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Effect of soil amendments on availability of soil phosphorus and uptake by maize in Vihiga County, western Kenya

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ABSTRACT

The combined use of organic inputs and fertilizers as promoted via Integrated Soil Fertility Management (ISFM) approach may have a significant effect on bioavailability of phosphorus (P) and enhance its uptake by crops. To assess this, a field study was conducted to determine the effects of combined use of lime, NPK fertilizer, farmyard manure (FYM) and Zinc (Zn) on short-term changes in available soil P. This was followed by determination of P uptake in the stover and the maize grain. Thus, four field experiments were established in four sites in Vihiga County, western Kenya; two sites (Gurugwa 1 and 2) in Sabatia sub-county and two (Bumuyange and Jivogoli) in Hamisi sub-county during the long rain (LR) and short rain (SR) seasons of 2015. The treatments comprised of (i) an absolute control, (ii) NPK (100 kg N ha^{-1}, 30 kg P ha^{-1} , 42 kg K ha^{-1}), (iii) NPK + FYM (2 t ha^{-1}), (iv) NPK + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}), (v) NPK + FYM (3 t ha^{-1}), (vi) NPK + FYM (4 t ha^{-1}) and (vii) NPK + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}). Each of these treatments were replicated three times and randomly allocated within each replicate. Soils were sampled at 0, 42, 86 and at 120 days after planting and analyzed for available P content. Results showed that combined use of NPK fertilizer, FYM, lime and Zn (treatment iv) gave significantly larger ($P<0.05$) available P levels after 42, 86 and 120 DAP (Days after planting) relative to the control. In the maize ear leaf, the largest total P content were observed in all treatments containing FYM. In the maize grain, again, the treatment (iv) resulted in the largest P content. Further, use of NPK fertilizer with FYM at 3 t ha-1 and 4 t ha^{-1} resulted in significantly larger ($P<0.05$) P content in the maize stover. By embracing ISFM strategies, low P uptake at farm level may be alleviated. Locally adapted fertilizer packages and amendment blends aimed at addressing specific limiting soil conditions such as Zinc deficiencies can further enhance P uptake in maize.

Key words: Farmyard manure, Integrated Soil Fertility Management, NPK, uptake, western Kenya, Zinc

RÉSUMÉ

L'utilisation combinée d'intrants organiques et d'engrais via la gestion intégrée de la fertilité des sols (GIFS) peut avoir un effet important sur la biodisponibilité du phosphore et améliorer son absorption par les cultures. Pour évaluer cet effet, une étude a été menée pour déterminer les effets de l'utilisation combinée de la chaux, de l'engrais NPK, du fumier (FYM) et du zinc (Zn) sur les changements à court terme du

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phosphore disponible dans le sol. Ceci a été évalué via la détermination de l'absorption de phosphore dans le chaume et les grains de maïs. Pour ce faire, quatre expérimentations ont été installées sur quatre sites du comté de Vihiga, dans l'ouest du Kenya; deux sites (Gurugwa 1 et 2) dans le sous-comté de Sabatia et deux (Bumuyange et Jivogoli) dans le sous-comté de Hamisi durant la grande saison des pluies (LR) et la petite saison des pluies (SR) de 2015. Les traitements incluaient (i) un témoin absolu; (ii) NPK (100 kg de N ha-1, 30 kg de P ha-1, 42 kg de K ha-1), (iii) NPK + FYM (2 t ha-1), (iv) NPK + FYM (2 t ha-1) + chaux (2 t ha-1) + Zn (3 kg ha-1), (v) NPK + FYM (3 t ha-1), (vi) NPK + FYM (4 t ha-1) et (vii) NPK + Chaux (2 t ha-1) + Zn (3 kg ha-1). Chacun de ces traitements a été répliqué trois fois et réparti de façon aléatoire dans chaque bloc. Les sols ont été échantillonnés à 0, 42, 86 et 120 jours après la plantation, puis analysés pour déterminer la teneur en phosphore bio-disponible. Les résultats ont montré que l'utilisation combinée d'engrais NPK, de FYM, de chaux et de Zn (traitement iv) donnait des niveaux de phosphore bio-disponible significativement plus élevés (P<0,05) après 42, 86 et 120 jours (après le semis) par rapport au témoin. Dans le chaume du maïs, la plus grande teneur totale en phosphore a été observée dans tous les traitements contenant du fumier (FYM). De même, la plus forte teneur en phosphore a été donnée le traitement (iv). En outre, l'utilisation d'engrais NPK combiné au fumier à 3 t ha-1 et 4 t ha-1 a produit une teneur en phosphore significativement plus élevée (P<0,05) dans la tige de maïs. En adoptant les stratégies de la GIFS, il est possible d'endiguer la faible absorption de phosphore au niveau de la ferme. Des formulations d'engrais et des mélanges d'amendements adaptés aux conditions locales, destinés à remédier à des conditions de sol spécifiques, telles que les carences en zinc, peuvent améliorer l'absorption de phosphore par le maïs.

Mots clés: fumier, gestion intégrée de la fertilité du sol, NPK, absorption, ouest du Kenya, zinc

BACKGROUND OF THE STUDY

Maize production in most East African countries is constrained by widespread soil acidity coupled with P deficiencies. Various reports have indicated high rates of P depletion; > 6 kg P ha^{-1} yr $^{-1}$ especially in integrated smallholder systems (Haileslassie *at al.*, 2005; Bationo *et al.,* 2008; Nziguheba *et al.,* 2016)). This in turn affects the P uptake due to its low concentrations in the soil solution. As a result, low agricultural productivity and consequently food insecurity has become the norm in the region. Further, the profitability of fertilizer in such cases is unattractive to farmers and, therefore, threatens its use in the region (Njoroge *et al.,* 2017).

With the increasing demand for food due to population pressure and the dwindling crop yields in most smallholder farms, Integrated Soil Fertility Management strategies have been increasingly promoted the researchers and development community as a framework for boosting crop productivity (Vanlauwe *et al.,* 2011). The main approach within the framework has been the combination of organic and inorganic inputs for increased crop production. This strategy has been successfully implemented via on-farm trials in some parts of western Kenya. For instance, in Nyalgunga, Nyabeda and Emusutwi sub-locations in western Kenya, combining Farmyard manure with inorganic fertilizer increased maize yields by 148% above the control (Abuom *et al.,* 2014). Similarly, in Vihiga County, a combined application of FYM, Mavuno fertilizer and a top dressing fertilizer led to over 300% yield increases above the zero input treatment (Cebula, 2013). Combining mineral fertilizers with organic resources leads to long-term positive impact to the environment and hence improves the use efficiency of mineral fertilizers (Okalebo *et al.,* 2002; Vanlauwe *et al.,* 2011; Mucheru-muna *et al.,* 2014). Additional benefits of organic inputs such as manure include the supply of micronutrients that are mostly absent in the conventional inorganic fertilizers (Onduru *et al.,* 2008).

The intensive nature of crop production in most smallholder farms has led to decreases in soil pH and available P content in western Kenya soils (Nziguheba *et al.,* 2016). This has led to reduced P solubility in the soils making its acquisition through plant roots difficult. Practices such as application of Nitrogen based fertilizers acidify the soils leading to P fixation. Further, the high concentrations of Al and Fe oxides in these soils significantly reduce P availability through P fixation (Otinga *et al.,* 2013). Processes affected include precipitation, solubilization and other chemical reactions. Measures such as the application of lime have been promoted widely to address this problem (Haynes and Mokolobate, 2001; Fageria and Baligar, 2008; Nduwumuremyi, 2013; Paradelo *et al.*, 2015; Goulding, 2016; Opala *et al.*, 2017). Other studies have opined that organic amendments, such as manure can raise the oil pH making insoluble nutrients soluble (Hue, 1992; Otinga *et al.*, 2013; Gitari *et al,* 2015). In this study, changes of soil available P was assessed in four growth stages in cropping season as affected by fertilizer and amendment combination. The assessment was facilitated by the proven fact that various fertilization regimes can increase or decrease the P bioavailability in the soil. Thus, determining the seasonal changes in available P can be a predictive index in estimating total and available P pools within a growth period. Further, P uptake in the ear-leaf, grain and stover can be utilized in nutrient budget determination at the end of each cropping cycle especially in intensively farmed soils of western Kenya.

MATERIAL AND METHODS

Description of study sites . This study was conducted in two sub-counties of Vihiga County, namely Sabatia and Hamisi. Both sub-counties lie between upper midland and lower midland agro-ecological zones (Jaetzold *et al.,* 2006). Vihiga County lies between longitude 34 ,30' East and 35 , 0' West and between 0, and 0 , 15' North. The county experiences high equatorial climate with well-distributed rainfall throughout the year (average 1900 mm) (Jaetzold, *et al.,*2006). Temperatures range are between 14° C and 32° C, with the hottest months being December through February. Long rains (LR) spread through the months of March, April, and May while short rains (SR) occur from September through November. The dominant soil types in both sub-counties are Acrisols and Cambisols (Jaetzold *et al.*, 2006). Majority of farm holdings practice mixed farming system that includes the food crop, cash crop, livestock and tree production (Jaetzold *et al.,* 2006). Vihiga County is one of the most populated areas in Kenya with over 1078 persons per km^2 (GOK, 2013). Average farm sizes are 0.5 ha (Tittonell *et al.,* 2005; GOK, 2014).

Experimental Design and treatment structure. A randomized complete block design (RCBD) with three replications was adopted for the two experimental sites. The experiment had seven treatments consisting of (i) NPK (300 kg ha^{-1}); (ii) NPK (300 kg ha^{-1}) + FYM (2 t ha^{-1}); (iii) NPK (300 kg ha^{-1}) + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1});(iv) NPK (300 kg ha^{-1}) + F YM (3 t ha^{-1}); (v) NPK (300 kg ha^{-1}) + FYM (4 t ha^{-1}) (vi) NPK (300 kg ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) and (vii) an absolute control (without fertilizer), (Table 1). The NPK fertilizer supplied 100kg N ha^{-1}, 30 kg P ha^{-1} and 42 kg K ha^{-1}, based on recommendations given by the Ministry of Agriculture, Livestock and Fisheries (MOALF, 2014) for western Kenya. Each plot measured 5m x 4.5m with six maize lines at an interspacing of 75 cm running along the length and always against the general gradient. In general, NPK was applied in form of a compound fertilizer (17:17:17), a type that is currently recommended for the region (MOALF, 2014). Zinc was applied as zinc sulphate while lime was applied as $CaCO_3$ (Koru lime) sourced from Homalime Company Limited Kenya.

Trial establishment and maintenance. Maize seed, hybrid 516, recommended for western Kenya (Schroeder *et al.,* 2013) was planted in all sites at an intra-row spacing of 30 cm. Two maize seeds were planted per hole and later thinned to one two weeks after emergence to give a plant population of 44,444 plants per hectare. During each cropping season, maize was weeded twice and harvested at physiological maturity, i.e., approximately 30 days after silking. This is when a "black layer" is noticeable at the tip of each kernel, where cells die and block further starch accumulation into the kernel (Belfield and Brown, 2011).

Soil, ear leaf, maize stover, grain sampling and analysis. For each of the experimental plots, a surface soil sample (0-15 cm) was collected from five random points, air dried for a period of about two weeks and passed through a 2 mm sieve for P determination. The available P (Olsen) were determined at 42, 86 and 120 DAP (days after planting) for both the LR and SR 2015 season and the values averaged for the four experimental sites (Figure 1).

Treatment code	Nutrient + Amendment applied	Source
Control	NPK(0,0,0) + 0	without N, P and K and amendments
NPK	NPK (100 kg N ha^{-1}, 30 kg P ha^{-1}, 42 kg K ha^{-1}) + 0	NPK, TSP and Urea and no amendments
NPK + FYM 1	NPK (100 kg N ha -1, 30 kg P ha^{-1}, 42 kg K ha-1 + FYM (2 t ha^{-1})	NPK, TSP, Urea, FYM
NPK + FYM 2	NPK (100 kg N ha^{-1}, 30 kg P ha^{-1}, 42 kg K ha^{-1} + FYM (3 t ha^{-1})	NPK, TSP, Urea, FYM
NPK + FYM 3	NPK (100 kg N ha^{-1}, 30 kg P ha^{-1}, 42 kg K ha^{-1}) + FYM (4 t ha^{-1})	NPK, TSP, Urea, FYM
NPK + Zn + FYM 1+ L	NPK (100 kg N ha^{-1}, 30 kg P ha^{-1}, 42 kg K ha^{-1}) + Zn (3 kg ha^{-1}) + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1})	NPK,TSP, Urea, Zinc sulphate, FYM, Lime
NPK+ Zn + L	NPK (100 kg N ha -1, 30 kg P ha^{-1}, 42 kg K ha^{-1}) + Zn (3 kg ha^{-1}) + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1})	NPK,TSP, Urea, Zinc sulphate, Lime

Sampling of ear leaf tissue at silking stage (R1 stage, i.e., approximately 30 days after silking) for both growing seasons followed a modified procedure as described by Njoroge *et al.* (2017). The leaf sampling points were confined to a net plot of 3x3m^{2} consisting of four inner planting rows and within 1 m away from the edge. The samples were oven dried at 70 C for 48 h in the University of Eldoret laboratories and later transported to KU Leuven for P determination. A powdered (agate mortar and pestle or ball mill, also in agate) sample of 50 mg was digested in 1 ml hot nitric acid for 3 h at 180 C and diluted 3 times (2 ml aliquot and 4 ml ultrapure water) awaiting P concentration measurements via Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Agilent7700X). At harvest, maize stover parts were sampled from a net plot of 3x3m^{2} consisting of four inner planting rows and within 1 m away from the edge. The harvested plants were later divided into stover (stalk and leaves), cob, and grains. The stover portion was chopped into small pieces, weighed and sub-sampled for dry matter determination. The cobs were similarly treated. The grain was weighed, and moisture content measured using moisture meter (Agromatic Mark II, Farmer Tronic, Denmark), and then sub-sampled for dryness to constant weight. The dry weights were recorded and used to calculate total above-ground dry matter yields. Plant sub-samples were then fine ground for subsequent digestion and analysis of P content using procedures outlined by Okalebo *et al.* (2002).

Statistical analysis . Statistical analysis was performed on all the datasets using Analyses of variance (ANOVA) procedure using Genstat 16th edition software. The sites, fertilizer treatments, season, and their interactions were the fixed factors while replicates within each treatment were considered as the random factors. Treatment differences were evaluated by computing the Standard error of differences (SED) at a significance level of $P \leq 0.05$.

RESULTS

Soil available P at different sampling stages. The treatment combinations showed significant differences across sites after treatment application (Figure 1). At topdressing stage (42 days after planting), application of NPK fertilizer with or without other soil amendments increased P concentration in the soils. At this stage the treatment NPK+FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3kg ha^{-1}) gave the largest P concentration at 13.38 mg kg^{-1}. At tasseling stage (86 days), the treatments NPK+FYM (2 t ha^{-1}) and NPK+FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3kg ha^{-1}) gave the largest P levels at 7.98 mg kg^{-1} and 8.17 mg kg^{-1} respectively, while at harvesting stage(120 days), the treatments NPK, NPK+FYM (2 t ha^{-1}) and NPK+FYM (3 t ha^{-1}) gave the largest P levels at 6.09 mg kg^{-1}, 6.24 mg kg^{-1} and 6.15 mg kg^{-1}, respectively.

Total P (‰) content in the ear leaf. Most treatments recorded values that were above the 0.25 mg kg^{-1}, the critical concentration in maize ear leaf (Figure 2), indicated by the boundary line. Significant differences were observed between treatments at ($P<0.001$). Irrespective of the treatments and sites, mean P levels increased significantly from the control. However, the extent of this increase was strongest with NPK alone and/or amendment combinations. Further, the P concentrations were not significantly affected by the rate of FYM added. Site comparisons showed significantly smaller zinc levels in Bumuyange and Jivogoli regardless of the treatment. Overall, the treatments NPK + FYM (2 t ha^{-1}), NPK + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}), NPK + FYM (3 t ha^{-1}) and NPK+ FYM (4 t ha^{-1}) recorded the largest P concentrations averagely at 0.27 %.

Total P (%) in the maize grain. Treatment comparisons within the sites showed high levels of % P in NPK + FYM (4 t ha^{-1}) and NPK 1 + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) in Gurugwa 1, at 0.29 % and 0.32%, respectively (Figure 3). In

Gurugwa 2, the treatment NPK and NPK+ FYM (2 t ha^{-1}) gave large Total P (%) concentrations at 0.37 and 0.41 % P respectively. In Bumuyange and Jivogoli, the treatments combining NPK + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) and NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) led to the largest percent total P values of 0.43 and 0.44 P, respectively. Averagely, mean percent P concentrations were largest in Gurugwa 2, Bumuyange and Jivogoli at 0.33 %, with Gurugwa 1 recording the least P concentration (0.28%).

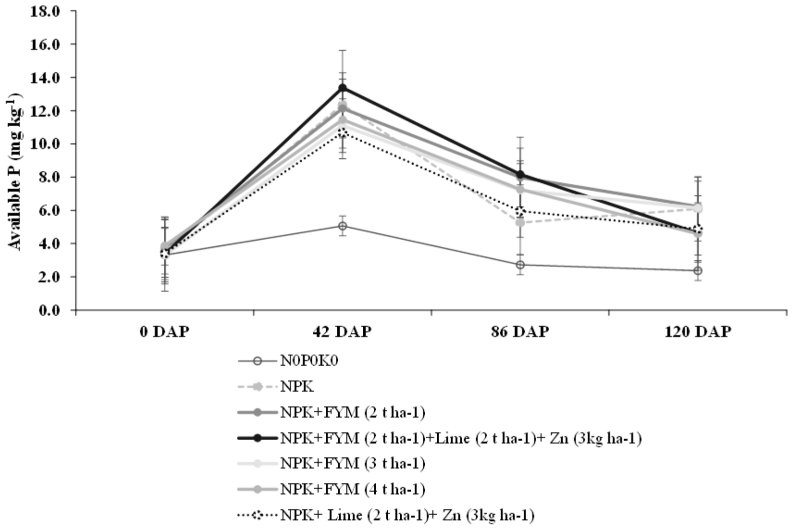

Figure 1. Overall changes in soil available P over a maize growing season and as affected by various combinations of soil amendments. DAP = days after planting; NPK-(100kg N ha^{-1}, 30 Kg P ha^{-1}, 42.33 Kg K ha^{-1})

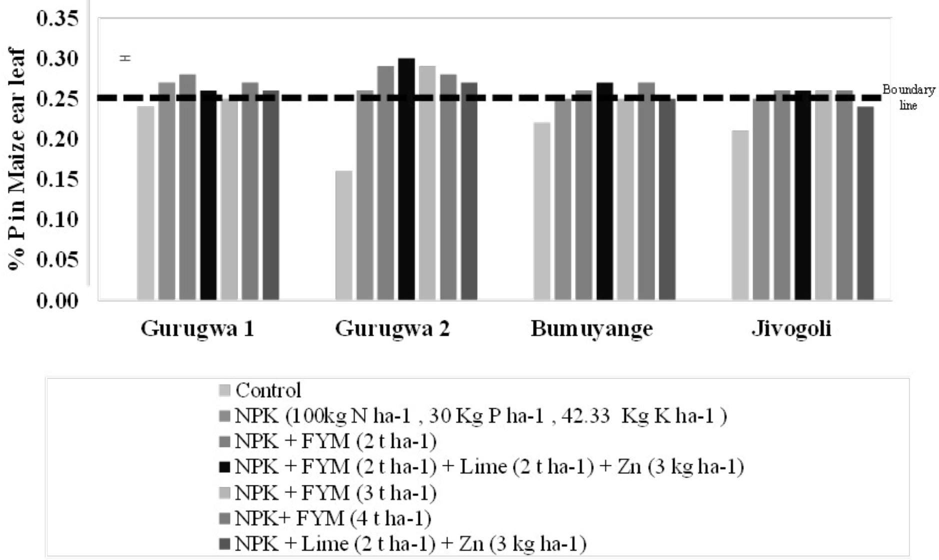

Figure 2. Total P (%) comparison in the maize ear leaf as affected by various combinations of soil amendments. DAP = days after planting; NPK- (100kg N ha^{-1}, 30 kg P ha^{-1}, 42.33 kg K ha^{-1}).

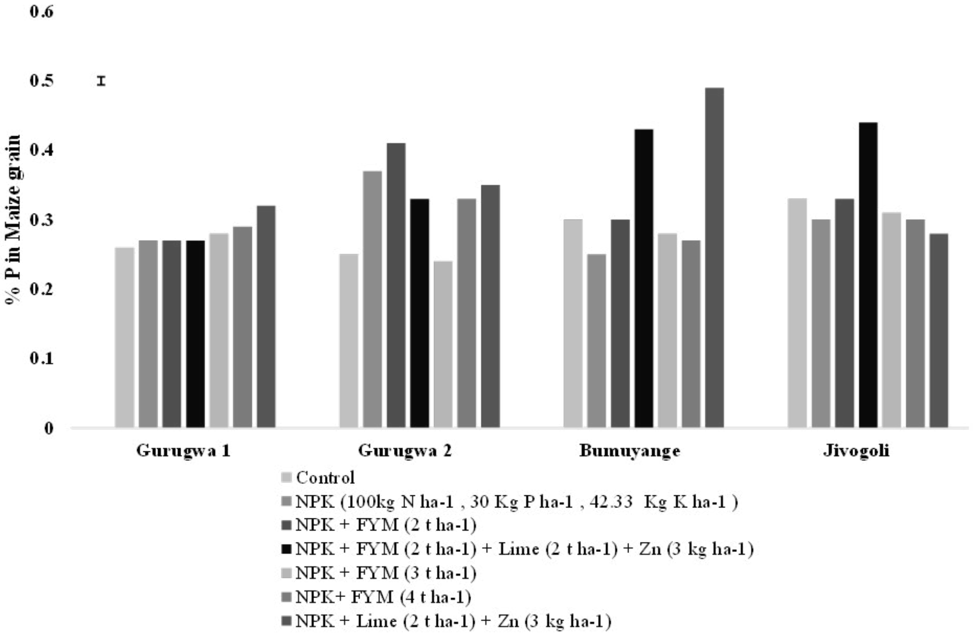

Figure 3. Percent (%) P in the maize grain as affected by various combinations of soil amendments. DAP = days after planting; NPK- (100kg N ha^{-1}, 30 kg P ha^{-1}, 42.33 kg K ha^{-1})

Total P (%) in the maize stover. The concentrations of % P in maize stover are presented in Figure 4. Irrespective of the sites, the treatments NPK, NPK + FYM (3 t ha^{-1}) and NPK + FYM (4 t ha^{-1}) recorded the largest mean P levels at 0.06 %. Site comparisons showed larger levels of P in Gurugwa 1, averagely at 0.06. Treatment comparisons within the sites showed larger P levels for treatments NPK + FYM (3 t ha^{-1}), NPK + FYM (4 t ha$^{-1)}$ and NPK + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) at 0.08 %, 0.08 % and 0.07 % respectively in Gurugwa 1. In Gurugwa 2, the treatments NPK (100kg N ha^{-1}, 30 Kg P ha^{-1}, 42.33 kg K ha^{-1}) and NPK + FYM (3 t ha^{-1} recorded larger P level; 0.06%. Notably, the control and NPK + FYM (4 t ha^{-1}) recorded large P levels, at 0.06% in Bumuyange. Further, the largest P levels were recorded for the treatments NPK and NPK + FYM (2 t ha^{-1}) at 0.06 % in Jivogoli.

DISCUSSION

Changes in available P (Olsen) as influenced by treatments. Changes in available P content in a growing season were observed, reflecting changes in crop growth conditions. The change in P content may have arisen based on the type soil, soil chemical conditions, the material applied and the P buffering capacity of the soil (Shirvani *et al.,* 2005). Further, this change may be advantageous or detrimental depending on the starting P level of the soil and the direction and speed of P change. In the present study, the addition of NPK and the soil amendments led to sharp increase in P especially at Topdressing (42 DAP) followed by a gradual decline towards the end of the season (Figure 1). This could be attributed to P solubilization which could have been the highest at this stage; followed by a gradual decrease up to the end of the season. Apart from the control, levels at the end of the season were larger than those at the beginning

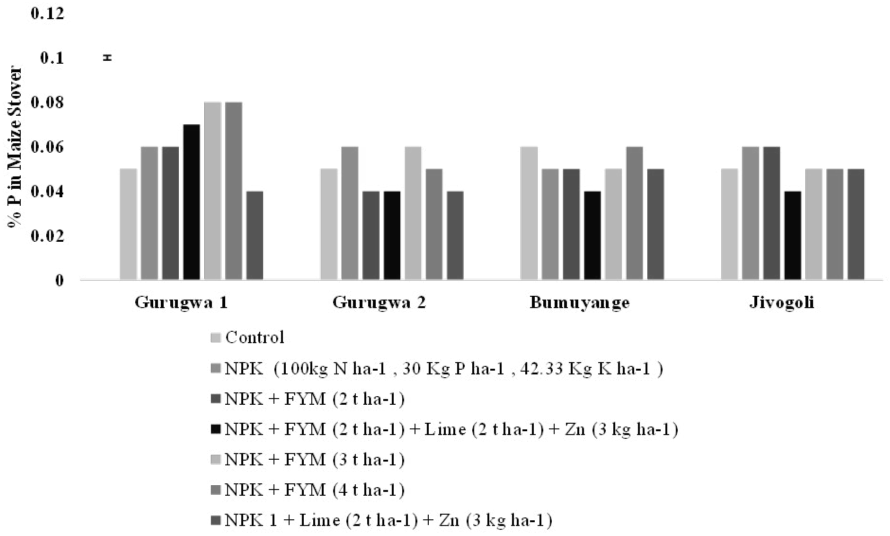

Figure 4. Percent (%) P in the maize stover as affected by various combinations of soil amendments. DAP = days after planting; NPK- (100 kg N ha^{-1}, 30 kg P ha^{-1} , 42.33 kg K ha^{-1}). Error bar is indicated

of the season. This could be explained by increased P solubilisation through P additions and perhaps through the reduced acidic conditions due to the action of FYM and lime. This is likely to happen on a seasonal scale too (Johnston *et al.,* 2016 ; Kvifte, 2016;). Further, the plants are able to transform heavily plant available P to easily available form earlier on in the season leading to this initial increase in P (Kvifte, 2016). In addition, the decrease in available P after the initial increase could be attributed to soil P buffering capacity. The soil buffers the available P fraction geochemically, and fast enough for the available phosphorus not to be depleted over the course of a single growing season (Kvifte, 2016). Patterns of P solubilisation in the soil solution make it difficult to exhaust all the available P in the soil as less available P fractions react and become more labile making it available (Bergström *et al.,* 2015).

Influence of treatments on P uptake. The application of NPK, with or without soil amendments, caused a significant increase in P uptake in the plant biomass. Phosphorus concentrations in the ear leaf were significantly larger in the FYM treated plots highlighting its contribution in plant P nutrition. Farmyard manure is able to increase the availability of P when supplied together with other inorganic sources (Nziguheba *et al.,* 2016). The increased uptake could be attributed to synergistic effect of FYM in increasing nutrient availability in the soil solution. In the maize grain (Figure 3) significant differences in P content were observed, as affected by the treatment application. The treatment NPK, FYM, lime and Zinc recorded the largest total P uptake (0.37%) followed by the NPK, lime and Zinc (0.36%). This was possible due to the combined influence of lime and FYM in soil pH correction which eliminated aluminum toxicity, thus increasing P solubility in the soil. Further, the addition of NPK fertilizer increased P content in the soil solution considering that the P in the fertilizer is readily soluble. Inclusion of zinc enhanced enzymatic activities within the plant leading to larger P uptake. For the maize stover, Gurugwa 1 showed higher P concentration despite having the least P concentration in the ear leaf. This trend was unique to this study as most studies of this nature have suggested higher remobilization and translocation characteristics of P in the biomass, often from the older parts of the plant to the younger ones (Bender, 2012). In the other sites, treatments combining NPK with amendments gave significantly larger P (%) than the sole application of NPK or the control. It is thus noted that the effectiveness of any of the amendment strategies appeared to be highly soil type-specific and maize growth-stage dependent, supporting the need for site-specific and growth stage dependent nutrient management technologies targeting Western Kenya soils.

CONCLUSION

Patterns for mineral assimilation in maize are typically influenced by soil conditions and the forms and nature of the nutrients in the soil. Combining organic and inorganic nutrient sources has a potential of increasing crop nutrient uptake and confer better nutrient use efficiencies. This is achieved by processes that increase nutrient availability and utilization. However, despite its wide adoption in smallholder integrated systems of western Kenya, low agronomic efficiencies have been reported pointing to other limiting soil conditions. The inclusion of lime and Zn fertilization regimes becomes necessary in addressing this problem. From this study, lime and Zn application in combination with FYM and NPK additions increased P uptake. This strategy, if adopted, can lead to increased crop yields through enhanced nutrient use efficiencies, provided that all other limiting soil conditions are addressed wholesomely.

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STATEMENT OF NO-CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this paper.

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