Expl Agric. (1997), volume 33, pp. 91–102
Printed in Great Britain

RESPONSES OF IRISH POTATOES (*SOLANUM TUBEROSUM* L.) TO MINERAL AND ORGANIC FERTILIZER IN VARIOUS AGRO-ECOLOGICAL ENVIRONMENTS IN KENYA

By H. RECKE, H. F. SCHNIER, S. NABWILE *and* J. N. QURESHI

Fertilizer Use Recommendation Project, National Agricultural Research Laboratories, Kenya Agricultural Research Institute, PO Box 14733, Nairobi, Kenya

(Accepted 24 July 1996)

SUMMARY

The response of potatoes (*Solanum tuberosum* L.) to application of inorganic and organic fertilizer was studied in long-term field experiments between 1987 and 1994. Responses to phosphorus and nitrogen were tested at 27 sites and to potassium at 17 sites. The sites represented various agro-ecological zones in Kenya. Phosphate (triple superphosphate, TSP) and nitrogen (calcium ammonium nitrate, CAN) fertilizer were applied at 0, 25, 50 or 75 kg P_2O_5 ha^{-1} and 0, 25, 50 or 75 kg N ha^{-1}. Potassium (muriate of potash) was tested mainly on sites with low levels of K in the soil at rates of 0 or 50 kg K_2O ha^{-1}. Farmyard manure was applied at 0 or 5 t ha^{-1} with or without N and/or P_2O_5 fertilizer.

Over the study period average yields varied considerably between sites and agro-ecological zones. At 16 of the 27 sites, potatoes responded strongly to the application of P_2O_5 and at 9 sites to N application. A significant response to K_2O application was found at three out of the 17 sites. Nutrient use efficiency ranged from 13 to 214 kg tubers per kg P_2O_5 and from 20 to 113 kg tubers per kg N applied. In the majority of the sites, both N and P response followed a linear function which suggests that application rates higher than 75 kg N ha^{-1} and/or 75 kg P_2O_5 ha^{-1} could be beneficial. Economic analysis revealed that in most cases fertilizer application was highly profitable for potatoes.

The critical soil P value was about 15 ppm (mod. Olsen) for optimal potato nutrition; on soils with higher P levels generally no P response was found. The respective critical soil K value was found to be about 0.55 meq 100 g^{-1} (modified Olsen). Farmyard manure at 5 t ha^{-1} significantly increased yields of potatoes at 9 of the 27 sites. On soils with P levels below 12 ppm, there was a positive effect on potato yields with a combination of 50 kg P_2O_5 ha^{-1} and farmyard manure, although significant differences were achieved in only one out of the 19 sites.

INTRODUCTION

Potato (*Solanum tuberosum* L.) is an important food crop in Kenya in medium and high rainfall areas. Production is concentrated in the highlands above 2000 m above sea level, along both escarpments of the Rift Valley north and west of Nairobi, and on the north-eastern slopes of Mount Kenya. Potatoes are also grown on a smaller scale in the Taita Hills, on the slopes of Mount Elgon and in other areas down to elevations of about 1400 m (Crissman *et al.*, 1993; Dürr and

Lorenzl, 1980). Relatively high yields in a short growing season – which allows double cropping of the same land in a single year – and a growing market in urban centres make potato an attractive crop for small-scale farmers. As a nutritious food, potato is an important element in rural diets in the areas where it is produced, and a widely consumed 'fast food' in Nairobi and other cities (Woolfe, 1987; Woolfe, 1991).

The major biotic constraints in Kenya are the diseases late blight (*Phytophthora infestans*), bacterial wilt (*Pseudomonas solanacearum*) and several viruses. Research has concentrated on the development of tolerant, high-yielding varieties with good culinary qualities, and on the development of systems for the multiplication and distribution of seed (Kabira, 1994). Relatively little work has been carried out on the nutritional requirements of potatoes under the different soil and climatic conditions where the crop is grown in Kenya (Nabwile, 1995). Until 1994, there was only one fertilizer recommendation for potatoes in Kenya (90 kg N + 230 kg P_2O_5 ha^{-1}, Agricultural Information Centre, 1981), and this was regarded as rather high. The Fertilizer Use Recommendation Project (FURP) started a series of mostly on-farm long-term fertilizer trials in 1986/87 on about 70 sites all over Kenya. On 27 sites, potatoes were included in the range of crops grown.

This paper summarizes the results obtained for potatoes on the 27 sites and gives an outlook for further research work in this field.

MATERIALS AND METHODS

Field experiments were conducted at 27 sites representative of the major potato growing areas of Kenya. Table 1 gives an overview of the location of the sites, their elevation, agro-ecological zone and the soil types. The chemical characteristics of the soils at the experimental sites are shown in Table 2. At each site, potatoes were grown for one to four years. At all except one site, potatoes were grown in only one season, the 'long rains' (usually in March/April) in each year.

At each site, two experiments were carried out concurrently. In the first experiment, the response of potatoes to mineral nitrogen and phosphate was tested in a two-factorial complete randomized block design with two replications. Phosphate as triple superphosphate (TSP) was applied at 0, 25, 50 or 75 kg P_2O_5 ha^{-1} at planting. Nitrogen as calcium ammonium nitrate (CAN) at 0, 25, 50 or 75 kg N ha^{-1} was applied about six weeks later when the potatoes were between the budding and flowering stages. At this point, the development stage of the potatoes did not vary much with altitude, but depended more on the time of planting and the 'quality' of the rains thereafter.

In the second experiment, yields of potatoes were determined with applications of locally available farmyard manure either alone or with 50 kg N ha^{-1} or 50 kg P_2O_5 ha^{-1} (Table 3). At eight sites (Table 4), a combination of N and P_2O_5 fertilizer each at 50 kg ha^{-1} was applied with farmyard manure. Small-scale farmers in Kenya usually do not have enough farmyard manure to satisfy

Table 1. *Agro-ecological characteristics of the experimental sites*

Site number	Site	District	Elevation (m)	AEZ†	Soil classification
1	Tongaren	Bungoma	1725	UM4	Ferralo-chromic Acrisol
2	Chebunyo	Kericho	1840	UM4	Verto-eutric Planosol
3	Turbo	Uasin Gishu	1850	UM4	Ferralo-chromic Acrisol
4	Weruga	Taita	1690	UM3	Chromic Acrisol
5	Kamakoiwa	Bungoma	1710	UM2	Rhodic Ferralsol
6	Kaguru	Meru	1460	UM2	Humic Nitisol
7	Kerugoya	Kirinyaga	1480	UM2	Humic Nitisol
8	Kand. Kareti	Muranga	1640	UM2	Humic Nitisol
9	Chepkumia	Nandi	1750	UM1	Humic Acrisol
10	Sosiot	Kericho	1890	UM1	Humic Nitisol
11	Kavutiri	Embu	1700	UM1	Ando-humic Nitisol
12	Otamba	Kisii	1790	UM1	Mollic Nitisol
13	Githunguri	Kiambu	1930	UM1	Humic Nitisol
14	Vih.-Maragoli	Vihiga	1620	UM1	Nito-humic Ferralsol
15	Upepo	Laikipia	2180	LH4	Chromic Luvisol
16	Moi TTC	Uasin Gishu	2140	LH3	Ferralic Cambisol
17	Ol Ngarua	Laikipia	1970	LH3	Nito-ferric Luvisol
18	Rotian	Narok	2180	LH3	Ando-luvic Phaeozem
19	Eld. Ravine	Baringo	2100	LH3	Nito-ferric Luvisol
20	Baraton	Nandi	2000	LH2	Humic Nitisol
21	Kapenguria	West Pokot	2140	LH2	Humic Cambisol
22	Bugar	Elgeyo Marakwet	2320	LH2	Humic Nitisol
23	Kiamokama	Kisii	2020	LH1	Dystro-mollic Nitisol
24	Ol Joro Orok	Nyandarua	2360	UH3	Ando-luvic Phaeozem
25	Mau Summit	Nakuru	2530	UH2	Mollic Andosol
26	Tulaga	Nyandarua	2530	UH2	Eutric Planosol
27	Njabini	Nyandarua	2530	UH2	Ando-luvic Phaeozem

†AEZ = Agro-ecological zone; UH = Upper Highlands; LH = Lower Highlands, UM = Upper Midlands; 1 = humid; 2 = sub-humid; 3 = semi-humid; 4 = transitional.

the needs of all their crops and so they apply small amounts. Farmyard manure was applied according to farmers' habits at 0 or 5 t ha^{-1} before planting and was mixed thoroughly with the soil. The chemical composition of the farmyard manure was not tested before application due to the lack of laboratory equipment at that time; measurements of farmers' manure in the respective study areas at a later date showed that the average quality was not very high. N and P_2O_5 at 0 or 50 kg ha^{-1} were given at the same time as in the first experiment. At sites with low soil potassium, muriate of potash was applied at planting at 0 or 50 kg K_2O ha^{-1}.

The most suitable potato varieties for the specific sites, Anet, Kenya Baraka and B53, were planted at the onset of the rains. In both experiments the plot size was 6 × 6 m and potatoes were spaced at 75 × 30 cm giving a population density of 44 000 plants ha^{-1}. The harvest area was 25 m^2 and the crop was grown in rotation with cabbages to prevent a build-up of pests and diseases which were

https://doi.org/10.1017/S0014479797000203 Published online by Cambridge University Press

Table 2. *Chemical characteristics of the soils at the experimental sites*

Site number	Site	pH (H_2O)	Organic carbon (%)	P (ppm mod. Olsen)	K (meq 100 g^{-1})	Ca (meq 100 g^{-1})	Mg (meq 100 g^{-1})
1	Tongaren	4.8	1.1	7.2	0.4	1.5	1.0
2	Chebunyo	7.1	2.5	12.4	1.6	31.9	1.6
3	Turbo	5.4	1.3	14.5	0.6	1.2	1.5
4	Weruga	6.0	1.7	12.1	0.4	2.2	1.1
5	Kamakoiwa	4.8	1.3	8.8	0.2	2.3	0.7
6	Kaguru	5.6	1.2	36.7	1.0	4.9	1.5
7	Kerugoya	5.6	1.5	64.5	0.1	6.7	4.3
8	Kand. Kareti	5.8	2.2	13.2	0.3	10.7	3.1
9	Chepkumia	5.7	3.6	12.8	0.7	7.8	1.1
10	Sosiot	5.6	3.4	3.7	0.1	8.5	2.2
11	Kavutiri	4.1	2.9	10.2	0.2	traces	0.1
12	Otamba	5.8	2.6	2.3	1.1	16.8	2.4
13	Githunguri	5.7	2.0	2.8	1.3	4.4	2.9
14	Vih.-Maragoli	5.4	2.0	9.5	0.2	8.1	1.9
15	Upepo	6.2	2.2	9.3	1.6	13.6	3.0
16	Moi TTC	5.3	1.4	14.8	1.1	1.5	2.6
17	Ol Ngarua	6.2	2.1	32.3	2.1	6.5	3.9
18	Rotian	6.0	2.6	18.0	2.3	2.3	1.2
19	Eld. Ravine	6.0	1.5	11.9	1.1	5.9	3.2
20	Baraton	5.3	3.3	10.8	0.3	16.1	2.9
21	Kapenguria	5.9	2.7	22.1	1.5	20.3	2.7
22	Bugar	5.5	2.0	11.0	0.8	6.9	2.8
23	Kiamokama	5.2	1.8	2.9	0.5	5.1	1.5
24	Ol Joro Orok	6.1	2.6	64.5	2.3	20.2	3.7
25	Mau Summit	5.0	2.1	4.2	1.1	4.2	1.4
26	Tulaga	5.3	2.1	23.9	0.2	7.1	1.2
27	Njabini	5.6	3.1	54.6	1.1	22.8	1.9

controlled regularly using recommended procedures. Late blight was observed at Charagita in one season and frost damage occurred in one season at Njabini in the Nyandarua District. The Charagita site suffered from frequent waterlogging, so results are not presented in this paper. Since certified seed was used, no damage due to bacterial wilt was observed at any of the sites.

Soil samples were analysed using two methods: Mehlich I (Mehlich, 1953) and a modified Olsen method (Hunter, 1974), the composition of which is 0.5 N $NaHCO_3$ + 0.01 M EDTA at pH 8.5. Mehlich I is the commonly used method for soil analysis in Kenya but the modified Olsen method gave better results for plant available P in the soil.

For all seasons and all sites, fertilizer response curves were calculated by means of stepwise regression analysis. In this paper, average response functions over all years are presented. The economic optimum for mineral fertilizer was determined with an input:output price ratio of 13:1 for both N and P_2O_5, and a value:cost ratio (VCR) of 2:1.

Table 3. *Effect of farmyard manure (FYM) with or without nitrogen or phosphate fertilizer on the tuber yields of potatoes (t ha^{-1})*

Site number	Site	Treatment†			
		Control	FYM	FYM + N	FYM + P_2O_5
2	Chebunyo	14.6 a‡	15.7 a	17.3 a	15.1 a
4	Weruga	7.6 a	11.2 a	13.9 a	11.8 a
8	Kand. Kareti	9.3 a	9.2 a	9.6 a	9.5 a
9	Chepkumia	5.5 a	5.0 a	5.8 a	4.8 a
10	Sosiot	10.2 a	13.0 b	13.6 b	13.5 b
12	Otamba	13.5 a	20.1 b	20.6 b	21.2 b
13	Githunguri	7.7 a	8.2 a	8.0 a	8.1 a
14	Vih.-Maragoli	15.9 a	19.0 b	20.3 b	21.5 b
15	Upepo	10.1 a	12.6 b	12.1 b	13.4 b
17	Ol Ngarua	11.6 a	11.2 a	11.4 a	10.4 a
18	Rotian	9.6 a	9.0 a	8.8 a	8.7 a
19	Eld. Ravine	4.5 a	5.3 a	5.9 a	4.8 a
20	Baraton	10.7 a	12.3 a	13.8 b	12.0 a
21	Kapenguria	20.6 a	23.2 b	24.2 b	22.6 b
22	Bugar	10.5 a	13.1 b	11.3 b	13.5 b
23	Kiamokama	15.5 a	23.9 b	25.1 bc	25.8 c
24	Ol Joro Orok	14.9 a	15.0 a	15.3 a	14.7 a
25	Mau Summit	6.8 a	7.3 a	7.7 a	8.7 b
27	Njabini	24.4 a	20.7 a	22.2 a	23.1 a
	Mean	11.8	13.4	14.0	13.9

†Control, untreated; FYM (5 t ha^{-1}); FYM + N (50 kg N ha^{-1}); FYM + P_2O_5 (50 kg P_2O_5 ha^{-1}).
‡a,b,c: different letters indicate significant differences between treatments ($p < 0.05$), to be read horizontally.

RESULTS AND DISCUSSION

The intercept of the response functions determined, which can be called the yield potential of a specific site (Table 5), represents the average yield level obtained without N or P_2O_5 application over all experimental years. Yield potentials varied considerably between the different sites. Although only 1.8 t tubers ha^{-1} were harvested on the acid soils of the tea zone on the slopes of Mount Kenya (Table 5, site 11), yield in the Upper Highlands of Nyandarua District reached over 27 t ha^{-1} (Table 5, site 24). The average yield level generally increased with altitude. In the Upper Midlands the mean yields of 14 sites ranged between 1.8 and 18 t ha^{-1} with an average of about 10 t ha^{-1} without the influence of N or P_2O_5 application (Table 5, sites 1–14). In the Lower and Upper Highlands average yield potentials of almost 12 t ha^{-1} were found without fertilizer application although the variation between the individual sites was considerable (between 5 and 27 t ha^{-1}, Table 5, sites 15–27).

Application of mineral fertilizer raised potato yields from about 11 to over 15 t tubers ha^{-1} on average, but the response to N and P_2O_5 applications varied

https://doi.org/10.1017/S0014479797000203 Published online by Cambridge University Press

Table 4. *Effect of farmyard manure (FYM) with or without nitrogen and phosphate fertilizer on the tuber yields of potatoes*

		Treatment†		
Site number	Site	Control	FYM	FYM + NP
1	Tongaren	10.8 a‡	13.2 b	13.4 b
3	Turbo	14.8 a	15.2 a	16.1 a
5	Kamakoiwa	13.9 a	15.9 ab	17.8 b
6	Kaguru	10.7 a	12.2 a	14.5 b
7	Kerugoya	9.9 a	11.8 a	14.0 b
11	Kavutiri§	3.0 a	3.3 a	4.1 b
16	Moi TTC	11.8 a	11.2 a	11.8 a
26	Tulaga	6.3 a	7.7 b	8.3 b
	Mean	10.2	11.3	12.5

†Control, untreated; FYM (5 t ha^{-1}); FYM + NP (50 kg N + 50 kg P_2O_5 ha^{-1}). ‡a,b: different letters indicate significant differences between treatments ($p < 0.05$), to be read horizontally. §Tuber yields increased with 2.5 t lime ha^{-1}.

considerably from site to site. At 16 of the 27 sites (59%), potatoes gave a positive response to P_2O_5 application (Table 5) with agronomically optimum rates of 41–75 kg ha^{-1} (Table 6). At 9 of the 16 sites the response to P_2O_5 application was strongly linear. Therefore higher application rates (>75 kg ha^{-1}) might still be profitable for farmers. Two sites showed a response to N or P_2O_5 application only after 2.5 t lime ha^{-1} (Kavutiri) or 50 kg K_2O ha^{-1} (Kerugoya) was applied. The regression coefficients presented in Table 5 were obtained after these responses had been obtained.

Economic optimum fertilizer rates (Table 6) resulted in an average yield of over 97% (range 78–100%) of the maximum yield (agronomic optimum) achieved in the experiments. Comparing the change in economic optimum fertilizer rates for two crops, maize and potatoes, at different input:output price ratios and different VCRs for the site at Mau Summit in the Nakuru District revealed differences in price elasticity between the two crops. At input:output price ratios of 2:1, 4:1, 6:1 or 8:1, farmers around Mau Summit should apply 75 kg P_2O_5 ha^{-1} to their monocropped maize if they are satisfied with a VCR of 2:1. Should the VCR increase to 3:1 or 4:1, the input:output price ratios have to be a maximum of 6:1 and 4:1, respectively, to make P_2O_5 application profitable for maize.

Potatoes, a crop with a relatively higher market value than maize, exhibit a considerably higher price elasticity. If a VCR of 2:1 is assumed, the price for 1 kg P_2O_5 in the fertilizer can be 20 times as high as the price for 1 kg potatoes and it would still be profitable to apply 75 kg P_2O_5 ha^{-1}. Even if a VCR of 3:1 or 4:1 is assumed, the input:output price ratios can still be as high as 18:1 and 14:1, respectively, and the economic optimum fertilizer rate would still remain at 75 kg P_2O_5 ha^{-1}.

Table 5. *Regression coefficients for nitrogen and phosphate fertilizer response functions*† *calculated for potatoes at experimental sites (average over all experimental years)*

Site number	Site	Intercept	Regression coefficients					R²
			N	N^2	P	P^2	N*P	R^2
1	Tongaren	13339			403.0	−4.2		0.85
2	Chebunyo	10663						
3	Turbo	8961						
4	Weruga	9861	228.0	−1.74	48.6		1.2	0.94
5	Kamakoiwa	14812			88.0			0.40
6	Kaguru	8180	189.0	−1.60				0.77
7	Kerugoya	8012	51.7					0.61
8	Kand. Kareti	8923	29.0					0.29
9	Chepkumia	12086						
10	Sosiot	9520			53.4			0.71
11	Kavutiri	1781	34.8		182.0	−1.70		0.80
12	Otamba	13294			224.0	−1.66		0.74
13	Githunguri	7472	57.7	−0.80	58.0			0.87
14	Vih.-Maragoli	18124						
15	Upepo	17316						
16	Moi TTC	10567			21.1			0.31
17	Ol Ngarua	9614	19.9		13.2			0.47
18	Rotian	8388						
19	Eld. Ravine	5192			90.4	−1.09		0.21
20	Baraton	9881	50.7		44.5			0.62
21	Kapenguria	17681						
22	Bugar	10995			61.4			0.51
23	Kiamokama	10609			138.0			0.68
24	Ol Joro Orok	27209						
25	Mau Summit	5154			57.2			0.38
26	Tulaga	5091			47.9			0.44
27	Njabini	17082	96.9		221.0	−2.12		0.49

†The regression coefficients were determined by stepwise regression using the general response function: $y = a + bN = cN^2 + dP + eP^2 + fP*N$, in which the regression coefficients a = yield level without N and/or P_2O_5 application b,c = kg potato tubers ha^{-1} per kg applied fertilizer N ha^{-1} (linear and quadratic) d,e = kg potato tubers ha^{-1} per kg applied fertilizer P_2O_5 ha^{-1} (linear and quadratic) f = interaction between N and P_2O_5.

Similar calculations have been done for the other sites where potatoes were grown and the relative superiority of potatoes over maize regarding the profitability of fertilizer application was evident for nearly all sites. Since the response to N or P_2O_5 was generally strong too, differences in fertilizer or product prices hardly affect fertilizer recommendations for potatoes. Even at an input:output price ratio of 20:1 and a VCR of 3:1, application of N or P_2O_5 would still be profitable. Similar results were found for cabbages (Kanyanjua and Schnier, 1995).

Yield increases due to P_2O_5 application only occurred at relatively low soil P contents (Fig. 1). At soil P levels over 15 ppm P (mod. Olsen) virtually no response to P_2O_5 was found in potatoes. This level was slightly higher than that for maize

Table 6. *Agronomic and economic optimum nitrogen and phosphate fertilizer rates, tuber yields and nutrient use efficiency of nitrogen and phosphate applied to potatoes*

Site number	Site	Agronomic optimum fertilizer rates (kg ha^{-1})		Economic optimum fertilizer rates (kg ha^{-1})		Tuber yields (t ha^{-1})		Nutrient use efficiency† at agronomic optimum fertilizer rates	
		N	P_2O_5	N	P_2O_5	Agronomic optimum fertilizer rate	Economic optimum fertilizer rate	N	P_2O_5
1	Tongaren	0	48	0	45	23.0	23.0	–	214
2	Chebunyo	0	0	0	0	10.7	10.7	–	–
3	Turbo	0	0	0	0	9.0	9.0	–	–
4	Weruga	66	75	58	75	26.9	20.9	113	49
5	Kamakoiwa	0	75	0	75	21.4	21.4	–	88
6	Kaguru	59	0	51	0	13.8	13.7	95	–
7	Kerugoya	75	0	75	0	11.9	11.9	52	–
8	Kand. Kareti	75	0	25‡	0	11.1	9.6	29	–
9	Chepkumia	0	0	0	0	12.1	12.1	–	–
10	Sosiot	0	75	0	75	13.5	13.5	–	53
11	Kavutiri	75	54	75	46	9.3	9.2	35	91
12	Otamba	0	67	0	59	20.9	20.7	–	113
13	Githunguri	36	75	19	75	12.9	12.6	29	58
14	Vih.-Maragoli	0	0	0	0	18.1	18.1	–	–
15	Upepo	0	0	0	0	17.3	17.3	–	–
16	Moi TTC	0	75	0	0	12.2	10.6	–	21
17	Ol Ngarua	75	75	0	0	12.9	9.6	20	13
18	Rotian	0	0	0	0	8.4	8.4	–	–
19	Eld. Ravine	0	41	0	29	7.1	6.9	–	46
20	Baraton	75	75	75	75	17.0	17.0	51	45
21	Kapenguria	0	0	0	0	17.7	17.7	–	–
22	Bugar	0	75	0	75	15.6	15.6	–	61
23	Kiamokama	0	75	0	75	21.0	21.0	–	138
24	Ol Joro Orok	0	0	0	0	27.2	27.2	–	–
25	Mau Summit	0	75	0	75	9.4	9.4	–	57
26	Tulaga	0	75	0	75	8.7	8.7	–	48
27	Njabini	75	52	75	46	30.1	30.0	97	111
	Mean	68	68	57	64	15.5	15.0	58	75

†Nutrient use efficiency: kg tubers per kg N or P_2O_5 applied; ‡Economic optimum lower because of high risk of crop failure.

which did not show yield increases due to P_2O_5 application at soil P levels over 13 ppm (mod. Olsen) (Onyango *et al.*, 1995). This result was not surprising since maize is deep rooting and potatoes are shallow rooting. Cabbage plants with their very shallow root system and very few root hairs require 24 ppm soil P (mod. Olsen) for optimal P nutrition (Kanyanjua and Schnier, 1995).

Potatoes displayed a positive (mainly linear) response to nitrogen application at only one-third of the sites (Table 5). Agronomic optimum N application rates varied between 36 and 75 kg N ha^{-1} with an average of 68 kg N ha^{-1} for the sites where potatoes responded to N application (Table 6). The economic optimum

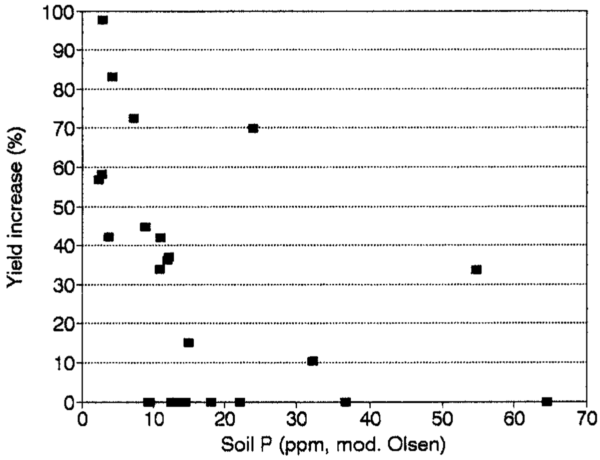

Fig. 1. Increase in potato yield with phosphate application (fertilized compared to unfertilized potato) versus available soil P content as determined by the modified Olsen extract.

rates ranged between 25 and 75 kg ha^{-1} with a mean of 57 kg ha^{-1} on sites that required N. At sites with a linear response, applications higher than 75 kg N ha^{-1} might be profitable.

At sites that displayed a response to P, 1 kg P_2O_5 increased potato yield by an average of 75 kg ha^{-1} with a range of 13 to 214 (Table 6). The nutrient use efficiency of N fertilizer varied between 20 and 113 kg tubers kg N^{-1} (average 58 kg tubers kg N^{-1}). An interaction between N and P_2O_5 response was found only at one site (Weruga), where N application affected the response to P fertilizer positively and vice versa (Table 5). Interactions between variety, altitude (climatic conditions) and application of fertilizers were not observed in the experiments, but were also not the focus of the field trials. These could constitute an aspect of future research in this area.

Yield increases due to K_2O application were obtained only at sites with low levels of K in the soil (Fig. 2). Generally, if the K content of the soil was higher than 0.55 meq K 100 g^{-1} (Mehlich I extract), no response to K_2O application was found. However, statistically significant ($p < 0.05$) yield increases with applications of K_2O were found in potatoes at three of the 16 sites.

Tables 3 and 4 show the response of potatoes to applications of farmyard manure (5 t ha^{-1}) in the absence and presence of mineral N and/or P fertilizer. On average, 5 t farmyard manure ha^{-1} raised potato yields by 1.5 t ha^{-1} (27 sites). Significant yield increases due to farmyard manure application were obtained at one-third of the sites. Additional applications of mineral N or P fertilizer further increased yields by an average of 0.5 t ha^{-1}, but only one site showed a significant difference between farmyard manure alone and the additional N or P fertilizer application. The combination of N and P fertilizer each at 50 kg ha^{-1} with farmyard manure at 5 t ha^{-1} increased yields significantly at

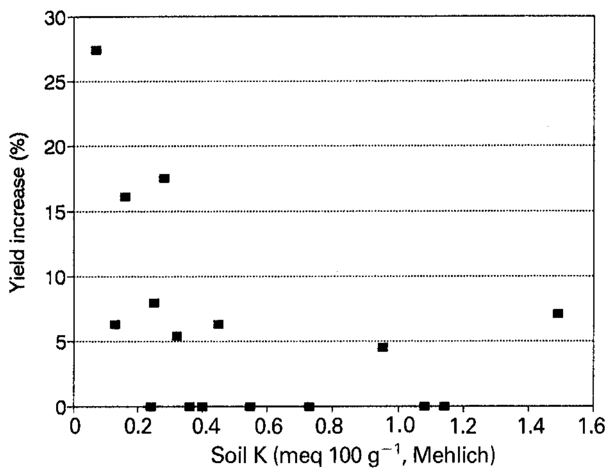

Fig. 2. Increase in potato yield by potassium application (fertilized compared to unfertilized potato) versus available soil K content as determined by the Mehlich I extract.

three of the eight sites when compared to farmyard manure only. On average, the combination of N and P_2O_5 applications with farmyard manure increased potato yields by 1.2 t ha^{-1}.

The relatively close relationship between yield increases obtained with farmyard manure and the contents of P in the soil (Fig. 3) suggested that the response to farmyard manure was caused mainly by the phosphate in the manure. The picture in Fig. 3 is very similar to that in Fig. 1. Additional yield increases obtained when P_2O_5 was applied with the farmyard manure were only obtained at sites where the soil P level (mod. Olsen) was below 12 ppm. This corresponded with the critical level for mineral P fertilizer application which was about 15 ppm P in the soil. It appeared that phosphate in the farmyard manure could not fully substitute for phosphate in mineral fertilizers when the soil P levels were low. However, where the soil contained 12–15 ppm P (mod. Olsen), farmyard manure could replace the P in mineral fertilizer (Fig. 3). Similar results have been reported by Kanyanjua and Schnier (1995) for cabbages in Kenya. These threshold values for optimal P nutrition of potatoes are preliminary results from 27 sites and need further verification.

CONCLUSIONS

The strong responses to P_2O_5 application found in potatoes on two-thirds of the sites and to nitrogen at one-third of the sites make the application of these nutrients highly economical for farmers in the respective areas. Field trials to test application rates higher than 75 kg N and P_2O_5 ha^{-1}, respectively, are necessary at sites where a linear response was found. At some of these sites field trials are already in progress.

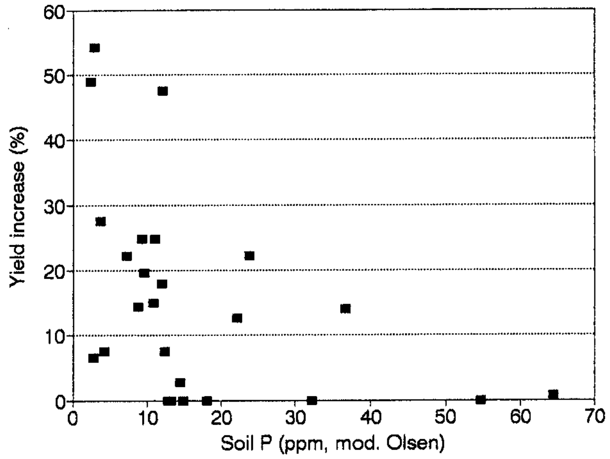

Fig. 3. Increase in potato yield by farmyard manure application (fertilized compared to unfertilized potato) versus available soil P content as determined by the modified Olsen extract.

Since the response of potatoes to P_2O_5 application decreased with increasing soil P levels, P_2O_5 application should be based on the results of soil analyses carried out every four or five years. Soil tests would also help to determine other soil chemical parameters which might limit crop growth and the response to applications of N, P_2O_5 or K_2O fertilizers.

When the soil contained more than 15 ppm P (mod. Olsen) potatoes were unlikely to respond to applied P. Farmyard manure could substitute for mineral phosphate application only when soil P levels were above 12 ppm (mod. Olsen). Below this level a combined application of farmyard manure and mineral P fertilizer was expected to increase tuber yields. When the soil contained more than 0.55 meq K 100 g^{-1} (Mehlich I) potatoes were unlikely to respond to applied K_2O. Possible interactions between variety, altitude (climatic conditions) and response of potatoes to fertilizer application would be a worthwhile research topic for the main potato production areas of Kenya.

REFERENCES

Agricultural Information Centre (1981). *Major Crops Technical Handbook.* Nairobi: Ministry of Agriculture, Livestock Development & Marketing.

Crissman, C. C., Crissman, L. M. & Carli, C. (1993). *Seed Potato Systems in Kenya: A Case Study.* Lima: International Potato Centre (CIP).

Dürr, G. & Lorenzl G. (1980). *Potato Production and Utilization in Kenya.* Lima: International Potato Centre (CIP).

Hunter, A. H. (1974) *Soil Analytical Procedure Using the Modified $NaHCO_3$ Extracting Solution. Laboratory Manual, ISFEI Program.* Raleigh: North Carolina State University.

Kabira, J. N. (1994). The Potato Programme at KARI. Paper presented at the 2nd KARI-CIP Technical Workshop. Nairobi: International Potato Centre (CIP).

Kanyanjua, S. M. & Schnier, H. F. (1995). Response of cabbage (*Brassica oleracea* L.) to phosphorus, nitrogen and manure application in Kenya. In *Proceedings of the 4th KARI Scientific Conference, October 1994.* Nairobi: Kenya Agricultural Research Institute (in preparation).

https://doi.org/10.1017/S0014479797000203 Published online by Cambridge University Press

Mehlich, A. (1953). Determination of P, Ca, Mg, K, Na, and NH_4 by the North Carolina Soil Testing Laboratory. Raleigh: North Carolina State University (mimeograph).

Nabwile, S. (1995). Optimal Fertilizer Use Recommendations in Irish Potato Production in Kenya. MSc thesis, University of Nairobi.

Onyango, J. W., Schnier, H. F., Qureshi, J. N. & Ayaga, G. O. (1995). Response of maize to nitrogen and phosphorus fertilizer application in the high and medium rainfall areas of Kenya. In *Proceedings of the 4th KARI Scientific Conference, October 1994.* Nairobi: Kenya Agricultural Research Institute (in preparation).

Woolfe, J. A. (1987). *The Potato in the Human Diet.* Cambridge: Cambridge University Press.

Woolfe, J. A. (1991). The contribution of potato to human diets. In *Production, Post-harvest Technology, and Utilization of Potato in the Warm Tropics*, 130–136 (Eds N. Govinden, M. R. K. Julien, G. L. T. Hunt and L. J. C. Autrey). Reduit: Mauritius Sugar Industry Research Institute.