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Research Application Summary

Macro and micronutrient fertilization and soil amendments for combating poor soil responsiveness in Maize-Desmodium intercrop in western Kenya

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Abstract

Poor soil responsiveness (PRS) is a major constraint to sustained crop production in sub-Saharan Africa (SSA). Combating PRS can be achieved through a combined application of organic and inorganic resources aimed at supplying both macro and micro nutrients. In addition, micronutrient supplementation in such fertilization regimes can help in enhancing agronomic efficiencies of added nutrients. A field experiment was carried out in Sabatia and Hamisi sub-counties in Vihiga county, western Kenya, to determine the effects of different application rates of macronutrients nitrogen (N), phosphorus (P), potassium (K) and micronutrient (Zn) on maize (*Zea mays*) and desmodium (*D. intortum*) production in poor responsive soils. Both the macro and the micronutrients were sourced from Farm Yard Manure and NPK fertilizer and commercially available Zinc sulphate heptahydrate. This was undertaken during the long rains (LR) and short rains (SR) seasons' of 2015. Treatments comprised of NPK fertilizer combined with FYM, each at different rates so as to supply an optimal rate of 100 kg N ha^{-1} and 30 kg P ha^{-1}, 60 kg K ha^{-1} and 3 kg Zn ha^{-1}. Three replications for each treatment in a Randomly Complete Block Design (RCBD) were implemented. Soils were sampled and analyzed for pH, N, P, K, Ca, Mg, Na and carbon at critical growth stages. Results showed that soils treated with a combination of NPK fertilizer, FYM, lime and Zn demonstrated better maize yield responses which were significant at ($p<0.05$) but the responses varied across sites. For the LR2015 season, the treatment with NPK, Lime, FYM and Zn yielded 7.5, 5.8, 6.6 and 7.3 t ha^{-1} in site 1 and 2 (Sabatia) and sites 3 and 4 in Hamisi sub-county, respectively. Desmodium did not show any clear responses across sites indicating a need to carry out further research on appropriate fertilization rates in a Maize-Desmodium intercrop. This technology can be adopted by farmers in Vihiga County, majority of whom practice intensified crop-livestock farming. By overcoming poor yields of food crops while addressing their nutritional value, poor soil responsiveness at farm level will be alleviated. In addition, the inclusion of micronutrient Zn in fertilization programmes can help in overcoming micronutrient deficiency prevalent in soils of Vihiga County.

Key word: Balanced fertilization, desmodium, soil amendments, western Kenya

Résumé

Une mauvaise réactivité du sol (PRS) est une contrainte majeure à la production agricole soutenue en Afrique sub-saharienne (ASS). La lutte contre PRS peut être atteinte grâce à une application combinée des ressources organiques et inorganiques visant à fournir les macro et micro nutriments. En outre, le supplément en micronutriments dans de tels régimes de fertilisation peut aider à améliorer l'efficacité agronomique des éléments nutritifs ajoutés. Une expérience sur le terrain a été réalisée dans les sous-comtés de Sabatia et Hamisi, dans le comté de Vihiga, l'ouest du Kenya, afin de déterminer les effets des différents taux d'application de macronutriments d'azote (N), le phosphore (P), le potassium (K) et les micro nutriments (Zn) sur la production de maïs (*Zea mays*) et de desmodium (*D. intortum*) dans les sols pauvres sensibles. La macro et la micro nutriments provenaient du fumier de la ferme et d'engrais NPK, le sulfate de zinc hepta-hydraté disponible commercialement. Ceci a été entrepris pendant les saisons de longues pluies (LR) et courtes pluies (SR) de 2015. Les traitements constitués d'engrais NPK combinés avec FYM, chacun à des taux différents de manière à fournir un taux optimal de 100 kg N ha^{-1} et 30 kg P ha^{-1}, 60 kg K ha^{-1} et 3 kg Zn ha^{-1}. Trois répétitions pour chaque traitement dans un Bloc de Forme Aléatoirement Complet (RCBD) ont été mises en œuvre. Les sols ont été prélevés et analysés pour déterminer le pH, N, P, K, Ca, Mg, Na et du carbone à des étapes critiques de la croissance. Les résultats ont montré que les sols traités avec une combinaison d'engrais NPK, FYM, chaux et Zn ont montré de meilleures réponses de rendement de maïs qui étaient significatives à ($p <0,05$), mais les réponses variaient entre les sites. Pour la saison LR2015, le traitement avec NPK, chaux, FYM et Zn a donné 7,5, 5,8, 6,6 et 7,3 t ha^{-1} dans le site 1 et 2 (Sabatia) et les sites 3 et 4 dans le sous-comté d'Hamisi, respectivement. Le Desmodium n'a pas montré de réponses claires à travers les sites indiquant une nécessité de procéder à d'autres recherches sur les taux de fertilisation appropriés dans une culture intercalaire de maïs-Desmodium. Cette technologie peut être adoptée par les agriculteurs dans le comté de Vihiga, dont la majorité pratique la culture-élevage intensifié. En surmontant des rendements médiocres des cultures vivrières tout en répondant à leur valeur nutritive, la faible réactivité du sol au niveau de la ferme sera allégée. En outre, l'inclusion de micronutriment Zn dans les programmes de fertilisation peut aider à surmonter les carences en micronutriments répandus dans les sols de la comté de Vihiga.

Mot clés: fertilisation équilibrée, desmodium, amendements du sol, l'ouest du Kenya

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Background

Smallholder farms in western Kenya suffer from severe nutrient depletion, soil acidity and low crop yields. This has led to low agricultural productivity and consequently food insecurity in the region. The situation is further compounded by insufficient and imbalanced nutrient additions of depleted nutrients normally lost through crop harvests, soil erosion and leaching (Alley and Vanlauwe, 2009). Furthermore, continued removal of nutrients by crop harvests and minimal return of crop residues has contributed significantly to low nutrient levels and organic carbon in most soils in the region (Drechsel *et al.*, 2001; Sanchez, 2002; Chianu *et al.*, 2012). As a result, low and declining yields have been reported, particularly in areas that depend on rainfall for food and fodder production (Nekesa *et al*., 1999, Okalebo *et al*., 2005). Similarly, in the region where integrated crops-livestock production systems dominate, nutrient cycling and animal productivity are greatly impeded leading to losses.

Another reason accounting for the diminishing yields is poor soil responsiveness to fertilizer applications (Nziguheba *et al*., 2010; Vanlauwe *et al*., 2010), a phenomenon contributed by soil degradation either chemical, biological, or physical processes (Stocking, 2006; Palm *et al*., 2007) or a cascading combination of them.

Such soils show little or no yield increase after addition of the commonly used nutrient inputs particularly nitrogen (N), phosphorus (P) and potassium (K) (Vanlauwe and Zingore, 2011). The profitability of fertilizer use in these cases is low or negligible. With little soil organic carbon, low soil pH levels, low nutrient stocks and their highly weathered nature, these soils exhibit poor response to fertilizer application which invariably affect crop production and their nutritional value. Some of these soils have sufficiently high levels of soluble aluminum that may become toxic to crops (Woomer *et al*., 1997).

In mixed crop–livestock system, the combined application of manure from livestock and mineral fertilizers is one option proposed for efficient use of applied nutrients (Vanlauwe *et al*., 2001; Bationo *et al*., 2006). It is one of the key tenets of Integrated Soil Fertility Management (ISFM) recommended by Alliance for a Green Revolution in Africa (AGRA) for increased production in intensive small holder systems of Africa (Annan, 2008). These inputs when used individually have the disadvantage of availability in sufficient quantities and thus their efficiency would be increased by combining them. This strategy has been corroborated by several studies in western Kenya. For instance, in Nyalgunga, Nyabeda and Emusutwi sub-locations in western Kenya, combining manure with inorganic fertilizer increased maize yields by 148% above the control plot (Abuom, 2014). Similarly, in Vihiga County, a combined application of Farm Yard Manure (FYM), Mavuno fertilizer and a top dressing of calcium ammonium nitrate (CAN) led to yield increases above the use of each input alone (Cebula, 2013). Bationo *et al.* (2006) suggested that maize yield increases due to NPK fertilizer application can be as high as 150 %, but with addition of soil amendments like lime and manure, yield increases of 184 % can be obtained. Further, Sanginga and Woomer (2009) noted that combining mineral fertilizers with organic resources leads to long-term beneficial impacts to the environment and hence improves the use efficiency of mineral fertilizers. These studies underline the importance of combined use of the two inputs so as to increase crop production. In order to overcome poor soil responsiveness, adopting ISFM technologies involving managing organic inputs and the efficient use of mineral fertilizers holds the promise for improved yields and increased economic gains to the farmers. Increased productivity will require investments in inputs so as to improve and sustain soil fertility. Indeed, overcoming poor soil responsiveness through efficient use of organic and inorganic resources is achievable in integrated crop–livestock systems managed with small inputs. Additional benefits of organic inputs like manure include supply of NPK and micronutrients, where in highly weathered soils, it can supply most of the exchangeable cations (Gao and Chang, 1996; Eghball Power, 1999; Mucheru-Muna *et al*., 2013). A study was set up in western Kenya to quantify yield response of maize (*Zea mays*) and green leaf Desmodium

(Desmodium intortum) to NPK, lime and Zn fertilization as a rehabilitation strategy for poor responsive soils in Sabatia and Hamisi sub-counties.

Study sites description

The study was conducted in two sub-counties with almost similar agro-ecological zones (AEZs) in the west of Kenya namely Sabatia and Hamisi. They are two of the five sub-counties of Vihiga county. 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 and an average annual precipitation of 1900 mm. The rainfall ranges from 1800 – 2000 mm with variations due to altitude. Temperatures range between 14 ºC and 32 ºC, with the hottest months being December, January and February. Long rains are experienced in the months of March, April and May which are the wettest while short rains are experienced in the months of September. The dominant soil types in both sub counties are Humic Acrisols, Drystic Nitisols, Nito-Rhodic Ferralsols and Cambisols (Jaetzold *et al.,* 2005a; MOA*,* 2014*)*. The farm holdings are made up of diûerent farming sub-systems, namely the food crop, cash crop, livestock and tree production. Practically all the farm-households include these four farm sub-systems in their production (Jaetzold *et al.*, 2005). Normal land sizes average at 0.5 ha (Waithaka *et al.*, 2002).

Experimental setup. Four experimental sites were identified in Vihiga county (2 in Sabatia sub-county and 2 in Hamisi sub-county) where the experiment was laid out. The sites were located in Gurugwa, Bumuyange and Jivogoli villages. For each site, 21 experimental plots were demarcated at 5 m (length) x 4.5 m (width) and prepared for the maize and Desmodium seeds in an intercrop stand. The field experiment comprised of 7 treatment combinations replicated thrice in each site using RCBD experimental design. These treatments were applied to the maize and Desmodium lines based on each crops' nutritional requirements. For example, for the maize crop, the intention was to supply nitrogen (N), phosphorus (P) and potassium (K) at 100 kg N ha^{-1}, 30 kg P ha^{-1}, 60 kg K ha^{-1} and 3 kg Zn ha^{-1} from an organic source (FYM), inorganic source (NPK-17:17:17) and zinc sulphate granules. The calculations were undertaken after determination of initial nutrients concentration in FYM. For the maize treatments, treatment 1 comprised of 0 input which formed the experimental control. The second treatment was purely NPK 1 (100 kg N ha^{-1}, 30 Kg P ha^{-1}, 42 kg K ha^{-1}). Trt 3- NPK 1 + FYM (2 t ha^{-1}), Trt 4- NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1})+ Zn (3 $kgha^{-1}$), Trt 5- NPK 1 + FYM (3 t ha^{-1}), Trt 6- NPK 2 + FYM (4 t ha^{-1}) and Trt 7- NPK 1 + Lime (2tha^{-1}) + Zn (3 kg ha^{-1}).

Desmodium received a basal phosphorus application of 30 kg P ha^{-1} which was supplemented with different levels of FYM. Zinc fertilization was undertaken at a constant rate of 3 kg ha^{-1} for treatments 3 and 7. The treatment combinations are illustrated as follows: Trt 1- control, Trt 2- 30 kg P ha^{-1} + FYM (4 t ha^{-1}) , Trt 3-30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1}), Trt 4-30 kg P ha^{-1} + FYM (3 t ha^{-1}), Trt 5-30 kg P ha^{-1} + FYM (2 t ha^{-1}),Trt 6- 30 kg P ha^{-1} and Trt 7- 30 kg P ha^{-1} + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}). Due to the slow rate of establishment of Desmodium, it was allowed to establish fully, up to the end of the LR2015 season. Thus, the first cutting was undertaken at the end of the 16^{th} week after planting (16

WAP) which coincided with the end of LR2015 season. It is at this stage that the Desmodium plant had attained its blooming stage. After the first cutting, the Desmodium was allowed to regrow and subsequent cutting regimes undertaken at 24 WAP and 32 WAP during the SR2015 season.

Results

Maize yields in the long rains 2015 (LR2015). During the long rains 2015 season there was variable responses to treatment applications with clear distinctions from the control plot (Table 1). Most treatments differed significantly ($p<0.05$) from each other in all the sites. From Gurugwa (1), the treatment NPK 1 (100 kg N ha^{-1} , 30 kg P ha $^{-1}$, 42.33 Kg K ha^{-1}) + FYM (2 t ha^{-1}) gave the highest yield of 7.9 tons ha^{-1} which is partly attributed to initial soil fertility levels in this site. In Gurugwa (2), the treatments NPK 1 + FYM (2 t ha^{-1}) and NPK 1 + FYM (3 t ha^{-1}) gave the highest yields of 6.4 t ha^{-1} for both sites. Similarly, in Bumuyange, the treatment NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) and NPK 2 (100 kg N ha^{-1}, 30 Kg P ha^{-1}, 26 Kg K ha^{-1}) + FYM (4 t ha^{-1}) demonstrated the highest yields. In Jivogoli, NPK 1 + FYM (2 t ha^{-1}) and NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1})+ Zn (3 kg ha^{-1}) gave the highest yields An overall mean assessment of the treatments across all sites illustrated that the treatment NPK 1 + (FYM 2 t haa^{-1}) + Lime (2 t ha^{-1}) + Zn (2 kg ha^{-1}) gave highest yields.

Maize yield in the short rains 2015 (SR2015). In the SR (2015) (Table 2), generally, yields across the four sites were lower than long rains (2015). This was attributed to lower rainfalls recorded for SR2015. The treatment effects were similar to LR2015 although the

Table 1. Average maize grain yields (t ha^{-1}) influenced by inputs application during the 2015 LR season

Treatment (T)	Site (S)				Means
	Gurugwa(1)	Gurugwa (2)	Bumuyange	Jivogoli	
Control	2.3	0.1	2.4	2.6	1.9
NPK 1	6	5	5.2	5.6	5.5
NPK 1 + FYM (2 t ha^{-1})	7.9	6.4	5.5	7.1	6.7
NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1})+ Zn (3 kg ha^{-1})	7.5	5.8	6.6	7.3	6.8
NPK 1 + FYM (3 t ha^{-1})	7.4	6.4	6.1	6.1	6.5
NPK 2 + FYM (4 t ha^{-1})	6.4	5.9	6.5	6.5	6.3
NPK 1 + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1})	6.8	6	5.1	5	5.7
Means	6.3	5.1	5.3	5.7	5.6
SED (S)	0.47				
SED (T)	0.62				
SED (T x S)	1.24				

Table 2. Maize grain yields (t ha^{-1}) as influenced by inputs during the 2015 SR season

Treatment (T)	Site (S)				Means
	Gurugwa (1)	Gurugwa (2)	Bumuyange	Jivogoli	
Control	0.6	0	0.1	0.9	0.4
NPK 1	1.1	2.5	0.5	2.5	2.2
NPK 1 + FYM (2 t ha^{-1})	2.9	3.9	4.4	3.3	3.6
NPK 1 + FYM(2 t ha^{-1}) + Lime (2 t ha^{-1})+ Zn (3 kg ha^{-1})	2.6	4.7	4.4	4.9	4.2
NPK 1 + FYM (3 t ha^{-1})	2	4.4	3	4.9	3.6
NPK 2 + FYM (4 t ha^{-1})	2	4.3	3.1	3.7	3.3
NPK 1 + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1})	1.8	3.9	3	3.3	3
Means	1.9	3.4	2.9	3.4	2.9
SED. (S)	0.3				
SED. (T)	0.4				
SED. (S X T	0.8				

treatments containing NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) and NPK 1 + FYM (2t ha^{-1}) did not differ significantly for Gurugwa (1) and Bumuyange. Overall treatment means for Control, NPK 1, NPK 1 + FYM (2 t ha^{-1}) and NPK 1 + FYM (2 t ha^{-1}) + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1}) differed significantly.

Desmodium yields. The yields for the first desmodium cutting regime (Table 3), were significantly lower than those for the subsequent cutting regimes (Table 4 and 5). This was due to the slow rate of establishment witnessed during the LR 2015 season. The treatment involving 30 kg P ha^{-1} + FYM (4 t ha^{-1}), 30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1}) and 30 kg P ha^{-1} + FYM (2 t ha^{-1}) showed significantly higher yields than the other treatments.

From Table 3, Gurugwa (1) and Gurugwa (2) recorded higher biomass yields as compared to Bumuyange and Jivogoli sites. This may have been contributed by site-specific soil constraints that provided better initial soil fertility status of the soils compared with the other two sites.

In subsequent cutting regimes (Tables 4 and 5), yields were significantly higher for all the treatments as compared to the first cutting regime. In Table 4, the treatments involving 30 kg P ha^{-1} + FYM (4 t ha^{-1}), 30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1}) and 30 kg P t ha^{-1}+ FYM (3 t ha^{-1}) and 30 kg P ha^{-1}+ FYM (2 t ha^{-1}) gave the highest yields. This trend is similar from the third cutting (Table 5) with the treatment containing 30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1}) giving the highest yields at 8.1 t ha^{-1} .

Table 3. Desmodium biomass yields (t ha^{-1}) as influenced by inputs for the first cutting regime (16 WAP)

Treatment (T)	Site (S)				Means
	Gurugwa (1)	Gurugwa (2)	Bumuyange	Jivogoli	
Control	1.2	0.8	0.3	0.7	0.8
30 kg P ha^{-1} + FYM (4 t ha^{-1})	2.4	4.6	1.8	3	3
30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1})	3.3	4.3	1.8	2.8	3.1
30 kg P ha^{-1} + FYM (3 t ha^{-1})	3.1	1.8	1.6	3.2	2.4
30 kg P ha^{-1} + FYM (2 t ha^{-1})	3.4	3.1	1.8	2.6	2.7
30 kg P ha^{-1}	2.2	2.5	0.7	1	1.6
30 kg P ha^{-1} + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1})	2.1	2.8	0.8	1.8	1.9
Means	2.5	2.9	1.3	2.2	2.2
SED (S)	0.5				
SED (T)	0.3				
SED (S X T)	0.9				

Table 4. Average Desmodium shoot yields (t ha^{-1}) as influenced by inputs for second cutting regime (24 WAP)

Treatment (T)	Site (S)				Means
	Gurugwa (1)	Gurugwa (2)	Bumuyange	Jivogoli	
Control	8.1	2.1	1.4	3.4	3.8
30 kg P ha^{-1} + FYM (4 t ha^{-1})	15.6	14.1	9.1	11.1	12.5
30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn (3 kg ha^{-1})	12	14.3	7.5	11.5	11.3
30 kg P ha^{-1} + FYM (3 t ha^{-1})	16.4	6.4	5.9	14.5	10.8
30 kg P ha^{-1} + FYM (2 t ha^{-1})	15.3	8.4	6.7	10.4	10.2
30 kg P ha^{-1}	13.9	8.5	3.9	4.5	7.7
30 kg P ha^{-1} + Lime (2 t ha^{-1}) + Zn (3 kg ha^{-1})	9.5	7.2	3.5	7.4	6.9
Means	13	8.7	5.4	9	9.0
SED (S)	0.6				
SED (T)	0.8				
SED (S x T)	1.6				

Table 5. Average Desmodium shoot yields (t ha^{-1}) as influenced by inputs for third cutting regime (32 WAP)

Treatment (T)	Site (S)				Means
	Gurugwa (1)	Gurugwa (2)	Bumuyange	Jivogoli	
Control	3.0	1.9	0.7	3.1	2.2
30 kg P ha^{-1} + FYM (4 t ha^{-1})	8.2	7.9	3.2	5.1	6.1
30 kg P ha^{-1} + FYM (4 t ha^{-1}) + Zn(3 kg ha^{-1})	14.3	10.0	3.3	4.9	8.1
30 kg P ha^{-1} + FYM (3 t ha^{-1})	12.5	6.7	2.9	4.5	6.7
30 kg P ha^{-1} + FYM (2 t ha^{-1})	8.1	7.3	2.7	5.6	5.9
30 kg P ha^{-1}	8.4	10.2	1.5	3.9	6.0
30 kg P ha^{-1} + Lime (2 t ha^{-1}) + Zn(3 kg ha^{-1})	7.7	3.1	2.2	4.3	4.3
Means	8.9	6.7	2.4	4.5	5.6
SED (S)	0.5				
SED (T)	0.6				
SED (T X S)	2.5				

Discussion

From this study, the results obtained for maize yields (LR 2015 and SR 2015 season) demonstrated increased yields with FYM, N, P K fertilization. Similarly, the treatment with Zinc addition incorporated with FYM and N, P K demonstrated a significant increase in yield pointing to the importance of this micronutrient, FYM and inorganic fertilizer combination in intensive farming systems. This strategy conforms to several research findings reported by Vanlauwe *et al*. (2001) among others. The use of organic resources in combination with mineral fertilizers offers potential for improving soil fertility and crop yields as "both inputs contain varying combinations of nutrients and/or carbon, thus addressing different soil fertility-related constraints" (Vanlauwe *et al*., 2015). Furthermore, organic materials are known to supply other lacking nutrients not supplied from conventional fertilizers leading to enhanced agronomic efficacies of inputs used. This technology, if adopted could contribute to increased crop responses to fertilizers through enhanced soil responsiveness. Further, a soil that is responsive to inputs will lead to increased crop yields culminating in increased returns for majority of resource poor famers dwelling in western Kenya.

Addressing other soil limiting conditions that could be existing at farm scale can help in designing crop and site specific recommendations in integrated systems experiencing poorly responsive soils. This should include such cases as secondary and micronutrient deficiencies which can have a marked effect on crop yields. It is also expected that soils with one or more limiting nutrients will produce crops with low nutritive capabilities. This, in essence will affect human and animal health.

The findings from this research study emphasize the importance of both macro and micro fertilization in combination with soil amendments like FYM so as to increase crop yields in small holder farming systems. From the maize and Desmodium yields, it can be argued that micronutrient addition contributed significant increases in yield in all the sites. This trend, however, became more distinct for Desmodium during the third cutting regime. In addition, the increases in Desmodium yields were significantly higher in Sabatia than in Hamisi Sub County which could be attributed to enhanced soil responsiveness. The lowest yields, however, were recorded from untreated maize and Desmodium plots. Thus, an improved nutrient supply involving macro and micro nutrients will ultimately translate to improved crop performance though enhanced soil responsiveness.

Conclusion

In conclusion, combining organic and inorganic nutrient sources has a potential of increasing crop yields in soils exhibiting poor responsiveness. This is achieved by favouring processes towards increased nutrient availability and utilization. However, despite its wide adoption in smallholder integrated systems of western Kenya, little yield increases have been reported pointing to other limiting soil conditions such as micronutrient deficiencies. Therefore, incorporation of micronutrients such as Zn in fertilization regimes becomes necessary in addressing this problem. From this study, Zinc fertilization in combination with FYM and fertilizer additions increased crop yields. This strategy, if adopted, can lead to increased crop yields through enhanced fertilizer nutrient use efficiencies, provided that all limiting nutrients are addressed. The cost effectiveness of such a strategy, in relation to the prevailing socio economic conditions of the famers should be evaluated as this may affect their willingness to adopt the practice.

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