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Effect of Soil Fertility Management and Nitrogen Fertilizer Rate on Maize Yield in Small Holder Farmers Fields

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Abstract: An experiment was carried out to determine the effect of soil fertility management and N fertilizer rates on maize yield in farmers' fields. Participatory (transect walks and soil mapping) and laboratory analysis methods were used to identify and quantify the soil fertility management niches. A Completely Randomized Block Design experiment was then conducted whereby hybrid maize (H625) was planted in plot sizes (4×5) m^2 and N treatments 0, 20, 40 and 60 kg ha^{-1} applied. A significant interaction between soil type and soil fertility management niche showed that farmers' practice could improve crop yield irrespective of indigenous fertility. Optimal N fertilizer rate in the productive niches ranged from 20 to 40 kg N ha^{-1}. The non-productive soil fertility niches required more than 60 kg N ha^{-1} leading to the conclusion that site-specific nitrogen management is important for maize production in farmers' fields.

Key words: Site-specific management, nitrogen fertilizer, optimum maize yield, farmers' fields

INTRODUCTION

Nitrogen is one of the most important nutrients limiting maize production in the tropics. The limitation is pronounced in *Ferralsols* and *Acrisols* that are acidic, have low organic matter and dominate the medium to high potential agricultural areas of Kenya (Sanchez *et al*., 1997). The inherently infertile soils coupled with the critical nutrient mining in farmers fields implies that external N fertilizer has to be applied if optimal crop yield is to be achieved. Based on the soil types and agro-ecological zones, an N rate of 75 kg ha^{-1} for maize production (Anonymous, 1995) has been recommended in western Kenya. A survey of the fertilizer use however shows that farmers use sub-optimal levels probably because of the poor resource level and non-specific recommendations that aim at optimizing crop yield but not necessarily nutrient use efficiency (Smaling and Braun, 1996; Mose *et al*., 1996; Giller *et al*., 2005). Intrinsic variations in soil fertility a common feature in small-scale farmers' fields negate the efficiency of such blanket fertilizer recommendations. Paradoxically, small-scale farmers use variations in soil fertility to maximize crop yield and avoid risk of crop failure (Fietz *et al*., 1996; Murage *et al*., 2000; Titonell *et al*., 2005). While some efforts have been geared towards identifying and modeling variation in soil fertility, at farm level they have rarely been used for practical management to increase nutrient use efficiency (Giller *et al*., 2005; Tabu, 2003).

Under the heterogeneous soil conditions, Site-specific Nutrient Management (SSNM) has to be used if under or over application in some areas of the farmers' fields is to be avoided (Verhagen and Bouma, 1997). Models and methods aimed at optimizing nutrient use efficiency at farm level have been developed (Giller *et al*., 2005; Booltink *et al*., 2001; Carr *et al*., 1991; Mulla and Schepers, 1997) but their success requires a thorough understanding of the crop requirements and the indigenous soil supplying ability. Identifying and quantifying soil fertility variation and subsequently determining the optimal N levels associated with different management niches are a priority for implementation of SSNM. Conventional methods of fertility assessment that include soil sampling, laboratory analyses and the state of art (geographic positioning and geographic information systems) methods are slow and/or expensive and not accessible to small scale resource poor farmers. Studies in search of low cost effective methods show that farmers use agro-ecological knowledge to allocate crop types to the soil fertility niches based on variations in nutrient status and requirements (Giller *et al*., 2005; Murage *et al*., 2000; Titonell *et al*., 2005; Desbiez *et al*., 2004). Farmers' local knowledge is cost effective and could be pertinent to the implementation of SSNM (Fleming *et al*., 1999). Nitrogen application targeting farmers' management zones has been found to enhance crop yield and NUE (Khosla *et al*., 2002). A study was conducted to determine the effect of soil fertility management and N rates on the growth and yield of maize in small-scale farmers' fields.

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MATERIALS AND METHODS

The study was carried out between 1998 and 1999 in two villages (Muhoni and Shitirira) located between longitudes 34^0 52' and 15^0E, latitude 00^0 26' and 00^0 52' N and altitude of 1300 to 1900 m above sea level in Western Kenya. The area receives bimodal rainfall of about 2000 mm per annum and has deep, highly weathered *rhodic Ferralsols* and *humic Acrisols*. Farmers keep livestock (cattle, sheep, goats and chicken) and grow maize, beans and bananas for subsistence. The villages were purposefully selected, physically identified and delineated on the ground based on interviews with local leaders and ministry of agriculture staff and soil profile pit analysis. Muhoni with 100 households and mean land area of two hectares per household was dominated by *humic Acrisols*. Shitirira with 120 households and mean land area of seven hectares per household was dominated by the *rhodic Ferralsols*. Eight farms per soil type were randomly selected after an initial study to characterize the fertility status. Using participatory methods (transect walks and mapping), soil fertility management niches within each farm were identified and delineated (Defoer *et al*., 1996). The soil fertility management niches classified as productive included; Homegardens (HG), old kraal sites (Oboma), natural pasture (Npasture) and valley bottomlands (Vbottom). Outfields (Ofmm) that were generally located far off from the homesteads and were classified as less productive were also observed. Top soil (0-20 cm) samples were taken using an auger, air-dried and ground to pass through a 2 mm sieve and analyzed for soil texture, pH and available nutrients. Soil samples from the nearby Malava forest were also analyzed and used as a reference to evaluate the effect of the farmers' management on soil fertility.

Soil texture was determined by the hydrometer method and pH by a pH meter after extraction from the soil: water ratio of 1:2.5. Total organic carbon (C) was determined by the Walkey and Black dichromate method, total Nitrogen (N) by semi micro-kjedhal digestion, P and K by spectropho tometery and Ca and Mg by atomic absorption spectrophotometery (Okalebo *et al*., 1993). Exchangeable acidity (Hp) was determined on soils with pH less than 5.5 by KCl extraction and titration with NaOH (Mango, 1999).

In each farm, (4×5) m^2 observational plots were laid out in a completely randomized block design to cover the soil fertility management niches. Hybrid maize (H614) was then planted at a spacing of 0.75 m×0.25 m. A basal rate of 60 kg P_2O_5 (Triple Superphosphate) per hectare was applied at planting according to standard recommendation (Anonymous, 1995). Nitrogen in form of Urea (46% N) at the rate of 0, 20, 40 and 60 kg ha^{-1} was applied in each management niche. One third of the N rate was applied at planting and the rest as topdress eight weeks after emergence. Crop data collected included plant height, number of fully formed leaves, grain and stover weight.

RESULTS AND DISCUSSION

Farmers using the local agro-ecological knowledge identified soil types and soil fertility niches by soil colour, plant vigour, weed types and productivity. The farmer perceived soil fertility niches varied significantly from each other in terms of texture and chemical properties (Table 1). Similar work in Nepal, Kenya and Rwanda observed farmers' ability to identify and rate soils (Desbiez *et al*., 2004; Mango, 1999; Habururema and Steiner, 1997).

The productive niches (HG, Oboma and Vbottom) had significantly higher pH, P, N, organic matter and CEC probably because of the anthropic activities as confirmed by results of Desbeig *et al*. (2004). The high soil organic matter, N and available nutrients in the forest compared to farmland however implies that continuous cultivation may be responsible for the reduction.

Soil type, soil fertility management and nitrogen fertilizer significantly affected the growth (height and number of leaves at tasselling) of maize (Table 2). The *humic Acrisols* had taller plants with a larger number of leaves per plant i.e., 8 and 109 cm compared to 7 and 63 cm in the *rhodic Ferralsols*.

Chemical soil analysis similarly showed that the two soil types were different. The difference in growth of maize between the two soil types was indicative of their effect on the rate of leaf formation and leaf area development. Elsewhere, soil types have been found to influence crop development (Uhart and Andrade, 1995).

Soil fertility management significantly affected the height and number of leaves of maize at tasselling. In the

Table 1: Physical and chemical properties of the farmer perceived soil fertility niches

	Sand	Clay	Silt			K	Ca	Mg	Ex. acidity	N	Carbon
Niche type	(g kg^{-1})			pH	P (mg kg^{-1})	(cmol kg^{-1} soil)				(%)	
HG/Oboma	230[a]	549[a]	213[a]	5.41[a]	2.91[a]	1.09[a]	1.61[a]	2.68[a]	0.95[a]	0.08[a]	2.27[a]
Npasture	270[a]	476[b]	250[a]	5.50[a]	2.55[a]	1.28[a]	1.79[a]	2.40[a]	0.76[a]	0.08[a]	2.15[a]
Vbottom	320[a]	439[bc]	234[a]	5.11[a]	3.43[a]	0.59[b]	1.41[a]	2.14[a]	1.77[a]	0.15[b]	2.40[a]
Forest	260[a]	544[abd]	193[a]	5.35[a]	2.61[a]	0.84[b]	3.74[b]	5.00[b]	1.20[a]	0.21[b]	4.97[c]
Ofmm	260[a]	520[ab]	260[c]	3.99[b]	2.51[b]	0.65[b]	1.31[a]	2.01[a]	1.54[a]	0.07[a]	1.90[b]

*Numbers followed by the same letter(s) in a column are not significantly different

Table 2: Effect of niche type on height (cm) and number of leaves per plant

Soil fertility management niche	1998 No. of leaves	1998 Plant height (cm)	1999 No. of leaves	1999 Plant height (cm)
Old kraals (Oboma)	8^{a*}	108^{a}	8^{a}	120^{a}
Homegardens (HG)	8^{a}	94^{a}	9^{a}	89^{b}
Outfields (Ofmm)	7^{b}	56^{b}	7^{b}	54^{c}

*Numbers followed by the same letter(s) within a column are not significantly different

Table 3: Effect of Nitrogen rate on the height and number of leaves per plant

Nitrogen rate (kg ha^{-1}) leaves	1998 No. of (cm)	1998 Plant height leaves	1999 No. of (cm)	1999 Plant height
0	7^{a*}	69^{a}	7^{a}	71^{a}
20	8^{a}	92^{a}	7^{a}	88^{a}
40	8^{cb}	90^{a}	7^{a}	90^{a}
60	8^{b}	93^{b}	8^{ab}	101^{b}

*Numbers followed by a same letter(s) within a column are not significantly different

productive niche (HG and Oboma), crops had significantly higher growth than that in the less productive (Ofmm) niches. Since the farms were located on the same soil type and topographic positions, the difference in maize growth could be attributed to differences in soil fertility management.

Nitrogen fertilizer significantly increased the height and number of leaves per plant (Table 3).

Compared to other treatments, 60 kg N ha^{-1} had the highest plant growth. Similarly, other studies have also observed that N fertilizer can increase maize growth rate by promoting the leaf area index and the photosynthate source and sink (Uhart and Andrade, 1995).

In addition to growth, soil type, soil fertility management and nitrogen fertilizer rate also influenced the yield of maize (Table 4). The significant soil type by management interaction observed implies that reasons other than soil type contributed to the differences in yield.

As expected, *humic Acrisols* had higher grain yield than *rhodic Ferralsols*, but the trend was reversed in Oboma niches in 1998 and HG in 1999. The reversed trend could be attributed to more fertile Oboma niches in the *rhodic Ferralsols* (Shititira village) where farmers had more livestock and land area per capita, hence more FYM. The interaction also showed that farmers' activity could increase maize yield irrespective of the inherent soil fertility. Outfields had significantly less crop yield than other niches probably because of the farmers' nutrient mining practices where more nutrients were taken out compared to those returned to the soil (Giller *et al*., 2005). The low soil organic matter in Ofmm may also have led to higher nutrient loss through leaching. The results further showed that the two soil types had different yield potential and that local knowledge could be used to fine tune recommendations.

In Kenya, fertilizer use recommendations for maize are specific to major soil types (Smaling and Braun, 1996). The higher yield that was observed in productive niches concurred with the farmers' soil fertility rating and confirmed its potential use as a basis for fine tuning agronomicrecommendations. Previous studies have similarly found that farmers' knowledge can be used to discern productive from less productive niches (Desbiez *et al*., 2004; Buerkert *et al*., 1995). Co-existence of productive (niches with labile and passive nutrient pools) and the non productive niches within the same farm provided farmers with an opportunity to maximize crop yield and avoid risk of crop failure in the face of limited resources. Farmers used productive niches for growing priority crops like maize and vegetables because of the perceived niche productivity, food security needs and the high nutrient requirements of the crops under question. Conversely, the soil fertility replenishment strategy in the productive niches was a deliberate action by farmers to make niches amenable for high value crops. Analysis of crop production in farmers' fields in Senegal also found that management rather than field location per se dictated the crop yield (Posner and Crawford, 1992).

Nitrogen fertilizer significantly increased the yield of maize (Table 5). The fertilizer rate however varied with niche. For example, whereas 20 to 40 kg ha^{-1} would suffice for productive niches, because of the labile nutrients from FYM, more than 60 kg ha^{-1} was required for less productive niches.

Unexpectedly, although HG is classified as productive, they need more than 20 kg N ha^{-1} to achieve optimal yield. This is probably because the dominant inputs (household wastes) had high C: N ratio, which may have immobilized some of the N applied. Outfields required more than 60 kg N ha^{-1} probably because of the inherently low nutrient and soil organic matter that may have reduced fertilizer use efficiency and ultimately the crop yield. The blanket recommendation of 75 kg N ha^{-1} should therefore mainly target the outfields (Anonymous, 1995). The variation with respect to management practice however implies that N rate at farm levels has to be refined. The scheduling and matching of cropping practices (crop culture and choices) to the niches showed that farmers appreciated the agro-diversity.

In the absence of the preferred resource, FYM, farmers used household wastes to optimize yield. They also staggered mazie planting in order to avoid the risk of crop failure and spread availability of food over time. The

Table 4: Effect of soil fertility management on grain yield (kg ha⁻¹) of maize

	Soil fertility management					
	1998			1999		
Soil type	Old kraals	Homegardens	Outfields	Old kraals	Homegardens	Outfields
humic Acrisols	4978[a]	5386[a]	3973[a]	5973[a]	4465[a]	2791[a]
rhodic Ferralsols	5980[b]	3227[b]	3732[a]	7764[b]	4504[a]	3816[b]

[*]Numbers followed by the same letter(s) within a column are not significantly different

Table 5: Effect of Nitrogen fertilizer rate on grain yield (kg ha⁻¹) of maize

	Soil fertility management					
	1998			1999		
N rate (kg ha⁻¹)	Old kraals	Homegardens	Outfields	Old kraals	Homegardens	Outfields
0	4916[a]	3018[a]	2997[a]	5524[a]	3431[a]	2466[a]
20	6010[b]	3511[b]	3473[b]	6640[b]	3839[a]	3042[b]
40	5811[b]	4522[ab]	4220[c]	7792[c]	4932[b]	3446[bc]
60	5997[b]	5560[c]	4721[cd]	7515[c]	5735[c]	4259[d]

[*]Numbers followed by the same letter(s) within a column are not significantly different

suggested niche specific soil and crop management practices were at variance with blanket recommendations (Anonymous, 1995). For small-scale farmers who can not afford the recommended rates, site-specific management provides an insurance against crop yield loss. The variation in N requirements in the productive niches (HG and Oboma) implies that indigenous knowledge may be ideal mainly for exploratory purposes. The low N required by the productive niches further implies that optimal level should be quantified to avoid nutrient overload and pollution of water. A survey of the soil fertility status in farmers fields in Kenya found that irrespective of the supra-optimal levels of manure in the productive niches, the soil organic matter and available nutrients never rose beyond that in the forest (Tabu, 2003) i.e., the nutrient losses through leaching and decomposition may could have increased with increasing levels.

CONCLUSIONS

Variation in management led to differences in chemical soil fertility. Growth and yield of maize varied with soil type, niche management and fertilizer N rate. The *humic Acrisiols* had inherently higher crop growth and yield of maize than the *rhodic Ferralsols*. A significant interaction between soil type and management implies that irrespective of the inherent soil fertility, management could close the yield gaps between productive and non-productive niches. The most productive niches had the highest yield compared to the least productive niches. The effect of N rate varied with soil and niche type, hence implying that recommendation should be specific to the farmers' management level.

REFERENCES

Anonymous, 1995. New fertilizer recommendations for small scale farmers in Kenya. Information Bulletin No. 12, pp: 9.

Booltink, H.W.G., B.J. van Alphan, W.D. Batchelor, J.O. Paz, J.J. Stoorvogel and R. Vargas, 2001. Tools for optimizing magamernt of spataially variable fields. Agric. Syst., 70: 445-476.

Buerkert, A., R.D. Stern and H. Marschner 1995. Post stratification clarifies treatment effects on pearl millet in the Sahel. Agron. J., 87: 752-761.

Carr, P.M., G. Carlson, J.S. Jacobsen, G.A. Nielson and E.O. Skogley, 1991. Farming soils not fields. A strategy for increasing fertilizer profitability. J. Prod. Agric., 4: 57-61

Defoer, T., D.T Kante, T. Hilhorst and H.O. Groote, 1996. Towards more sustainable soil fertility management. ODI-AgREN Network paper No. 63.

Desbiez, A., R. Mathews, B. Tripathi. and J. Ellis-Jones, 2004. Perceptions and assessment of soil fertility by farmers in the mid-hill of Nepal. Agric. Ecos. Envirn., 103: 191-206.

Fietz, E., C.B. Miller and W.L. Pan, 1996. Assessment of spatially variable nitrogen fertilizer management in winter wheat. J. Prod. Agric., 7: 86-93.

Fleming, K.L., D.G. Westfall, D.W. Weins, L.E. Rothe J.E. Cipra and D.F. Heerman 1999. Evaluating Farmer Developed Management Maps for Precision Farming. In: Robert, P.C. and R.H. Rust (Eds.). Proceedings of 4th International Conference on Precision Agriculture.

Giller, KE., C.D.E. Rowe, Ridder de Nico and H. van Keulen, 2005. Resource use dynamics and interactions in the tropics. Scaling up use dynamics and interactions in the tropics. Agric. Sys., (In Press).

Habururema, E. and K.G. Steiner, 1997. Soil suitability classification by farmers in Southern Rwanda. Geoderma., 75: 75-87.

Khosla, R.K., K. Fleming, J.A. Delgado, T.M. Shaver and D.G. Westfall, 2002. Use of site-specific management zones to improve nitrogen management for precision Agriculture. J. Soil Water Manage., 57: 513-518.

Mango, N.A.R., 1999. Integrated soil fertility management in Siaya District Kenya. Managing Africa's Soils No. 7.

Mose, L.O., H.O. Nyangito and L.G. Mugunieri, 1996. An analysis of the socio-economic factors that influence chemical fertilizer use among small holder maize producers in Western Kenya. A Paper presented at the 5th Eastern and Southern Africa regional maize conference Held at Arusha Tanzania from 3rd to 7th June 1996.

Mulla, D.J. and J.S. Schepers, 1997. Key processes and properties for site-specific soil and crop management. In: The Site-specific management for agricultural systems. ASSA-CSSA-SSSA, Madison, USA.

Murage, E.W., N.K. Karanja, P.C. Smithson and P.L. Woomer, 2000. Diagnostic indicators of soil quality in productive and non-productive small holder fields of Kenya's Central Highlands. Agric Ecos. Envirn., 19: 1-8

Okalebo, J.R., K.W. Gathua and P.L. Woomer, 1993. Laboratory Methods of Soil and Plant Analysis. A Working Manual. TSBF, Nairobi.

Posner, J.L. and E.W. Crawford, 1992. Improving fertilizer recommendations for subsistence farmers in W. Africa. The use of Agro-economic analysis of on-farm trials. Fert. Res., 32: 33-342.

Sanchez, A.P., K.D. Shepherd, M.J. Soule, F.M. Place, R.J. Buresh and A.M.N. Lzac, 1997. Soil fertility replenishment in Africa. An investment in Natural resources capital. In: Replenishing Soil fertility in Africa. SSSA Special publication No. 51.

Smaling, E.M.A. and A. Braun, 1996. Soil fertility research in sub-Saharan Africa: New dimensions new challenges. Comm. Soil Sc. Plant Anal., 27: 365-386.

Tabu, I.M., 2003. Soil fertility niches, farmer perception and maize yield: A case for improved crop yield in Kabras Division of Western Kenya. Ph.D Thesis, Egerton University.

Titonell, P., B. Vanlauwe, P.A. Leffelaar, K.A. Shepherd and K.E. Giller, 2005. Exploring diversity in soil fertility management in small holder farms in western Kenya. II. Within farm variability in resource allocation, nutrient flows and soil fertility status. Agric Ecos. Envirn., (In Press).

Uhart, S.A. and F.H. Andrade, 1995. Nitrogen deficiency in maize: I. Effects on the crop growth development, dry matter partitioning and kernel set. Crop Sci., 35: 1375-1383.

Verhagen, A. and J. Bouma, 1997. Modelling soil variability. In: Pierce F.J. and E.J. Saddler (Eds.). The Site-specific Management for Agricultural Systems. ASSA-CSSA-SSSA, Madison, USA.