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Effect of Phosphorus Levels on Soil Properties and Plant Tissues of Two Nerica Varieties

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Authors' contributions

This work was carried out in collaboration between all authors. Author EEM designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors NKK and JPGO reviewed the study design and all drafts of the manuscript. Authors EEM and WNW undertook the statistical analysis of the data collected. Author EEM managed the literature searches and reference-citations. Finally, all the authors read and approved the final manuscript.

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ABSTRACT

Phosphorus levels in the soil are easily fixed and rendered unavailable to plants even if they are found to be high and therefore, its influence on uptake of other nutrients such as nitrogen, and potassium cannot be overemphasized. In that view, an experiment was set out at KALRO-Mwea to investigate on the effect of phosphorus levels on soil properties and plant tissue nutrient contents of Nerica rice variety. The experiment was laid out in a Randomized Complete Block Design in split-split plot arrangement and replicated thrice. Two rice varieties (Nerica 11 and Nerica 4) formed the main plots and 4 phosphorus levels (0 kg P/ha, 25 kg P/ha, 50 kg P/ha and 75 kg P/ha) formed the sub plots. Highest net pH decreases of 0.20 and 0.22 units were recorded at 75 Kg ha^{-1} P_2O_5 in season 1 and season 2 respectively, while the lowest net decreases of 0.12 and 0.16 were elicited at 50 Kg ha^{-1} P_2O_5 treatment in season 1 and season 2 respectively. A net decrease was observed in all the CEC levels where phosphorus was applied in all the seasons in which the highest net

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decrease of 1.09 and 1.03 during season 1 and 2 respectively was elicited on the control treatment, while the lowest net decrease of 0.61 and 0.59 was elicited by the 50 Kg ha^{-1} P_2O_5 rate in season 1 and 2 respectively. There was an inverse relationship exhibited between the phosphorus level of applications and the soil phosphorus net decrease across the two seasons. The net decrease was highest at 0 Kg ha^{-1} P_2O_5 and increased significantly with increasing phosphorus rate. That content of soil nitrogen were low with a marginal increase recorded with application of phosphorus across the seasons. The highest net increase of 0.05% was observed at the 75 Kg ha^{-1} P_2O_5 rate and control in season 1 while the application rate of 50 Kg ha^{-1} P_2O_5 had the lowest net increase of 0.02% in season 2. Highest mean plant-tissue phosphorus of 62.05 ppm was recorded in Nerica 4 under 75 kg P/ha treatment. Highest plant tissue nitrogen of 0.686% and 0.713% for Nerica 4 and 11 respectively were elicited at 75 kg ha^{-1} P_2O_5 in season 1, whereas in season 2 the highest plant tissue nitrogen of 0.721% and 0.691% at 75 kg ha^{-1} P_2O_5 for Nerica 11 and 4 respectively was recorded. Application of phosphorous led to the highest plant-tissue phosphorus in both seasons indicating the importance of proper P fertilizer application where from this study 50-75 kg ha^{-1} P_2O_5 rate is recommended in rice growing.

Keywords: Variety; fertilizer; levels; soil properties; phosphorus.

1. INTRODUCTION

Rice (*Oryza sativa,*L) is a prime important lifestyle cereal crop in the Kenya's contemporary society today. It is the third highly cultivated and utilized cereal crop in Kenya only after maize and wheat [1]. As a lifestyle food, many Kenyans across the settings magnificently consume it in various forms, yet its consumption levels are so high than are not met by the production [2] within the country, thereby leading to rice imports to meet the increasing demands. Low production is probably due to a myriad of factors that include fixed and unavailable soil Phosphorus [3] to crops in the rice-growing areas including Mwea irrigation scheme is one of the main factors. The addition of phosphatic fertilizers into the soils to avail phosphorus to plants in the field is necessary for crop's root-establishment, growth, development, grain-formation, grain-filling, and for the intrinsic composition of grain yield; that forms the consumed part of the rice crop. Through proper application of P-based fertilizers, phosphorus would be available for plant-use by rice crop thus leading to increased yields [4] where this increase would translate to increment in food security, economic empowerment and improve living standards of the farmers in the rice growing regions in Kenya.

Phosphorus relation with nitrogen and potassium, as well as with micronutrients facilitates their absorption by plants, which if not properly applied compromises plant nutrition in a wider scale. The choice of rice varieties depend on various factors where consideration of focuses on adaptation to the specific environments, however, information is limited and scarce on screening these varieties adaptation to phosphorus and how it influences their tissue nitrogen and potassium contents [5]. Therefore, the current study was carried out at Mwea irrigation scheme in Kirinyaga County in order to evaluate the proper P fertilizer application on Nerica rice varieties.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted for two seasons at Mwea irrigation scheme's-Kirogo farm which lies at Latitude 0°37'S and Longitude 37°20′E and at an altitude of 1159 meters above sea level [6]. It has two rainy seasons and two dry seasons, with rains being of uneven distribution. Temperature ranges from 15.6°c to 28.6°c with a mean of 22°c. Soil types are classified as red soils with a slightly acidic pH of 6.18 [7], 0.119% N, 107.0% P (ppm) and 0.085% K me/140 g. The specific study field had soil properties analyzed at the beginning and at the end of the two seasons.

2.2 Experimental Design, Materials, Treatments, Data Collection and Analysis

The experiments were laid out in Randomized Complete Block Design (RCBD) in a split-split plot arrangement [8] with four Phosphorus levels (0, 25, 50 and 75 kg P/ha) and two Nerica varieties (Nerica 4 and Nerica 11) between December 2016 and May 2017(season 1) and between July to November 2017 (season 2). Soil sampling was done before planting and after harvesting on 0-15 cm soil layer by a zigzag method. The 96 composite samples of 100 gram each from the 96 split-split plots that were air-dried, crushed and passed through a 2 mm-mesh sieve. The samples were chemically-analyzed for pH, cation exchange capacity, soil phosphorus and total soil nitrogen. The growth, yield components' and grain yield data were collected at different phenological stages. Nitrogen uptake and phosphorus in plant tissues was determined through nitrogen and phosphorus tissue analysis. Collected data was cleaned and analyzed using GenStat version 15.1 and means separated using Fischer's Protected LSD test [7].

3. RESULTS AND DISCUSSION

3.1 Soil Properties

3.1.1 Soil pH

The Soils at the study sites in Mwea were moderately acidic [8] before treatments were applied with initial pH of 5.96 and 5.98 in season 1 and season 2 respectively which is suitable for rice growing [9]. The Phosphorus treatments did not have significant effect *(*$p<.0.05$) on soil pH in the two seasons. Nevertheless, highest net decrease of 0.20 and 0.22 was observed at 75 Kg ha^{-1} P_2O_5 during season 1 and season 2 respectively, while the lowest net decrease of 0.12 and 0.16 was elicited at 50 Kg ha^{-1} P_2O_5 in season 1 and season 2 respectively (Table 1). The predominant trend of the decreasing soil pH in the experiment for the two seasons was attributed to the progressive release of hydrogen ions into the soils thereby acidifying the soil surrounding band. The general net decrease of pH in the soil in season two was due to the residual effect of the acidity caused by the residual effect of phosphorus applied in the preceding season. Continuous cultivation of the same farm, sustained application of acidic fertilizers every season without liming practice, in most cases lead to a drop in the soil pH [10].

3.1.2 Soil cation exchange capacity

Results revealed that there was no significant effect on CEC (meq/100 g) in both seasons due to phosphorus application. The initial CEC (meq/100 g) was 23.41 meq/100 g and 23.38 meq/100 g in season 1 and 2 respectively (Table 2). A net decrease was observed in all the CEC levels due to all phosphorus level treatments in all the seasons in which highest net decrease of 1.09 meq/100 g and 1.03 meq/100 g in season 1 and 2 respectively, while least net decrease of 0.61 meq/100 g and 0.59 meq/100 g was elicited as a result of 50 Kg ha^{-1} P_2O_5 in season 1 and 2 respectively. There was no significant effect of variety that resulted from phosphorus level treatments, though the CEC mean difference was observed at 50 ha^{-1} P_2O_5, where least net decrease was elicited in the two varieties similarly in the two seasons. The reduced trend of soil CEC must have been due to reduced nutrients in the soil since CEC is the reservoir of nutrients that correlates with nutrients in a direct relationship manner [11]. Such low level of soil CEC signified also that the soils became of low water holding capacity. Among the nutrients that must have been utilized by the rice plants tested were the applied phosphates, organic matter and clay minerals, thereby reducing the anions in the soils that were not able to holdfast cations by electrostatic force created by them [12]. This therefore was thereby unable to allow dissolution of substantial level of cations (nutrient form) into the soil-water that ended up reducing nutrient adsorption on soil colloids' surface.

Table 1. Response of soil pH to phosphorus in Mwea, Kirinyaga County

	Season 1			Season 2		
Kg ha^{-1} P_2O_5	**Before planting**	**After harvesting**	**Net gain/loss**	**Before planting**	**After harvesting**	**Net gain/loss**
Control	5.96	5.79	-0.17 a	5.98	5.77	-0.21 a
25 kg	5.96	5.83	-0.13 a	5.98	5.80	-0.18 a
50 kg	5.96	5.84	-0.12 a	5.98	5.82	-0.16 a
75 kg	5.96	5.76	-0.20 a	5.98	5.76	-0.22 a
			NS			**NS**

Values with the same letters in a column do not differ significantly

Table 2. Response of soil CEC to phosphorus in Mwea, Kirinyaga County

	Season 1			Season 2		
Kg ha^{-1} (P_2O_5)	**Before planting**	**After harvesting**	**Net gain/loss**	**Before planting**	**After harvesting**	**Net gain/loss**
Control	23.41	22.32	-1.09 a	23.38	22.35	-1.03 a
25 kg	23.41	22.43	-0.98 a	23.38	22.45	-0.93 a
50 kg	23.41	22.8	-0.61 a	23.38	22.79	-0.59 a
75 kg	23.41	22.61	-0.8 a	23.38	22.66	-0.72 a
			NS			**NS**

Values with the same letters in a column do not differ significantly

3.1.3 Soil phosphorus

There was an inverse relationship exhibited between the phosphorus level of applications and the soil phosphorus net decrease across the two seasons. The net decrease was highest as a result of control, moderate at 25 Kg ha^{-1} P_2O_5, low at 50 Kg ha^{-1} P_2O_5 and least at 75 Kg ha^{-1} P_2O_5 treatments. Such extant net decrease in Soil P implied considerable uptake of phosphorus by plants in a manner that with addition of di-ammonium phosphate, conversion of phosphorus in the soils from unavailable forms into plant-available forms increased with increased fertilizer treatments. The soil pH of the experiment was initially acidic and remained sustainably acidic, signifying that inasmuch as there was expectation that phosphorus in soils remained in stable and unavailable forms. The application of the phosphate fertilizer increased acidity that favoured the solubility and availability of diphosphates into the Nerica rice crops. The control exhibited highest net decrease of soil phosphorus; a scenario that indicated that acidic soils tend to turn stable and insoluble forms of soil phosphorus into unstable and soluble forms in the phenological period of plants especially when the acidic conditions favoured the availability and uptake of diphosphates in plants.

The decreased soil phosphorus levels did not mean that the soil phosphorus accumulated into the soils after grain yield harvest reduced, indicating that with additional inorganic phosphorus got utilized fully, and above it, the initially fixed and unavailable soil phosphorus got converted to soluble and available form that was also taken up, therefore leading to the reduction of the soil accumulated phosphorus at the end of the experiment (Table 3).

The relationship between phosphorus level applications and soil phosphorus after harvest in the experiment. That signified that, it was predictable that the net decrease of phosphorus in the could be attributed to the inorganic phosphorus levels applied at planting, while other sources of phosphorus such as organic matter, parent rock material and clay could have contributed to the soil phosphorus accumulation into the soils of the experimental units after grain yield harvest.

3.1.4 Total soil nitrogen

The initial soil nitrogen in the experimental location was 0.14% and 0.16% in season 1 and 2 respectively (Fig. 1). That soil nitrogen reduced within the lower level, and still remained low even after phosphorus level treatments were applied though negligible net increase was elicited as a result of each treatment across the seasons. The highest net increase of 0.05% was observed on the 75 Kg ha^{-1} P_2O_5 treatment and control in season 1. The treatment of 50 Kg ha^{-1} P_2O_5 had the lowest net increase of 0.02% in season 2. There was no significant differences on the net increase of total soil nitrogen as a result of the phosphorus level applications in both seasons since phosphorus in the soils tested was optimally available. That is consistent with the argument advanced that the availability of phosphorus to plants has proved to be driving efficient utilization of nitrogen by plants for in the form of adenosine triphosphate(ATP), phosphorus necessitates plant absorption of soil nitrogen by active transport for plant metabolism. Wafula et al. [10] expressed that soils that contain sufficient plant available phosphorus necessitate the uptake of nitrogen from the soils most effectively due to their synergistic interaction. In this study, it was observed that, with net decrease in phosphorus in the soils after phosphorus treatments, sufficient absorption of phosphorus by plants signified synergy in the two nutrients' uptake by plants from the soils tested [13]. The net increase in soil nitrogen could be due to the addition of nitrogenous fertilizers into the soils or from organic matter breakdown already in the soils or via topdressing of calcium ammonium nitrate at active tillering and panicle-initiation stages after immobilization-mineralization processes taking place [14].

3.2 Influence of Phosphate Fertilizer on Phosphorus and Nitrogen Tissue Contents

3.2.1 Plant tissue phosphorus

The results revealed that there was no significant effect ($P>0.05$) on plant tissue phosphorus due to phosphorus application, but a consistent trend of increasing plant tissue phosphorus correlated with increased phosphorus applications in the two seasons was observed. Phosphorus level of 75 kg ha^{-1} P_2O_5 showed highest plant tissue phosphorus of 58.1 ppm in season 1 and 58.5 ppm in season 2, yet lowest of 53.8 ppm in season 1 and 54.6 ppm in season 2 was on the control. Both varieties; Nerica 11 recorded highest plant-tissue phosphorus of 62 ppm in season 1 and 62.1 ppm in season 2 at the 75 kg ha^{-1} P_2O_5 phosphorus level. Moreover, Nerica 4 recorded 59.6 ppm in season 1 and 62.9 ppm in season 2. Both Nerica 11 and 4 recorded lowest plant–tissue phosphorus of 54.7 ppm and 54.2 ppm in the control in season 1, while in season 2, Nerica 11 and 4 recorded 51.6 ppm and 50.9 ppm plant-tissue phosphorus respectively, with that of Nerica 4 having a lower count compared to that of Nerica 11 across the two seasons (Fig. 2). It was also probably that there were no significant on Nerica varieties due to phosphorus levels probably because of their close genetic similarities. Highest plant-tissue phosphorus in both seasons was realized in plants that had the highest phosphorus level application as compared to those with lower phosphorus application. In that tune, there must have been

Table 3. A comparative net decrease of soil Phosphorus due to phosphorus levels for two seasons in Mwea, Kirinyaga County

	Season 1			Season 2		
Kg ha^{-1} (P_2O_5)	**Before planting**	**After harvesting**	**Net gain/loss**	**Before planting**	**After harvesting**	**Net gain/loss**
Control	242	206.2	-35.8a	239	205.6	-33.4a
25 kg	242	211.5	-30.5a	239	209.4	-29.6a
50 kg	242	212.5	-29.5a	239	211.2	-27.8a
75 kg	242	219.5	-22.5a	239	217.7	-21.3a
			NS			**NS**

Values with the same letters in a column do not differ significantly

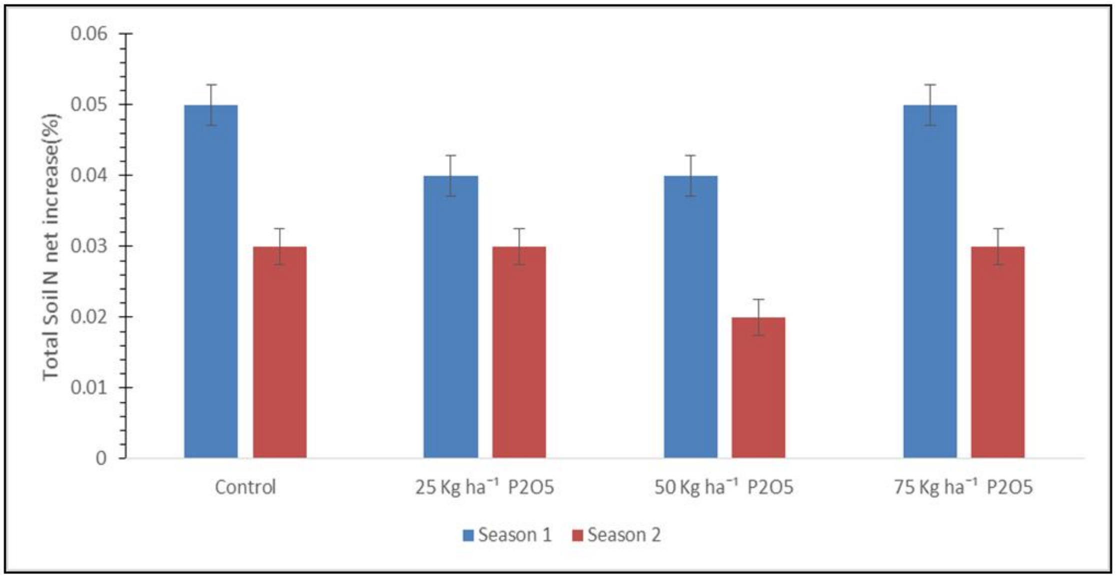

Fig. 1. Influence of phosphorus levels on total nitrogen net increase for the two seasons in Mwea soils

commensurate plant-available phosphorus to the referred tested plants that got absorbed appropriately by the plants [15], as reported by Raghothana & Karthikeyan [16] that high soil extractable phosphorus translates to high phosphorus concentration in plant tissue.

The relationship between phosphorus levels applied and plant-tissue phosphorus could be explained by a coefficient of determination. The coefficient of determination for the said relationship stood at r=0.6647 (Fig. 3); which informed on the fact that probably the difference is due to application of inorganic phosphorus at planting or attributable to other sources such as mineralization of organic matter, parent material and clay in the soils.

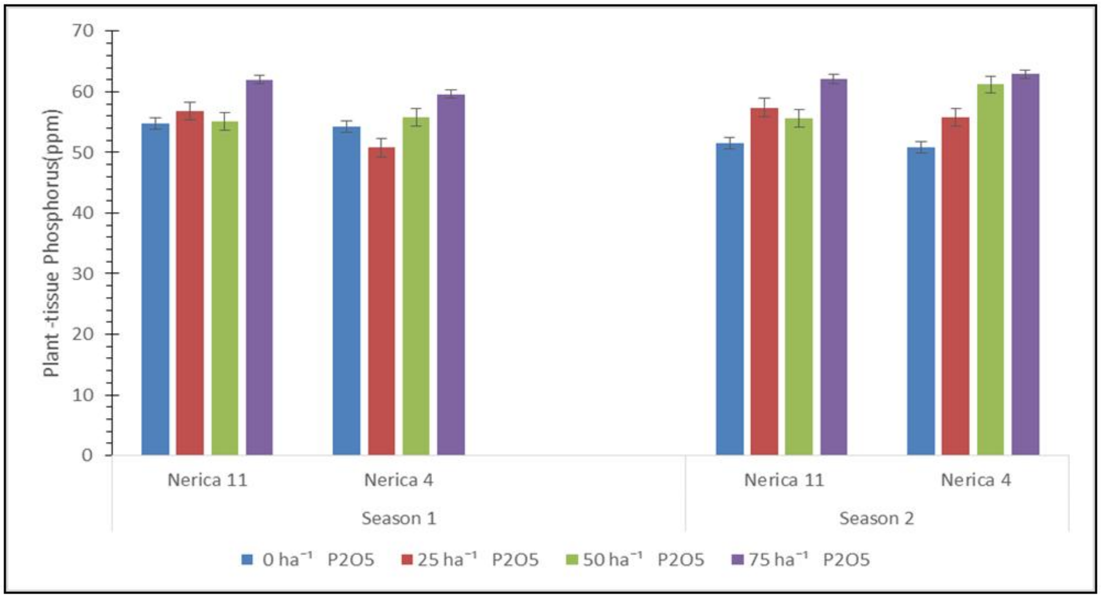

Fig. 2. Influence of Phosphorus level applications on plant-tissue Phosphorus of Nerica varieties in two seasons

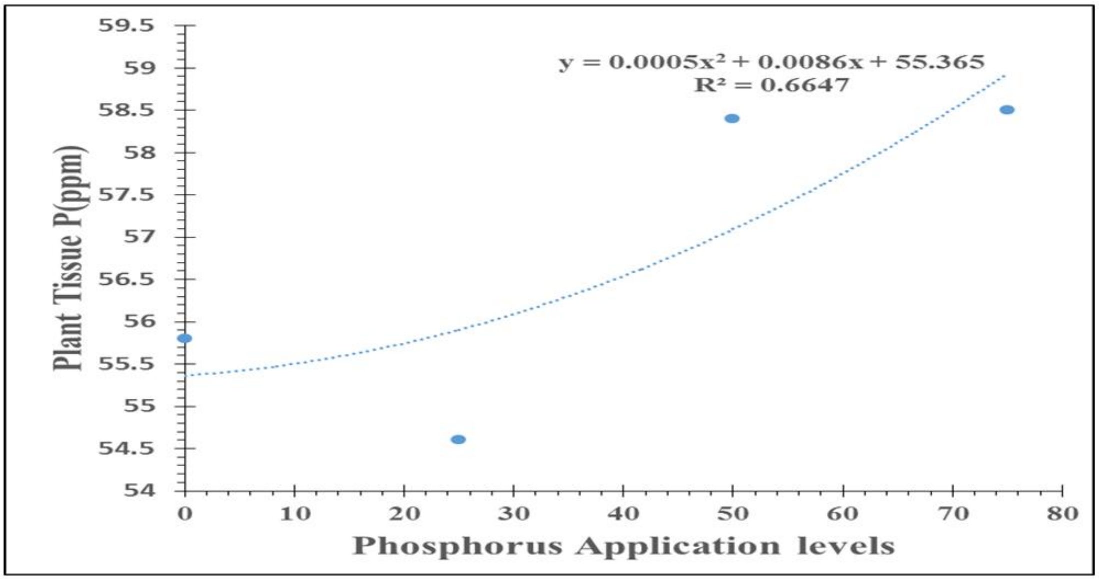

Fig. 3. Relationship between phosphorus level application and plant tissue phosphorus

3.2.2 Plant tissue nitrogen

No significant effect (P>0.05) on plant tissue nitrogen due to phosphorus applications on soils, it was consistently noted that with increased level of application of phosphorus into the soils for plant use, there occurred increased plant tissue nitrogen in the plants studied (Fig. 4). That by small and large demonstrated that plant uptake of nitrogen by plants depended heavily on the amount of phosphorus applied on soil root zones or bands. That trend confirmed what [6] found in their past similar experiment that, positive change in nitrogen uptake efficiency due to the application of phosphorus into the soils occurs as a result of the utilization of phosphorus in cell division of shoot and expanded growth of meristematic tissues or foliage. Such scenario repeated itself in the currently reported experiment whereby highest plant tissue nitrogen of 0.699% in season 1 and 0.706% in season 2 was realized in plots with soils that were treated with 75kg ha⁻¹ P_2O_5, while the lowest plant tissue nitrogen of 0.589% in season 1 and 0.590% in season 2 were elicited in plants had no phosphorus applied (Fig. 4). Control in that case proved that there was organic matter in the soils which by timely mineralization was released into absorbable form, which got absorbed by plants. There was also likelihood that even with the additional nitrogen by split applications to all plots by blanket formula, that conversion of NH^{4+}-N to NO^{3-}-N; a form by which nitrogen would be readily available to plants probably reduced, thereby inhibiting loss of soil nitrogen to the advantage of nitrogen uptake by plants.

The strength of relationship between phosphorus levels applied and plant-tissue nitrogen could be explained by a coefficient of determination. The coefficients of determination for the said relationship stood at r=0.9723 (Fig. 5); which informed on the fact that 97.23% and 98.59% of plant-tissue nitrogen in season 1 and 2 respectively was uptaken and assimilated by the Nerica plants by active transport process driven by adenosine triphosphate (ATP) sourced from the inorganic phosphorus applied at planting, the fraction was attributable to other sources such as mineralized organic matter in the soil, animal wastes, rainfall nitric acid, application of Calcium Ammonium Nitrate at active tillering and at panicle initiation.

Phosphorus availability or unavailability in the rhizosphere to plants critically affected the uptake of nitrogen and other nutrients. That was an indicator that plants' uptake of phosphorus influenced the uptake of nitrogen to a small extent, but to a large extent its uptake may have been influenced by other factors including site of application, time of application, stage of development, interactions with other compatible or antagonistic mineral elements during crop growth, as well as stoppage of NH^{4+}-N conversion to NO^{3-}-N that would necessitate "less loss of soil nitrogen and more nitrogen plant uptake [15,17].

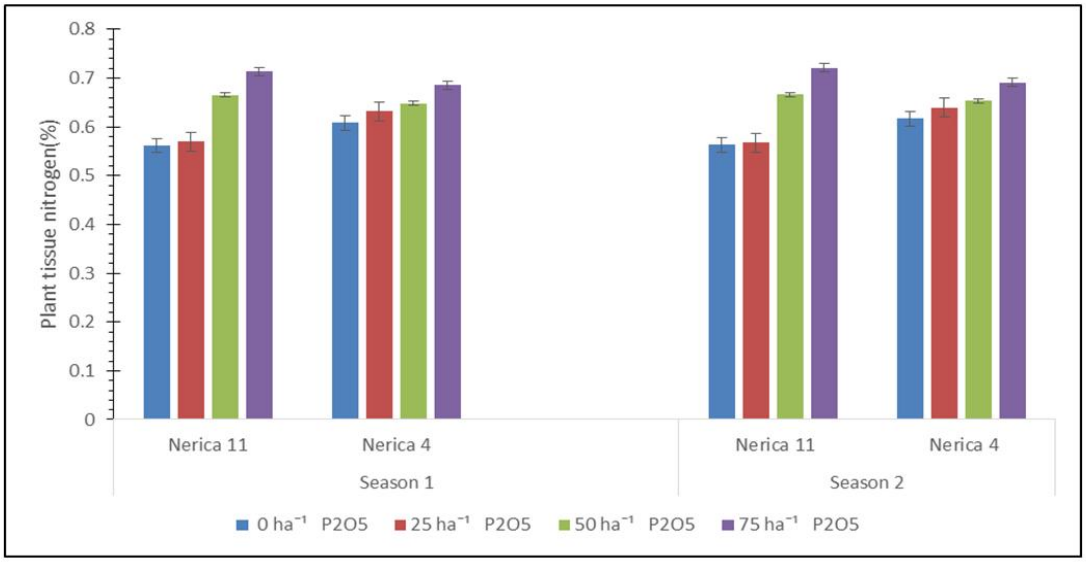

Fig. 4. Effect of phosphorus level applications on soils in Mwea on the uptake of nitrogen by Nerica plants across two seasons in Mwea, kirinyaga

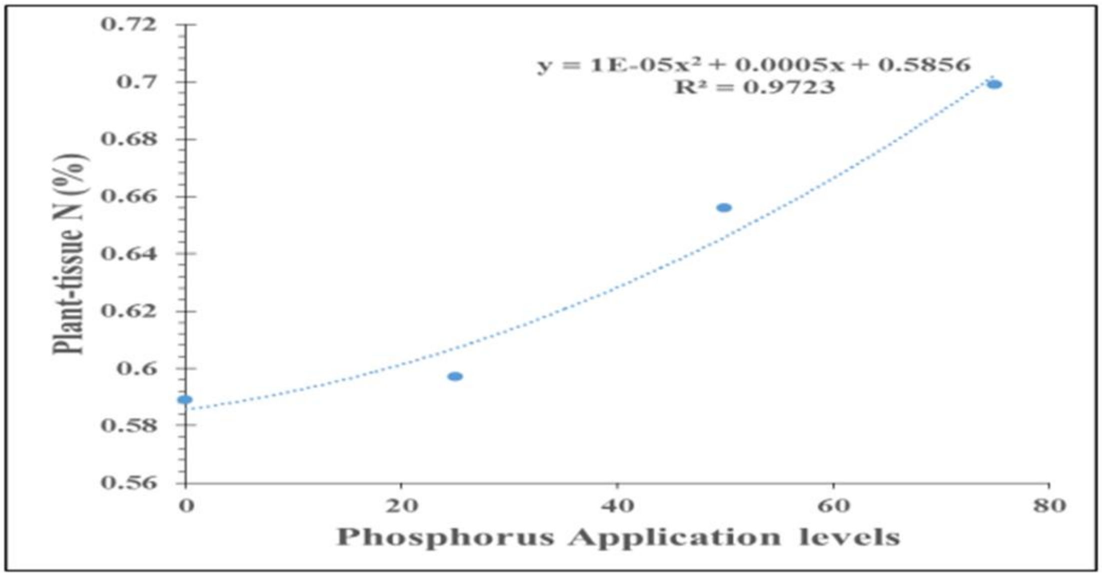

Fig. 5. Relationship between phosphorus application and plant tissue Nitrogen across two season in Mwea, Kirinyaga

4. CONCLUSION

There was generally a slight drop in soil pH, cation exchange capacity and soil phosphorus under the influence of phosphorus level treatments in both seasons. Despite the drop, the soil pH after crop harvest in the two seasons still remained within the range of moderate acidity as it were at planting. Highest drop from 5.96 and from 5.98 in season 1 and 2 respectively to 5.76 as a result of 75 kg P/ha treatment was observed in both seasons. Finally, phosphorus applications had a positive influence on the selected soil properties at the study sites and therefore a rate of 75 kg P/ha is recommended in both Nerica rice varieties. Further research should be conducted to establish the maximum application rate of phosphorus in reference to the plant tissue N and P contents as the regression model indicated no tail off at the highest level of 75 kg P/ha.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kimani JM, Tongoona P, Derera J, Nyende AB. Upland rice varieties development through participatory plant breeding. ARPN Journal of Agricultural and Biological Science. 2011;6(9):39-49.
2. Momo JA. Effect of witholding irrigation water after complete heading on rice yield and seed quality in Mwea-Kirinyaga County. Master's Thesis, Kenyatta University. Nairobi, Kenya; 2013.
3. Shen J, Yuan L, Zhang J, Li Haigang, Bai Z, Chen X, Zhang W, Zhang F. Update on phosphorus dynamics in the soil-plant continuum. China Agricultural University, Beijing, Kenya; 2011.
4. Takahashi S, Uesosono S, Nagatomo M. Rice uptake of nitrogen from aerobically and anaerobically composted poultry manure. Journal of Plant Nutrition. 2004;27(4).
5. Matsunami M, Matsunami T, Kokubun M. Growth and yield of new rice for Africa (NERICAs) under different ecosystems and nitrogen levels. Plant Production Science. 2009;12(3).
6. Jaetzold R, Schmidt B, Shisanya CA. Farm management handbook of Kenya. Natural Conditions and Farm Information, 2nd 11/C. Ministry of Agriculture/GTZ, Nairobi, Kenya (Eastern Province); 2006.
7. Gary W. Oehlert. First course in design and analysis of experiments. University of Minnesota, Minnesota, United States of America; 2010.

8. Kanyanjua SM, Ireri L, Wambua S, Nandwa SM. Acidic soils in Kenya. Constraints and Remedial Options. KARI Technical Note No. 11, Nairobi, Kenya; 2002.
9. Somado EA, Guei RG, Keya SO. NERICA. The New Rice for Africa-a compendium. Africa Rice Center (WARDA). Cotonou, Benin; 2008.
10. Wafula NW, Nicholas Kibet Korir, Moses Siambi, Henry F. Ojulong, Joseph P. Gweyi-Onyango. Agromorphological performance and character association of finger millet under varying phosphorus regimes. Journal of Agricultural Studies. 2017;5(1):90-102. ISSN: 2166-0379.
11. Arthur E. Rapid estimation of cation exchange capacity from soil water content. European Journal of Soil Science. 2017;68(3).
    DOI: https://doi.org/10.IIII /ejss.12418
12. Morteza Khorshidi, Ning Lu. Determination of cation exchange capacity from soil water retention curve. Journal of Engineering Mechanics. 2017;143(6).
13. Fayiga, Abioye, Obigbesan. Effect of two moisture regimes on P-release from P-treated soils. Journal on Archives of Agronomy & Soil Science. 2018;64(3).
14. Verde BSMM. Effects of manure, lime and phosphorus fertilizer on soil properties and soybean yields in Embu County-Kenya. Master's Thesis. Kenyatta University. Nairobi, Kenya; 2014.
15. Wafula NW, Nicholas K. Korir, Henry F. Ojulong, Moses Siambi, Joseph P. Gweyi-Onyango. Nitrogen and phosphorus uptake and partitioning in finger millet as influenced by phosphorus fertilization. Journal of Experimental Agriculture International. 2016;14(4):1-11. ISSN: 2231-0606.
16. Lamb John A, Fernandez Fabian G, Kaiser Daniel E. Nutrient management: Understanding nitrogen in soils. University of Minnesota Extension, Minnesota, United States of America; 2014.
17. Raghothana G, Karthikeyan N. Phosphate acquisition. Annual Rev Plant Physiology & Molecular Biology; 2005.

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