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A guide to choice of mineral fertilisers in Kenya

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Contents

Summary

Many farmers have a problem choosing the right type of fertiliser to apply in their fields. A study was conducted to determine the cheapest source of nitrogen (N) at 60 kg/ha, phosphate (P_2O_5) at 60 kg/ha, and potassium (K_2O) at 40 kg/ha. Prices for common fertilisers containing the nutrients were collected from stockists in Nairobi. The data was used to determine the cost of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) in standard fertilisers; determine the fertilisers that supply the nutrients most cheaply, and derive the cheapest way of combining fertilisers to achieve the recommended rate of application. The costs were KES 104 for N, 70 for P_2O_5, and 53 for K_2O nutrients. Fertiliser prices should correspond to the relative composition of each of these nutrients. Cost of recommended P_2O_5 ranged from KES 3,231 to 11,296/ha and was increasingly more expensive in monoammonium phosphate (MAP) < triple superphosphate (TSP) < diammonium phosphate (DAP) < single superphosphate (SSP) < other incomplete and complete fertilisers. Cost of N was 54% higher in calcium ammonium nitrate (CAN), than in urea. Costs for planting (P_2O_5) and top-dressing (N) fertilisers ranged from KES 6,393—12, 237 and were cheapest when MAP or DAP were used with Urea or CAN. A combination of N, P_2O_5 and K_2O was most cheaply obtained from incomplete fertiliser 23:23:0 and complete fertiliser 17:17:17. Farmers can save substantially if they compare the various options, and buy fertilisers in which nutrients are available most cheaply. Fertiliser merchants and government agencies dealing with fertilisers can assist farmers by ensuring that such fertilisers are readily available to local stockists. There is need to educate farmers on how best to make informed decisions when choosing the fertilisers to apply on their crops.

Introduction

Like other sectors of a liberalised Kenyan economy, agriculture has to cope with influx of different fertiliser products marketed locally by importers, blenders and distributors. Small- and large-scale fertiliser consumers keep seeking for information that can guide them in selecting the best type of organic and inorganic fertiliser, or their combinations. If properly selected, an ideal fertiliser would guarantee an increase in crop yields, improved quality of produce, higher profits, and sustainable soil productivity. This need is greater now than ever before, when horticultural exporters are required to conform to the traceability rules, generally referred to Euro-Retailer Produce Association Good Agricultural Practices (eurepgap) before exporting to European markets. Excessive fertiliser and pesticide application pollutes the environment, particularly soils and stream waters, with serious health repercussions on human, and other terrestrial and aquatic life (IFA, 1998).

Crops take up all the essential nutrients from the soil through their roots (Barber, 1995; Marschner, 1995). The primary source of these nutrients in soils is the slow breakdown (weathering) of bedrocks underlying the surface of the earth, and breakdown of organic residues (the rotting of vegetation from cleared bushes, weeds, crop residues and trees and dead animals) (Mohr *et al.,* 1972). Deficiencies occur when the natural sources of nutrients do not satisfy crop demand per unit time and in total amounts (Heckman and Kamprath, 1995). When deficiencies occur, crops do not produce high and nutritious grains, roots, fruits and vegetables. Deficiencies encountered depend on the geology, climate, natural vegetation, relief, period since opening of land and human activity (Ahn, 1970; Amerijckx, 1985).

Fertiliser is an expensive input and its choice should be based on type of nutrients to be applied at a particular crop growth stage, and convenience in meeting the recommended rate of application. While the common practice is to apply fertilisers to supplement deficient, soil-sourced nutrients, modern practices recommend balanced fertilisation (IFA, 1998). Balanced fertilisation entails application of fertilisers that contain major and secondary micronutrients in proportions that ensure adequate supply of essential nutrients during crop growth, while at the same time conserving the environment. The fertilisers of choice should supply these nutrients easily, safely and cheaply, to meet the objectives of balanced fertilisation.

The most widely used fertilisers in Kenya since the 1960s contained N and P, which explains why the 300,000 t of fertilisers consumed in the country annually is more than 90% N and P based (Kanyanjua and Buresh, 1999; Mwaura and Woomer, 1999). This is due to the assumption that most Kenyan soils are adequately supplied with other essential nutrients (Kanyanjua and Buresh, 1999). Results obtained in the 1960s and 1970s by the Ministry of Agriculture (MoA, 1969, 1970, 1975) show none, low, or negative response to other nutrients, including potassium. Potassium is the third most important plant nutrient after N and P. However, potassium is emerging as a major limiting nutrient (Nandwa, 1988; ICRAF, 1995; Mochoge, 1991; Kanyanjua and Buresh, 1999). The other reason for dependence on N and P fertilisers was that most of the fertilisers were donor sourced and there were little or no opportunities to suggest the inclusion of other essential nutrients in the fertiliser programs.

The continuous sole application of N and P fertilisers has created a deficiency of potassium and perhaps other essential nutrients. Research results are scanty in this area. However, there is a general decline in soil organic matter and a drop in soil pH in most Kenyan soils, a trend that is common in degraded soils (Kamprath, 1984). This is perhaps a major contributing factor to the stagnant or declining crop yields (Ayaga *et al*., 2004). Intensification of cropping (continuous cropping without nutrient replenishment, and higher plant populations) and breeding of more nutrient-demanding, high-yielding crops leads to a drop in nutrient stocks in the soil (Loes and Ogaard, 2003; Smaling *et al*., 1993). Inherent sources are, therefore, increasingly unable to cope with the high nutrient demands. It is perhaps the main reason behind declining harvest quality, expressed in higher percentage of low-grade potato tubers, low sugar content in tomatoes, bananas and sugarcane, low crude protein content in wheat, low acid content in tomatoes, pineapples and oranges, and low grain filling, and grain weight for maize, rice and wheat (Peter, 1980).

Excessive application of N fertiliser increases the vulnerability of crops to diseases and pests in the field and deterioration of crops while in storage. Nitrate (NO_3^-) form of nitrogen and phosphates are lost through the drainage system to ground and stream waters, which compromises the quality of drinking water (Briggs and Courtney, 1989). Excessive N in drinking water has been associated with the "blue babies" syndrome (IFA, 1998). The full impact on soil environment from the heavy mining of nutrients and pollution of resource base may not be immediately clear, but there is need to address these issues, if our export produce has to meet EuroGap standards and complete effectively in international markets.

In order to reverse the decline in crop yields, farmers have to increase the use of organic and inorganic fertilisers, and adopt more balanced fertilising regimes to improve and sustain soil fertility. This calls for judicious application of available fertilisers and introduction of new fertiliser blends that ensure balanced supply of nutrients to crops. Informal surveys on the Kenyan market show the emergence of new fertilisers containing multiple nutrients. These fertilisers should be evaluated for effectiveness and environmental friendliness. If improperly used, short-term gains from such fertilisers may have long-term negative effects. Farmers should also not be exploited in the pretext that such fertilisers are superior. In most cases, introduction of more nutrients in one fertiliser formula is done at the expense of high analysis of the more expensive nitrogen and phosphates.

Different fertiliser grades, which can be combined in various ways to achieve the recommendations, are available on the Kenyan market. However, guidelines on the most feasible and cheapest way of combining these available fertilisers are lacking. This has led to the inefficient and unsuitable use of the fertilisers. The Kenya Agricultural Research Institute (KARI) has for a long time conducted research on appropriate use of fertilisers in various cropping systems and assisted farmers in identifying deficient nutrients through soil analysis (KARI, 1995). With the compiling of this guide, farmers can re-evaluate their fertiliser programs, and where necessary adjust them to maximise outputs and profits from their farms.

Methods of identifying suitable fertilisers, include enquiries from fertiliser merchants, agricultural extension offices and other organisations. In all cases, however, the method used should identify fertilisers that are available and within reach to farmers, affordable, contain the nutrients required, applied conveniently, and contain nutrients in a form that is efficiently utilised. During this study, a list of fertiliser types and their prices were recorded from four stockists in Nairobi. The data obtained was used in calculations and drawing of conclusions aimed at arriving at best fertilising options.

The objectives of the study were: (1) to determine the cost of major crop nutrients (N, P_2O_5 and K_2O) in common fertilisers found on the Kenyan market, (2) to determine which fertiliser (s) on the market can supply N and P_2O_5 most cheaply, and (3) to derive the cheapest way of combining N and P_2O_5 nutrients in a fertiliser program for maize.

Cost of nitrogen, phosphate and potash on the Kenyan market

Nitrogen, phosphate and potassium are the most limiting nutrients in most maize growing areas of Kenya (MoA, 1975). Potassium is considered a rarely deficient nutrient but if present is a bonus as long as it does not result in escalating prices and costly application procedures. The same may apply to secondary (calcium, magnesium, sulphur) and trace (iron, copper, zinc, molybdenum, boron, manganese and chlorine) elements. For the sake of pricing, three standard straight fertilisers have been used: calcium ammonium nitrate (CAN), (26-0-0), as source of nitrogen, triple super-phosphate (TSP), (0-46-0), as source of phosphate, and potassium chloride (KCl), (0-0-60), as source of potassium. Results from cost analysis are given in Table 1. The most expensive nutrient is nitrogen, followed by phosphate, and potash.

Table 1. Costs of N, P_2O_5 and K_2O[1]

Fertiliser	Price per 50-kg bag (Kshs)	Weight of N, P_2O_5 and K_2O in a 50-kg bag (kg)	Cost (kg^{-1}) nutrient (Kshs)
CAN (26-0-0)	1,350	13	103.85
TSP (0-46-0)	1,600	23	69.57
KCl (0-0-60)	1,600	30	53.33

[1]- Fertiliser prices collected in Nairobi in February 2005

Most farmers apply fertiliser twice in a season: at planting and a few weeks (depending on the rains) after emergence. Phosphorus is always applied in planting holes (it is debatable whether the phosphate applied as a topdress or sidedress is less efficiently utilised) and nitrogen as a topdress mainly to maximise on uptake as plant roots are assumed to be well developed at that stage and avoid losses. A small starter N is recommended at planting. Potassium is applied at either of the two times. Finally, a rate of 60, 60 and 40 kg ha^{-1} of nitrogen, phosphate and potash which lies within the range of recommended fertiliser rates by KARI (1995) is adopted.

Phosphate sources at planting

As already discussed, the lead nutrient at planting is phosphate, but some starter nitrogen is required to build sufficient microbial biomass that would unlock the N in organic matter. It is assumed that starter N, and N released from organic matter is sufficient to take the crop through planting to topdressing. Potassium and other secondary, and trace elements if present are an added advantage, but not enough reason to discriminate a fertiliser if absent. A list of some planting fertilisers, their cost analysis (nutrient costs in Table 1), market prices and cost of application of recommended rates are given in Table 2.

The calculated value of nutrients (Table 2), shows that fertilisers have various nutrient worth, from KES 626-2534 per 50-kg bag, which was increasingly high in the order SSP < TSP < NPK 20:20:0 < NPK 17:17:17 < NPK 23:23:0 < MAP < DAP. Taking TSP as the standard, the ratio of calculated nutrient worth-to-market price of the 50-kg bag were calculated (Fig. 1). Any fertiliser with a ratio of less than one costs more than the nutrient worth, and the market price is currently inflated. Fertilisers with a value of more than one currently cost less than the value of nutrients in them, calculated from standard fertilisers.

Monoammonium phosphate and DAP are the cheapest in the local market due to the high P analysis and sufficiently high contents of starter N. Single superphosphate contains Ca, Mg and S, which were not considered in the evaluation, but whose value may make up for the difference in nutrient worth (Fig 1).

Table 2. Planting fertilisers and costs of application[1]

Fertiliser	Nutrient content (kg) in one 50-kg bag of fertiliser					Current price[3]	Fertiliser amount (bags) to supply recommended rate of P_2O_5 ha^{-1}	
	N	P_2O_5	K_2O	Others	Calculated[2] value		Bags	Cost (KES)
TSP (0:46:0)	0	23	0	0	1,600	1,600	2.61	4,176
SSP (0:18:0)	0	9	0	Ca, S	626	900	6.67	6,000
MAP (11:52:0)	5.5	26	0	0	2,380	1,400	2.31	3,231
DAP (18:46:0),	9	23	0	0	2,534	1,750	2.61	4,567
N:P:K 20:20:0	10	10	0	0	1,734	1,500	6.00	9,000
N:P:K 23:23:0	11.5	11.5	0	0	1,994	1,600	5.22	8,352
NPK 17:17:17	8.5	8.5	8.5	0	1,926	1,600	7.06	11,296

[1] Recommended P at 60 kg P_2O_5 ha^{-1}; [2] Sums of products of N, P_2O_5 and K_2O in kg, and their respective prices calculated in Table 1. [3]Sale price of a 50-kg bag of fertiliser as of 3 February 2005 in Nairobi

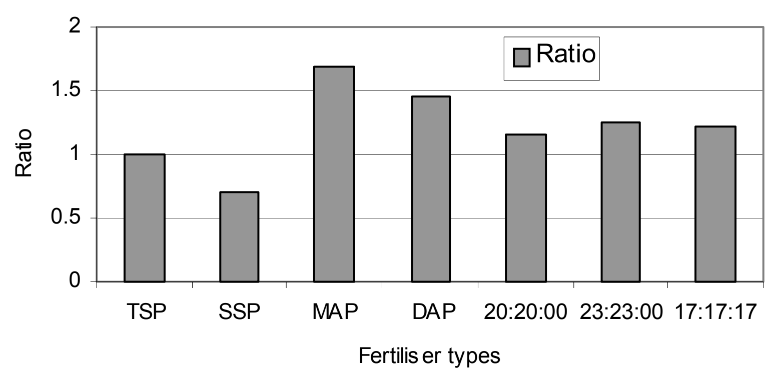


Fig. 1. Nutrient worth/market price for fertilisers

Table 2 provides a guide to choose fertiliser that provides phosphates most cheaply as a function of the nutrient analysis in blend. It is increasingly cheaper to source phosphate from fertilisers in the order: NPK 17: 17: 17 < NPK 20:20: 0 < NPK 23:23:0 < SSP < DAP < TSP < MAP. It is thus economically imprudent to use NPK fertilisers if the need is to apply the recommended phosphate, all at once. This is because of high nitrogen and potash contents in the NPK blends.

If NPK fertilisers are applied to meet all the P requirements, it may lead to high nitrogen application at planting which could result to excessive losses. Most farmers do not topdress their crops; either because of high costs involved, lack of rain, or they get late. Monoammonium phosphate and DAP are very ideal in such situations because of the high N in blend. Equally, the starter N in these two grades keeps crops growing without serious stress due to nitrogen deficiency before topdressing.

Topdressing fertilisers

The two commonly used topdressing fertilisers are CAN (26-0-0) and Urea (46-0-0). Ammonium sulphate nitrate (ASN), (26-0-0), which is often recommended in non-acidic soils was not in the market at the time of writing this article. In non-acidic soils, ASN can replace CAN as shown in Table 3.

Urea is the cheapest source of nitrogen in the market. However, it is manufactured under high temperatures and pressures, and unstable under standard environmental conditions. It volatilises on exposure to air and absorbs a lot of moisture to become a solution. The ammonia released as it volatilises burns seed and seedlings, resulting in very low efficiency of utilisation. Urea may also cause serious acidification of the soils on prolonged application.

Table 3. Topdressing fertilisers and costs of application

Fertiliser	Nutrient content in one 50-kg bag of fertiliser					Current price [3]	Fertiliser amount (bags) to supply recommended rate of N ha^{-1}	
	N	P	K	Others	Calculated[2] value		Bags	Cost (KES)
CAN (26:0:0)	13	0	0	0	1,350	1,350	4.62	6,237
Urea (46:0:0)	23	0	0	0	2,387	1,550	2.61	4,045

[1] Recommended N at 60 kg ha^{-1}, KES; [2] Sums of products of N, P_2O_5 and K_2O kg^{-1}, and their respective costs calculated in Table 1; [3] Prices as of 3 February 2005 in Nairobi

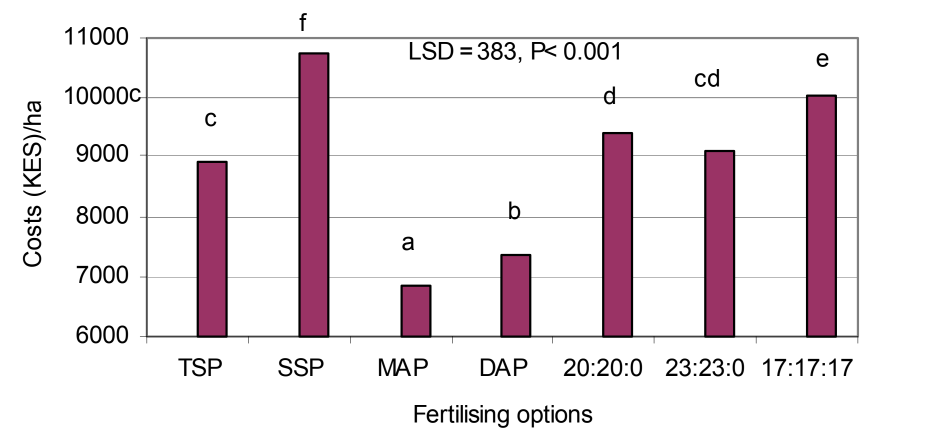
The combined fertiliser program for nitrogen and phosphate

Though the two events of basal and topdressing fertiliser applications are done at different times, it is recommended that a fertiliser program for the crop is made in one sitting so that a budget is drawn. This is because some fertilisers have N and P, or all the nutrients N-P-K in one formulation. It implies that part of the nutrient requirement applied at planting can be discounted during topdressing. The alternative options are shown in Table 4, and costs of applying N and P only (planting fertiliser + Urea, and planting fertiliser + CAN as replicates) compared in Fig 2.

Table 4. A comparison of various fertiliser options for maize				
Option	Planting	Topdressing	Total cost (KSHS)	Comments
1	Apply TSP at 2.61 bags ha^{-1}	2.61 bags of Urea**	8,221	Lack of starter N in TSP is considered a limitation
		4.62 bags of CAN	10,413	
2	Apply SSP at 6.67 bags ha^{-1}	2.61 bags of Urea	10,045	The S in SSP is not evaluated in this case
		4.62 bags of CAN	12,237	
3	Apply MAP at 2.31 bags ha^{-1}	2.04 bags of Urea	6,393	MAP and DAP remain the cheapest planting fertilis-ers in the Kenyan mar-ket. The NH_4^+ in MAP and DAP may cause soil acid-ity
		3.62 bags of CAN	8,118	
4	Apply DAP at 2.61 bags ha^{-1}	1.60 bags of Urea	7,045	
		2.89 bags of CAN	8,467	
5	Plant with NPK 20:20:0 at 2 bags ha^{-1}	4 bags 20:20:0	9,000	17:17:17 has K_2O worth KSHS 2,131
		4.7 bags 17:17:17	10,520 (8369)	
		3.5 bags 23:23:0	8,600	
6	Plant with NPK 23:23:0 at 2 bags ha^{-1}	3.7 bags 20:20:0	8,750	17:17:17 has K_2O worth KSHS 1,995
		4.4 bags 17:17:17	10, 240 (8245)	
		3.2 bags 23:23:0	8,320	
7	Plant with NPK 17:17:17 at 2 bags ha^{-1}	4.3 bags 20:20:0	9,650	17:17:17 has K_2O worth KSHS 3,200, which can be excessive and cause Mg deficiency
		5.1 bags 17:17:17	11,360 (8,160)	
		3.7 bags 23:23:0	9,120	

**Urea has low efficiency of use and volatilising ammonia is toxic to seeds and seedlings

Figures in brackets are costs (KES) of N and P_2O_5 in the absence of K in formula



Bars carrying the same letter are not significantly different

Fig. 2. Cost of combined N and P in different fertilisers

Fertiliser application options became more costly in the order MAP < DAP < TSP < 23:23:0 < 20:20:0 < 17:17:17 < SSP. In the absence of either MAP or DAP, farmers can apply low doses (2 bags ha^{-1}) of NPK (20:20:0, 23:23:0, 17:17:17) fertilisers at planting, and the greater bulk of it as a topdress. Planting with TSP or SSP is more expensive than planting with MAP or DAP, and can only be recommended in the absence of other fertiliser types, or when there are other perceived benefits in these fertilisers, but not in others.

Application of NPK fertilisers

Studies by Nandwa (1988), ICRAF (1995), and Kanyanjua and Buresh (1999) have shown that intensively cropped soils have developed K deficiency, in contrast to an old belief that soils in Kenya have sufficient amounts of K and would not benefit from K fertilisers (Hinga and Foum, 1972; Muchena, 1974).

There is need to adjust fertiliser programs in such soils from the sole N-P to a program that includes K, denoted NPK. Potassium can be sourced from a single fertiliser like muriate of potash, KCl, or from complete fertilisers such as 17:17:17. Costs involved in using a mixture of DAP + CAN + KCl is compared

with the alternative use of a mixture of other incomplete fertilisers and 17:17:17 in Table 5. It is cheaper to apply NPK fertilisers in form of a combination of incomplete fertiliser 23:23:0 than from applying MAP, CAN and KCl. This decision is further supported by the fewer number of 50-kg bags to be transported, which is higher if K is sourced from KCl. It is assumed that the efficiency of utilisation of nutrients in either of these forms is the same.

Table 5. Costs of NPK fertilising options

Planting fertiliser	Topdressing fertiliser	No of 50-kg fertiliser bags	Total cost (KES)
2.31 bags of MAP (3231)	4.62 bags of CAN (6237) + 1.3 bags KCl (2133)	8.23	11,601
2 bags of 20:20:0 (3,000)	4.7 bags of 17:17:17 (7,520)	6.7	10,520
2 bags of 23:23:0 (3,200)	4.4 bags of 17:17:17 (7,040)	6.4	10,240
2 bags of 17:17:17 (3,200)	5.1 bags 17:17:17 (8,160)	7.1	11,360

Values in brackets are costs (KES)

Conclusion

Nitrogen is the most expensive nutrient, followed by phosphate and potash. If all the phosphate were to be applied at once (no splitting), then it is most cheaply sourced from MAP, TSP and DAP, but most expensively sourced from the NPK 17:17:17, 20:20:0 and 23:23:0. The cheapest source of nitrogen is urea, but its low efficiency of utilisation justifies the continued use of CAN for topdressing. With split application of nutrients, the cheapest option is that of planting with either MAP or DAP, and topdressing with CAN or urea, but planting with NPK fertilisers is costly. Planting with straight fertilisers TSP or SSP and topdressing with CAN or urea are expensive options. Other benefits that accrue from the use of SSP and compound fertiliser 17:17:17, or the convenience of mixing fertilisers 20:20:0 and 23:23:0, and 17:17:17 were not considered in the evaluation. A complete evaluation can only be done after testing the options on farm.

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References

[1] Ahn, P.M. (1970). West African soils. *West African Agriculture, 1*, 3rd ed. Oxford Univ. Press.
[2] Amerijckx, J.B. (1985). General pedology: International Training Centre for Postgraduate Soil Scientists, State University of Ghent, Belgium.
[3] Ayaga, G., Kibunja, C.N., Kanyanjua, S.M., Gikonyo, E.W. and Wamae, D.K. (2004). Improving soil fertility through integrated nutrient management. Proceedings. Agricultural Research and Development for Sustainable Resource Management and Food Security in Kenya. 11-12 Nov 2003. Kenya Agricultural Research Institute, Nairobi, Kenya. Pg 1-11.
[4] Barber, S.A. (1995). Soil nutrient bioavailability. A mechanistic approach. John Wiley and Sons, Inc. (ed.). USA.
[5] Briggs, D. and Courtney, F. (1989). Agriculture and environment. The Physical Geography of Temperate Agricultural Systems. Longman Group, UK Ltd.
[6] Heckman, J.R. and Kamprath, E.J. (1995). Potassium accumulation and soybean yield related to potassium fertiliser rate and placement. *Commun. Soil Sci. Plant anal. 26* (*1&2*). pp 123-143.
[7] Hinga, G.A.N. and Foum, M.A. (1972). The effects of P, K and Mg on the dry matter yield and nutrient uptake by tomatoes in the greenhouse. Annual Report, National Agricultural laboratories, Soils and Agricultural Chemistry Section. pp 34-40.
[8] ICRAF. (1995). International Centre for Research in Agroforestry. Annual Report, 1994. ICRAF, Nairobi, Kenya.
[9] IFA. (1998). International Fertiliser Industry Association. Mineral Fertiliser Use and the Environment. United Nations Environmental Programme (UNEP). Paris, France.
[10] Kamprath, E.J. (1984). Crop response to lime on soils in the tropics. Department of Soil Science, North Carolina State University. *In*: ASA-CSSA-SSSA, Soil acidity and liming. *Agronomy Monograph, 12* (2nd edition).
[11] Kanyanjua, S.M. and Buresh, R. J. (1999). Potassium related soil fertility and plant nutrition problems in Kenya. *In*: Proceedings, IFA Agricultural Conference on Managing Plant Nutrition, 29 June - 2 July 1999, Barcelona, Spain. International Fertiliser Industry Association, Paris, France. Pg 233.
[12] KARI. (1995). Kenya Agricultural Research Institute. National Agricultural Research Laboratories, Fertiliser Use Recommendations for Various Districts, Vol 1-24.

[13] Loes, A.K., Ogaard, A.F. (2003). Concentrations of soil potassium after long-term organic dairy production. *International Journal of Agricultural Sustainability, 1,* 14-29.

[14] Marschner, H. (1995). Mineral nutrition of higher plants. 2nd ed. Academic Press.

[15] MoA. (1969). Ministry of Agriculture. NPK fertiliser trials on various crops; Western Agricultural Research Station, Kakamega. Annual Report, 1969.

[16] MoA. (1970). Ministry of Agriculture. NPK fertiliser trials on various crops; Western Agricultural Research Station, Kakamega. Annual Report, 1970.

[17] MoA. (1975). Ministry of Agriculture. NPK fertiliser trials on various crops; Western Agricultural Research Station, Kakamega. Annual Report, 1975.

[18] MoA. (1984). Ministry of Agriculture. Kakamega Research Station. Fertiliser response trial. Annual report 1984.

[19] Mochoge, B. (1991). Fertiliser and amendment uses. Fertiliser Use Recommendation Project. National Agricultural Laboratories. Annual Report 1991. pp 32-33.

[20] Mohr, E.C.J., van Baren F.A. and van Schuylenborgh, J. (1972). Tropical soils. A comprehensive study of their genesis. Printed in the Netherlands by Geuze Dordrecht.

[21] Muchena, F. (1974). The availability of potassium in some Kenyan soils. Kenya Soil Survey, National Agricultural Laboratories.

[22] Mwaura, F.M. and Woomer, P.L. (1999). Fertiliser retailing in the Kenyan highlands. *Nutrient Cycling in Agroecosystems 55,* 107-116.

[23] Nandwa, S.M. (1988). Fertiliser and amendment uses. Fertiliser Use Recommendation Project, National Agricultural Laboratories, Annual Report 1988. pp 12-13.

[24] Peter, A.V. (1980). The role of potassium in world agriculture. *In*: The role of potassium in crop production. Proceedings. Joint Int. Potash Inst. and FSSA Int. Seminar. Pretoria. pp 13-23.

[25] Smaling, E.M.A. and Stoorvogel, J.J., Windmeijer, P.N. (1993). Calculating soil nutrient balances in Africa at different scales: II. District scale. *Fert. Res. 35*, 237-250.

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