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Yield trends in the long-term crop rotation with organic and inorganic fertilisers on Alisols in Mata (Rwanda)

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A crop rotation system with various species was established on «Alisols» at Mata grassland site, oriental side of Zaire-Nile Watershed Divide (CZN), Rwanda. Inorganic and organic fertilisers were applied in various plots led in randomised complete blocs with three replicates. Crop yield data were each season recorded over a 9-year period. Results showed that there was very low or no harvest in plots without fertilisers. Where fertilisers were applied, the yield generally increased but remained relatively low: only few crops and varieties adapted to the Mata ecology such as potatoes and finger millet responded well to fertilisers. Liming was absolutely necessary to get any acceptable crop yield improvement with NPK. High rate of rich farmyard manure was efficient alone and its effect was seen up to 4 seasons after its four regular seasonal applications. Mata compost (C/N>25, 0,3 g P·kg^{-1}) had little beneficial effect. One, four and half, and eight tons of lime per ha applied 3 times in 8 years increased soil pH (in water) but not up to 6,5. It is then concluded that to succeed improving food production at the CZN area, selection of crops and varieties to fit ecological conditions and amending soils to fit crops be combined, but not opposed.

Keywords. Mata/Rwanda, Alisols under grass, inorganic and organic fertilisers, crop rotation, yield improvement.

Un système de rotation constitué de plusieurs espèces de cultures a fait l'objet d'expérimentation sur des « Alisols » sous prairie à Mata, versant oriental de la Crête Zaïre-Nil (CZN) au Rwanda. Des fumures minérales et organiques ont été apportées dans différentes parcelles arrangées suivant un dispositif en blocs complétement aléatoires en trois répétitions. Les données de rendements des cultures ont été mesurées chaque saison pendant une période de neuf ans. Les résultats ont montré que les rendements des cultures étaient faibles ou nuls dans les parcelles n'ayant pas reçu de fumures. En parcelles fumées, le rendement a augmenté en général mais est resté relativement bas. Seules quelques espèces ou variétés adaptées aux conditions écologiques de Mata telles les tubercules et racines tubéreuses ainsi que l'éleusine ont mieux réagi à la fumure. Le chaulage était indispensable pour obtenir tout effet positif de l'engrais minéral NPK sur la production des cultures. La forte dose de bon fumier avait un effet notoire et ses trois applications successives durant quatre saisons avaient un arrière-effet bénéfique jusqu'à quatre saisons après son application. Le compost de Mata (C/N>25, 0,3g P·kg^{-1}) produisait par contre un effet négligeable dans l'amélioration des rendements des cultures. Une, quatre et demi, et huit tonnes de chaux appliquée trois fois en huit ans ont augmenté le pH (eau) du sol mais pas jusqu'à la valeur de 6,5. Toutes ces constatations montrent que pour maîtriser la production performante des cultures à la CZN, la sélection des espèces et variétés adaptées aux conditions écologiques et l'amendement des sols constituent deux stratégies obligées plutôt complémentaires, mais pas séparées.

Mots-clé. Mata/Rwanda, Alisols sous prairie, fumures minérales et organiques, rotation de cultures, amelioration des rendements.

1. INTRODUCTION

Rwanda is a very high densely populated country and this has led to arable land scarcity. On average, the farms are smaller than 1 ha (Clay, 1996). Farmers are forced to do continuous cropping and to use soils of low fertility status for food production. Among the Rwanda less-productive soils are those low in bases, very acid and with high content in exchangeable Al, generally classified as Ferralsols, Acrisols and Alisols (World Reference Base). Crop yield obtained on such soils is very low when no fertiliser is applied (Driessen *et al.*, 2002). Alisols dominate three agro-ecological zones i.e. Zaïre-Nile Watershed Divide (CZN), Buberuka and Ndiza Highlands (Birasa *et al.*, 1992) that are situated at an altitude between 1900 and 2500 m from the sea level. They are also found in the «plateau central» zone attaining to the former zones and lying between 1500 and 1900 m of altitude. Approximately, Acrisols and Alisols occupy 25% of the Rwanda area (Verdoodt, van Ranst, 2003). Many farmers live in this area and their most important traditional crops are sweet potatoes (*Ipomea batatas* (L.) Lam), Irish potatoes (*Solanum tuberosum* L.), peas (*Pisum sativum* L.), beans (*Phaseolus vulgaris* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.) and sorghum (*Sorghum vulgare* Pers.) (Delepierre, 1974). Frankart *et al.* (1974) reported that crop yields on soils where farmers have applied organic farm manure for many times and during a long period (anthropic soils) are medium to good while they are too low or zero on soils under grassland with *Eragrostis* sp. as dominant species. Soil chemical and biological properties were improved under anthropic soils (low or no exchangeable Al, water pH above 5 and relatively high nutrient content and microbial activity). This technology for improving soils is efficient but requires long period and is then not appropriate for farmers who need high production in the short time for surviving.

Field research was carried out from 1971 to 1980 in order to identify the most appropriate inorganic and organic fertilisers to apply for improving crop yields on these Alisols and Acrisols in a short time. These long-term field experiments contribute to a better quantitative knowledge of influences of soil properties, weather conditions and management system on the value of soil for crop production (Haans, Westerveld, 1970). Rutunga *et al.* (1998) reported results on non-humiferous Alic ferralsols in Rwanda «plateau central». The current paper provides the results on humiferous Alisols at an altitude of 1650 m from the sea level.

2. MATERIAL AND METHODS

From 1971 to 1980 a rotational experiment with inorganic and organic fertilisers was established in Mata, Gikongoro region where the secondary forest had been cleared in the 1900's. After the nutrients from forest biomass were exhausted through non-sustainable continuous cropping the site was abandoned and became public grassland dominated with *Eragrostis blepharoglumis* K. Schum. The climate at the site is Cw2 (ILACO, 1985) with a dry season occurring from June to August. The monthly rainfall and average temperature during the experimental period are given in **table 1**. Soil temperature regime is udic isothermic (Verdoodt, van Ranst, 2003). The slope at the site is 6 to 25 % but was 5 % in the experimental plots. Soil chemical properties at the beginning of the experiment are shown in **table 2**. A pot fertiliser trial with finger millet (*Eleusina coracana* Goertn) as test plant revealed high N, P and K deficiency and low to medium Ca and Mg deficiency in the soil (ISAR, 1972).

The experiment was carried out in 4 benches: benches 1 to 3 comprised 16 treatments (**Table 3a, b and c**) while bench 4 was for validating in few treatments 2 types of fertiliser combination i.e., lime with NPK and manure with phosphorus. Fertilisers tested were burnt lime (39.2% CaO, 4.0% MgO), mineral NPK fertilisers i.e. urea (46% N), triple super-phosphate (19% P) and various NPK formula (20-4-8; 15-4-12; 15-9-8 and 10-11-8)[(1)], Mata compost (1.3g N, 0.3g P and 15g K·kg^{-1}, prepared from *Setaria sphacelata* (Schum.) Moss and *Eragrostis blepharoglumis*) and ISAR farmyard manure (FYM: 6g N, 2.5g P and 14.2g K·kg^{-1}). The bench 1 was for a crop response to mineral NPK rates on limed plots up to Feb 1974; in Sep 74 the bench was converted into a factorial trial as shown in **table 3a**. The bench 2 was similar to bench 1 but was not limed up to Feb 74; it was also converted into a factorial trial in Sep 74 (**Table 3b**). The bench 3 received three rates of lime (1.0, 4.5 and 8.0 Mg·ha^{-1}) and various rates and formula of NPK during the 9 year-experimental period (**Table 3c**). The bench 4 was for testing liming, NPK fertilisers and farmyard manure rates and their period of application (**Table 3d**). The various treatments and the fertiliser-detailed rates over time are shown in the **tables 3**. Treatments in each bench were laid out in complete randomised block design with 3 replicates. Plot size for each treatment was 16 m^2 (4 m by 4 m).

Test plants used in the rotation comprised traditional crops and 2 new crops introduced by ISAR i.e. sunflower (*Helianthus annuus* L.) and soya (*Glycine max* (L.) Merr.) (**Table 4**). Crop husbandry was manually done according to the ISAR recommendations (ISAR husbandry guides for various crops) summarised as follows:

Land preparation: the land was manually tilled with a hoe and *Digitaria scalarum* (Schweinf.) Chiov. roots uprooted and removed from the field. This 1st digging was followed by a 2nd cultivation for soil levelling before planting.

Fertiliser application and soil sampling: lime was broadcast by hand after the 1st soil tillage, 15 days before the planting period and immediately incorporated in 0-15 cm soil depth, using a hoe. Mineral NPK, compost and FYM fertilisers were broadcast by hand after soil levelling just before planting and incorporated in 0-15 cm depth, using a hoe. One year after the 3rd liming, soil samples were taken from the limed plots, bench 3, at 0-15 cm soil depth and the pH in a suspension of soil/water of 1/2.5 was measured with a pH-meter in order to identify the pH improvement due to liming.

Crop management: cereal, legume and sunflower grains, potato tubers and sweet potato vines were provided by ISAR and were established as follows:

[(1)] In this study P and K fertilisers are exposed as P and K units and not as P_2O_5 and K_2O_5.

Table 1. Rainfall (mm) and average temperature (°C) at Mata site during the experimental period — *Pluviométrie (mm) et température moyenne (°C) au site de Mata durant la période expérimentale.*

Month	Year 0		1		2		3		4		5		6		7	
	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C	mm	°C
January	172	18.3	101	17.9	207	19.1	129	18.1	109	18.1	125	17.6	141	18.5	157	19.9
February	98	17.6	174	18.4	161	19.5	55	18.0	112	17.7	88	16.5	91	16.6	168	19.3
March	171	18.0	173	18.0	160	18.1	168	18.5	108	18.1	216	17.3	161	17.7	265	18.8
April	331	17.5	144	17.7	225	18.0	253	18.3	306	18.0	160	16.4	204	17.2	160	18.9
May	289	17.3	140	17.4	313	17.6	197	17.7	56	17.1	139	15.7	166	15.8	158	17.7
June	**0**	**16.5**	**81**	**17.1**	**53**	**17.0**	**72**	**17.9**	**21**	**17.1**	**9**	**15.7**	**19**	**17.1**	**44**	**17.0**
July	**39**	**16.8**	**0**	**16.4**	**0**	**17.6**	**53**	**16.5**	**62**	**17.7**	**14**	**16.1**	**1**	**16.6**	**0**	**16.9**
August	**93**	**17.7**	**50**	**18.1**	**13**	**18.6**	**2**	**17.9**	**17**	**17.2**	**113**	**16.5**	**125**	**17.0**	**42**	**17.8**
September	65	17.8	98	18.6	241	18.5	124	19.7	177	16.5	105	16.6	117	19.3	89	18.5
October	117	18.1	174	18.5	144	18.1	32	18.5	185	16.8	63	17.3	98	20.3	108	18.2
November	11	17.8	197	18.1	214	18.2	165	18.5	84	17.1	93	16.9	235	19.2	125	17.6
December	106	17.3	122	18.5	63	18.1	55	17.4	308	17.0	115	16.9	144	19.7	199	18.3
Total rainfall	**1597**		**1455**		**1794**		**1304**		**1544**		**1238**		**1501**		**1515**	
Average annual temperature		**17.5**		**17.9**		**18.2**		**18.1**		**17.4**		**16.6**		**17.9**		**18.2**

Table 2. Mata soil analytical data in 0-30 cm depth — *Données analytiques du sol de Mata à 0-30 cm de profondeur.*

	Clay ($<2\ \mu m$) (%)	C (g·kg⁻¹ of soil)	N	pH water	Ca^{2+} (mmol·kg⁻¹ of soil)	Mg^{2+}	K^{+}	Al^{3+}	P_{Olsen} (mg·kg⁻¹)	Base saturation rate (Al not included) (%)	Al saturation (%)
Bench 1	55	37	3	4.7	18	6	0.9	41	2	14	62
Bench 2	55	37	3	4.7	17	6	0.8	43	3	14	64

Particle size analysis by heating with H_2O_2 followed by dispersion with Na hexameta-phosphate; C determined with Walkley-Black method; N with Kjedahl digestion method, pH determined in soil water suspension of 1/2.5; bases percolated with 1M ammonium acetate pH7; Al extracted with KCl; P with Olsen method.
Pot trials with coracana finger millet as test plant and soil taken at 0-30 cm depth in *Eragrostis* sp. grassland.

Table 3a. Fertiliser rates and design of treatments in the bench 1 — *Doses de fertilisants et protocole expérimental appliqués au bloc 1.*

« 2 Mg·ha⁻¹ lime and 4 rates of NPK » applied before Sep 74	Types of fertilisers: Fresh NPK (rates 0 or Fo; 200 or F1; 400 or F2 and 600 kg·ha⁻¹ or F3) + 2 Mg fresh lime·ha⁻¹ (L2)	Fresh NPK (rates as in previous column)	No fresh fertilizers (0)	One rate of compost (H)	Mean
0 kg·ha⁻¹ (R0)	R0 + F0 + L2	R0 + F0	R0 + 0	R0 + H	R0F0
200 kg·ha⁻¹ (R1)	R1 + F1 + L2	R1 + F1	R1 + 0	R1 + H	R1F1
400 kg·ha⁻¹ (R2)	R2 + F2 + L2	R2 + F2	R2 + 0	R2 + H	R2F2
600 kg·ha⁻¹ (R3)	R3 + F3 + L2	R3 + F3	R3 + 0	R3 + H	R3F3
Mean	RFL2	RF	R	RH	

Bench 1: 4×4 factorial experiment (4 NPK rates and lime applied before Sep 74* and 4 types of fertilisers applied from Sep 74 and consisting of rates of fresh NPK combined with 2 Mg lime·ha⁻¹, 4 rates of fresh NPK, no fresh fertilisers and one rate compost**.

* 2 Mg lime·ha⁻¹ were applied in all plots in Sep 71 and Sep 72 while NPK formula 20-4-8 was applied in Sep 71. Sep 72 and Feb 73, and NPK 10-11-8 in Sep 73 and Feb 74. This fertiliser combinations (R0, R1, R2, R3) done before Sep 74 are referred as to « residual lime-NPK ».

** Fertiliser rates/formula applied from Sep 74 and time of application: Sep 1974: 2 Mg lime, 10 Mg compost, NPK 15-9-8; Feb 1975: 10 Mg compost and 50 kg N·ha⁻¹ from urea applied in all treatments exept in the absolute control plots (R0 + 0 and R0 - F0); Sep 1975: 2 Mg lime, 35 Mg compost, NPK 15-9-8; Feb 1976: 35 Mg compost, NPK 15-4-12; Sep 1977: 2 Mg lime, 20 Mg compost, NPK 20-4-8; Feb 1978 #: NPK 20-4-8; Sep 1978#: No fertilisers in control plots; 50 kg N, 8.5 kg P and 84 kg K·ha⁻¹ for all other treatments; each s. potato variety was planted on the half elementary plot, i.e. 8 m².

1Mg : 1 megagram = 1 ton.

Table 3b. Fertiliser rates and design of treatments in the bench 2 — *Doses de fertilisants et protocole expérimental appliqués au bloc 2*.

4 rates of NPK applied before Sep 74	4 types of fertilisers				
	No fresh fertilizers (0)	2 Mg lime·ha^{-1} (L2)	One rate of compost (H)	2 Mg lime·ha^{-1} (L2) + one rate of compost (H)	Mean
0 kg·ha^{-1} (R0)	R0 + 0	R0 + L2	R0 + H	R0 + L2 + H	R0
200 kg·ha^{-1} (R1)	R1 + 0	R1 + L2	R1 + H	R1 + L2 + H	R1
400 kg·ha^{-1} (R2)	R2 + 0	R2 + L2	R2 + H	R2 + L2 + H	R2
600 kg·ha^{-1} (R3)	R3 + 0	R3 + L2	R3 + H	R3 + L2 + H	R3
Mean	R	RL2	RH	RL2H	

Bench 2: 4×4 factorial experiment (4 rates of NPK applied before Sep 74* and 4 types of fertilisers applied from Sep 74 and consisting of no fresh fertiliser, 2 Mg lime·ha^{-1}, 1 rates of compost and 2 Mg lime·ha^{-1} + 1 rate compost**.

* NPK formula 20-4-8 was applied in Sep 71, Sep 72 and Sep 73, and NPK 10-11-8 in Sep 73 and Sep 74. These fertiliser combinations (R0, R1, R2, R3) are refered as to « residual NPK ».

** Fertiliser rates/formula and application calendar: Sep 1974: 2 Mg lime, 10 Mg compost; Feb 1975: 10 Mg compost and 50 kg N·ha^{-1} from urea applied in all treatments except in the absolute control plots; Sep 1975: 2 Mg lime, 35 Mg compost; Feb 1976: 35 Mg compost; Sep. 1977: 2 Mg lime, 20 Mg compost; Feb 1978: NPK 20-4-8; Sep 1978: # No fertilisers in absolute control plots; 50 kg N, 8.5 kg K·ha^{-1} for all other treatments; each s. potato variety was planted on the half elementary plot, i.e. 8 m^2.

Table 3c(1). Fertiliser rates and design of treatments in the bench 3 — *Doses de fertilisants et protocole expérimental appliqués au bloc 3*.

NPK	Lime			
	0.0 lime·ha^{-1} (L0)	1.0 Mg lime·ha^{-1} (L1)	4.5 Mg lime·ha^{-1} (Lb)	8.0 Mg lime·ha^{-1} (L8)
0 (F0)	F0L0	F0L1	-	-
NKP0 (F1)	-	F1L1	F1Lb	-
NKP1 (F2)	-	F2L1	F2Lb	F2L8
NKP2 (F3)	-	F3L1	F3Lb	F3L8
NKP3 (F4)	-	F4L1	F4Lb	F4L8
KP2 (F5)	-	-	F5Lb	-
NP2 (F6)	-	-	-	F6L8
P2 (F7)	-	-	-	F7L8

Bench 3: 3×3 factorial trial (P rates, lime rates) and some extra-treatments.

Table 3c(2). Fertiliser rates and application calendar in bench 3 — *Doses de fertilisants et calendrier d'application au bloc 3*.

Fertilisers applied	Sep 72	Sep 74	Sep 75	Feb 76	Sep 77	Feb 78	Sep 78
Various NPK element applied, kg·ha^{-1}			60-44-49	90-11-74	90-11-74	90-11-74	50-8.5-41
			60-88-49	90-22-74	90-22-74	90-22-74	50-17-41
	RE*	RE*	60-132-49	90-44-74	90-44-74	90-44-74	50-25-41
Lime (3rates: 1.0, 4.5 and 8.0 Mg·ha^{-1})	Yes	Yes			Yes		

*RE is residual effect of lime and of 100 kg N and 189 kg K applied in Sep 72; 30 kg N, 88 kg P and 42 kg K applied in Sep 73 and 60 kg N, 88 kg P and 42 kg K·ha^{-1} applied in Feb 74. From Sep 72 to Feb 73, F7L8 received lime alone. From Sep 72 to Sep 73, F6L8 was receiving only the seasonal amount of N and K.

- wheat and soya seeds sown continuously in the rows, distance of 40 cm between two rows, manually weeding, and harvest at 138 days after planting (DAP);
- maize sown at 3 grains/hole on the rows with 50 cm between two holes and 60 cm between two rows, thinning to 2 seedlings one month after planting, weeding two times and harvest after 217 DAP;
- finger millet seeds broadcast continuously in the rows, distance of 30 cm among rows, manually weeding, and harvest at 150 DAP;
- sunflower sown at 2 seeds/hole on the rows with 30 cm between two holes and 60 cm between rows, thinning to 1 seedling one month after planting, weeding and harvest after 150 DAP;

Table 3d. Fertiliser rates and design of treatments in the bench 4. Applied treatments — *Doses de fertilisants et protocole expérimental appliqués au bloc 4. Traitements appliqués.*

Treatments in the lime experiment*	NPK element rates					
	Feb 74	Sep 74	Feb 75	Sep 75	Feb 76	Sep 76
T1: Control	Control	Control	Control	Same as in Feb 74	Control	Control
T2: 2 Mg lime·ha^{-1}	60-66-52	50-22-52	50-22-52		50-11-21	60-0-0
T3: 2 Mg lime·ha^{-1}	45-88-84	100-44-42	100-44-42		100-22-84	60-0-42
T4: 2 Mg lime·ha^{-1}	70-88-84	60-33-32	60-33-32		50-11-42	60-22-0
T5: 2 Mg lime·ha^{-1}	70-99-84	100-66-84	100-66-84		120-27-52	60-27-42
Treatments in manure experiment						
T1: Control						
T2: 35 Mg FYM, RE**			50-0-0			
T3: 44 kg P + RE of 35 Mg FYM		0-44-0	50-44-0		0-44-0	
T4: 88 kg P + RE of 35 Mg FYM		0-44-0	50-88-0		0-44-0	

* Lime is tested every season up to Septembre 76.
** RE is residual effect of 4 application of 35 Mg FYM and 4 applications of phosphorus in Sep 72, Feb 73, Sep 73 and Feb 74.

Table 4. Crop rotation in Mata experiment from 1971 to 1980 — *Rotation des cultures dans l'essai de Mata de 1971 à 1980.*

Year	1	2		3		4		5		6	7		8	9	
Season	Sep	Sep	Feb	Sep	Feb	Sep	Feb	Sep	Feb	Sep	Sep	Feb	Sep	Sep	Feb
Crop	Finger millet	Peas	Wheat or maize	Beans	Wheat	Maize or potato	Maize or peas or beans	Beans or potato	Potato	Finger millet or soya	Soya	Potato	S.potato	Sunflower	Wheat

- peas sown at 1 grain/hole in the rows with a spacing of 5 cm by 40 cm, manually weeding, harvest after 112 DAP;
- non climbing beans sown at 1 grain/hole in the rows with a spacing of 10 cm by 20 cm, manually weeding, harvest after 98 DAP;
- potato tubers planted in rows, distance of 30 cm between two plants and 60 cm between two rows, weeding, spreading of dithane M45 for mildew control, harvest at 122 DAP;
- sweet potato vine cuttings planted on ridges of 30 cm diameter, two vine cuttings of 30 cm length hole, distance of 30 cm between two holes and ridges of 80 cm-diameter, manually weeding, harvest at 240 DAP.

Except for dithane M 45, no other crop protection chemicals were used.

At harvest, fresh cereal, legume and sunflower top biomass were cut near ground level, removed from the plots, sun dried, and then thresholds separated from grains. Grains were weighed at 12 % moisture content. For Irish and sweet potatoes, fresh tubers, storage-roots and vines were immediately weighed. Data recorded from the four benches were statistically analysed, using two and three-way analyses of variance. Factorial analysis was performed for data obtained from the benches 1 to 3. The yield means were compared, using the least significant difference (LSD) method at 0.05 and 0.01 probability level. For factorial treatments with equidistant rates the contrast method was used for knowing the nature of interactions (linear, quadratic). All calculations were performed with the SAS statistic program (SAS Institute, 1988).

3. RESULTS

Data from soil analysis showed that liming increased soil pH (**Table 5**). Crop harvest obtained from the 4th to 9th year is shown in **tables 6** to **9**. With data from bench 1 (**Table 6**) it appears that:

- fresh liming (year 4, year 5 and year 7), when supplemented with a seasonal NPK application and «residual lime-NPK» effect, (RFL2) significantly increase yields for all crops;

Table 5. pH changes in the 15 cm soil depth of the limed plots from year 1 to year 7, bench 3 — *Variation de pH dans 0-15 cm de profondeur de sol dans les parcelles chaulées depuis la 1re jusqu'à la 7^{e} année, bloc 3.*

Plots	Average pH in water
Control plots	4.7
Plots with 1 Mg lime·ha^{-1} (year 2, year 4 and year 7)*	4.8
Plots with 4.5 Mg lime·ha^{-1} (year 2, year 4 and year 7)*	5.1
Plots with 8 Mg lime·ha^{-1} (year 2, year 4 and year 7)*	5.2

* application dates: Sep 72, Sep 74 and Sep 77.

Table 6. Effect of « residual lime-NPK » rates* and that of 4 types of fresh fertilisers** on crop yields (tubers and roots in Mg·ha^{-1}, legume, cereal and sunflower grains in kg·ha^{-1}) in Mata 4×4 factorial experiment from year 3 to year 9, bench 1 — *Arrière-effet de doses de chaux-NPK et effet de 4 types de fertilisants sur le rendement des cultures (tubercules et racines en Mg·ha^{-1}, grains de légumineuses, céréales et de tournesol en kg·ha^{-1}) dans l'essai factoriel 4×4 depuis la 3^e jusqu'à la 9^e année, bloc 1.*

Types of fresh fertilisers	**Crops and cultural seasons**										
	Potato tubers (Mg·ha^{-1}) **Sep 1974**	**Peas grains** (kg·ha^{-1}) **Feb 75**	**Beans grains** (kg·ha^{-1}) **Sep 75**	**Potato tubers** (Mg·ha^{-1}) **Feb 76**	**Finger millet grains** (kg·ha^{-1}) **Sep 76**	**Soya grains** (kg·ha^{-1}) **Sep 77**	**Potato tubers** (Mg·ha^{-1}) **Feb 78**	**Rusenyas. potato roots** (Mg·ha^{-1}) **Sep 78#**	**Nsasagatebos. potato roots** (Mg·ha^{-1}) **Sep 78#**	**Sunflower grains** (kg·ha^{-1}) **Sep 79**	**Wheat grains** (kg·ha^{-1}) **Feb 80**
Fresh NPK + lime (RFL2)	8.5	280	148	5.2	2398	689	5.9	11.2	6.0	421	313
Fresh NPK fertiliser (RF)	8.4	178	120	4.3	2150	479	5.4	7.2	4.1	196	94
No fresh fertilisers (R)	5.7	173	25	2.4	712	217	2.3	4.7	4.4	90	27
Compost (RH)	6.4	210	83	3.4	1525	314	4.4	6.9	5.7	140	44
« Residual lime- NPK » and fresh NPF rates											
0 kg·ha^{-1} (R0F0)	4.1	129	22	3.0	1004	281	3.1	4.8	4.0	101	37
200 kg·ha^{-1} (R1F1)	5.9	175	37	3.7	1646	333	3.9	8.5	5.6	204	104
400 kg·ha^{-1} (R2F2)	9.4	305	93	4.3	2098	515	5.2	9.1	6.1	261	151
600 kg·ha^{-1} (R3F3)	10.4	233	223	4.3	2037	570	5.9	7.6	4.4	281	186
LSD 0.05	**2.3**	**102**	**65**	**1.2**	**498**	**127**	**1.2**				
LSD 0.01	**3.3**	**123**	**94**	**1.7**	**716**	**183**	**1.7**				
Absolute control (R0 + 0), the reference treatment for showing the native productivity of the Mata soil	3.0	112	6	2.9	408	193	2	1.7	1.5	48	5

See fertilizer rates and application calendar of fertilizer under Table 3a.
Each s. potato variety was planted on the half elementary plot, i.e. 8 m^2.

- crop production was significantly improved with fresh NPK added every season to the «residual lime-NPK» effect (RF). This would indicate that lime applied in year 1 and year 2 still had an efficient residual effect but such a long residual effect cannot be explained. NPK fertiliser impact for crop yield improvement was increasing as was NPK rates. However, from 400 kg (R2F2) to 600 kg of NPK ha^{-1} (R3F3) there was little or no yield increase for many crops;
- compared to the crop yield obtained with the «residual lime-NPK» effect alone (R), the compost (RH) produced crop yield increase, but little. Relatively acceptable yield increase was recorded only with potatoes and finger millet. The effect of compost on yield improvement was generally inferior to that of NPK (RH<RF);
- among crops finger millet showed the best response to the 2nd and 3rd residual effects of all fertilisers.

Data from bench 2 (**Table 7**) lead to similar observations as those in **table 6**:

- fresh liming (year 4, year 5 and year 7) was superior to the residual NPK effect and absolute control (R0+0) in improving crop yield (RL2>R=R0+0);
- NPK fertiliser applied alone had little residual effect (R) on crop yield improvement and this had been already reported by Neel (1974). Only the residual NPK at a rate of 600 kg ha^{-1} (R3) produced a slightly significant yield increase for some crops. Mata compost (RH) produced a slightly higher crop yield increase than the residual NPK effect (R) and absolute control;
- compost and fresh lime had beneficial direct and residual effects particularly on finger millet (1st and 3rd residual effect) production;
- two-ton lime and compost when applied in the same plot (RL2) generally showed an additional and beneficial effect on crop yield improvement.

With data from bench 3 (**Table 8**) the following comments are drawn:

- one-ton lime applied alone three times (year 2, year 4, year 7) had very low and no significant direct and residual effects on crop yield increase (F0L1 versus F0L0);
- NK fertiliser without P is not efficient (F0L1 versus F2L1): P is highly needed to improve crop yield (F0L1=F2L1<F3L1);

Table 7. Effect of the residual NPK rates* and that of 4 types of fresh fertilisers** on crop yields (tubers and roots in Mg·ha^{-1}, cereal, legume and sunflower grains in kg·ha^{-1}) in Mata (Rwanda) 4×4 factorial experiment from year 3 to year 9, bench 2 — *Arrière-effet de doses de NPK et effet de 4 types de fertilisants sur le rendement des cultures (tubercules et racines en Mg·ha^{-1}, grains de légumineuses, céréales et de tournesol en kg·ha^{-1}) dans l'essai factoriel 4×4 depuis la 3^{e} jusqu'à la 9^{e} année, bloc 2.*

Types of fresh fertilisers	**Crops and cultural seasons**										
	Annett potato tubers (Mg·ha^{-1}) **Sep 74**	**Kyondo peas grains** (kg·ha^{-1}) **Feb 75**	**Bataaf beans grains** (kg·ha^{-1}) **Sep 75**	**Condea potato tubers** (Mg·ha^{-1}) **Feb 76**	**Coracana finger-millet grains** (kg·ha^{-1}) **Sep 76**	**Palmetto soya grains** (kg·ha^{-1}) **Sep 77**	**Utila potato tubers** (Mg·ha^{-1}) **Feb 78**	**Rusenya s. potato roots** (Mg·ha^{-1}) **Sep 78 #**	**Nsasagatebo s. potato roots** (Mg·ha^{-1}) **Sep 78 #**	**Ofryfelle sunflower grains** (kg·ha^{-1}) **Sep 79**	**Norteno wheat grains** (kg·ha^{-1}) **Feb 80**
No fresh ferilisers (R)	2.1	1	0	0.9	469	16	0.4	0.7	1.2	22	23
Lime (RL2)	3.3	146	61	2.3	1531	206	3.7	6.3	6.7	345	194
Compost (RH)	2.3	10	54	2.5	1910	149	3.8	4.1	3.4	26	2
Lime + compost (RL2H)	2.9	220	190	3.3	2672	327	5.9	10.8	6.9	456	333
Residual NPK rates											
0 kg·ha^{-1} (R0)	2.1	93	69	2.0	1487	166	2.4	4.4	4.7	188	111
200 kg·ha^{-1} (R1)	2.4	77	91	2.2	1677	164	3.5	5.7	4.3	198	170
400 kg·ha^{-1} (R2)	2.5	87	62	2.1	1517	158	3.7	5.2	5.3	202	126
600 kg·ha^{-1} (R3)	3.5	119	83	2.6	1901	211	4.2	6.5	4.0	255	146
LSD 0.05	**0.6**	**63**	**42**	**0.5**	**424**	**56**	**0.8**				
LSD 0.01	**0.9**	**91**	**60**	**0.8**	**610**	**81**	**1.1**				
Absolute control (R0 + 0), the reference treatment for showing the native productivity of the Mata soil	1.9	0	0	0.5	500	6	0.2	0.6	1.2	19	0

See fertilizer rates and application calendar of fertilizer under Table 3b.
Each s. potato variety was planted on the half elementary plot, i.e. 8 m^{2}.

- used with direct and residual lime effects, the direct or residual effect of P2 and that of NP2 on crop yield increase were statistically equivalent but less efficient than that of NKP2 (F6L8=F7L8<F3L8). Crop yield obtained with KP2 was approaching that with NKP2 (F3Lb and F5Lb);
- direct and residual effects of CaO rates are observed with all crops but such an effect was higher with beans and wheat before year 4 (Neel, 1974). For more than a half of crops there is no yield increase due to lime rate higher than 4.5 Mg ha^{-1};
- Lime+NPK has significant direct and residual effects on crop yield improvement. However, there was P rate effect only with some crops (beans and condea potato) and high effect had been observed with peas and wheat in the beginning, from year 1 to year 4 (op. cit.).

Neel (1974) had reported that there was no effect of mineral NPK fertilisers applied alone (without prior liming) and no effect of P associated with 35 Mg of fresh FYM ha^{-1}. In addition data from bench 4 (**Table 9**) indicate that in Mata experiment, even with liming every season, there was no interest in increasing N, P and K to more than 60 kg N, 33 kg P and 42 kg K ha^{-1} with the used crop varieties. Another observation is that four seasonal continuous applications of 35 Mg of fresh FYM ha^{-1} had a beneficial residual effect on P availability and crop yield improvement for two years.

In summary, without fertiliser application, most food crops gave very low or no harvest at all on Mata Alisols. Stunted crop roots and shoots or low rate of germination of irish potato from the soil were commonly observed. Liming supplemented with NPK and/or compost had the best effect on crop yield when compared to the treatments with lime alone or NPK or compost applied alone. Mata compost had low effect in improving crop production. Farmyard manure at high rate (35 Mg·ha^{-1}, fresh weight) showed direct and residual effects on crop production improvement. In general crop yields remained low to medium with the best fertiliser treatments except for finger millet. Diseases and attacks from pests were also observed on some crop varieties.

4. DISCUSSION

Soils in Mata had low pH, high level of exchangeable Al (>60% Al saturation) and of organic C and N, and

Table 8. Average yield of species (tubers and roots in $Mg \cdot ha^{-1}$, cereal, legume and sunflower grains in $kg \cdot ha^{-1}$) used in Mata (Rwanda) fertilisation experiment with lime[1], NPK[1] and their R.E.[2] from year 3 to year 9 (selected treatments), bench 3 — *Rendement moyen de cultures (tubercules et racines en* $Mg \cdot ha^{-1}$*, grains de légumineuses, céréales et de tournesol en* $kg \cdot ha^{-1}$*) utilisées dans l'essai de fertilisation depuis la 3e jusqu'à la 9e année (traitement choisi), bloc 3.*

Treatments (amount ha^{-1})	Crops and cultural seasons									
	Bambu maize grains ($kg \cdot ha^{-1}$) **Sep 74 + Feb 75**	**Bataaf beans grains** ($kg \cdot ha^{-1}$) **Sep 75**	**Condea potato tubers** ($Mg \cdot ha^{-1}$) **Feb 76**	**Coracana finger-millet grains** ($kg \cdot ha^{-1}$) **Sep 76**	**Palmetto soya grains** ($kg \cdot ha^{-1}$) **Sep 77**	**Utila potato tubers** ($Mg \cdot ha^{-1}$) **Feb 78**	**Rusenya s. potato roots** ($Mg \cdot ha^{-1}$) **Sep 78[4]**	**Nsasagatebo s. potato roots** ($Mg \cdot ha^{-1}$) **Sep 78[4]**	**Ofryfelle sunflower grains** ($kg \cdot ha^{-1}$) **Sep 79**	**Norteno wheat grains** ($kg \cdot ha^{-1}$) **Feb 80**
F0L0: Control	0	2	1.1	267	15	0.4	0.7	0.7	40	8
F0L1: 1 Mg lime	100	5	1.4	450	48	1.3	1.4	2.8	48	21
F1L1: NK + 1 Mg lime	311	13	1.0	267	65	1.8	3.5	3.3	79	28
F3L1: NKP2 + 1 Mg lime	1611	190	4.8	2133	470	5.5	12.3	8.4	365	308
F5Lb: Kp2 + 4.5 Mg lime	1155	133	4.8	1767	280	4.3	11.3	11.9	540	516
F3Lb: NKP¨2 + 4.5 Mg lime	1733	339	6.4	2350	447	6.0	12.7	9.9	444	416
F4Lb: NKP3 + 4.5 Mg lime	1844	433	7.2	2117	394	5.9	11.5	12.6	444	367
F3L3: NKP2 + 8 Mg lime	1633	392	6.6	2233	576	6.5	15.3	16.1	444	377
F6L8: NP2 + 8 Mg lime	888	191	5.3	1867	257	3.0	1.7	3.8	127	108
F7L8: P2 + 8 Mg lime	888	31	3.2	1717	159	2.8	3.0	2.2	159	128
LSD 0.05	**743**	**148**	**1.2**	**620**	**184**	**1.4**	**3.8**	**4.9**	**132**	**195**
LSD 0.01	**1003**	**199**	**1.6**	**1028**	**248**	**1.9**	**5.1**	**6.5**	**178**	**263**
P rate effect (P1, P2, P3)	**p = 0.1**	**NS[3]**	**p = 0.05**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CaO rate effect (1.0, 4.5 and 8 Mg $lime \cdot ha^{-1}$)	**NS**	**NS**	**p = 0.05**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

(1) Lime was applied in Sep 72, Sep 74 and Sep 77. NPK fertilizers were applied as follows.
Sep 1975: 60 N and 49 K; P1 = 44, P2 = 88 and P3 = 132.
Feb 1976: 90 N and 74 K; P1 = 11, P2 = 22 and P3 = 44.
Sep 1977: 90 N and 74 K; P1 = 11, P2 = 22 and P3 = 44.
Feb 1978: 90 N and 74 K; P1 = 11, P2 = 22 and P3 = 44.
Sep 1978: 50 N and 41 K; P1 = 8.5, P2 = 17 and P3 = 25.
(2) RE is residual effect of lime and of 100 kg N and 189 kg K applied in Sep 72. 30 kg N, 88 kg P and 42 kg K applied in Sep 73 and 60 kg N. 88 kg P and 42 kg $K \cdot ha^{-1}$ applied in Feb 74. From Sep 72 to Feb 73, F7L8 received lime alone. From Sep 72 to Sep 73, F6L8 was receiving only N and K.
(3) NS means not significant.
(4) each s. potato variety was planted on the half elementary plot, i.e. 8 m^2.

very low available P and echangeable K (**Table 2**). They are classified as Alisols in the World Reference Base (Driessen *et al.*, 2002). High Al saturation leads to high soil P fixation (van der Eijk, 1997) and is toxic to many annual plant species (Adams, Hathcock, 1984; Marschner, 1986). Crops indeed require a minimum level of nutrients to develop and give yield (Fageria, 1992) and such a level of nutrients was not attained in the Mata control plots. Low or no crop harvest obtained in the unfertilised Alisols is well known especially for the less acid-tolerant food crops (Lal, Stewart, 1995, Splett *et al.*, 1992) and fodder species (Compère *et al.*, 1994).

In Mata soils the pH increase recorded in the 15 cm depth of the plots limed three times in 4 years (**Table 5**) was not high. Soil pH is the result of a large number of soil properties and processes and these do not change immediately upon liming. This is in accordance with Benites and Valverde (1982) who reported that the lime quantity determined by Al-neutralisation method is less than that needed to raise the soil pH at 6.5. The pH in Mata soils was not a permanent value (data not shown). It was higher some few days after liming, especially in plot limed with 8 $Mg \cdot ha^{-1}$, and then progressively decreased with time as Ca was used by plants, mixed with soil of deep layer through tillage and/

Table 9. Average yield of species (tubers and roots in Mg·ha^{-1}, cereal and legume grains in kg·ha^{-1}) used in Mata (Rwanda) fertilisation trial with lime, NPK fertilizers and farmyard manure (FYM) from year 3 to year 9, bench 4 — *Rendement moyen de cultures (tubercules en Mg·ha^{-1}, grains de céréales et de légumineuse en kg·ha^{-1}) utilisées dans l'essai de fertilisation à base de chaux, NPK et de fumier depuis la 3^{e} jusqu'à la 9^{e} année, bloc 4.*

Treatments*	**Crops and cultural seasons**				
	Romany wheat grains (kg·ha^{-1}) **Feb 74**	**Bambu + maize grains** (kg·ha^{-1}) **Sep 74 + Feb 75**	**Bataaf haricot grains** (kg·ha^{-1}) **Seb 75**	**Condea potato tubers** (Mg·ha^{-1}) **Feb 76**	**Palmetto soya grains** (kg·ha^{-1}) **Sep 76**
Lime and NPK fertilisers					
T1: Control	22	0	25	1.0	88
T2: Lime + (NPK)2*	250	2560	1015	6.0	765
T3: Lime + (NPK)3*	267	2842	1108	7.7	828
T4: Lime + (NPK)4*	233	3275	908	7.0	612
T5: Lime + (NPK)5*	256	3516	1021	7.8	860
LSD 0.05	**137**	**1275**	**139**	**1.4**	**228**
LSD 0.01	**189**	**1787**	**191**	**1.9**	**314**
Farm yard manure and Phosphorus	**Anett potato tubers** (Mg·ha^{-1}) **Sep 74**	**Kyondo peas grains** (kg·ha^{-1}) **feb 75**	**bataaf beans grains** (kg·ha^{-1}) **Sep 75**	**Condea potato tubers** (Mg·ha^{-1}) **Feb 76**	
T1: Control	1.7	43	0	0.5	
T2: R.E.** of 35 Mg Mg FYM	10.4	518	94	6.2	
T3: 44 kg P + R.E. of 35 Mg FYM	9.2	465	121	4.8	
T4: 88 kg P + R.E. of 35 Mg FYM	11.1	565	118	5.1	
LSD 0.05	**3.6**	**263**	**50**	**1.8**	
LSD 0.01	**5.5**	**399**	**83**	**2.7**	

* Amount of lime applied every season and amount (kg) of N, K, P, elements ha^{-1} used in various seasons as shown in Table 3d, under «treatments in the lime experiment».

** Residual effect of 4 applications of 35 Mg FYM and of 4 applications of phosphorus in Sep 72, Feb 73, Sep 73 and Feb 74. P was again applied in Sep 74, Feb 75 and Feb 76. Fifty kg N·ha^{-1} from urea were applied in treatments T2, T3 and T4 in Feb 75.

or lost through leaching and erosion. High rainfall and cool temperature at Mata (**Table 1**) and slope of 5% are conditions that favour leaching and erosion rather than evapo-transpiration. The current pH value only indicates the level of the Ca influence remaining after the 2nd season following liming and will continue decreasing with time if no other lime is applied to the soil. This was quite different in warmer area of Rubona where 2 Mg of lime ha^{-1} applied every two years led to over-liming after eight-year period (Rutunga *et al*., 1998).

Al toxicities and soil P-fixing capacity are alleviated or reduced through liming that neutralises exchangeable Al (Fageria *et al*., 1990), increases P availability from fixed-P fraction and provide Ca (280 kg/ton) and some Mg (24 kg/ton in this study) to crops (Smith, Sanchez, 1980). This was confirmed in Mata experiment where significant crop yield performance was recorded in treatments «lime + NPK». Lime alone had low effect on crop production, showing that either low amount of available P is released from soil fixed-P fraction or enough P is available but cannot have effect because of K deficiency naturally present in the soil (**Table 2**) or induced by excess of Ca provided by lime. Large amount of lime can lead to high Ca concentration in soil and this may increase P fixation capacity of the soil through adsorption and precipitation processes (Salingar, Kochva, 1994; Olsen, Watanabe, 1957) and may also induce K imbalance. This may probably be the case for the treatments with 8 Mg of lime ha^{-1} where for most crops no yield increase was observed in comparison to the yield with 4.5 Mg lime ha^{-1} (**Table 8**). If a crop tolerates the Al saturation level of 10% and its rooting depth is either 0-15 or 0-30 cm, theoretic calculation for neutralising 40 mmol (+) Al kg^{-1} of soil with 1 Mg m^{-3} bulk density and within 1ha gives 4.0 and 8.0 Mg of the Mata-used lime. This result of calculation indicates that the inefficiency of 8 Mg of lime ha^{-1} tested in this study might also be due to its application in 0-15 cm-soil depth (see material and methods). Such shallow lime incorporation was done because it was not possible to well mix lime in 0-30 cm depth with a hoe.

Adding mineral NPK fertiliser alone to Mata soils was not useful for crop production. When P water soluble fertilisers are applied to acid soils, P reacts with Al and Fe compounds (Sample *et al.*, 1980). Sanchez and Uehara (1980) identified application of large amount of P or small amount of P placed near the root zone as means of managing P-fixing soils. A portion of added P is fixed by soils and neutralise exchangeable Al and its toxicities while the remaining P is available to plants. This was not the case in the current experiment since P fertiliser was broadcast and its rate was not very high. Either all added P was just used to alleviate exchangeable Al and toxicities and nothing else to spare or it was totally fixed by the soil but insufficient to eliminate all Al stresses. The former hypothesis leads to low or no availability of P as a limiting-growth factor and according to Janssen *et al.* (1990) such lack of P set the limit to the uptake of the non-limiting nutrients. In the latter assumption the crops can take up no P and nutrients since P is unavailable and plants cannot develop sufficient roots in the presence of Al toxicity. The P fixation and/or Al toxicity constraints joined with the probably losses by erosion and leaching also explain why application of NPK alone had little residual effect on crop yields.

After liming, when required nutrients (NPK) were added, crop yields were significantly improved (**Table 6**, **8** and **9**). The optimum mineral fertiliser rate was somewhere around 60 kg N, 35 kg P and 32 kg K ha^{-1} (significant quadratic component). However at this optimum rate yield for most crops was still low to medium. This may be related to low potential of crop varieties influenced by unfavourable climatic conditions and inappropriate plant health status.

High organic C and N in soils, as the case of Mata, may be due to the poor status of other nutrients in the soil and strong organic matter complexation with Al and Fe oxides, preventing sufficient microbiological degradation as suggested by Hiemstra (Tjisse Hiemstra, personal communication, Wageningen University, 05 Jan. 2005). This changed after liming and addition of K and P, and thus some N from soil was provided to crop, for instance some production was obtained with F5Lb, **table 8**.

For fresh biomass, Chikowo et al. (2004) stressed that application of poor quality manure or compost is not enough in itself to overcome nutrient deficiencies in very depleted soils and for making high yield. The crop production was effectively fairly improved when the low quality compost of Mata was applied, even into the limed plots. Liming generally does increase the biomass decomposition rate in the soil (Ducheaufour, 1977), but for sufficient mineralisation rate enough P level in the applied biomass (Blair, Boland, 1978) or in soil (Kabba, Aulakh, 2004) is needed. Thus in presence of lime and low P availability Mata compost either quickly or slowly decomposed but the final result was probably few nutrients released.

Four consecutive seasonal application of farm-yard manure (35 $Mg \cdot ha^{-1}$ $season^{-1}$, fresh weight) significantly increased crop yield (Neel, 1974) and had even a lasting beneficial residual effect (**Table 9**). Same observation was done on non-humiferous Alic Ferralsols at Butare (Rutunga *et al.*, 1998). Large amount of FYM can provide enough various nutrients (Janssen, 2000; Van der Eijk, 1997) and may temporary reduce acidity constraints in the soil (Hue *et al.*, 1986). Organic manure, only when containing more than 3 g of P kg^{-1}, facilitates P availability by blocking P sorption sites of soils (McDowell, Sharpley, 2004). Mata experiment showed that regular application of 35 Mg of good quality FYM ha^{-1} did require no P supplement and no liming for ensuring acceptable to high yield. The problem is that such an amount is too large to be available on Rwanda farms.

Due to all various difficulties (incorporating lime in 30 cm soil depth, FYM unavailability, uncertain or low crop response to mineral NPK fertilisers, nutrient imbalance, etc.) in Rwanda agricultural context, the beneficial use of both organic and inorganic fertilisers together as already reported through the literature (Lal, Stewart, 1995) was confirmed. Low amount of fresh FYM such as 10 Mg combined with 2.0 Mg of lime every two years and seasonal application of 50-21-41 kg of N, P and K elements ha^{-1} was a rate and formula proposed for improving crop production on acid soils of Mata area.

Finally, before making the large investment highly needed for nutrient depleted soils other agricultural techniques such as use of appropriate varieties, minimising losses from pests and diseases and appropriate water management should be optimised (van Reuler, Prins, 1993). Most of crop varieties used in Mata experiment were traditional and had low response to fertilisers (ISAR, 1976); some were even not adapted to the Mata zone (i.e. bataaf bean was a variety screened for warm and dry land). Most of times the performance of Annett and condea potatoes, romany wheat and kyondo peas was also reduced by severe attack of fungus, bacterial and viral diseases. Rusenya s. potato showed better and more stable response to fertiliser than did nsasagatebo in the Mata growth conditions but the yield was still low because many ISAR crop cultivars were developed in areas with fertile soils, therefore under low or zero selection pressure for nutrient use efficiency and toxicity tolerance. Coracana finger millet is the one of the few crops that performed well in Mata fertilised plots. There are two reasons for this: a) finger millet responds to low fertiliser application such as 20-90 kg N, 4-43 kg P and 6-83 kg $K \cdot ha^{-1}$ (de Geus, 1973); b) the crop is well adapted to Mata climatic conditions where it is traditionally cropped with soil-sod chunk turning over and burning method (Rachie, Peters, 1977) in order to provide through the ashes, the minimum nutrients needed for a small harvest on infertile soils. Ash has direct effects as NPK fertiliser and as liming material (van Reuler, 1996).

5. CONCLUSION

Crop development and high yield depend on soil properties, climatic conditions, plant potential, disease and pest control and optimal crop management. If one of these factors is limiting, nutrient use efficiency reduced and crop yield declined. Application of fertilisers is a mean for correcting soil nutrient deficiencies and toxicities. Mata experiment confirmed that and this for Alisols: lime is essential but must be combined with N, P and K nutrients to be provided by organic manure or/and inorganic fertilisers in order to get adequate crop production. In Mata conditions, effect of two-ton lime ha^{-1} remained significant up to three-four seasons, that of "35 Mg fresh FYM ha^{-1} times four consecutive seasons" four seasons and that of mineral NPK fertiliser one season. Although Mata cropping had other limiting factors than soil properties, results over nine years were enough consistent for proposing 2 Mg of lime and 10 Mg of FYM every two years combined to a seasonal application of 50 N-21 P-41 K kg ha^{-1} as a start in improving crop yield on high altitude Alisols. Before April 1994 such a fertiliser combination was significantly increasing crop yields in many on-farm experiments carried out by agricultural projects (Ndindabahizi, Ngwabije, 1991). However, for Rwanda to succeed a high and sustainable improvement of food production, it remains essential that selection of crops to fit soil conditions, appropriate crop management and parasite control, and amending soils to fit crops be combined, but not opposed.

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