CROP PROTECTION PROGRAMME

Development of weed management in maize-based cropping systems

R7405 (ZA0302)

FINAL TECHNICAL REPORT

1 April 1999 – 31 March 2002

P J Terry
IACR-Long Ashton Research Station

Incorporating report by
D Overfield
Natural Resources Institute

Executive summary

This report provides a summary of the analytical results of on-farm participatory trials held in Kenya and Uganda during four growing seasons between 1999 and 2001 to evaluate the potential of herbicides to contribute to the development of a more economically viable maize based farming systems in the region.

Trials were conducted in two districts of Kenya (Embu and Kiambu) and three districts of Uganda (Iganga, Masindi and Mbale) over a period of four maize growing seasons, covering two short rains seasons and two long rains seasons between 1999 and 2001. In total, 110 farmers were involved in the trials, many of them over all four seasons.

All sites had mixed weed floras typical of smallholder farming systems where weeding is done by hand. All five districts had species (mostly annuals) that can be controlled by hand weeding. However, they also had perennial weeds that can be difficult to control.

The trials indicate that the application of herbicides within these maize based systems leads to an increase in yields of 21 per cent over the standard farmer practice of hand weeding due to more timely weed control through the alleviation of seasonal and gender based labour constraints. The same trials indicated an average fall in labour costs of 42 per cent compared to farmers' normal practice and a 20 per cent increase in gross benefits (a result of improved yields). When taken together, net benefits, or profits, increased by 42 per cent over farmer practice. There was considerable variation within the trials but even where production was generally found to be producing negative imputed net margins (particularly in Uganda) herbicides still demonstrated an ability to reduce the size of these and contribute to improved economic viability.

The contribution of herbicides to the determination yields, gross and net margins was out-weighed by inter-season and inter-site variation, often by several factors. It is this seasonal variation that makes it difficult for farmers to perceive the long- and short-term benefits associated with herbicides and creates a big challenge in the promotion of these products to resource poor farmers. This is added to other constraints to adoption associated with poverty, knowledge and access to credit, indicating the need for a broad dissemination and advocacy approach.

PROJECT STAFF AND COLLABORATORS

KARI National Agricultural Research Laboratories, Nairobi, Kenya	Mr G N Kibata Dr J M Maina E G Thuranira
KARI Regional Research Centre, Muguga, Kenya	Mr F J Musembi Mrs G Nyanyu
KARI Regional Research Centre, Embu, Kenya	Mr J Muthamia Mr J O Okuro Mr I Mutura Mr S Amboga Mr A N Micheni D r F M Mureithi
NARO Namulonge Agricultural and Animal Production Research Institute, Kampala, Uganda	Dr J Kikafunda Mr S B Kaboyo
Makerere University, Kampala, Uganda	Mrs F B Kyazze
Ministry of Agriculture, Animal Industry and Fisheries, Kampala, Uganda	Mrs R Nyamutale
Uganda field staff:	
Pakanyi, Masindi	Mr A Mukasa
Bukanga, Iganga	Mr J Bakalikwira
Bukhalu, Mbale	Mr M Napokoli
Natural Resources Institute, Chatham, UK	Dr D Overfield
IACR-Long Ashton Research Station, University of Bristol, UK	Mr P J Terry

CONTENTS

1. BACKGROUND

Maize is one of the most important food crops in East Africa and is the major staple food crop of Kenya (Chui *et al.*, 1997). It is grown by millions of smallholder farmers and is also produced on large, capital-intensive estates. Maintaining and increasing the production of maize is essential to meet the nutritional requirements of the region and to provide income for farmers who sell their crop. Weeds are one of the major constraints to production, causing significant crop losses. Akobundu (1987) cites losses of 34% in maize yield in Kenya by uncontrolled weeds, indicating the potential for significant damage. Many weed species occur in maize but the most problematical include perennial grasses (*Digitaria abyssinica, Cynodon dactylon* and *Pennisetum clandestinum*), annual grasses (*Rottboellia cochinchinensis, Setaria pumila, Setaria verticillata, Digitaria velutina* and *Eleusine indica*) and perennial sedges (*Cyperus rotundus* and *Cyperus esculentus*). Parasitic weeds (*Striga hermonthica* and *S. asiatica*) also cause serious crop loss in parts of East Africa. In small-scale farming systems, where little or no herbicide is used, the main problem is the competitive effect of a multispecies weed community as opposed to a single dominant species. However, when weed control is intensified, there is a tendency for the 'easy-to-control' species to be replaced by problem weeds. Hence, good weed management anticipates and seeks to prevent the establishment and proliferation of problem species.

Weed control is labour intensive when done with widely used and traditional hand tools. A typical recommendation is to weed maize twice in a season, once at 10 days after emergence and again at 30-40 days. Failure to remove weeds at these times exposes the crop to weed competition at a critical stage in its growth. However, farm households face acute labour shortages at critical weeding times; these shortages delay weeding and increase subsequent yield losses. Household labour constraints are often socially generated (related to the status and roles of women) and are being exacerbated by two factors reducing the size of the economically active population in rural areas: (a) rural/urban migration, and (b) HIV/AIDS, particularly in Uganda. Hence, this project addressed the critical socio-economic factors associated with weed control in developing improved weed control systems. Participatory techniques were used throughout and were closely linked to a project, *Socio-economic study of the uptake of herbicide technology in maize cropping systems* (HP104).

Plate 1. Smallholder maize farms in Kiambu District, Kenya

Alternatives to hand weeding are mechanical tillage, herbicides, cover crops, intercropping, etc. All of these methods are being used to some extent in East Africa and have been researched over several decades. There is no technical reason why virtually weed-free maize should not be grown in East Africa; the constraints are social and economic but environmental issues, such as increased soil erosion and loss of biodiversity, are also important. Hence, there is a demand to provide appropriate technology that meets socio-economic requirements and is delivered within the correct institutional settings.

Intercropping of maize and beans is a popular and predominant cultural practice among resource-poor farmers in central Kenya (Ikombo *et al.*, 1994). Maina *et al*. (1996) studied various combinations and spacings of maize and beans, concluding that two rows of beans intercropped with maize gave the better weed control and higher total yields and land equivalent ratios than a single row of beans. Chui *et al.* (1997) showed that a maize/bean intercrop treated with a herbicide mixture (metobromuron + metolachlor) gave good weed control in on-farm trials. Whilst total grain yields were not significantly affected by this and other methods of weed control which were tested, farmers indicated that they wanted to adopt this effective labour-saving technique.

Terry (1975) gave an overview of weed management in maize, based on the agricultural practices and potential in East Africa. This provided recommendations on land preparation, manual and mechanical weed control, and herbicides. Whilst this book has value as a teaching text and as a reference for researchers and the pesticide industry, it (and most other publications on weed control in maize) are not of direct benefit to smallholder farmers without a mechanism for demonstrating and transferring the technology.

Weed control is one component of the management of crops. Farmers have to maintain soil fertility, prevent erosion, conserve (or drain) water, control pests, etc. Good weed control must be a component of integrated crop production and conservation of resources. Likewise, crop management should not lead to unacceptable increases in the weed burden, such as can occur when uncompetitive crop varieties or row spacings are used.

Various organizations, including CIMMYT, Rockefeller Foundation, ICIPE and the African Highlands Initiative (AHI), are supporting research on maize-based farming systems in East Africa, which includes the universities, and NGOs. It was intended that this CPP-funded weed project would provide a weed dimension to this research, adding value to the activities of other organizations whilst also benefiting from their activities in terms of human and physical resources and research experience. The project involved weed scientists from KARI, including one (Dr J M Maina) who recently completed an ODA (DFID)-sponsored PhD on intercropping of maize in Kenya.

The project was implemented in Kenya and Uganda but the outputs will have wider applicability in smallholder maize production, especially in Africa.

2. PROJECT PURPOSE

The project sought to improve weed management in maize-based, smallholder farming systems in Kenya and Uganda through adaptive research. It achieved this by supporting national programmes in Kenya and Uganda and through links to a CPP project, *'Socio-economic study of the uptake of herbicide technology in maize based cropping systems'* (R7404) (Overfield, 2001).

3. RESEARCH ACTIVITIES

3.1 Trial design and approach

Trials were conducted in two districts of Kenya (Embu and Kiambu) and three districts of Uganda (Iganga, Masindi and Mbale) over a period of four maize growing seasons, covering two short rains and two long rains between 1999 and 2001. In total, 110 farmers were involved in the trials, many of them over all four seasons.

A consortium of local researchers, extension services and farmers managed the trials. The farm households involved were volunteers and were regarded as full research partners and representatives of their communities. There was considerable consultation with communities during the planning and initial trial execution. The trials were of a type II design, with the emphasis placed on researcher management, with the intention of movement to type III design (essentially farmer managed) during the latter stages of the project. The only inputs provided by the project were advice, herbicides and the appropriate application equipment.

On farm trial sites were selected randomly from divisions within the three districts of Uganda and two districts of Kenya. Every participating farmer compared his/her practice of weeding maize with a plot that was treated with herbicide plus supplementary hand weeding if necessary. In all other aspects (e.g. crop variety, spacing, fertilizer use), the plots were treated identically. Farmers in all districts planted crops according to their preferred practice.

On each farm, two areas were demarcated side by side on the sown area, one for a herbicide treatment, the other for the farmer's standard practice of hand weeding. In Embu District, all plots had areas of 500m^2 but in other districts there was considerable variability. In Kiambu, for example, plot sizes ranged from 83 to 1,256 m^2 with an average size of 577 m^2. On one plot, pre-emergence herbicide was applied to moist soil using a locally purchased knapsack sprayer. Herbicide treatments were selected according to availability in local markets and appropriateness for the crops and weeds. They were applied according to recommended practices. In Kiambu, a tank mixture of alachlor plus linuron at the rate of 1.2 + 0.6 kg a.i./ha was applied to sole crop maize and maize/bean intercrops. In Embu, the herbicide was a pre-formulated mixture of alachlor + atrazine for sole crop maize at a rate of 1.7 + 0.7 kg a.i./ha, or alachlor + linuron for maize/bean intercrops at a rate of 1.7 + 1.0 kg a.i./ha. The pre-formulated mixture of atrazine plus alachlor was also applied to sole crop maize in Uganda at a dose rate of 1.75 + 1.0 kg a.i./ha. Glyphosate at a dose rate of 1.08 kg a.e./ha was also used on some farms in Uganda as a minimum tillage treatment for land preparation prior to planting and the subsequent application of alachlor at 2.5 kg a.i./ha as a residual herbicide. A researcher or trained farmer applied the herbicides with emphasis placed on the safe application and handling of pesticides. Supplementary hand weeding should have been done as necessary but farmers did not rigorously apply this. The adjacent plot received no herbicide and was subjected to the farmer's practice of hand weeding as necessary (usually twice during the season). Farmers recorded the time spent weeding on both plots.

Weeds were assessed twice during each season, typically at 2-3 weeks and 7-8 weeks after germination (WAG) of the crop, coinciding with the times that farmers do their first and second weeding, respectively. Methods of assessment varied between districts according to the resources available and the experience of the monitoring staff. They followed commonly used protocols for assessing weeds, including subjective estimates of percentage ground cover, weed densities (based on counts of weeds in randomly placed quadrats), fresh weights and dry weights (also from random quadrats).

Wherever possible, plots were harvested to determine grain weights. Socio-economic analyses were done to determine the benefits of each treatment and farmers' perceptions were recorded during field days and through structured questionnaires. Further information on assessment techniques are given in project reports and publications (Annex 2)

During the period of these trials, there was wide climatic variation between seasons leading to considerable variation in the project data and the creation of some incomplete seasonal records. Opportunities for data collection were sometimes lost when farmers weeded or harvested their crops before assessments could be made or when plots were abandoned. Crop yields, labour costs, net benefits and gross revenues were subjected to statistical analyses but weed data were only subjected to the calculation of simple means.

4. OUTPUTS

4.1 Characterisation of weeds

All sites had mixed weed floras, typical of smallholder farming systems where weeding is done by hand. Species recorded from each district are given in Annex 1 and the main weed groupings are summarised in Table 1.

Table 1. Number of weed species by category in five districts of Kenya and Uganda

District	Total	Annuals	Perennials	Broad-leaves	Grasses	Sedges
Embu	22	19	3	15	6	1
Kiambu	62	54	8	46	11	5
Iganga	15	10	5	6	9	0
Masindi	11	5	6	5	5	1
Mbale	10	7	3	6	3	1

Perceptions of the importance of individual species of weeds varied between districts. In Uganda, *Digitaria abyssinica* (couch grass) was rated to be the most important weed in all three districts because this perennial grass is difficult to control. *Commelina* spp. and *Euphorbia heterophylla* are also difficult to control, especially in wet periods when the weeds rapidly become re-established after cultivation. The perennial sedge *Cyperus rotundus* was important in Mbale. In recent years, *Acanthospermum hispidum* has become an important weed in Mbale, where cattle rustlers may have introduced it from Karamoja.

The commonest weeds recorded from Embu district were *Digitaria velutina, Galinsoga parviflora, Commelina benghalensis* and *Digitaria abyssinica*. *Oxalis latifolia* was the commonest weed in Kiambu district, followed by *Galinsoga parviflora, Tagetes minuta, Bidens pilosa* and annual grasses.

The conclusion to be drawn about the weed flora is that all five districts had species, mostly annuals that can be controlled by hand weeding. However, all districts had perennial weeds as a component of the flora that tended to be difficult to control.

4.2 Control of weeds

Compared with the farmers' practice of hand weeding, all herbicide treatments reduced the density, mass (fresh or dry weights) or percentage cover of weeds at the first and second assessment times in all districts and in all seasons (Tables 2-6). A very rough indication of the efficacy of herbicides is that they gave about 75% control of weeds at the first assessment and about 65% control at the second assessment when averaged over all sites and seasons. As the assessments were done immediately before the farmers weeded their crops, it is not surprising that herbicides appeared to give good weed control. This is what the project aimed to demonstrate; that herbicides can give reasonably good control of weeds but using considerably lower labour inputs than the conventional practice of hand weeding.

Table 2. Weed assessments in Embu District, 1999-2001

Season	Crop	Herbicide	Dose kg a.i./ha	Assess-ment time	Assess-ment g/m^2 or $no./m^2$	No. of farmers	Farmer practice	Herbicide treatment
1999-00	Maize	alachlor + atrazine	1.7 + 0.7	1st	Dry wt	10 / 9*	360.8	5.0
"	Maize + beans	alachlor + linuron	1.7 + 1.0	"	"	3	248.8	0.2
2000	Maize	alachlor + atrazine	1.7 + 0.7	1st	Dry wt	18	105.8	33.5
"	Maize + beans	alachlor + linuron	1.7 + 1.0	"	"	11	148.9	47.1
2000-01	Maize	alachlor + atrazine	1.7 + 0.7	1st	Dry wt	17	399.9	44.5
"	"	" "	"	"	Fresh wt	17	500.0	57.3
"	"	" "	"	"	Density	17	203.7	28.9
"	"	" "	"	2nd	Fresh wt	17	144.3	30.0
"	"	" "	"	"	Density	17	28.9	6.8
"	Maize + beans	alachlor + linuron	1.7 + 1.0	1st	Dry wt	10	186.2	41.5
"	" "	" "	"	"	Fresh wt	10	155.1	29.1
"	" "	" "	"	"	Density	10	183.7	30.1
"	" "	" "	"	2nd	Fresh wt	10	154.9	13.9
"	" "	" "	"	"	Density	10	63.0	6.6
2001	Maize	alachlor + atrazine	1.7 + 0.7	1st	Dry wt	18	234.6	136.2
"	Maize + beans	alachlor + linuron	1.7 + 1.0	1st	"	26 / 11	216.5	79.7

* 10 / 9 indicates that 10 plots had the farmer's practice and 9 had the herbicide treatment, etc.

Table 3. Weed assessments in Kiambu District, 1999-2001

Season	Crop	Herbicide	Dose kg a.i./ha	Assess-ment time	Assess-ment % or g/m^2	No. of farmers	Farmer practice	Herbicide treatment
1999-00	Maize	alachlor + linuron	1.2 + 0.6	1st	% cover	7 / 8	39.3	1.9
"	"	" "	" "	1st	Dry wt	7	18.5	1.8
"	"	" "	" "	2nd	"	5 / 6	116.6	101.2
2000	Maize	alachlor + linuron	1.2 + 0.6	1st	Dry wt	10	31.1	14.8
"	"	" "	" "	2nd	"	10	8.9	7.6
2000-01	Maize	alachlor + linuron	1.2 + 0.6	1st	Dry wt	10 / 12	6.7	0.3
"	"	" "	" "	2nd	"	12	8.5	2.5
"	Maize + beans	alachlor + linuron	1.2 + 0.6	1st	"	13 / 18	11.1	0.7
"	" "	" "	" "	2nd	"	15	13.4	3.8
2001	Maize	alachlor + linuron	1.2 + 0.6	1st	Dry wt	10	11.3	0.5
"	"	" "	" "	2nd	"	9	18.3	4.4
"	Maize + beans	alachlor + linuron	1.2 + 0.6	1st	"	9	9.5	0.9
"	" "	" "	" "	2nd	"	9	14.4	3.4

Table 4. Weed assessments in Iganga District, 2000-2001

Season	Crop	Herbicide	Dose kg a.i./ha	Assess-ment time	Assess-ment %	No. of farmers	Farmer practice	Herbicide treatment
2000-01	Maize	alachlor + atrazine	1.75 + 1.0	1st	% cover	9	66.2	9.7
"	"	glyphosate	1.08	"	"	3	66.2	0.0
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	2	66.2	0.0
"	"	alachlor + atrazine	1.75 + 1.0	2nd	% cover	9	63.9	43.6
"	"	glyphosate	1.08	"	"	3	63.9	2.0
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	2	63.9	21.7
2001	Maize	alachlor + atrazine	1.75 + 1.0	1st	% cover	9	71.4	23.9
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	5	81.6	20.6
"	"	alachlor + atrazine	1.75 + 1.0	2nd	% cover	9	49.2	30.8
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	5	64.8	17.6

Table 5. Weed assessments in Masindi District, 2000-2001

Season	Crop	Herbicide	Dose kg a.i./ha	Assess-ment time	Assess-ment %	No. of farmers	Farmer practice	Herbicide treatment
2000	Maize	alachlor + atrazine	1.2 + 0.6	1st	% cover	14	85.2	39.6
"	"	glyphosate	1.08	"	"	9	85.2	29.4
"	"	alachlor + atrazine	1.2 + 0.6	2nd	"	14	3.7	5.0
"	"	glyphosate	1.08	"	"	9	3.7	3.0
2000-01	Maize	alachlor + atrazine	1.2 + 0.6	1st	% cover	7	61.4	33.0
"	"	glyphosate	1.08	"	"	8	61.4	24.0
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	9	61.4	26.6
"	"	alachlor + atrazine	1.2 + 0.6	2nd	% cover	7	39.9	0.0
"	"	glyphosate	1.08	"	"	8	39.9	1.1
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	9	39.9	0.0
2001	Maize	alachlor + atrazine	1.2 + 0.6	1st	% cover	1	60.0	43.0
"	"	glyphosate	1.08	"	"	2	13.0	2.0
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	3	50.7	5.5
"	"	alachlor	2.5	"	"	9	42.2	13.0
"	"	alachlor + atrazine	1.2 + 0.6	2nd	% cover	1	64.0	0.0
"	"	glyphosate	1.08	"	"	2	8.0	0.0
"	"	glyphosate + alachlor	1.08 + 2.5	"	"	3	21.3	0.0
"	"	alachlor	2.5	"	"	9	19.9	1.1

Table 6. Weed assessments in Mbale District, 2000-2001

Season	Crop	Herbicide	Dose kg a.i./ha	Assess-ment time	Assess-ment %	No. of farmers	Farmer practice	Herbicide treatment
2000	Maize	alachlor + glyphosate	2.5 + 1.08	1st	% cover	4	73.3	0.1
"	"	glyphosate	1.08	"	"	4	73.3	1.0
"	"	alachlor + glyphosate	2.5 + 1.08	2nd	% cover	4	48.3	22.2
"	"	glyphosate	1.08	"	"	4	48.3	24.1
2000-01	Maize	alachlor + glyphosate	2.5 + 1.08	1st	% cover	2	87.3	10.0
"	"	glyphosate	1.08	"	"	5	87.3	14.4
"	"	alachlor + glyphosate	2.5 + 1.08	2nd	% cover	2	41.3	26.0
"	"	glyphosate	1.08	"	"	5	41.3	53.2
2001	Maize	alachlor + glyphosate	2.5 + 1.08	1st	% cover	7	84.3	30.9
"	"	alachlor	2.5	"	"	2	90.5	36.5

The differences between treatments for individual species of weeds were recorded on only one occasion because of the high demand for researchers' time. Alachlor + atrazine in sole crop maize and alachlor + linuron in maize intercropped with beans greatly reduced the fresh weights of weeds in the 2000-01 short rains season at Embu (Table 7).

Table 7. Fresh wt of weeds (g/m^2) at Embu District in short rains 2000-01

Weed	Sole maize		Maize + beans	
	Farmer practice	Alachlor + atrazine	Farmer practice	Alachlor + linuron
Digitaria velutina	121.0	0.4	64.2	0.0
Eleusine indica	27.6	0.0	6.2	0.0
Rottboellia cochinchinensis	15.7	4.7	2.7	0.3
Setaria pumila	3.8	0.1	0.2	0.0
Total annual grass	**168.1**	**5.2**	**73.3**	**0.3**
Acanthospermum hispidum	9.7	1.4	2.2	1.2
Ageratum conyzoides	0.9	0.0	0.3	0.0
Bidens pilosa	6.4	2.3	0.6	0.0
Cleome monophylla	3.3	0.7	4.4	2.1
Euphorbia hirta	53.3	15.6	8.4	1.9
Fallopia convolvulus	2.1	0.0	2.3	0.1
Galinsoga parviflora	19.7	0.0	14.8	0.0
Oxygonum sinuatum	60.3	8.9	23.9	5.6
Portulaca oleracea	36.1	0.0	0.9	0.0
Sida alba	0.1	0.0	0.9	8.0
Sonchus oleraceus	6.2	0.0	0.0	0.0
Total annual broadleaves	**198.2**	**28.9**	**58.8**	**18.9**
Cyperus spp.	3.0	0.0	1.8	0.9
Commelina spp.	127.8	23.2	11.0	9.0
Digitaria abyssinica	2.9	0.0	10.2	0.0
Total perennial weeds	**133.7**	**23.2**	**23.0**	**9.9**

4.3 Labour costs

The most important benefit associated with herbicides is the reduction in the amount of labour required which both reduces production costs and alleviates labour bottlenecks allowing more timely weed control and improved yields. Table 8 and Figure 1 summarise the information from the trials and indicate that labour costs were reduced, on average, by nearly 42 per cent. There were variations between the different areas but in all cases (across all seasons) labour costs were reduced. However these results are much more difficult to interpret statistically because of the influence of substantial outliers (which cannot really be removed from the analysis because of their large numbers) and the distribution of these is presented in Figure 2 (highly skewed distribution). There are strong indications that herbicides dramatically reduce labour requirements but this cannot be statistically proven on the basis of these data. Labour data from Kenya indicate that there is a 72 per cent reduction in labour requirements when herbicides are applied. This difference is statistically significant and 95% confidence intervals indicate that there is a reduction in labour of between 57% and 88% where herbicide application takes place.

Table 8. Labour costs (£/hectare) for each district in four cropping seasons

District	Weed control treatment	Short rains 1999/2000	Long rains 2000	Short rains 2000/01	Long rains 2001	Average for all seasons
Embu	Farmer practice	26.67	27.79	26.79	34.42	28.91
	Herbicide	3.07	3.52	3.12	3.43	3.28
	Difference	**-23.61**	**-24.27**	**-23.68**	**-30.98**	**-25.63**
Kiambu	Farmer practice	337.91	38.31	81.32	147.75	117.29
	Herbicide	108.15	52.98	43.23	-	43.92
	Difference	**-229.76**	**+14.67**	**-38.08**	**-**	**-73.37**
Iganga	Farmer practice	-	539.91	116.43	183.48	247.54
	Herbicide	-	461.49	51.94	152.23	193.77
	Difference	**-**	**-78.14**	**-64.49**	**-31.25**	**-53.76**
Masindi	Farmer practice	-	-	92.77	253.61	189.88
	Herbicide	-	-	190.44	189.23	168.16
	Difference	**-**	**-**	**+97.67**	**-64.38**	**-21.71**
Mbale	Farmer practice	-	97.91	174.96	130.07	133.87
	Herbicide	-	59.66	105.26	107.99	52.92
	Difference	**-**	**-38.25**	**-69.7**	**-20.08**	**-80.95**
				Farmer's practice average		**100.45**
				Herbicide average		**58.52**
				Average difference		**-41.94**

Figure 1. Mean labour costs for farms in five districts

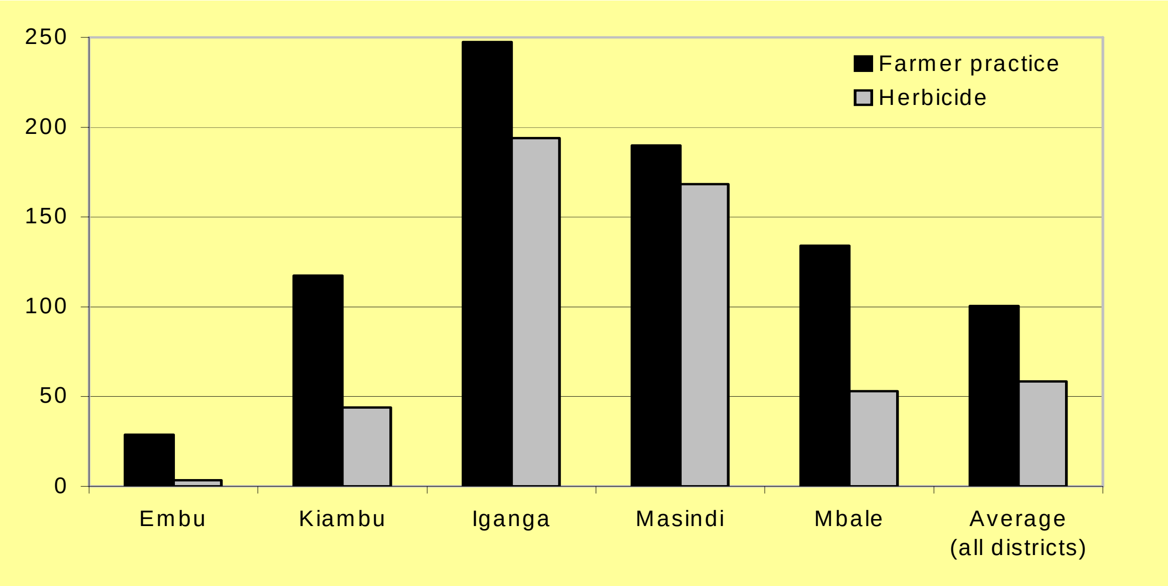
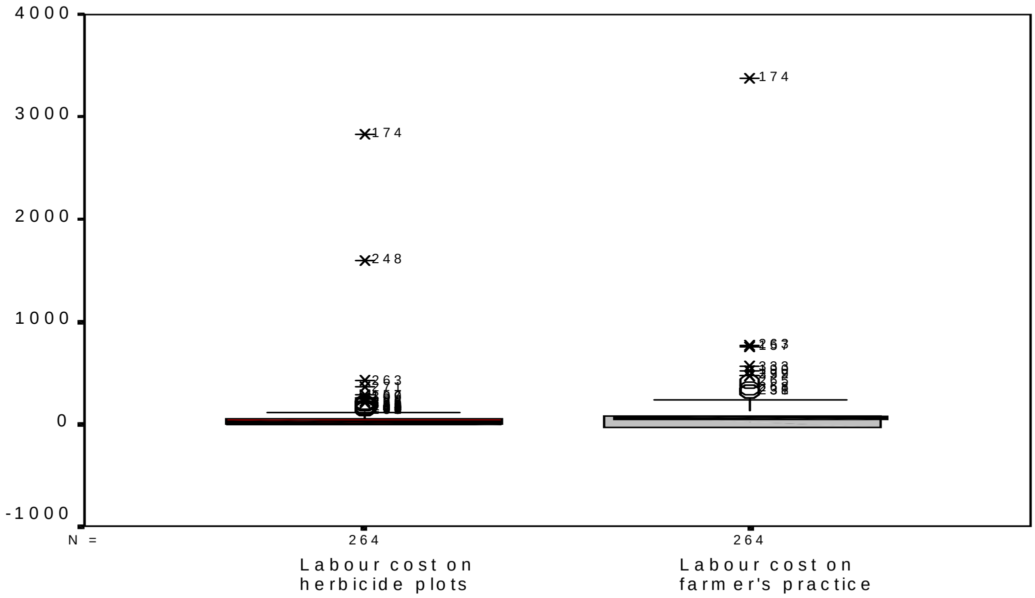


Figure 2. Box plot of labour costs (£/ha) overall

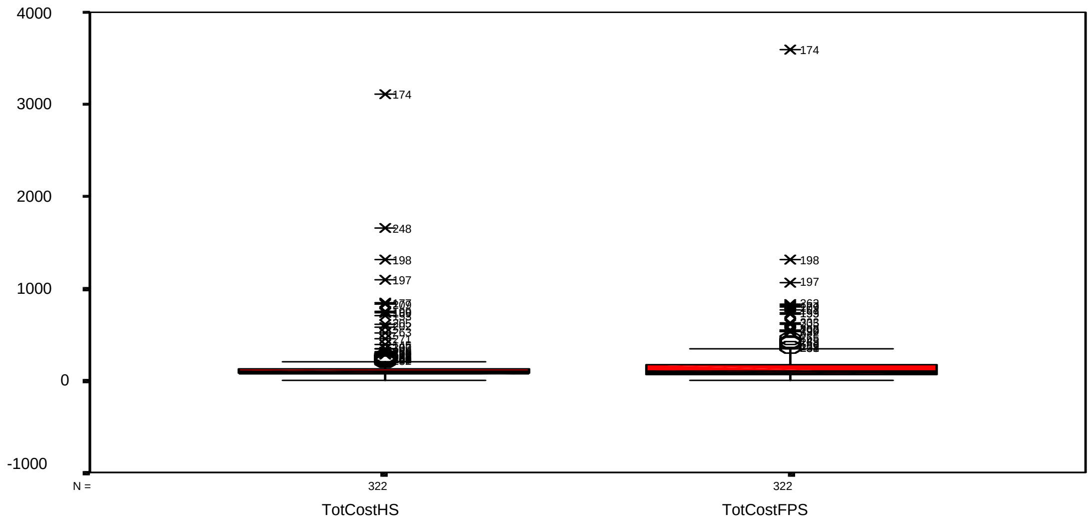


The application of herbicides, whilst reducing labour costs, incurs expenditure on chemicals and spray equipment. Table 9 summarises the overall cost situation and indicates that there is not a substantial difference between herbicides and the traditional practice of hand weeding. However, the same problem remains in interpreting the statistical differences in these cost data due to the high proportion of statistical outliers, which are summarised in Figure 2.

Table 9. Total production costs (£/ha)

District	Weed control treatment	Short rains 1999/0000	Long rains 2000	Short rains 2000/01	Long rains 2001	Average for all seasons
Embu	Farmer practice	75.98	76.10	72.28	72.76	74.20
	Herbicide	82.15	81.61	78.31	69.16	77.62
	Difference	**5.33**	**5.34**	**6.03**	**-3.23**	**3.18**
Kiambu	Farmer practice	348.20	91.04	130.36	170.95	153.68
	Herbicide	193.49	132.77	123.36	85.73	124.20
	Difference	**-154.71**	**41.73**	**-7.00**	**-80.73**	**-29.08**
Iganga	Farmer practice	-	473.00	123.52	471.74	356.05
	Herbicide	-	483.84	108.41	483.17	358.45
	Difference	**-**	**9.29**	**-14.03**	**11.43**	**2.23**
Masindi	Farmer practice	-	41.35	200.77	231.66	154.49
	Herbicide	-	77.26	159.11	332.00	180.65
	Difference	**-**	**35.90**	**-41.67**	**100.35**	**26.15**
Mbale	Farmer practice	-	166.67	317.37	102.03	190.05
	Herbicide	-	145.39	247.47	87.24	156.23
	Difference	**-**	**-21.28**	**-69.90**	**-13.15**	**-32.41**
					Farmer practice average	**147.85**
					Herbicide average	**144.59**
					Average difference	**-3.11**

Figure 3. Box plot of total production costs (£/ha) overall



Total cost on herbicide plots Total cost on farmer practice plots

4.4 Crop yields

Table 10 provides a summary of the yields obtained under these trials. It indicates that the application of herbicides increased yields by 21 per cent over standard farmers' practice (hand weeding) over the five sites and four seasons, and that this difference is statistically significant. The 95% confidence intervals indicate that this improvement is between 13% and 30% over normal farmers' practice in these areas. This is believed to be related to more timely weed control and the alleviation of seasonal (and gender) based labour constraints identified by a number of authors (most recently Overfield *et al*., 2001). Within this overall picture, there is considerable variation with yields being much higher in Kenya (especially in Kiambu) than in Uganda, but with herbicides making a positive, and statistically significant, contribution to yields at each site on average across all seasons. The short rains were so good at Masindi in 2000/01 that there was a glut of maize on the market and prices were so low that it was not economical for farmers to harvest the crop. There are individual site and season results which indicate the positive influence of herbicides (i.e. the mean difference is positive) but this cannot be statistically established for any one site because the confidence intervals are wide and do not retain positive signs throughout. These include Kiambu (Long Rains 2000, Long Rains 2001) and Iganga (Long Rains 2001). These results are highlighted in Figure 4.

A small number of farmers (14) were involved in intercropping in these trials and Figure 5 indicates the positive, and statistically significant, contribution of herbicides to bean yields over standard farmer practice. On average this was a 24 per cent improvement, with 95% confidence intervals indicating this could be between 2 and 45 per cent. The confidence intervals were wide at both sites and at Kiambu did not retain positive signs throughout (i.e. cannot statistically establish a positive yield effect due to herbicide).

Table 10. Average yields at project areas (t/ha)

Area	Treatment	Short rains 1999/00	Long rains 2000	Short rains 2000/01	Long rains 2001	Average All seasons
Embu	Farmer practice (FP)	1.12	*	2.57	1.09	1.81
	Herbicide (H)	1.61	*	3.15	1.56	2.21
	Difference between FP and H	0.48 (0.32-0.65)	*	0.59 (0.40-0.78)	0.47 (0.22-0.72)	0.40 (0.12-0.67)
Kiambu	Farmer practice (FP)	5.92	4.00	4.41	3.20	4.05
	Herbicide (H)	6.45	4.92	5.41	3.50	4.84
	Difference between FP and H	0.53 (0.33-0.72)	0.95 (-0.36-2.26)	0.99 (0.36-1.62)	0.31 (-0.55-1.17)	0.79 (0.34-1.24)
Iganga	Farmer practice (FP)	0.98	1.18	1.00	0.28	0.82
	Herbicide (H)	1.64	1.58	1.77	0.35	1.20
	Difference between FP and H	0.66	0.4 (0.14-0.65)	0.77 (0.48-1.05)	0.12 0.0-0.2	0.38 (0.18-0.45)
Masindi	Farmer practice (FP)	-	0.53	*	0.88	0.70
	Herbicide (H)	-	0.69	*	0.92	0.80
	Difference between FP and H	-	0.16 (0.11-0.20)	*	0.04 (0.01-0.07)	0.10 (0.06-0.13)
Mbale	Farmer practice (FP)	-	0.31	0.28	0.41	0.34
	Herbicide (H)	-	0.41	0.33	0.52	0.42
	Difference between FP and H	-	0.1 (0.02-0.16)	0.05 (0.02-0.11)	0.11 (0.05-0.21)	0.09 (0.04-0.12)
					Farmer practice average	1.84
					Herbicide average	2.22
					Average difference	0.38 (0.25-0.55)

* = no data due to climatic factors
\- = no data due to trial management problems

Figure 4. Maize yields (t/ha) averaged over all cropping seasons in five districts

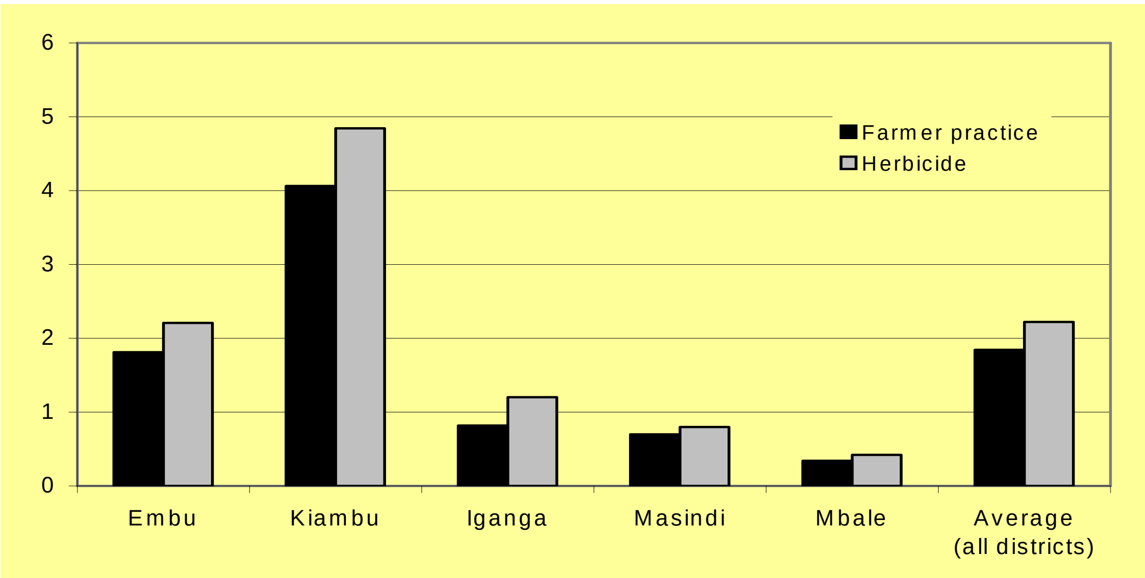
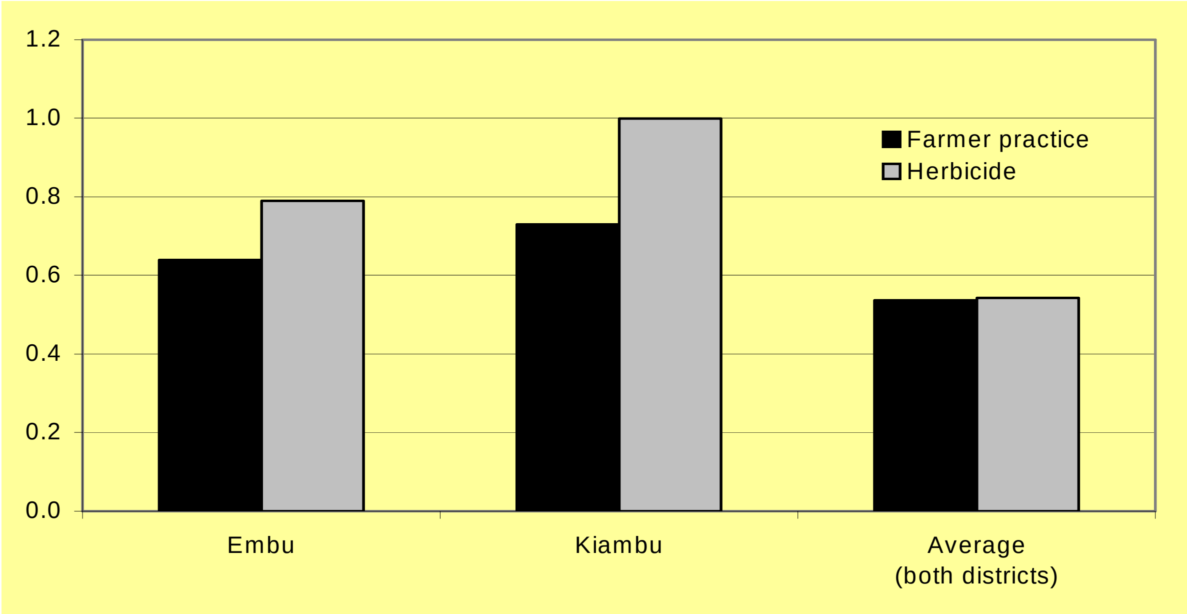


Figure 5. Bean yields (t/ha) averaged over all cropping seasons in Embu and Kiambu



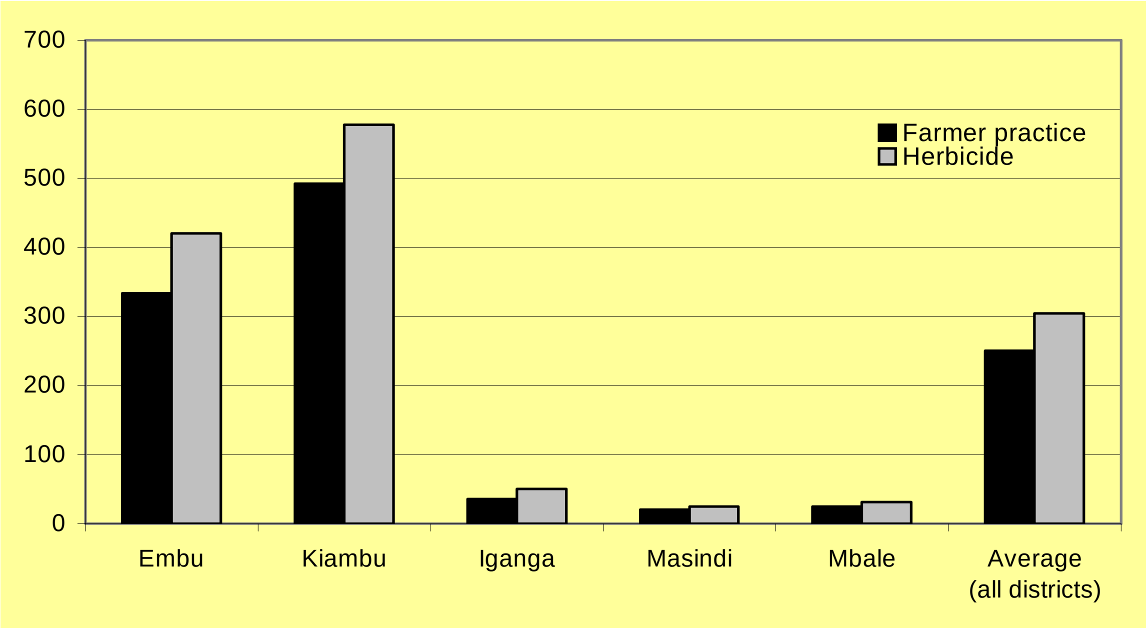
4.5 Gross margins

Yield levels and the prices that farmers receive for their produce, essentially determine gross margins (production multiplied by price). Table 11 and Figure 6 indicate that there is a lot of variation between different areas and seasons with most of this being determined by yield changes.

Table 11. Gross margins in districts and seasons (£/ha)

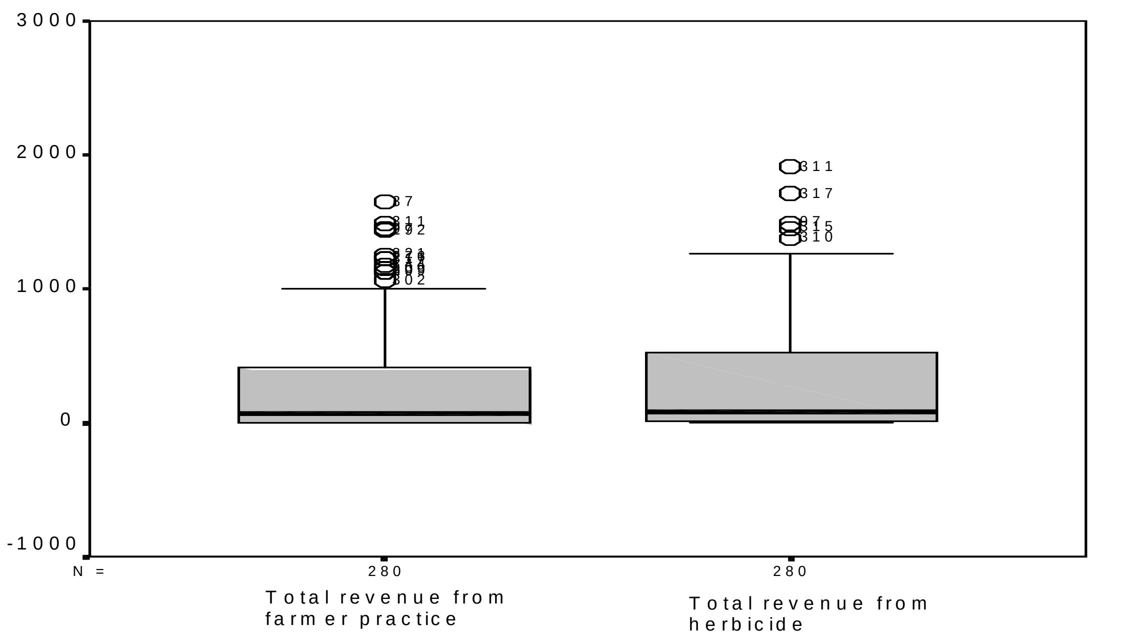
District	Weed control treatment	Short rains 1999/0000	Long rains 2000	Short rains 2000/01	Long rains 2001	Average for all seasons
Embu	Farmer practice	326.87	-	471.61	208.69	333.83
	Herbicide	375.93	-	604.12	276.57	419.98
	Difference	**49.06**	**-**	**132.51**	**67.88**	**86.16**
Kiambu	Farmer practice	235.65	399.40	628.17	485.41	492.28
	Herbicide	256.53	494.86	751.41	526.91	577.43
	Difference	**20.88**	**95.45**	**123.24**	**41.49**	**85.15**
Iganga	Farmer practice	-	88.69	17.31	6.50	35.39
	Herbicide	-	118.44	30.58	10.05	50.24
	Difference	**-**	**29.75**	**13.27**	**3.55**	**14.85**
Masindi	Farmer practice	35.25	-	29.47	-	20.70
	Herbicide	45.75	-	30.79	-	24.71
	Difference	**10.50**	**-**	**1.32**	**-**	**4.01**
Mbale	Farmer practice	-	32.79	29.05	13.68	25.00
	Herbicide	-	42.75	34.17	17.25	31.26
	Difference	**-**	**9.96**	**5.12**	**3.57**	**6.26**
					Farmer practice average	**250.61**
					Herbicide average	**304.76**
					Average difference	**54.14**

Figure 6. Gross revenue (£/ha) averaged over all cropping seasons in five districts



There is a strong indication that the application of herbicides may increase gross margins by 21 per cent on average, but there is a problem with statistical interpretation due to the influence of outliers summarised in Figure 7. However, in addition to this, there have been very adverse price movements in Uganda for farmers with prices in 2001 being only 40 per cent of those in 1999 and 2000, which have substantially reduced gross benefits in this period.

Figure 7. Box plot of gross revenues (£/ha) overall



4.6 Net margins

The most important financial measure of any technology to farmers is the level of profit, or net benefit, that it generates. Table 12 indicates that the net benefits of maize production when herbicide is applied are increased by nearly 42 per cent on average (over farmers practice), this been a product of increased yields (and hence revenue) and reduced labour costs. The analyses in previous sections indicate that total costs are barely changed by applying herbicide, implying that increased net benefits are mainly the result of yield improvements. However, net benefits increased by much greater levels than yields, indicating another source of benefits that can only be labour savings. Statistically it is difficult to interpret the differences, again due to the influence of substantial numbers of outliers which are summarised in Figure 8. It also important to note that these do not take account of the cost of spray equipment which according to calculations in Overfield *et al.* (2001) could increase costs and reduce net margins by £20-£30 per hectare, i.e. about 20 per cent of average current net benefits.

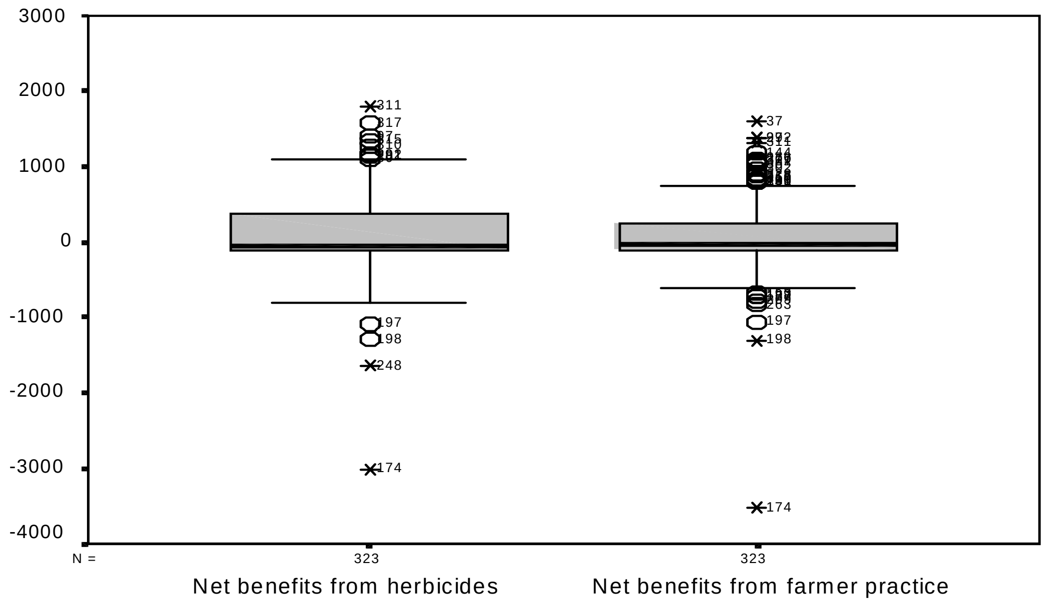
Table 12. Net margins (£/ha)

District	Weed control treatment	Short rains 1999/0000	Long rains 2000	Short rains 2000/01	Long rains 2001	Average or all seasons
Embu	Farmer practice	164.05	-76.10	372.38	135.92	153.84
	Herbicide	193.75	-81.61	491.28	207.41	209.16
	Difference	**29.70**	**-5.51**	**118.91**	**71.49**	**55.32**
Kiambu	Farmer practice	-112.54	308.37	497.81	314.47	338.58
	Herbicide	63.04	362.09	628.05	441.18	435.23
	Difference	**175.59**	**53.72**	**130.24**	**126.71**	**114.63**
Iganga	Farmer practice	-	-384.32	-106.21	-465.23	-320.66
	Herbicide	-	-365.40	-77.82	-473.12	-308.21
	Difference	**-**	**18.91**	**28.38**	**-7.88**	**-22.14**
Masindi	Farmer practice	-	-6.10	-200.77	-202.19	-133.79
	Herbicide	-	-31.51	-159.12	-301.22	-155.93
	Difference	**-**	**-25.40**	**41.67**	**-99.02**	**-22.13**
Mbale	Farmer practice	-	-133.88	-288.32	-88.35	-165.05
	Herbicide	-	-102.64	-213.30	-69.99	-124.96
	Difference	**-**	**31.23**	**75.02**	**18.36**	**40.08**
					Farmer practice average	**69.86**
					Herbicide average	**120.04**
					Average difference	**50.18**

4.7 Determinants of yields, gross benefits and net benefits

A number of OLS regressions were run to identify the determinants of yields, gross benefits and net benefits; the results are summarised in Table 13 with further details in the statistical appendices.

Figure 8. Box plot of net benefits (£/ha) overall



The primary interest of these trials was to establish the impact of herbicides. The results in Table 13 indicate that herbicides have a positive, and statistically significant, impact on maize yields, gross and net margins. These results also reveal that the influence of different areas and seasons often massively outweigh that of herbicides often by a factor of more than two. However, the factor with often the greatest influence is the presence of a bean intercrop; although this does have a negative impact on maize yield levels (as would be expected), it has a highly positive effect on gross and net margins, outweighing all other factors in gross margins.

All the estimated regression equations only explain about half of the variation in the dependent variables (yield, gross and net margins) but these represent the best-fit models.

Table 13. Summary of OLS regression analyses

Variable, factor or measure of fit	Maize yield	Gross benefits	Net benefits
Short rains 1999/2000	-0.14 (-3.79)***	-0.16 (-4.62)***	-0.20 (-5.61)***
Long rains 2000	-0.15 (-3.43)***	-0.05 (-1.372)	-0.03 (-0.83)
Long rains 2001	-0.28 (-6.99)***	-0.18 (-5.20)***	-0.19 (-5.22)***
Kiambu	0.49 (12.53)***	0.17 (4.48)***	0.07 (1.81)*
Mbale	-0.26 (-6.73)***	-0.21 (-6.12)***	-0.22 (-6.32)***
Iganga	-0.159 (-3.97)***	-0.26 (-6.94)***	-0.41 (-10.87)***
Masindi	-0.18 (-4.17)***	-0.32 (-8.23)***	-0.33 (-8.36)***
Herbicide	0.099 (3.04)**	0.07 (2.41)**	0.061 (1.95)**
Bean intercrop	-0.061 (-1.72)*	0.34 (10.27)***	0.29 (8.58)***
R2	0.561	0.486	0.449
F-ratio	59.364***	57.549***	51.709***

Significant at 90%; ** significant at 95%; *** significant at 99%
All coefficients are standardised and are all dummy variables
All coefficients retain signs throughout 95% confidence intervals – see statistical appendix for greater detail.

This is for a number of reasons: (a) for yields, all factors besides herbicides were held constant, and (b) for gross and net margins, the influence of prices and yields (and costs) have been left out because of strong co-linearity effects which may invalidate the estimated relationship (for example gross margins are the total product of yield and price). The important conclusion is that herbicides have a positive influence, but their impact is outweighed by other factors, particularly interseasonal variation. This makes it hard for farmers to see the benefits of herbicides when seasonal variation is so high – which makes promotion a very hard task.

4.8 Farmers' opinions

Farmers' views were sought throughout the project to ensure that the research was meeting their interests and aspirations. Surveys were done to gain their opinions about herbicide use and their responses are summarised in Tables 14 and 15. All recorded comments were positive about herbicide use. Increased crop yields, fewer weeds and reduced labour inputs were noted by farmers. Researchers were pleased that farmers had observed these effects as this had been a primary purpose of the project.

Table 14. Farmers' opinions concerning herbicide use in Kiambu District (n = 19)

Farmer’s opinion/observation	No. of farmers	% no. of farmers
Treated plots have less weeds than untreated plots	19	100
Herbicide could be effective/is good/preferred	12	63
Maize/beans had more vigour/growing fast in treated plots	14	74
Soil on treated plots loose/soft easy to weed/uproot weeds	5	26
No weeding done on treated plots	9	47
Delayed weeding on treated plots	10	53
Saved labour, time, cost	4	21
Herbicide has no residual effect on maize, beans, potatoes	3	16
Second weeding on treated plots done/necessary	1	5

NB: Where numbers of farmers is low, it is because the farmers didn’t reach that stage due to drought.

5. Contribution of Outputs

5.1 Contribution of outputs to project goal

The goal of the production system is "Yields improved and sustainability enhanced in high potential cropping system by cost effective reductions in losses due to pests." In participatory trials with over 100 farmers in Kenya and Uganda, the project has clearly demonstrated over four seasons that herbicides improve yields, reduce weed populations and they are cost effective compared with the farmers' practice of hand weeding. Sustainability could not be demonstrated within the three-year life of the project but cropping systems that deploy herbicides are sustainable in many parts of the world, particularly in the developed countries. However, there are grounds for believing that herbicides in maize-based cropping systems may not yet be a sustainable technology for Kenya and Uganda in the immediate future.

Table 15. Farmers' opinions concerning herbicide use in three districts of Uganda (n = 41)

Farmer's opinion/observation	No. of farmers	% no. of farmers
Less labour and time needed to weed	25	61
Less money spent on labour	13	32
No first weeding needed	9	22
Good maize growth	7	17
Improved maize yields	7	17
Weeds controlled	6	15
Light second weeding	5	12
No competition with weeds	4	10
Stubborn weeds controlled	4	10
Allows timely planting	3	7
Can manage and plant larger area	3	7
Saved cash	3	7
Time saved for other activities	3	7
Good crop germination	2	5
No weeding done	2	5
Reduced number of weedings	2	5
Cheaper land preparation	1	2
Decreased drudgery of weeding	1	2
Ground softer and easier to plough after herbicide application	1	2

A companion project (R7404) found that herbicides were used in maize by less than 3 per cent of the households surveyed in Kenya and Uganda (with no instances in Uganda at all). It was concluded that the prospects for widespread uptake of herbicides in maize are low, despite the potentially high benefits associated with yield improvements, removal of seasonal and gender-based labour constraints and cost reductions (labour savings). This is due to a number of binding constraints related to poverty, knowledge systems, poor access to credit and gender issues (particularly intrahousehold income flows).

Farmers may not yet adopt herbicides for maize production but the project succeeded in introducing them to the use of herbicides, especially for the control of noxious weeds. In Mbale, for example, farmers quickly recognised the benefits of using glyphosate for the control of the perennial grass weed, *Digitaria abyssinica*. They also recognised that herbicides reduced or eliminated dependency on hiring scarce and expensive labour.

5.2 Achievement of outputs stated in the project memorandum

Output 1. A literature review of weed management in East African, maize-based farming systems

Literature on weed management was reviewed but it was not published as a review article. Information on weed research in East Africa was identified and this provided a background against which project research was conducted. For example, the use of alachlor + atrazine for sole crop maize, and alachlor + linuron for maize inter-cropped with beans, was based on published research in Kenya.

Output 2. An analysis of weed management in maize and its relevance to farming systems in East Africa

In the study areas of five districts in Kenya and Uganda, over 70 different species of weeds were found, of which about 15% were perennial species. A socio-economic component of the project evaluated the potential of herbicides to contribute to the development of more economically viable maize-based farming systems in the region. It was shown that net benefits (i.e. profits) increased by 42 per cent over farmer practice. There was considerable variation within the trials but it was shown that herbicides can contribute to improved economic viability. However, inter-season variation makes it difficult for farmers to perceive the long- and short-term benefits and creates a big challenge in promoting herbicides to resource-poor farmers.

Output 3. Publications of research results in local and international journals

Research results have been disseminated through two international conferences, one regional conference and one local farming journal. The latter was produced in time for the Nairobi Show in 2001 where the journal was widely distributed. It is anticipated that at least one article will be prepared for publication in an international journal after the project has been completed.

Output 4. Recommendations to the extension service and other agricultural advisers in the form of appropriate dissemination products

Leaflets on weed control in maize have been prepared in English and Swahili. These A4-size, double-folded leaflets, containing line drawings and simple instructions, have been field tested to verify that farmers and extension officers understand them. The leaflets are being distributed to farmers and extension officers in all five districts of Kenya and Uganda where the project operated.

5.3 Contribution to DFID's development goals

Whilst the outputs of this project are unlikely to have any immediate, direct impact on the poorest farmers in a community, the benefits of herbicides have been seen by numerous farmers (many more than actually participated in the project). Feedback from collaborating farmers has been universally positive about the performance of herbicides, so there is a reasonable expectation that some farmers will use these products in the near future. It would be interesting to measure the impact of the project on these farmers in 2-3 year's time.

5.4 Promotion pathways to target institutions and beneficiaries

The project has reached stage ‘G’ (Promotion of technology among end users by target institutions) on the ‘A-H research uptake pathway’. The next step is the adoption of the technology by end users and generation of economic benefits. The project has sought to aid this process by working closely with farmers and extension officers in the on-farm trials and by producing literature that they can use. If these promotion activities are successful in encouraging the uptake of the outputs, the project will have contributed to the DFID programme purpose indicator of "adopting management strategies for the major pest constraints in maize-based cropping systems adopted in one country by 2003".

5.5 Follow up action/research to promote findings

At the final Stakeholder Workshop on 25 March 2002, the participating farmers recommended that (a) smaller, more affordable packets of herbicides should be available, and (b) credit facilities should be available to purchase herbicides and other inputs. The latter is beyond the scope of a CPP-funded project but packaging could be an appropriate topic for promotional research in partnership with the pesticide industry.

The project only addressed herbicide use through overall applications to treated plots. There is scope for reducing dose rates by 50% or more by using band applications over crop rows, providing that farmers are willing to use hand labour to control weeds in the untreated inter-rows. This is something that could be pursued by local research and extension officers.

Weed management using outputs of the project could be part of new research to be supported by the CPP on integrated crop management in maize.

5.6 Publications

5.6.1 Conference proceedings and posters

KIKAFUNDA, J. *ET AL.* (2001) Chemical weed control in maize-based cropping systems in Uganda. In: *Proceedings of the 18th Weed Science Society for Eastern Africa Conference*, Nairobi, Kenya, 29 Oct - 2 Nov 2001. [In press]

MAINA *ET AL*. (2001) Participatory development of weed management strategies in maize based cropping systems in Kenya. pp. 199-204. In: *Proceedings The BCPC Conference - Weeds 2001*, Brighton, 12-15 November 2001.

MUSEMBI, F. (2002). Farmers' perceptions of weed problems in maize-based cropping systems in Embu and Kiambu Districts, Kenya. In: *Proceedings 7th Eastern and Southern Africa Regional Maize Conference,* CIMMYT, Nairobi, 11-15 February 2002. [In Press]

MURITHI *ET AL.* (2000) Weed management practices in the maize cropping systems of the Central Highlands of Kenya. In: *Abstracts Third International Weed Science Congress*, Foz do Iguassu, Brazil, 7-11 June 2000. CD-ROM available from International Weed Science Society, Oxford, MS, USA.

MUTHAMIA, J. *ET AL*. (2001) Community approach to weed management practices in the maize-based cropping systems of Central and Eastern highlands of Kenya. In: *Proceedings of the 18th Weed Science Society for Eastern Africa Conference*, Nairobi, Kenya, 29 Oct - 2 Nov 2001. [In press]

MUTHAMIA, J. *ET AL.*, (2002) Participatory on-farm trials on weed control on smallholder farms in maize-based cropping systems. In: *Proceedings 7th Eastern and Southern Africa Regional Maize Conference,* CIMMYT, Nairobi, 11-15 February 2002. [In Press]

5.6.2 Journals

ANON (2001) Improving crop yields in smallholder maize based cropping systems through use of herbicides in Kenya. *Farmer's Journal* (Sept - Oct): 7-10.

5.6.3 Internal reports

Back-to-Office report, May-June 1999
Back-to-Office report, September 1999
Back-to-Office report, May 2000
Back-to-Office report, September-October 2000
Back-to-Office report, February-March 2001
Project completion summary sheet, March 2001
Final Technical Report, April 2001

Report of Planning Workshop on Herbicide Usage in Maize-based Farming Systems, KARI NARL, Nairobi, 27 June 1999.

Proceedings of Project Review and Planning Workshop, Jinja, Uganda, 27-28 February 2001.

OVERFIELD, D. *ET AL.* (2001) Analytical results of on-farm participatory trials. Report of Natural Resources Institute, December 2001.

5.6.4 Other dissemination of results

Fifteen field days were held for farmers (one per year in each of the five districts).

Three extension leaflets were produced on weed management in maize (4,800 in Swahili and 1,200 in English):

a. Zero tillage for maize and bean production in Kenya [Kilimo kisichotifua udongo kwa ukuzaji wa mahindi na maharagwe katika Kenya]
b. Use weed killers to grow maize [Tumia madawa ya kuangamiza kwekwe kwa shamba la mahindi]
c. Use of herbicides to save time and labour in maize and bean intercrops [Kutumia jembe dawa ili kuokoa wakati na kurahisisha kazi katika shamba la mahindi na maharagwe]

Video on weed control using herbicides. Produced by the Agricultural Information Centre, this 15-minute video will be broadcast several times in KARI's programmes on the national TV network.

6. ACKNOWLEDGEMENTS

All project staff and collaborators listed on page 3 of this report made significant contributions towards the success of the project. This would not have happened without the support and goodwill of over 100 farmers and their local extension officers. Assistance by all involved in the project is gratefully acknowledged.

7. REFERENCES

AKOBUNDU, I.O. (1987) *Weed Science in the Tropics: Principles and Practices*. John Wiley & Sons, 522 pp.

CHUI, J.N., KAHUMBURA, J.M. and KUSEWA, T.M. (1997) On-farm weed control in maize using cultural, physical and chemical methods. Proceedings of the Brighton Conference - Weeds, 179-184.

IKOMBO, B.M., ESILABA, A. and KILEWE, A.M. (1994) A diagnostic survey of the farming systems in Kiambu District; a report of survey results from Kikuyu, Kiambaa, Gatundu and Thika Divisions. Report of NARC Muguga, KARI.

MAINA, J.M., DRENNAN, D.S.H. and CHWEYA, J.A. (1996) Effects of intercropping on weeds and weed management. Proceedings of the Second International Weed Control Congress, Copenhagen, 749-759.

OVERFIELD, D. (2001) Socio-economic study of the uptake of herbicide technology in maize based cropping systems (R7404, ZA0301). Final Technical Report, University of Greenwich, Natural Resources Institute, Chatham, 39 pp.

TERRY, P.J. (1975) *A Guide to Weed Control in East African Crops*. Kenya Literature Bureau, Nairobi, 186 pp.

ANNEX 1

INVENTORY OF WEEDS IN FIVE DISTRICTS OF KENYA AND UGANDA

Iganga District, Uganda

Ageratum conyzoides	*Cymbopogon* sp.	*Euphorbia heterophylla*
Amaranthus sp.	*Cynodon dactylon*	*Galinsoga parviflora*
Biden pilosa	*Digitaria abyssinica*	*Imperata cylindrica*
Brachiaria sp.	*Digitaria velutina*	*Rottboellia cochinchinensis*
Commelina sp.	*Eleusine* sp.	*Setaria verticillata*

Masindi District, Uganda

Ageratum conyzoides	*Digitaria abyssinica*	*Panicum maximum*
Biden pilosa	*Euphorbia heterophylla*	*Pennisetum purpureum*
Commelina sp.	*Galinsoga parviflora*	*Rottboellia cochinchinensis*
Cyperus sp.	*Imperata cylindrica*	

Mbale District, Uganda

Acanthospenum hispidum	*Commelina* sp.	*Dactyloctenium aegyptium*
Ageratum conyzoides	*Galinsoga parviflora*	*Digitaria abyssinica*
Biden pilosa	*Cyperus* sp.	*Sorghum arundinaceum*
Cassia sp.		

Kiambu District, Kenya

Acanthospermum hispidum	*Cyperus teneristolon*	*Nicandra physalodes*
Ageratum conyzoides	*Dactyloctenium aegyptium*	*Oxalis corniculata*
Amaranthus graecizans	*Datura stramonium*	*Oxalis latifolia*
Amaranthus hybridus	*Digitaria abyssinica*	*Oxygonum sinuatum*
Amaranthus sp.	*Digitaria velutina*	*Panicum maximum*
Asystasia schimperi	*Eleusine indica*	*Phyllanthus* sp.
Bidens pilosa	*Eleusine multiflora*	*Portulaca oleracea*
Bromus sp.	*Eragrostis* sp.	*Rhynchelytrum roseum*
Celosia sp.	*Erucastrum arabicum*	*Richardia scabra*
Chenopodium sp.	*Euphorbia heterophylla*	*Rottboellia cochinchinensis*
Chenopodium murale	*Fallopia convolvulus*	*Senecio discifolius*
Chenopodium schraderianum	*Galinsoga parviflora*	*Solanum incanum*
Chenopodium sp.	*Galium spurium*	*Solanum nigrum*
Chloris pycnothrix	*Gnaphalium luteo-album*	*Sonchus oleraceus*
Cleome monophylla	*Gutenbergia cordifolia*	*Stellaria media*
Commelina benghalensis	*Ipomoea* sp	*Tagetes minuta*
Conyza bonariensis	*Launea cornuta*	*Thunbergia* sp.
Crotolaria sp.	*Leonotis* sp.	*Tridax procumbens*
Cyperus blysmoides	*Leucas martinicensis*	*Trifolium* sp.
Cyperus esculentus	*Mariscus macrocarpus*	*Xanthium strumarium*
Cyperus rigidifolius	*Mimosa* sp	

Embu District, Kenya

Acanthospermum hispidum	*Digitaria velutina*	*Portulaca oleracea*
Ageratum conyzoides	*Eleusine indica*	*Richardia brasiliensis*
Amaranthus sp.	*Euphorbia hirta*	*Rottboellia cochinchinensis*
Bidens pilosa	*Fallopia convolvulus*	*Setaria pumila*
Cleome monophylla	*Galinsoga parviflora*	*Setaria verticillata*
Commelina benghalensis	*Launaea cornuta*	*Sida alba*
Cyperus sp.	*Oxgonum sinuatum*	*Sonchus oleraceus*
Digitaria abyssinica		

ANNEX 2

STATISTICAL MODELS

The details of four statistical models are presented here: (1) determinants of maize yields; (2) determinants of gross margins; (3) determinants of net margins; (4) determinants of bean yields.

(1) Determinants of maize yields

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.749	0.561	0.552	1.3664

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, KIAMBU, IGANGA, 99SR, MASINDI, 00LR

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	997.585	9	110.843	59.364	.000
	Residual	780.480	418	1.867		
	Total	1778.065	427			

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, KIAMBU, IGANGA, 99SR, MASINDI, 00LR
b) Dependent variable: maize yield

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	2.543	.171		14.859	.000	2.207	2.880
	99SR	-.888	.235	-.142	-3.785	.000	-1.350	-.427
	00LR	-.743	.217	-.152	-3.430	.001	-1.169	-.317
	01LR	-1.216	.174	-.284	-6.986	.000	-1.558	-.874
	Herb Dummy	.402	.132	.099	3.042	.003	.142	.661
	KIAMBU	2.339	.187	.486	12.528	.000	1.972	2.706
	MBALE	-1.683	.250	-.256	-6.730	.000	-2.175	-1.192
	IGANGA	-.978	.247	-.159	-3.966	.000	-1.462	-.493
	MASINDI	-1.022	.245	-.176	-4.167	.000	-1.504	-.540
	IntercropAll	-.309	.180	-.061	-1.717	.087	-.663	.045

a) Dependent variable: maize yield

ANNEX 2 CONTINUED

(2) Determinants of gross margins

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.697	0.486	0.477	266.207

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, IGANGA, 99SR, KIAMBU, 00LR, MASINDI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	36704489.750	9	4078276.639	57.549	.000
	Residual	38834707.569	548	70866.255		
	Total	75539197.318	557			

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, IGANGA, 99SR, KIAMBU, 00LR, MASINDI
b) Dependent variable: gross benefit

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95% Confidence Interval for B Lower Bound	Upper Bound
1	(Constant)	352.779	30.112		11.716	.000	293.630	411.928
	99SR	-185.089	40.082	-.160	-4.618	.000	-263.823	-106.356
	00LR	-45.062	32.832	-.049	-1.372	.170	-109.555	19.431
	01LR	-142.795	27.525	-.181	-5.188	.000	-196.862	-88.727
	Herb Dummy	54.336	22.539	.074	2.411	.016	10.063	98.609
	KIAMBU	139.199	31.091	.166	4.477	.000	78.126	200.271
	MBALE	-286.470	46.786	-.214	-6.123	.000	-378.372	-194.567
	IGANGA	-272.005	39.213	-.256	-6.937	.000	-349.032	-194.978
	MASINDI	-300.447	36.503	-.318	-8.231	.000	-372.150	-228.744
	IntercropAll	339.257	33.028	.342	10.272	.000	274.380	404.133

a) Dependent variable: gross benefit

ANNEX 2 CONTINUED

(3) Determinants of net benefits

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.670	.449	.441	348.5870

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, IGANGA, KIAMBU, 99SR, 00LR, MASINDI

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	56549604.894	9	6283289.433	51.709	.000
	Residual	69262353.325	570	121512.901		
	Total	125811958.219	579			

a) Predictors: (Constant), IntercropAll, Herb Dummy, 01LR, MBALE, IGANGA, KIAMBU, 99SR, 00LR, MASINDI

b) Dependent variable: net benefits

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	288.828	38.422		7.517	.000	213.362	364.293
	99SR	-272.655	48.607	-.204	-5.609	.000	-368.125	-177.184
	00LR	-35.559	42.931	-.030	-.828	.408	-119.882	48.764
	01LR	-186.926	35.845	-.185	-5.215	.000	-257.330	-116.521
	Herb Dummy	56.447	28.949	.061	1.950	.052	-.412	113.306
	KIAMBU	72.757	40.221	.068	1.809	.071	-6.243	151.756
	MBALE	-384.671	60.917	-.223	-6.315	.000	-504.320	-265.021
	IGANGA	-553.444	50.928	-.405	-10.867	.000	-653.475	-453.414
	MASINDI	-395.684	47.325	-.326	-8.361	.000	-488.636	-302.731
	IntercropAll	367.033	42.771	.288	8.581	.000	283.024	451.041

a) Dependent variable: net benefits

ANNEX 2 CONTINUED

(4) Determinants of bean yields

Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.420	.177	.135	.48150

a) Predictors: (Constant), Herb Dummy, EMBU, 00SR, 99SR

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.931	4	.983	4.239	.004
	Residual	18.316	79	.232		
	Total	22.246	83			

a) Predictors: (Constant), Herb Dummy, EMBU, 00SR, 99SR
b) Dependent variable: bean yield

Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.592	.112		5.298	.000	.370	.814
	99SR	2.575E-02	.175	.018	.147	.883	-.323	.374
	00SR	-.241	.114	-.234	-2.111	.038	-.469	-.014
	EMBU	.294	.114	.285	2.586	.012	.068	.521
	Herb Dummy	.150	.105	.146	1.428	.157	-.059	.359

a) Dependent variable: bean yield

ANNEX 3

EXTENSION LEAFLETS

[English versions]