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An economic assessment of cowpea and groundnut IPM production technologies used by farmers in eastern Uganda

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Abstract

Groundnut (*Arachis hypogea* L.) and cowpea (*Vigna unguiculata* L. Walp) come second and third respectively as the most widely grown legumes in Uganda especially in the northern and eastern regions. However, the yields of these crops have stagnated in recent years, mainly due to pests and diseases. As alternative control methods for pests and diseases, several integrated pest management (IPM) technologies that rely on less use of pesticides have been developed and demonstrated on-farm in eastern Uganda for over 7 years, with farmers adopting some of them. The objective of this study was to determine the profitability of groundnut and cowpea IPM technologies. Farm data were obtained from surveys conducted in March–May 2001 in eastern Uganda, where 136 farmers were selected using purposive and random sampling procedures. The profitability of different IPM technology packages for each of the two crops was estimated using the partial budget approach and marginal rate of return (MRR). Results showed that changing from farmers' traditional production practices to recommended IPM practices was profitable for both groundnut and cowpea. Marginal rate of return obtained ranged from 108% to 6,671% and 173% to 700% in groundnut and cowpea respectively; all these are well above the minimum accepted MRR of 100%.

Key words: *Arachis hypogea,* integrated pest management options, marginal rates of return, partial budget, pest control, profitability, *Vigna unguiculata*

Introduction

Groundnuts (*Arachis hypogea* L.) is the second most widely grown food legume in Uganda after common beans (*Phaseolus vulgaris* L.) while cowpeas comes third (Busolo Bulafu, 2000; Obuo *et al.,* 2000). These crops are grown in all parts of Uganda, especially in the northern and eastern regions. According to FAO, cowpea yields have increased from 0.42 t ha^{-1} in 1980 to 1 t ha^{-1} in 2000 (Table 1) but an actual field survey by Sabiti *et al.* (1994) reported much lower yields, <450 kg ha^{-1}. For groundnuts, yields fluctuated from 0.46 t ha^{-1} in 1997 to 0.85 t ha^{-1} in 1990 and remained constant from 1998 to 2001 at 0.7 t ha^{-1} (Table 1). For both crops, on-station yields as high as 3000 kg ha^{-1} have been reported (Rusoke and Rubaihayo, 1994; FAO, 1998) although yields average only 0.8 t ha^{-1} for groundnuts (FAO, 1998) and 450 kg ha^{-1} for cowpea (Sabiti *et al.*, 1994; Adipala *et al.*, 1997).

The low cowpea and groundnuts yields at farmers level is attributed to various factors, such as insect pests, diseases, low yielding varieties and poor management practices (Sabiti *et al.*, 1994; Edema, 1995; Obuo, 1996; Edema and Adipala, 1996; Omongo, 1996; Adipala *et al.*, 1997; Mukankusi *et al.*, 1999a). Among these factors, insect pests have been found to be the most important on cowpea. In cowpea production, Edema and Adipala (1996) reported that insect pests cause yield losses of up to 70%. In groundnut, rosette disease is important and is transmittedly by *Aphis craccivora* (Mukankusi *et al.*, 1999a,b).

Farmers have responded to the pest problems by applying various pesticides (Isubikalu *et al.,* 1999). However, the use of chemicals is restricted to only a few farmers, because of the high costs associated studies have revealed high profitability of some of the IPM technologies. Upton (1987), however, asserted that standard of management in experiments is much higher than that found in practice at peasant farm level, implying that the responses measured under researcher managed trials normally exceed those obtained under peasant farmer conditions. Results from the trials are therefore of limited value in advising farmers or in planning their farms. Farmers in eastern Uganda, particularly in Mayuge and Pallisa districts, are currently applying different levels of cowpea and groundnut IPM technologies that are believed to be profitable. However, economic ranking of these IPM technologies is necessary because of differences in factor costs especially at farm level. A more realistic assessment can therefore be obtained when data from farm surveys are used to analyse profitability of these IPM technologies. The objective of this study was to determine the profitability of groundnut and cowpea IPM technologies and to examine changes in net income associated with their adoption.

Materials and methods

Farm data collection

Data were gathered using pre-tested questionnaires during farm surveys carried out in March–May 2001 in eastern Uganda. In Mayuge district, the survey covered three groundnut IPM field sites (Musita, Bugodi and Waina) but only one cowpea site (Katukei) in Pallisa district. The study sample was obtained through the use of a combination of purposive and random sampling procedures for IPM technology adopters and non-adopters, respectively. In Musita, 20 adopters and 21 non-adopters of IPM technologies were selected, 6 adopters and 7 non-adopters were selected in Bugodi and in Waina 10 adopters and 10 non-adopters were selected. In Pallisa district 30 adopters and 30 non-adopters in Katukei were studied making a sample size of 134 respondents (74 in Mayuge and 60 in Pallisa). No attempt was made to study the profitability of IPM technologies for cowpea production in Mayuge because such technologies have not been adopted in the area.

Adopters of groundnut IPM technologies were farmers who grew the rosette resistant *Igola* 1 variety or any of the local varieties using two or more of the recommended IPM practices (early planting, correct spacing and three well timed chemical sprays). In cowpea, the adopters were farmers who used two or more of the recommended IPM practices (early planting, correct spacing and three well timed chemical sprays). This is why late planting in the tables of results is considered an IPM practice. The farmers that never satisfied the above requirements in any of the two crops were considered non-adopters of IPM technologies.

The data collected included farmer's household socio-economic and demographic characteristics such as age, sex, education and family size; crop and variety grown (local and improved); cultural practices (intercropping, mixed cropping and crops used in the intercrops, spacing, time of planting); production costs (labour costs for different farm operations); cost of seed, pesticides and other chemicals; farm yield data (output and area) and farm gate prices of outputs.

Analytical methods

Data collected from all farmers were pooled for all study sites, separating adopters and non-adopters of IPM. Pooling of data was done for particular technologies. Results were pooled to permit generalisation of all farmers in study sites (CIMMYT, 1988). The market prices for inputs during planting and farm gate prices at harvest as recorded from farmer responses were used for economic analysis. All the variable costs and benefits were expressed on a hectare basis in Uganda shillings (Ug. shs. ha^{-1}). The profitability for each technology, and combined package of IPM technologies for cowpea and groundnuts were estimated using partial budgeting and marginal rates of return (MRR) techniques as described by CIMMYT (1988). Partial budgeting is a method developed to examine alternative plans for farms and estimating profitability.

with the use of this technology. As such many farmers cannot afford to purchase pesticides in the required quantities (Mugisha, 1999).

To manage the pests and diseases of cowpea and groundnuts, several Integrated Pest Management (IPM) technologies with minimum use of pesticides have been developed by Makerere University and are being demonstrated on-farm in eastern Uganda. In the case of cowpeas these technologies involve integrated use of foliar pesticides, seed dressing with pesticides, intercropping, plant density, planting time and use of improved varieties (Nampala, 1998; Karungi, 1999). Karungi *et al.* (2000) recommended the following IPM package for cowpea; early planting (2 - 4 weeks after the on-set of the rains), close spacing (30 cm x 20 cm) and three foliar insecticide sprays per season (spray once at budding, flowering and podding). This spray frequency is lower than the 4-6 and 6-10 sprays per season reported for transition and commercial farmers, respectively (Isubikalu *et al.*, 1999). Another IPM technology for cowpea is cowpea-sorghum intercrop at a spacing of 60 cm x 20 cm, carbofuran seed dressing, (applied as a soil drench) and minimum foliar insecticide spray (Nampala, 1998).

For groundnuts, use of high plant density (30 cm x 10 cm or 45 cm x 15 cm), planting 2 - 3 weeks after the on-set of rains and use of resistant varieties are some of the recommended IPM technologies. Mukankusi *et al.* (1999a, b) reported that the local groundnut genotypes *Igola-1, Etesot* and *Erudurudu* performed relatively better than ICRISAT elite genotypes in terms of resistance to rosette and cercospora leaf spots. According to their results, even the susceptible local variety *Erudurudu* out-performed the elite varieties because they were more adapted to the local Ugandan conditions. Thus, integration of host resistance to especially rosette, insecticide spray and other cultural practices are being disseminated to various farmer groups in eastern Uganda.

Agronomic data from on-farm trials in eastern Uganda have indeed revealed superiority of the IPM packages over farmers' traditional practices. Gross margin analysis from some of the IPM biological

Table 1. Production and yields of cowpea and groundnuts in Uganda from 1980-2000.

Year	Area ('000 ha)	Cowpea production ('000 mt)	Yield (m t ha^{-1})	Area ('000 mt)	Groundnut production ('000 mt)	Yield (m t ha^{-1})
1980	38	16	0.42	95	70	0.74
1981	41	18	0.44	110	90	0.82
1982	45	20	0.44	120	90	0.75
1983	46	37	0.80	124	99	0.79
1984	49	39	0.79	148	102	0.69
1985	44	35	0.79	137	93	0.68
1986	50	39	0.78	177	118	0.67
1987	42	37	0.88	148	122	0.82
1988	46	38	0.83	179	134	0.71
1989	47	38	0.81	189	145	0.77
1990	49	39	0.79	186	158	0.85
1991	48	40	0.83	180	144	0.80
1992	49	41	0.84	184	147	0.80
1993	51	43	0.84	187	153	0.82
1994	53	45	0.85	189	142	0.75
1995	54	45	0.83	192	144	0.75
1996	56	47	0.84	195	125	0.64
1997	58	46	0.79	197	91	0.46
1998	60	50	0.83	200	140	0.70
1999	62	62	1.00	196	137	0.70
2000	64	64	1.00	199	139	0.70
2001	64	64	1.00	208	146	0.70

[1]Source: FAOSTAT Database: http//www.fao.org
[2]Statistics for cowpea yields are highly doubtful as yields in Uganda rarely exceed 0.5 t ha^{-1} (Adipala *et al.*, 1997).

The partial budget is organised in rows and columns (Table 2). The first row shows average crop yields for each of the given production technology. Average farm gate prices are given in the second row, while gross farm income (a product of price and yield) is given in the third row. Total variable costs (TVC) per hectare follow next and the net income (NI) (gross farm income minus total variable costs) appears at the bottom of the partial budget.

The information in Tables 2 and 3 was used in estimation of the marginal rates of return for each IPM technology for each commodity. The MRR was computed according to CIMMYT (1988) as:

$$MRR = \frac{(NI_a - NI_b)}{(TVC_a - TVC_b)} \times 100 \qquad (1)$$

Where: NI is net income, TVC is total variable costs, a is the next production technology with higher TVC and b is the previous production with lower TVC technology dropped.

This analysis was used to reveal how the net income from investment in a given production technology increases as investment (TVC) increases. The MRR indicates what farmers expect to gain on average, in return to their investments when they decide to change from one practice (or a set of practices) to another.

Results and discussion

Groundnuts

Results (Table 2) shows that yield levels vary across the different production technologies. The lowest average yields (142.2 kg ha^{-1}) were obtained from the local groundnut variety *Ensoga* planted by chop and drop method, followed by *Erudurudu* red (203.2kg ha^{-1}) at 30x10 cm^2 spacing, planted late and sprayed three times, *Erudurudu* red (250.5 kg ha^{-1}) planted by chop and drop method, while *Igola* I (930.3 kg ha^{-1}) planted early at a spacing of 30 x 10 cm gave the highest yields (Table 2).

Erudurudu red grown at a spacing of 30x10cm and planted early with four sprays had the highest TVCs (666,780 Ug. shs ha^{-1}) (Table 2). This is attributed to the high cost of chemical, labour and hire cost of spray equipment. The lowest total variable costs were obtained in local groundnut *Ensoga* planted by chop and drop method. The highest net income (848,053 Ug. shs ha^{-1}) was recorded in the production of *Igola* I planted early at 30 x 10 cm spacing. But the high labour costs for planting (50,000 Ug. shs ha^{-1} compared to average of 25,000 Ug. shs ha^{-1} required in chop and drop), and expensive seed (160,000 Ug. shs ha^{-1} compared to about 80,000 Ug. shs ha^{-1} required in *Erudurudu* red) could be a possible hindrance to full adoption of this technology. Farmers used not to spray *Igola* I, *Etesot* and *Ensoga* groundnuts since they were considered moderately resistant to rosette. Similar reports were made by Mukankusi *et al.* (1999).

Marginal rates of return

The derived MRRs for the recommended IPM technologies are above 100% (as a guiding benchmark given by CIMMYT, 1988) with exception of technologies involving the local variety *Etesot* (Table 3). The reasons for low MRR for the *Etesot* technology was the high cost of harvesting (60,000 Ug. shs ha^{-1}) compared to the other groundnut varieties (that averaged 30,000 Ug. shs ha^{-1}).

Farmers who changed from growing *Ensoga* by chop and drop planting to growing *Igola* I, planted early and intercropped with maize obtained marginal rate of return of 289.4%. This means that a farmer who uses this groundnut production technology earns 2.8 shillings (1 US$ = 1,650 kg. Shs.) for every

Table 2. Pooled partial budget for groundnut production technologies in Mayuge district.

technologies	IPM technologies										Non-IPM
	Igola +planted early +(45x15)**	*Igola* +planted late +(45x15)	*Igola* +planted early +(30x10)**	*Igola* +planted late (30x10)	*Igola* +planted early + intercropped	Erudu red+ 30x10+ +3 sprays**	Erudu red+ 30x10+ planted early +3 sprays	Erudu red+ 30x10+planted planted late	Eteso+ planted early+4 sprays (45x15)**	Erudu red +chop & early+ drop	Ensoga+ chop & drop
Sample size	N = 21	N = 2	N = 10	N = 2	N = 1	N = 5	N = 1	N = 2	N = 3	N = 34	N = 2
Yield kg ha^{-1}	741.75	590.88	930.27	879.42	279.40	497.46	203.20	578.02	414.52	250.48	142.24
Farm gate Price (Ug. Shs kg^{-1})	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1,500	1500	1,500
Gross income (Ug. Shs ha^{-1})	1,112,622.59	886,320.00	1,395,403.42	1,319,136.00	419,100.00	746,195.56	304,800.00	867,032.43	621,783.42	375,728.66	213,360.00
Variable costs (Ug. Shs ha^{-1})											
Bush clearing	37,838.28	36,427.32	41,930.16	35,560.00	7,620.00	32,549.65	25,400.00	66,108.65	32,511.22	29,849.37	10,160.00
Ploughing	91,414.26	79,545.37	92,246.35	115,840.00	58,420.00	73,189.61	57,573.27	106,748.65	138,173.65	61,161.86	20,320.00
Planting	47,670.78	51,347.32	54,960.76	37,253.37	55,880.00	36,500.76	15,240.00	43,214.32	29,463.41	30,381.05	20,320.00
Weeding	65,777.26	80,763.90	54,057.65	46,566.63	39,370.00	44,779.28	10,160.00	83,854.32	39,623.41	40,496.00	25,400.00
Labour spray	0	0	0	0	0	19,755.56	15,240.00	54,369.73	0	19,734.00	0
Chemical cost	0	0	0	0	0	31,608.87	35,560.00	108,739.46	0	24,194.26	0
Harvesting	31,838.78	31,223.41	35,672.89	39,793.37	30,480.00	42,897.78	20,320.00	30,617.30	60,959.35	23,057.15	15,240.00
Drying	27,883.53	28,089.76	26,577.27	20,997.37	12,700.00	27,187.43	10,160.00	62,044.65	28,447.48	17,931.70	15,240.00
Shelling	0	0	5,418.67	0	0	8,466.67	0	10,160.00	20,320.00	18,405.52	2,032.00
Storage Costs	16,808.89	8251.90	9,224.63	7,620.00	7,620.00	14,280.44	10,160.00	14,766.32	7,111.54	8,773.00	8,636.00
Cost of seed	166,570.00	166570.00	227,262.11	227,262.11	34,290.00	86,156.80	86,156.80	86,156.80	58,925.52	69,482.13	76,200.00
Total variable costs Ug. Shs ha^{-1}	507,969.07	482,218.98	547,350.48	530,892.84	246,380.00	417,372.85	285,970.07	666,780.21	415,535.60	343,466.99	193,548.00
Net income Ug. Shs ha^{-1}	604,653.52	404,101.02	848,052.94	638,243.16	172,720.00	328,822.71	18,829.93	200,252.23	206,247.81	32,261.67	19,812.00

** Indicates the recommended full IPM technology for respective groundnut varieties. Late planting was considered an IPM since farmer uses two IPM technology because it involved 2 IPM components.

Variable costs differ between cropping seasons among households mined by labour and other operating costs.

shilling invested. The net incomes marked **D** were from dominated technologies, which gave the lowest net incomes (NI) compared to the previous ones and yet they had higher total variable costs (TVCs). They were therefore excluded from MRR analyses. This is illustrated graphically as shown in Figure 1. Thus, based on the yield data alone, some technologies are recommended, but based on economic analysis the same technologies may not be recommended.

Cowpea

In Table 4, growing *Ebelat* by broadcasting with only 2 sprays and planted late, gave the lowest yields of 284 kg ha^{-1} followed by *Ebelat* + broadcast +3 sprays +planted early, *Ebelat* + 30 x 10 cm^2 spacing +3 sprays + planted early and *Ebelat* + broadcast + 4 sprays + planted early with yields of 304 kg ha^{-1}, 520 kg ha^{-1} and 685 kg ha^{-1}, respectively. The total variable costs (TVC) and net income (NI) also increased in the same order among the production technologies (Table 4).

The average yields of 520 kg ha^{-1} and 685 kg ha^{-1} got by farmers using the production technologies shown in Table 4 are not far from those got by Karungi *et al* (2000), who reported that, overall, higher yield gains were obtained in plots receiving a combination of control measures (983.5 kg ha^{-1}) as opposed to those which received chemical (783.1 kg ha^{-1}) or cultural (127.3 kg ha^{-1}) control alone. The differences in yield could be attributed to the high standard of management normally found in research stations compared to farmers' situation (Upton, 1987; CIMMYT, 1988). Row cropping lowered the profits obtained from the recommended IPM for cowpea due to high costs of labour (35,000 Ug. shs ha^{-1}) required during planting compared to 3,000 Ushs ha^{-1} used in broadcasting (Table 4).

Marginal rates of return

Growing *Ebelat* by broadcasting + 4 sprays + planted early gave the highest MRR of 700%. The recommended cowpea IPM technology of planting *Ebelat* at 30 x 10cm +3 sprays +planted early also had MRR of 378.9% (Table 5). This implies that if a farmer spent 1 shilling in cowpea production using this technology he/she earns 3 shillings plus one shilling he/she invested.

All MRRs obtained are well above the minimum rate of return of 100%, and none of the treatment was dominated (Table 5). Thus it was profitable to plant cowpea at the onset of rains at 30 x 10 cm and using three well timed chemical sprays, but this was less profitable compared to the traditional technology of broadcasting *Ebelat* early with 4 chemical sprays. The four sprays could have controlled pests effectively and led to relatively high yields in this technology. The highest point in the curve

Table 3. Total variable costs, net income and MRR for respective groundnut production technologies.

Production technology	Total variable costs	Net income (Ug. $shsha^{-1}$)	MRR (%) (Ug. $shsha^{-1}$)
Ensoga + chop and drop planting	193,548	19,812	
Igola+planted early intercropped with maize	246,380	172,720	289.4
Erudurudu red+30x10+planted late+3sprays	285,970	18,830**D**	
Erudurudu red chop and drop planting	343,467	32,262**D**	
Etesot + planted early + 45x15cm^2 spacing	415,535	206,248	(19.8)
Erudurudu red+30x10 cm^2+planted early+3sprays	417,373	328,823	6,671.6
Igola+planted late+45x15 cm^2 spacing	482,219	404,101	116.0
Igola+planted early+45x15 cm^2 spacing	507,969	604,654	778.8
Igola+planted late+30x10 cm^2 spacing	530,893	638,243	108.6
Igola+ planted early+30x10 cm^2 spacing	547,350	848,052	1,274.8
Erudurudu red+30x10+planted early+4sprays	666,780	200,252**D**	

D = Dominated technology.

shows the most profitable technologies and the percentages along the curve are percentage income gains resulting from adopting the next technology.

Conclusions and challenges

The study used a partial budget method to derive net benefits and marginal rates of return to determine the profitability of groundnut and cowpea IPM technologies disseminated in Iganga and Pallisa districts. The study shows that farmers who grow the local groundnut variety *Erudurudu* early at the onset of rains at 30 x 10 cm spacing and spray three times can be able to obtain a net income of 404,101 Ug. shs ha^{-1}. Likewise, planting *Igola* I early at 30 x 10cm spacing improved farmers' income to 638,243 Ug. shs ha^{-1}. However, *Etesot* had the least net income when subjected to other IPM technology innovations involving imported groundnut varieties.

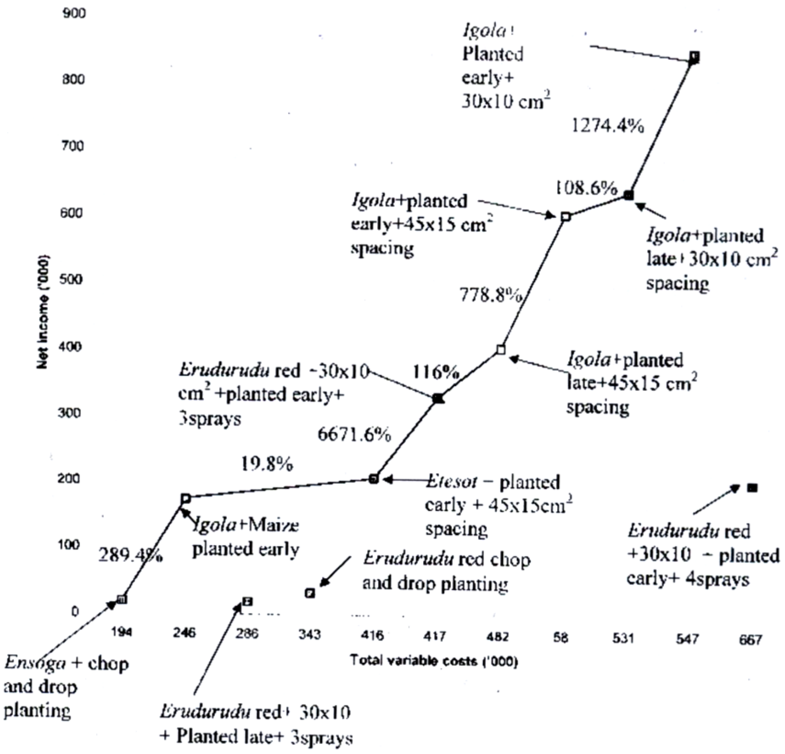

Figure 1. A plot of the net income curve for groundnut.

Table 4. Partial Budget for cowpea for Katukei, Pallisa district.

	IPM technologies		Non IPM technologies	
	Ebelat+ broadcast +3 sprays +planted early	Ebelat+ 30x10 cm +3 sprays +planted early	Ebelat+ broadcast +4 sprays +planted early	Ebelat+ broadcast +2 sprays +planted early
Sample size	N = 23	N = 7	N = 6	N = 24
Yield (kg ha^{-1})	304.80	520.70	685.80	284.48
Farm gate price (Ug. Shs kg^{-1})	400	400	400	400
Value of output (Ug. Shs ha^{-1})	121,920.00	208,280.00	274,320.00	113,792.00
Variable costs (Ug. Shs ha^{-1})8				
Bush clearing	12,700	17,780	8,509	12,700
Ploughing	25,400	25,400	36,830	25,400
Planting	5,080	35,560	3,175	2,540
Weeding	20,320	12,700	24,130	30,480
Labour spray	3,810	3,810	5,080	2,810
Chemical costs	5,080	5,080	7,620	2,350
Cost of seed	6,096	7,620	12,573	11,430
Harvesting	25,400	12,700	31,750	20,320
Drying	7,620	7,620	8,255	3,810
Storage costs	5,080	6,350	4,445	1,778
Total variable costs Ug. Shs ha^{-1}	116,586	134,620	142,367	113,618
Net Income Ug. Shs ha^{-1}	5,334	73,660	131,953	174

Costs vary across farmer groups because of the nature of the labour market, one may get cheap labour in a season and expensive labour in another or variations can even occur within a season depending on the labour source and the farmers' bargaining power; the sampe applies to other costs as well.

Table 5. Total variable costs (TVC), net benefits (NB) and %MRR for different cowpea production technologies.

Technology	Total variable cost (TVC) (Ug. shs ha^{-1})	Net incomes (NI) (Ug. $shsha^{-1}$)	%MRR
Ebelat+broadcast+2 sprays+planted late	113,618.00	174.00	
Ebelat+broadcast+3 sprays+planted early	116,586.00	5,334.00	173.85
Ebelat+30 x 20 +3 sprays+planted early	134,620.00	73,660.00	378.85
Ebelat+broadcast+4 sprays+planted early	142,567.00	131,953.00	700.82

In cowpea, growing *Ebelat* by broadcasting + 4 sprays + planted early was the most profitable, but the recommended cowpea IPM of planting *Ebelat* at 30 x 10cm +3 sprays +planted early was also profitable. Because of high labour costs in row cropping and weeding, the issue of alternative labour saving techniques remains to be addressed in the quest to develop profitable and sustainable production technology sets for cowpeas and groundnuts at farmer level.

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postharvest diseases, but neither the mechanism of resistance nor the correlation between resistance to various fungal diseases is known (Clark, 1992). Germplasm evaluations conducted in the United States of America (Harter and Weimer, 1921; Clark and Hoy, 1994) and in Tanzania (Muhanna *et al.*, 2001) have shown that the level of resistance to Rhizopus soft rot vary widely in sweetpotato genotypes. Similar results have also been obtained in preliminary germplasm evaluation in Kenya (Kihurani, 1997). The aim of this study was to evaluate local and introduced sweetpotato germplasm for resistance to Rhizopus soft rot caused by *R. stolonifer* and *R. oryzae* in Kenya.

Materials and methods

Single-spore isolates of *R. stolonifer* and *R. oryzae* were obtained from naturally infected sweetpotato storage roots. The diseased root samples were obtained from main sweetpotato growing areas around the lake Victoria basin in western Kenya and at the Kibirigwi irrigation scheme in central Province. Relative virulence of ten single spore isolates of each test pathogen was determined by inoculating health storage roots of the sweetpotato cultivar KSP 20. The most virulent isolate of each test pathogen was selected and preserved in sterile soil according to Smith and Onions (1983) and subsequently used to inoculate healthy storage roots of the test sweetpotato germplasm.

Fifteen test germplasm comprising of eight important local, and seven introduced sweetpotato cultivars were used in the study (Table 1). These varieties were selected on the basis of their relative importance in the sub-Saharan region for human consumption, animal feed and income generation (Carey *et al.*, 1999). They were grown on 30 m long ridges spaced at 80 cm, in an experimental plot at the National Agricultural Research Laboratories (NARL) about 6 km west of Nairobi City. Planting materials comprised 25 cm long apical-end vine cuttings. They were obtained from the International Potato Centre (CIP) sweetpotato germplasm conservation plot at the field station of the University of Nairobi, Kabete Campus and planted at a spacing of 30 cm between hills.

The experimental site has deep well drained friable clay soil (Nitosols) (Siderius, 1976). It is 1740 m above sea level and experiences bimodal precipitation with a main rainy season from mid-March to May and a secondary one from Mid-October to December (Siderius and Muchena, 1977). No fertiliser or manure was applied to the plants during the growing season, and the plot was kept weed-free by regular hand weeding. Harvesting was done at 22 weeks after planting using a hand hoe, and care was taken to minimise mechanical damage to the roots during harvesting and handling.

Harvested storage roots of uniform size were selected and washed in tap water to remove adhering soil, and surface sterilised with alcohol (96% ethanol). Each root was injured at the median by creating a shallow wound of about nine-mm in diameter and six mm in depth. A sterile nine-mm cork borer was used to cut agar plugs from the margin of an actively growing two-day-old potato dextrose agar cultures of the test pathogen. The agar plugs were removed and placed onto the wounds with the mycelium side facing down. Control roots were also inoculated using similar, but sterile, agar plugs. The inoculated roots were placed in polyethylene bags (autoclavable sun-transparent Sigma cell culture 44.0 x 20.5 cm with 24 mm 0.02 micron filter disc) and incubated at room temperature for 48 hours.

The experiment was first conducted in 1999 and repeated in 2000. In each experiment susceptibility of the sweetpotato germplasm to infection by isolates of *R. stolonifer* and *R. oryzae* was tested. In the first trial, roots were inoculated on 10th November 1999, using 12 stored roots per entry, and in the second test, roots were inoculated on 17th May 2000 using 15 freshly harvested roots per entry. The experiments were arranged following a randomised complete block design with three replicates.

Disease development was assessed by cutting each inoculated root longitudinally through the inoculation wound and measuring diameter and depth of the developing internal lesion. Mean internal lesion dimension was used as a measure of lesion size and was obtained by computing the average mean lesion diameter and depth according to Duarte and Clark (1993). The data were analysed by analysis of variance (ANOVA) using Statgraphics plus 3.1 software and cultivar means compared by Duncan's Multiple Range Test (DMRT) at the 95% confidence level.

Results

The interaction between cultivar and pathogen was not significant in the first test, but it was significant ($P<0.05$) in the second. In addition, all the cultivars were susceptible to infection by both *R. stolonifer* and *R. oryzae*. In both trials, lesion size on the inoculated storage roots differed significantly ($P<0.05$) among the cultivars and between the pathogens (Table 1). The cultivars *Maria Angola, Santa Amaro*, SPK 013, KEMB 10 and *Marooko* developed smaller lesions compared with the other cultivars, while the cultivars *Naveto, Tainung* 64, KEMB 23, and *Yanshu* 1 developed larger lesions compared to the other cultivars in both tests. Lesion size in the cultivars KEMB 36, SPK 004, KSP 20, *Jayalo, Mugade* and KSP 11 differed between the two trials. All the cultivars developed larger lesions with both pathogens in the first trial (1999) compared to the second (2000) (Table 1).

Lesion sizes were larger with *R. stolonifer* compared with *R. oryzae* in the first trial (1999). They ranged from 37.43 mm to 58.43mm compared to 9.39 mm to 37.33mm with *R. oryzae*. In the second trial (2000), with the exception of *Yanshu* 1, lesions sizes were larger with *R. oryzae* infection compared to *R. stolonifer* in six cultivars, KSP 20, KEMB 10, *Mugade*, SPK 004, SPK 013 and *Tainung* 64. In addition, lesions sizes did not differ between the pathogens in the remaining eight cultivars.

Discussion

The fact that interaction between cultivar and pathogen was significant in one trial and not in the other showed that the cultivars reacted to the pathogens in a similar manner in one trial and differently in

Table 1. Mean internal lesion dimensions (mm) on storage root cultivars inoculated with Rhizopus stolonifer and Rhizopus oryae in 1999 (trial 1) and 2000 trial 2).

Cultivar	CIP No. or local Name	Origin	*Rhizopus stolonifer*		*Rhizoipus oryzae*	
			1999	2000	1999	2000
Maria Angola	420008	Peru	37.43a	7.00a	12.30ab	08.56a
KEMB36	*Muibai*	Local	39.02a	9.81a	24.70cd	12.56ab
SPK004	*Kakamega 4*	Local	40.67ab	7.23a	23.04bcd	17.60abc
Santa Amaro	400011	Brazil	40.67ab	9.08a	16.00abc	11.17ab
SPK013	None	Local	43.44abc	6.33a	09.39a	11.44ab
KSP20	440170	IITA	44.80abcd	7.30a	25.60cde	16.60ab
KEMB10	440169	Local	45.80abcd	7.0a	23.53bcd	16.00ab
Marooko	*Marooko*	Local	46.50abcd	8.00a	17.08abc	12.21ab
Jayalo	*Jayalo*	Local	49.13bcde	6.33a	23.50bcd	11.43ab
Mugade	440163	Rwanda	49.37bcde	10.17a	22.00bcd	30.87c
Tainang 64	440189	Taiwan	50.47bcde	11.70cde	32.00de	24.23bc
KSP11	None	Local	51.70cde	8.60a	26.67cde	13.22ab
KEMB23	*Gikanda*	Local	54.63de	19.11b	27.04cde	24.42bc
Naveto	440131	P.N.Guinea	58.29e	11.17a	36.75e	18.04abc
Yanshu 1	440024	China	58.43e	32.94c	37.33e	20.25abc
Mean			47.36	10.79	28.80	16.57
			1999		**2000**	
LSD ($P\leq0.05$) for comparing cultivar means			9.12		8.25	
LSD ($P\leq0.05$) for comparing pathogen means			6.45		5.83	
LSD ($P\leq0.05$) for cultivar X pathogen interaction			Not significant		11.66	

other test. This inconsistency in the interaction is an indication that cultivar susceptibility to infection was influenced by other factors besides presence of the pathogens.

Cultivar response to infection was consistent in the majority of cultivars tested, and this was an indication of stability in resistance or susceptibility to Rhizopus soft rot disease. The cultivars *Maria Angola, Santa Amaro*, SPK 013, KEMB 10 and *Marooko* exhibited stable resistance to infection, while the cultivars *Naveto, Tainung* 64, KEMB 23, and *Yanshu* 1 exhibited stable susceptibility. The cultivars KEMB 36, SPK 004, KSP 20, *Jayalo, Mugade* and KSP 11 exhibited unstable susceptibility/ resistance. Similar findings have been reported in Tanzanian sweetpotato germplasm and the phenomenon was attributed to the influence of the prevailing storage and crop growth conditions (Muhana *et al.,* 2001). The reason for the observed disease reactions was not investigated in the present study.

The results also showed that all cultivars were more susceptible to infection by both pathogens in the first trial (1999) compared to the second (2000), and this was attributed to differences in the prevailing temperature during incubation. During the first trial the ambient temperature ranged from 22°C to 28°C and in the second trialranged from 20°C to 25°C. The higher temperature during the first test provided a more favourable environment for pathogen activity, and this may have enhanced infection. The influence of the prevailing environmental conditions on infection and decay of sweetpotato roots has also been reported by Clark and Moyer (1988) and Wills *et al.* (1998).

Although in the first trial, all the cultivars developed larger lesions, suggesting greater susceptibility to *R. stolonifer* compared with *R. oryzae,* this trend was repeated in the second trial. Six of the cultivars, KSP 20, KEMB 10, *Mugade*, SPK 004, SPK 013 and *Tainung* 64, developed larger lesions and therefore showed greater susceptibility to *R. oryzae*. In addition, the other eight cultivars did not show any difference in susceptibility to either *R. stolonifer* or *R. oryzae*. Although Clark and Hoy (1994) reported that sweetpotato genotypes are generally more susceptible to *R. stolonifer* than to *R. oryzae,* the results of this study showed that the tested sweetpotato germplasm varied in susceptibility to either of the two *Rhizopus* species. Cultivar variability in susceptibility to *R. stolonifer* and *R. oryzae* exhibited by the tested sweetpotato germplasm shows that it is possible to pursue host resistance as a means of controlling Rhizopus soft rot in some sweetpotato cultivars. While this may be possible in cultivars exhibiting consistent response to infection, it may not work in cultivars that fail to show consistency in their response to infection. There is therefore need to regulate the storage environment for sweetpotato roots since cultivar susceptibility to infection is influenced by the prevailing environmental conditions.

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