Effects of Duration of Contact and Rates of Minjingu Phosphate Rock (MPR) on its Release of P in a Kanhaplic Haplustult

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Abstract

An incubation pot experiment was conducted at the Sokoine University of Agriculture, Morogoro, Tanzania to study the effects of times of contact and rates of Minjingu phosphate rock (MPR) applied to a Kanhaplic Haplustult on the release of P from the MPR. The soil was mixed with MPR at rates equivalent to 0.0, 25.0, 37.5, 50.0 and 75.0 mg P/kg soil. The incubation periods were 30, 60, 90, and 120 days. The moisture content of the soil in the pots was maintained at about field capacity during the incubation periods using distilled water. Release of P from the MPR increased with increase in MPR rates and incubation periods. The interaction between incubation periods and MPR rates explained about 86.8% of the variation in P release from the MPR. MPR rates accounted for 76.6% of the release of P, while incubation periods accounted for 10.3% of the dissolution. The soil pH and extractable Ca were found to increase slightly with increase in MPR rates but decreased with increase in incubation periods. The exchangeable acidity and exchangeable Al decreased with increase in MPR rates, and slightly increased with incubation periods.

Keywords: Minjingu phosphate rock, Kanhaplic Hapluslult, Bray-1-P, exchangeable acidity, exchangeable Al, exchangeable Ca, soil pH, P-release.

Introduction

The development of appropriate technologies to maintain and improve soil fertility is paramount in order to produce large quantities of food for the world's population. This is particularly so in the tropical African countries which have been quoted to have the highest population growth rates. Soils in these areas, including Tanzania tend to have low inherent fertility status hence low crop production capacities. The population of Tanzania was estimated to be about 29 million people in year 2000 and expected to reach 84 million by the year 2025, whereby 17 out of the 20 regions would become food deficient if soil productivity is not improved (FAO, 2000).

The low levels of available phosphorus (P) is considered to be one of the soil fertility constrains in tropical soils. This problem of low plant available phosphorus is due to low P-content in the soils' parent materials and the high capacity of other soils to immobilize P. Decline in plant available P has also been brought about by successive and continuous cropping without P fertilizer applications.

Adequate P fertilization has, therefore, been recommended as one of the essentials for economic and sustained crop production in such highly weathered soils. However, the use of water soluble P fertilizers like triple superphosphate (TSP), single superphosphate (SSP), NPK and diammonium phosphate (DAP) and other soluble P fertilizers in Tanzania has decreased from about 99,000 tonnes in 1993/95 to about 65,000 tonnes in 1996/97 season (Turuka and Ulotu, 2000). This decline in P fertilizer use is a consequence of the decrease of crop prices and the increase in P fertilizer prices.

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A search for effective but cheaper alternative P sources is, therefore, of great necessity if production is to be sustained. Farmers should, therefore, be advised to use cheaper P sources like farmyard manure, composts and phosphate rocks (PR). However, based on the reactivity and dissolution of PR, these have been found to be more suitable for direct application to ameliorate P deficiency in acid soils (Engelstad and Terman, 1980; Semoka *et al.*, 1992). Engelstad and Terman (1980), documented further that no PR source would be effective in soils, having pH levels > 6.0. Since the majority of the tropical soils, are highly weathered with acid reactions then undoubtedly, PR would be an appropriate P source for crop production.

Minjingu phosphate rock (MPR) is a sedimentary phosphorite, found in the northern zone of Tanzania near Lake Manyara. The use of MPR in crop production in Tanzania is limited by its low reactivity in soils and solubility, as it is 100% water insoluble, hence its P release for plant use is extremely limited. In order for the MPR to be effective as a P fertilizer, substantial amounts of the MPR should dissolve immediately after application and this can be achieved in soils with very strong acid reaction and low levels of phosphorus and calcium. However, the time of application for maximum availability of P from MPR like many other PR in various soils is still a subject of some degree of uncertainty. MPR like many of the PR sources tend to vary widely in their agronomic effectiveness due to many factors that prevail in a particular PR-soil-plant cropping system which in turn determines its rate of P-release and hence P availability to plants (Khasawneh and Doll, 1978). Furthermore, the rate at which it is applied also affects the MPR dissolution, hence the release of P for plant uptake.

There is a need, therefore to establish the appropriate time of application of MPR prior to planting and rates to be applied so as to attain optimal crop response to the MPR applied. In view of the above, the present study was undertaken to study the influence of duration of contact between MPR and soil and rates of MPR on its release of P and Ca and various chemical properties of the soil, like pH and exchangeable acidity, just to mention a few.

Materials and Methods

An incubation pot experiment was conducted at the Sokoine University of Agriculture (SUA), Morogoro, Tanzania to evaluate the effect of duration of contact between Minjingu phosphate rock and soil and MPR rates on its release of P when applied to a Kanhaplic Haplustult.

Four hundred kilograms of a composite soil sample (0-30 cm depth) were collected from the SUA farm which is located at 6°51'S and 37°39'E, at an altitude of approximately 550 m asl. The experimental soil has been classified as Kanhaplic Haplustult (Kaaya *et al.*, 1994) equivalent to Dystric Nitosol (FAO-UNESCO, 1974). The composite soil sample was air dried, and ground to pass through 2 mm sieve for the pot experiment and for chemical and physical characterization of the soil.

Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986) and soil pH was measured in 1:2.5 soil: water suspensions (McLean, 1982). Available P was extracted by the Bray-1-P procedure (Shiou, 1996). Cation exchange capacity was determined by the neutral ammonium acetate saturation method (Thomas, 1982). The exchangeable cations (K^+, Ca^{2+}. Mg^{2+} and Na^+) in the ammonium acetate extracts were determined by atomic absorption spectrophotometer (Thomas, 1982). Exchangeable Al and H and exchangeable acidity were determined by the KCl method (McLean, 1982). Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1982) and total nitrogen by the micro-Kjeldahl digestion-distillation method (Bremner and Mulvaney, 1982).

For the glasshouse incubation study, 4 kg portions of the composite soil sample were weighed into sixty plastic pots of five-litre capacity with holes at the bottom loosely plugged with cotton wool for drainage. These plastic pots were divided into four batches of fifteen pots each for incubation with MPR for 30, 60, 90 and 120 days.

The potted soil portions were thoroughly mixed with MPR at the rates of 0, 0.80, 1.20, 1.60 and 2.30 g MPR soil equivalent to 0.0, 25.0, 37.5, 50.0 and 75.0 mg P/kg soil for each incubation period. Distilled water was added to the soil to about field capacity. Any solution draining out from the soil in the plastic pots was collected in saucers placed under the plastic pots and returned back to the soil. Each treatment was replicated three times in a completely randomised block design. Soils in the pots were incubated at about field capacity throughout the respective periods of incubation. Immediately at the end of each of the respective incubation periods, soil samples were taken from each pot, air-dried, ground and sieved through 2 mm sieve and used for the determination of soil pH, exchangeable acidity, exchangeable Al, Bray –1 extractable P and exchangeable Ca.

The soil analytical data for the sub-samples of the soils collected at the end of each incubation period were statistically analysed using MSTATC computer program. All analyses of variance (ANOVA) were performed based on the 5 x 4 factorial experiment arranged in a completely randomised block design (Snedecor and Cochran, 1989) and treatment means were separated according to Duncun's New Multiple Range Test (DNMRT).

Table 1. Some physical and chemical properties of the study soil

Parameter	Unit
pH (water)	4.9
Bray-1 P (mg kg^{-1})	2.9
Organic C(%)	1.3
Total N (%)	0.1
Exchangeable bases ($cmol_ckg^{-1}$):	
Ca	2.0
Mg	2.3
K	0.7
Na	0.2
CEC (NH_4Ac)[$cmol_ckg^{-1}$]	13.4
Base saturation (%)	38.4
Titratable acidity [$cmol_ckg^{-1}$]	1.6
Exchangeable Al[$cmol_ckg^{-1}$]	1.0
Particle size distribution:	
Sand (%)	30.9
Silt (%)	5.4
Clay (%)	63.7
Textural class	Clay

Results and discussion

Some of the physical and chemical properties of the soil are presented in Table 1. The textural class of the soil was designated as clay (FAO, 1990), which has an influence on the moisture retention, transmission and cation exchange and retention capacity of the soil. According to the categorization by Landon (1991) the soil pH value of 4.9 is rated as low hence the soil reaction is strongly acid. The very low pH of the soil could be attributed to the extensive weathering of the soil and leaching (Thomas and Hargrove, 1984). According to the categorization by Landon (1991), the extractable phosphorus for the soil is rated as low which could be due to low levels of P in the soil parent materials and conversion of P into forms not extractable by the Bray-1-P reagent. The organic carbon (1.3%), organic matter (2.2%) and total nitrogen (0.1%) were low according to ratings by Landon (1991). This is apparently due to high rates of organic matter transformations which normally take place in tropical soils.

The low values of exchangeable Ca, Mg and Na are indications of the extensive weathering of the soil and the low soil pH. According to Landon (1991), the CEC of the soil was ranked as low and this is due to the low organic matter and probably the nature of the clay minerals in the soil, hence low fertility status of the soil.

The amounts of Bray-1-extractable P for the different treatments are presented in Tables 2 and 3. The amounts of P released at different rates of MPR added to the soil, increased with increasing period of incubation up to about 75 days of incubation, and then tended to decline with further increase in period of contact between soil and MPR. The increases in Bray-1-extractable P at various incubation periods and with increasing rates of MPR application were significant ($P> 0.05$) (Table 2). The low soil pH, low extractable P and exchangeable Ca (Table 1) were the driving forces for the significant MPR release of P. The findings from the present study conform to those reported by Ikerra (1986), Mackay *et al.* (1986) and Mnkeni *et al.* (1992). Relatively gradual decrease in the amounts of available P beyond 75 days of incubation might have been associated with amounts of MPR applied and the increased time for reaction of the released P with hydrous oxides of Al and Fe of the soil in question which have been reported to have high P fixation capacity (Babili, 1999).

Table 2. Effect of MPR rates and MPR-Soil incubation periods on Bray-1 Phosphorus (mg P kg^{-1} soil)

MPR rates (mg P kg^{-1})	Incubation period (Days)				Mean effects of MPR rates
	30	60	90	120	
0.0	1.35 i[1]	1.54 i	1.04 i	0.94 i	1.17 e[1]
25.0	4.24 jk	4.23 ik	3.56 k	3.39 k	3.85 d
37.5	5.65 hi	6.30 gh	5.10 ij	4.93 ij	5.49 c
50.0	7.29 ef	8.70 d	7.81 de	6.84 fg	7.66 b
75.0	14.25 a	14.13 a	12.64 b	11.40 c	13.11 a
Mean effects of Incubation Periods	6.56 a[2]	6.94 a	6.03 b	5.50 c	
CV (%)	8.75				

1, 2 = all means (in their respective columns and rows) followed by the same letter do not differ significantly ($P \leq 0.05$) according to DNMRT.

Table 3. Mean MPR Release of P ($\Delta P\%$) as affected by incubation periods and application rates

MPR incubation period (days)	Δ Bray -1- P(%)
30	13.16 b[1]
60	14.10 a
90	12.48 bc
120	11.55 c
MPR rates applied (mg P kg^{-1})	
25.0	10.74 c[2]
37.5	11.52 c
50.0	13.12 b
75.0	15.91 a
CV % = 5.47	

1, 2 = all means followed by the same letter are not significantly different ($P < 0.05$) according to DNMRT.

Simple and multiple regression analyses were done to trace back the overall influence of incubation period and application rates on the extent of MPR-P release. On the basis of multiple regression relations, these two factors together explained about 86.8% ($P < 0.001$) of the variation in the change (Δ) in Bray-1-P from MPR. However, MPR rates evidenced to have superiority over the incubation period by explaining about 76.6% of the released MPR-P availability trend in the soil as compared to the latter variable (10.3%). Also MPR rates were found to be highly significantly correlated ($r = 0.875$) with the MPR released P (%), which was not the case with the incubation period, as had non-significant ($P > 0.05$) and negative relationship ($r = -0.321$) with the same dependent variable.

The observations confirm the argument that increase in time of soil - MPR contact leads into a reaction between the released P with the Al and Fe hydrous oxides in the soil hence transforming the released P into forms not available to plants (Hughes and Gilkes, 1986). The progressive increase in amounts of P released from MPR following the increase in MPR rates was probably due to higher amounts of protons, P and Ca sinks or decrease in the number of P fixing sites in the soil as compared to the lower amounts of MPR applied (Robinson *et al.,* 1992).

There was a slight decrease in exchangeable acidity with decrease in incubation time and increase in MPR rates (Tables 4 and 5). Exchangeable acidity also decreased substantially as compared to the control with increase in amounts of MPR applied to the soil from 1.61 to 1.00 cmol(+)kg^{-1} (Table 4). The results are consistent with dissolution characteristics of MPR which releases Ca ions and consumes H^+ thus decreasing exchangeable acidity and likewise increasing pH (Mnkeni *et al.*, 1992).

Table 4: Effect of MPR-Soil incubation periods and MPR rates on exchangeable acidity (cmol(+)kg-1)

MPR rates (mg P kg-1)	Incubation periods (days)				Mean effects of MPR rates effects
	30	60	90	120	
0.0	1.55 bc[1]	1.54 c	1.70 a	1.60 ab	1.61 a[1]
25.0	1.41 d	1.35 de	1.31 ef	1.38 de	1.36 b
37.5	1.23 fg	1.25fg	1.30 ef	1.29 ef	1.26 c
50.0	1.17 g	1.22 fg	1.15 g	1.18 g	1.18 d
75.0	1.00 h	1.02 h	0.97 h	1.01 h	1.00 e
Mean effects of equilibration periods	1.27 a[2]	1.27 a	1.29 a	1.30 a	
CV (%)	4.01				

1, 2 = all means (over rows or columns) followed by the same letter do not differ significantly (P ≤ 0.05) according to DNMRT.

Table 5. Effect of MPR-Soil incubation periods and MPR rates on the pH of the Kanhaplic Haplustult

MPR rates (mg P kg-1)	Incubation periods (days)				Mean effects of MPR rates effects
	30	60	90	120	
0.0	4.93fg[1]	4.98 def	4.69 h	4.73 h	4.83 e[1]
25.0	4.99 de	4.97 def	4.89 g	4.89 g	4.94 d
37.5	5.01 cd	4.99 de	4.94 efg	4.92 fg	4.96 c
50.0	5.05 abc	5.02 bcd	4.92 fg	4.97 def	4.99 b
75.0	5.07 ab	5.09 a	5.00 cd	5.04 a	
Mean effects of equilibration periods	5.01 a[2]	5.01 a	4.89 b	4.90 b	
CV (%)	0.67				

1,2 = all means (over rows or columns) with the same letter are not significantly different (P < 0.005) according to DNMRT

The quantities of exchangeable Ca at different rates of MPR and incubation periods are presented in Table 6. There were no significant (P = 0.05) differences in exchangeable Ca at different incubation periods. However, exchangeable Ca increased steadily with increasing rates of MPR from 2.84 to 3.81 cmol (+)/kg in the control and 150 kg MPR-P ha-1, respectively.

Table 6. Effect of MPR rates and MPR-soil incubation periods on exchangeable Ca (cmol(+)kg^{-1})

MPR rates (mg P kg^{-1})	Equilibration period (days)				Mean effects of MPR rates effects
	30	60	90	120	
0.0	2.91 i[1]	2.92 i	2.85 ij	2.68 j	2.84 e[1]
25.0	3.20 gh	3.23 fgh	3.17 h	3.19 gh	3.20 d
37.5	3.42 ef	3.40 efg	3.26 fgh	3.40 efgh	3.37 c
50.0	3.65 bcd	3.56 cde	3.50 de	3.36 efgh	3.52 b
75.0	3.74 abc	3.77 ab	3.83 ab	3.89 a	3.81 a
Mean effects of equilibration periods	3.38 a[2]	3.38a	3.32 a	3.30 a	
CV (%)	3.38				

1, 2 = all means followed by the same letter are not significantly different (P≤0.05) according to DNMRT.

The increase in the amounts of exchangeable Ca was attributed to the dissolution of MPR in the soil based on the chemical constitution of the MPR, which has a probable chemical formula $[Ca_3 (PO_4)_2]_3 C_aF_x (CaCO_3)_x (Ca(OH)_2)_x$. The decrease in exchangeable Ca with the increase in incubation period, and increase in exchangeable Ca with increase in MPR rates agrees with the work of Ikerra (1986) and Mnkeni *et al.* (1991).

There was a positive significant correlation (r = 0.724) between soil pH and the amounts of exchangeable Ca at the end of the incubation periods (Table 7), which concurs with the fact that, MPR like many other phosphate rocks have small liming effect (Hellums *et al.*, 1989).

Table 7: Correlation analyses between some chemical properties of the soil at various incubation periods

	Exchangeable acidity	Exchangeable Al	Available P	Exchangeable Ca
pH (water)	-0.754***	-0.706***	0.668***	0.724 ***
Exchangeable Acidity			-0.908***	
Exchangeable Al			-0.855***	-0.902***
Available P				0.893***

***** = highly significant (P < 0.001)**

Nevertheless, results from this study were found to show significant (P < 0.001) negative correlation between exchangeable Al and pH similar to the results of Hochman *et al.* (1992). Similarly, a negative significant relationship (r = -0.902***) between the exchangeable Al and exchangeable Ca still indicates that as the soil acidity decreased the exchangeable Ca in the soil increased, and vice versa probably due to the slight liming effect of MPR.

However, the simple correlations (Table 7), showed that the exchangeable acidity was negatively and significantly correlated with available P (r = -0.908) which could be argued that the increase in free Al ions in the soil tended to precipitate the released P from MPR into insoluble forms (Al-phosphates). In contrast, the positive correlation (r = 0.668***) between extractable P and soil pH, indicates that all these two parameters were liable to increase simultaneously as a result of Minjingu phosphate rock dissolution which also released P and Ca as two of its products (components) (r = 0.893***).

Conclusions

Based on the incubation experiment, Bray-1-P increased with increasing rates of MPR applied to the soil. On the other hand, the amount of P released increased with time of incubation up to about 75 days and decreased thereafter probably following its reaction with Al and Fe hydrous oxides forming Al and Fe phosphates. The soil pH increased with increasing MPR application rate, but decreased with increasing incubation period, particularly after about 75 days of incubation. Similarly the extractable Ca tended to increase with MPR rate, and slightly decreased with increase in the incubation period. These results indicate that MPR dissolution releases Ca^{2+} and OH^-, as two of the constituent components of MPR, which subsequently increased the pH of the soil. Both exchangeable acidity and exchangeable Al tended to decrease with increasing rates.

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References

Babili, I. H. (1999) Effect of combining Minjingu phosphate rock with selected plant biomass on phosphorus availability in two soils with contrasting properties. *M.Sc. Dissertation.* Sokoine University of Agriculture, Morogoro, Tanzania.

Bremner, J.M. and Mulvaney, C.S. (1982) Total Nitrogen, In: *Methods of Soil Analysis. Part 2. 2nd edition. (Edited by Page, A.L. Miller, R.H. and Keeney, D.R.)* American Society of Agronomy, Monograph No. 9. Madison, Wisconsin, pp 149-157.

Engelstad, O.P. and Terman, G.L. (1980) Agronomic effectiveness of phosphate fertilizers. In: *The Role of Phosphorus in Agriculture (Edited by Khasawneh, F.E., Sample, E.C. and Kamprath, E.J.)* American Society of Agronomy, Madison, Wisconsin, pp 311-332.

FAO (1990) *Guideline for soil profile description.* Rome, Italy. Pp 70.

FAO (2000) *Fertilizers and their use. 4th Edition.* International Fertilizer Industry Association (IFA). Rome. Pp 70.

FAO-UNESCO (1974) *Soil Map of the World,* 1:5,000,000. Vol. 1. Legend. UNESCO-Paris. Pp 59.

Gee, G.W. and Bauder, J.W. (1986) Particle size analysis. In: *Methods of Soil Analysis Part 1. Physical and Mineralogical Methods. Soil Science Society of America Book Series No.* 5. Madison, Wisconsin, USA. Pp 383-409.

Hellumns, D.T., Chien, S.H. and Touchton, J.T. (1989) Potential agronomic value of Calcium in some phosphate rocks from South America and West Africa. *Soil Science Society of America Journal* 53:459-62.

Hochman, Z: Edmeades, D.C. and White, E. (1992) Changes in effective cation exchange capacity and exchangeable aluminium with soil pH in lime amended field soils. *Australian Journal of Soil Research* 30:177-187.

Hughes, J.C. and Gilkes, R.J. (1986) The effect of rock phosphate properties on the extent of fertilizer dissolution in soils. *Australian Journal of Soil Research 24:209-217.*

Ikerra, T.W.D. (1986) Evaluation of Minjingu phosphate rock as a source of phosphorus for maize applied in combination with compost or FYM. *M.Sc. Dissertation.* Sokoine University of Agriculture, Morogoro, Tanzania.

Kaaya, A.E. Msanya, B.M. and Mrema, J.P. (1994) Soil survey and land suitability evaluation of the central part of Sokoine

University of Agriculture farm for rain fed crops. *African Study Monographs* 15(2): 97-117.

Khasawneh, F.E. and Doll, E.C. (1978) The use of phosphate rock for direct application to soils. *Advances in Agronomy* 30:159-206.

Landon, J.R. (1991) *Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in tropics and sub tropics*. Longman, New York. Pp 474.

Mackay, A.D., Syers, J.K., Tillman, R.W. and Gregg, P.E.H. (1986) A simple model to describe the dissolution of phosphate rock in soils. *Soil Science Society America Journal* 50, 291-296.

McLean, F.O. (1982) Soil pH and lime requirement. *In: Methods of Soil Analysis. Part 2: Chemical and Microbilological Properties, (Edited by Page, A.L. Miller, R.H. and Keeney, P.R.)*. Agronomy

Monograph No. 9. 2nd Edition. American Society of Agronomy. Madison, Wisconsin, USA, pp 199-224.

Mnkeni, P.N.S., Semoka, J.M.R. and Buganga, J.B.B. (1991) Effectiveness of Minjingu phosphate rock as a source of phosphorus for maize in some soils of Morogoro, Tanzania. *Zimbabwe Journal of Agricultural Research* 29: 27-37.

Mnkeni, P.N.S., Semoka, J.M.R. and Mwanga, S.N. (1992) Dissolution of some Tanzanian phosphate rocks of igneous and sedimentary origin. *Zimbabwe Journal of Agriculture Research* 30 (1): 67-76.

Nelson, D.W. and Sommers, L.W. (1982) Organic carbon. In: *Methods of Soil analysis. Part 2. 2nd edition (Edited by Page, A.L., Miller, R.H. and Keeney, D.R.)* American Society of Agronomy, Monograph No. 9. Madison, Wisconsin. Pp 561-573.

Robinson, J.S., Syers, J.K. and Bolan, N.S. (1992) Importance of proton supply and calcium sink size in the dissolution of phosphate rock materials of different reactivity in soil. *Journal of Soil Science* 43: 447-459.

Semoka, J.M.R, Mnkeni, P.N.S. and Ringo, H.D. (1992) Effectiveness of Tanzanian phosphate rocks of igneous and sedimentary origin as sources of phosphorus for maize. *Zimbabwe Journal of Agricultural Research* 30 (2): 127-136.

Shiou, K. (1996) Extraction of phosphorus with dilute acid fluoride. In: *Methods of Soil Analysis Part 3*. Chemical Methods. *Soil Science Society of America Book Series. No. 5*. Madison, Wisconsin, USA .Pp 894 – 895.

Snedecor, G.W. and Cochran, W.G. (1989) *Statistical Methods. 8th edition*. Iowa State University Press, AMES, Iowa. Pp 503.

Thomas, G.W. (1982) Exchangeable cations. In: *Methods of Soil Analysis* Part 2. 2nd edition *(Edited by Page, A.L. Miller, R.H. and Keeney, D.R.)* American Society of Agronomy, Monograph No. 9. Madison, Wisconsin. Pp 159-165.

Thomas, G.W. and Hargrove, W.L. (1984). *The chemistry of soil acidity*. In: *Soil acidity and liming*. 2nd Edition. *(Edited by Adams, F.)* Agronomy No. 12. American Society of Agronomy, Madison, Wisconsin. Pp 3049.

Turuka, F.M. and Ulotu, H.A. (2000) Review of input supply status and economic aspects of soil fertility management. *Working Paper No. 7*. ECAPAPA, Kampala, Uganda.