 kg N per ha. In this study, the initial NH4+-N loss among the fertilizer treatments was in the range of 1.279 – 2.218 kg N per ha while the corresponding values in NO3- -N was 0.999 – 3.507 kg per ha. The peak nutrient loss occurred at the fourth week after the fertilizer application and in that week the urea fertilizer recorded the highest NH4+-N losses. The difference in NH4+-N losses between urea fertilizer and its compacted form, the USG, was 57 % while that between NPK and briquetted NPK was 31.8 %. In the case of NO3- -N loss at the peak week, the highest was measured in the urea fertilizer treated plots and the difference between the urea and USG was about 47% while about 49% was the difference between NPK and briquetted NPK. The effective nitrogen loss shows that during the 8-week period, the granular fertilizers lost more nitrogen than the compacted form. When the effective nitrogen losses were compared with nitrogen input, it was observed that USG and briquetted NPK lost 5.3 and 4.1 % within the 8 week after application while that of the granular urea and NPK were 13.5 and 13.3 % respectively. Compacting the fertilizer reduces the surface area per unit mass (IFDC 2007, 2013) and that helps to reduce nutrient loss (Adu-Gyamfi *et al*., 2019)

Phosphorus leaching in this study was very low when compared with N and K confirming the slow mobility of P in soils (Sharpley, 1997). Phosphate is very reactive and forms insoluble precipitate with Fe3+ and Al3+ and other elements present in soils (Klepker and Anghinoni 1996). In a study by Werner *et al*. (2019) P losses of less than 1 kg/ha was reported. In this study peak losses of P occurred in the second week after fertilizer application and losses were less than 0.2 kg per ha. In that week, both urea-based fertilizers recorded higher P levels than the NPK-based fertilizers. The highest P loss of 0.115 kg/ha observed in the urea treatment was as a result of TSP that was added to both the urea and the USG. Leached P in the briquetted NPK and granular NPK was very low and was similar to the untreated control. This shows that P losses in clay soils is not a worrying problem as nitrogen.

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Potassium losses were relatively higher when compared to the other nutrients. Werner *et al*. (2019) reported K losses between the range of 2- 4 kg per ha. The range found in this study at the peak loss (3.7-9.2 kg/ha) was higher than what Werner *et al*. (2019) reported. In contrast to other major nutrients, K is almost totally water soluble + and is thus readily available (Mengel and Kirkby 1987). Potassium losses was high but it appeared to have less effect on rice yield. Abel (2017) reported that K exclusion in fertilizer applied to rice least affected tillering and grain yield when compared with other nutrients excluded.

CONCLUSIONS

The urea-based fertilizers promoted tillering and panicle development better than the NPK-based fertilizers. At the peak of nutrient losses in the fourth week, Nitrate-N losses were higher than that of Ammonium-N. The granular fertilizers lost more N than the USG and briquetted NPK. The compacted USG and briquetted NPK respectively lost 5.3 % and 4.1 % of the nitrogen applied while the granular urea and NPK leached 13.5 % and 13.3 % respectively within eight weeks after application. Phosphorus losses were low, less than 0.2 kg/ha. Potassium losses through leaching were the highest among the three nutrients studied, about 3.7 – 9.2 kg/ha. It is recommended that rice farmers should use urea super granules and briquetted NPK to reduce nutrient loss in rice production.

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CONTRIBUTION OF AUTHORS

Raphael Adu-Gyamfi conceived the idea, sought for funding, implemented the idea and took part in the writing of the manuscript.

Alhassan Hafiz took part in the designing of the experiment data collection, analysis and writing of the manuscript.

Vincent K. Avornyo contributed to the implementation of the idea, data analysis and writing of the manuscript

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