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Economic analysis of different options in integrated pest and soil fertility management in maize systems of Western Kenya

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Abstract

The major biotic constraints to the production of maize, the major staple food in Western Kenya, are field pests such as *Striga* and stem borers, and low soil fertility. To counter these constraints, new cropping systems have been developed, including "push-pull," rotations with promiscuous soybean varieties and green manure crops, and imidazolinone resistant- (IR-) maize. To analyze the technical and economic performance of these technologies, both with and without fertilizer, on-farm researcher-managed long-term trials were implemented over six seasons in two sites each in Vihiga and Siaya districts of Western Kenya. The economic results, based on marginal analysis using a multioutput, multiperiod model, show that the new cropping systems with fodder intercropping (push-pull) or soybean rotations were highly profitable. Push-pull is more profitable but requires a relatively high initial investment cost. Green manure rotation, IR-maize, and fertilizer all increased yields, but these investments were generally not justified by their increased revenue. We argue that research on rotation and cropping systems to tackle pest and soil fertility problems in Africa deserve more attention. This will require increased collaboration between agronomists and economists to set up long-term experiments with new cropping systems to develop proper economic models.

Keywords: *Striga*; Stem borers; Soil fertility; Participatory evaluation; Economic analysis; On-farm trials

1. Introduction

Agricultural production in sub-Saharan Africa (SSA) has difficulties keeping up with population growth. In East and Southern Africa, maize is the major food crop, and also an important cash crop (Pingali, 2001). But after the gains from the mid 1960s to the mid 1980s, maize yields in the region have, with the exception of South Africa, stagnated (FAOSTAT, 2009), indicating a decrease in production per capita. Traditional cropping systems included long fallow periods and shifting cultivation, which allowed soil replenishment and reduced pest problems. In densely populated areas such as Western Kenya, increased population pressure has strongly reduced the use of fallow, and continuous maize production is now common. This has led to decreased soil fertility and increased pest pressure, which is especially felt in the smallholder and subsistence sector. While intercropping with beans is common, rotation with legumes is rare, and the use of fertilizer, limited.

The policy environment has not been helpful either. There was an effort toward liberalization in Kenyan agriculture in the mid- to late 1990s, which saw the lifting of the controls of price and movement within the country on products such as maize (Wangia et al., 2004). While extension and other government services were scaled back, the private sector has been slow to replace those services, and input use, especially fertilizer, remains low (Crawford et al., 2003). Many export and cash crops are still dominated by government parastatals.

In discussions, maize farmers in Kenya consistently rank low soil fertility, *Striga* and stem borers as their major problems (De Groote, Okuro, et al., 2004; Odendo et al., 2001). Over the last decade, several new technologies have been developed to alleviate these constraints, including the push-pull technology for the stem borer and *Striga* control, imazapyr resistant (IR) maize for *Striga* control, and cereal-legume rotations to enhance the soil fertility status and reduce *Striga* incidence.

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The push-pull strategy was developed by the International Centre of Insect Physiology and Ecology (ICIPE) in collaboration with Rothamsted Research, and is defined as maize intercropped with a stem borer moth-repellent legume, *Desmodium*, and surrounded with an attractant host plant, Napier grass, planted as a trap plant for stem borers (Khan et al., 2000). Chemicals released by *Desmodium* roots induce abortive germination of the parasitic striga weed, providing control of this noxious weed (Khan et al., 2002).

IR-maize, developed by the International Maize and Wheat Improvement Centre (CIMMYT) and the Weizmann Institute, is resistant to imazapyr, a popular imidazolinone herbicide (Kanampiu et al., 2003). Its seed can be coated with the herbicide, which is first absorbed by the crop roots and later released, killing *Striga* seedlings and seeds (Kanampiu, Ransom, Friesen, et al., 2002), providing good control (De Groote et al., 2007), especially in the early growth stages (Kanampiu, Ransom, Gressel, et al., 2002), the period when most of the damage is done (Berner et al., 1995).

Soil fertility problems can also be addressed by the rotation of cereals with fast-growing nitrogen-fixing herbaceous legumes such as *Crotalaria* (Versteeg et al., 1998). Although this rotation substantially increases productivity (Ibewiro et al., 2000), adoption has been minimal, largely due to the lack of immediate benefits to the farmers, despite the research and extension efforts made by institutes such as the International Institute of Tropical Agriculture (IITA) and the Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT) (Vanlauwe et al., 2003). Grain legumes, such as cowpea or soybean, on the other hand, often leave little N in the soil since a large proportion of their nitrogen fixed is removed with the grains. Scientists at IITA in Nigeria have, therefore, developed dual purpose soybean varieties that produce large amounts of leafy biomass without compromising grain yields (Sanginga et al., 2003), and are able to establish symbiosis with native *Bradyrhizobium spp*., thus reducing the need for inoculation. Maize, growing after these improved soybean varieties, can double the grain yield compared to the control (Sanginga et al., 2002). Soybean and *Crotalaria* have been shown to reduce the *Striga* seed bank when planted in rotation with maize, due to the ability of these legumes to trigger suicidal germination of *Striga* (Carsky et al., 1994; Sanginga et al., 2003). *Striga* can also be reduced by improving soil fertility (Gacheru and Rao, 2001; Oswald, 2005; Oswald and Ransom, 2001). Given the interactions between soil-borne pests and soil fertility status, a new Integrated Pest and Soil Fertility management paradigm is emerging that aims, simultaneously, to alleviate soil nutrient depletion and the incidence of crop pests, and to optimize the total agroecosystem function. Healthy soils grow healthy crops or healthy crops require healthy soils to grow (Altieri and Nicholls, 2003).

Unfortunately, these technologies have not been submitted to rigorous economic analysis. Informal discussions with farmers indicate that many of these technologies do not work as well on-farm as expected, requiring more effort and yielding less output than expected. These hypotheses need to be tested with more complicated multiperiod and multioutput models, for which data are often lacking. While methods to calculate optimal soil fertility levels over time have been available for some time (Burt, 1981; Burt and Allison, 1963), they do not seem to have been applied to African agriculture, despite the prominence of the soil fertility problem in the literature (Barrett et al., 2002; Pender et al., 2006; Sanchez et al., 1997; Vanlauwe et al., 2002). Most analysis is limited to comparing new technologies or options over time, which is common in agroforestry research (Franzel, 2004; Jama et al., 1998).

To test these technologies by a multidisciplinary team and evaluate them with farmers and other stakeholders, a collaborative project was initiated in the Lake Victoria basin in 2003 by ICIPE, TSBF, CIMMYT, and the Kenya Agricultural Research Institute (KARI). In contrast to previous efforts, data were systematically collected to allow for an economic analysis using a multiperiod and multioutput model. The socioeconomic analysis of pest control methods was organized in five steps: (i) estimating the extent and intensity of the problem (or diagnostics); (ii) trials with and appropriate economic analysis of new control methods; (iii) farmer evaluation of these methods; (iv) modeling of the interactions; and (v) impact assessment (De Groote, 2007).

In this article, we focus on the second step: the economic analysis of on-farm trials. The objective of this study is to evaluate and compare the profitability of different pest and soil fertility management technologies over time. For this analysis, we expand the classic partial budget and marginal analysis to a multiperiod, multioutput model, and estimate a multiperiod profit function.

2. Methodology

2.1. Site selection and overview

The target zone for testing the technologies was the *Striga hermonthica* infested zone in Western Kenya, which has been identified as a band around Lake Victoria, from the shore at 1,100 meters above sea level (masl) to around 1,600 meters (De Groote et al., 2008). Within this zone, two districts were selected (Siaya and Vihiga), based on heavy *Striga* infestation and good accessibility (Fig. 1). In each of the districts, four sites were purposely selected for the Participatory Rural Appraisals (PRAs), which took place in 2002–2003. Participants discussed their production constraints, pest problems, and selection criteria for new technologies, and discussed with the scientists the different technologies and options that could be included in the participatory trials. In each district, two villages were purposely selected for participatory trials, based on easy access during the rainy season, presence of well-organized farmer groups and their interest in the project, and the ranking of severity of the Striga, stem borer, and soil fertility constraints during the PRAs.

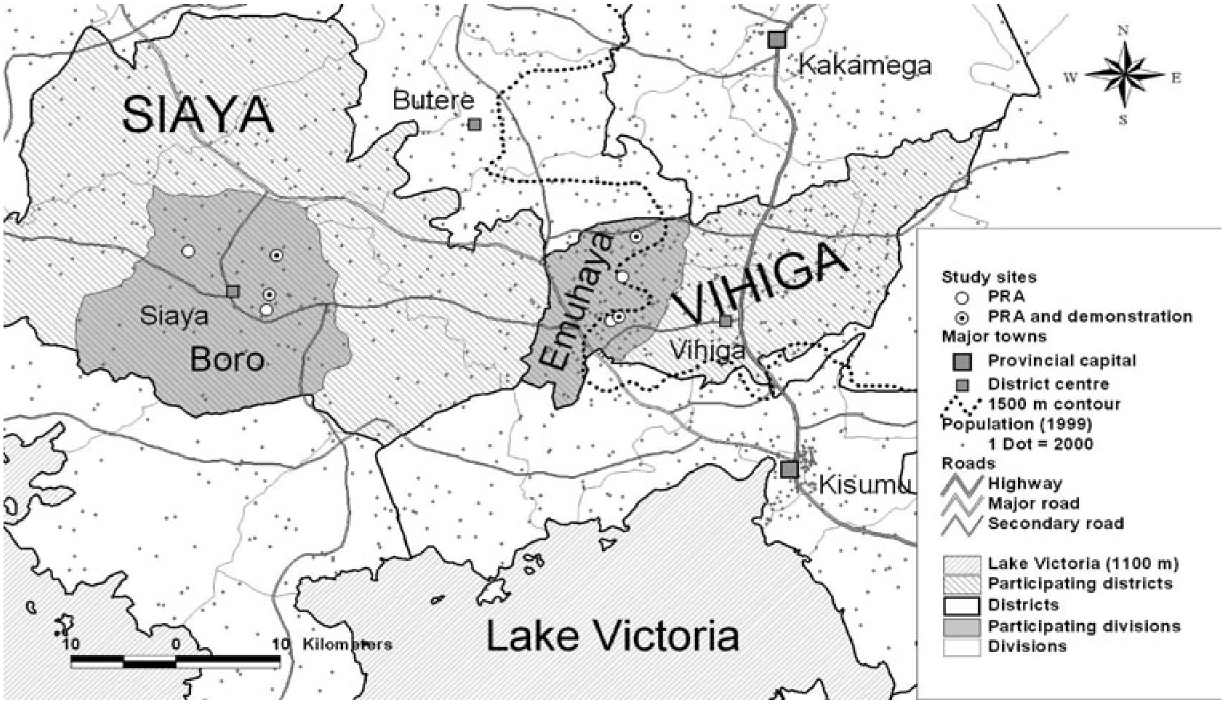

Fig. 1. Map of the study area with the PRA sites and demonstration sites.

The technologies to be tested in the trials were jointly agreed upon by scientists, extension staff, and the participating farmers. The trials were conducted over six consecutive seasons, during both the long and short rainy seasons, from 2003 until 2005. Data were regularly collected to allow for agronomic as well as economic evaluation, including scientists' observations on stem borer incidence, soil fertility problems, and the farmers' evaluation according to the criteria they had expressed during the participatory technology evaluation.

2.2. Diagnostics: assessing the importance of different production constraints

Before addressing a constraint by developing and disseminating new technologies, the importance of that constraint needs to be assessed by estimating the extent and the intensity of the problem at hand. Therefore, the literature on Western Kenya and the constraints addressed in the project were extensively reviewed, and combined with farmers' observations and opinions, captured during PRAs in the selected villages (Chambers, 1994). During the PRAs, tools such as group discussions, transect walks, and participatory mapping of the village were used (Werner, 1993). The group discussions were held with men and women, and followed a checklist of discussion points, including the importance of different crops and livestock, constraints in maize production, with an emphasis on pest and soil fertility problems, and selection criteria for maize varieties and cropping systems.

In total, 216 people, 115 of which were women, participated in 16 group discussions, organized with the men and women separated. Farmers discussed their farming systems and described their most important crop and livestock activities. They explained the constraints they face as farmers, elaborated on their major pest problems, and described the criteria they use to select maize varieties and cropping systems. Separate groups organized transect walks and mapped the major pest problems such as stem borers and *Striga*. The detailed results are reported elsewhere (Odhiambo et al., 2007). At the end of the PRAs, farmers and scientists discussed the options for the participatory trials, and two of the four villages in each district were selected.

2.3. On-farm trials: agronomic and participatory evaluation

To address the three major constraints expressed by farmers (*Striga*, stem borers, and low soil fertility), and based on the discussions with them, three cropping systems were selected through a consensus for the trials: push-pull, dual purpose soybean (variety TGX-1448–2E) – maize rotation, and *Crotalaria ochroleuca* – maize rotation, to be compared to the control, maize monocropping. The four farming systems were evaluated with two other factors: maize variety and fertilizer, resulting in 16 treatments. The lay-out and technical specifications of the trials are presented in more detail elsewhere (Vanlauwe et al., 2008). The "variety" factor had two levels: IR-maize and local maize (Msamaria, an open-pollinated local variety, in 2003 and 2004 while in 2005, a commercial hybrid WH502, was used). The "fertilizer" factor had two levels: with and without fertilizer application, where the former used the recommended dose for maize in the area: 100 kg/ha each for di-ammonium-phosphate

(DAP), and calcium-ammonium-nitrate (CAN). Each of the 16 treatments was established on a plot of 10.5 m by 10 m, randomly assigned in a randomized complete block design. In each of the four villages, the trial was replicated once, and carried out over three years and in both seasons each year: the long rains (March-August) and the short rains (September-December). In Siaya, which is less-densely populated and where farms are larger, each block was planted continuously on one farm. In Vihiga, however, with its higher population density and small and fragmented farms, the block was split over two or more farms.

In the push-pull system, Napier and *Desmodium* were established during the first season, and maize planted in all seasons. Napier grass was planted in three lines of 1.5 m wide on the outside of the plot, leaving the inside (about three quarters of the plot) for maize and *Desmodium,* in alternating lines. While the maize is replanted and harvested each season, the other crops are perennial so they did not need replanting, but they were harvested regularly, several times each season. In the monocropping and push-pull cropping systems, the same crops were grown in both seasons. In the other rotation systems, maize was grown in the short rainy season, while the rotation crop (soybean or *Crotalaria*) was grown in the long rainy season.

2.4. A model for the economic analysis of multioutput, multiperiod technologies

All technologies were analyzed for their economic performance using discounted partial budget and marginal analysis, and estimating a multioutput, multiperiod profit function. For the partial budget analysis, outputs were first organized in a matrix Y_i for each farmer i where each element y_{lti} represents the output of product l in period t for farmer i. Prices of the different outputs, assumed constant over the study period, were organized in a vector $\boldsymbol{p}$, so the product $\boldsymbol{p}' Y_i$ results in a value vector, with each element representing the value of all outputs of a season. Multiplication with the vector of discount factors $\boldsymbol{\delta}$ (where $\delta_t = 1/(1+r)^{\,t}$, and r is the discount rate, estimated at 10% per season) results in the value V_{ik}, the revenue for each farmer i from technology or treatment k:

$$\boldsymbol{V_{ik} = p'Y_{ik}\delta}. \tag{1}$$

Similarly, assuming constant input prices, the total cost C_{ik} for each treatment k on farm i can be calculated by multiplying the price vector $\boldsymbol{q}$ with the input matrix X_{ik}, including labor, seed, and fertilizer:

$$\boldsymbol{C_{ik} = q'X_{ik}\delta}. \tag{2}$$

Assuming costs are constant between farmers, the discounted profits, also called net present worth or net present value (NPV) (Gittinger, 1982, p. 361), can be calculated as:

$$\boldsymbol{\pi_{ik} = p'Y_{ik}\delta - q'X_k\delta}. \tag{3}$$

This indicator allows us to compare the different options and to find the technology with the highest discounted profit at the end of the period. However, it does not take into account the cost of the technology, or how much investment was needed to reach that profit.

Comparing benefits to costs can be done by marginal analysis. First, the technologies are ranked in order of descending NPV, and the extra benefit of moving from one technology to the other is compared to the extra cost (CIMMYT, 1988). Formally, the marginal rate of return (MMR) is calculated as the marginal net benefit over the marginal cost. Experience has shown that the MMR for a new technology needs to be at least 50% for a simple adjustment, and 100% for a completely new technology (CIMMYT, 1988). For our purpose, this definition can be expanded to a multioutput technology and multiple periods, resulting in the discounted MRR:

$$\boldsymbol{DMRR = \frac{\pi_{ik} - \pi_{il}}{C_{ik} - C_{il}}}, \tag{4}$$

where k is the treatment under analysis and l the control or the best alternative.

For the econometric analysis, finally, a profit function $\boldsymbol{\pi_{ik} = f(s, x)}$ was estimated, regressing the discounted profits on a vector of cropping systems $\boldsymbol{s}$ (with a binary variable for each cropping system), and a vector of inputs $\boldsymbol{x}$ (a binary variable for IR-maize seed and one for fertilizer use). Profitability is then calculated by comparing the marginal benefit to the marginal costs, similarly discounted. A basic linear model was estimated, followed by a linear model with cross effects between $\boldsymbol{s}$ and $\boldsymbol{x}$.

2.5. Data collection

To evaluate the biophysical performance of the different treatments on the pests and soil fertility, data were collected on levels of *Striga* and stem borer infestation and soil fertility, the methodology and results of which are presented in more detail elsewhere (Vanlauwe et al., 2008). For the economic analysis, data on yields, labor, input use, and prices were regularly collected over the six seasons. Maize and soybean grain production was obtained from the central six rows of each plot (10 m long, an area of 45 m^2), adjusted for stand density, and transformed to estimated yield per ha. The fodder crops, Napier grass and *Desmodium*, were harvested several times during each season, and the production measured for each plot. Yield data for crops in push-pull were converted to represent their relative proportion in the system. Maize and *Desmodium* yields per ha of maize/*Desmodium* area were multiplied by 0.66, representing their proportion in the system, while Napier yields per ha were multiplied by 0.33 to obtain the yield in the cropping system. In this region, beans are regularly intercropped in the maize.

Table 1
Input and output prices, input use and cost per ha

Input/output	Type	Product	Units	Price (US$/unit)	Quantity (units/ha)	Cost per ha (US$/ha)
Output	Grain	Maize	Kg	0.199		
		Soybean	Kg	0.527		
	Fodder	Desmodium	Kg	0.033		
		Napier	Kg	0.075		
Input	Fertilizer	DAP	Kg	0.461	100	46.1
		CAN	Kg	0.395	100	39.5
		Urea	Kg	0.395	100	39.5
	Labor	Labor	Man day	0.922		
	Seed	IR maize seed	Kg	1.778	25	44.4
		WH502 seed	Kg	1.712	25	42.8
		Local maize seed	Kg	0.659	25	16.5
		Soybean	Kg	0.922	70	64.5
		Crotalaria	Kg	0.659	17	11.2
		Desmodium seed	Kg	15.804	2.75	43.5
		Napier	Cutting	0.001	40,000	52.6

Since the aim of the trial was to approximate farmers' practices, this was replicated in the trials' maize fields (apart from push-pull). However, the bean density was small and its harvest was conducted over a period of time, making it impossible to collect good output and input data for this crop. Thus, beans are excluded from this analysis.

The price for maize was found to be about $200/ton in the local markets during the study period, while the price for soybeans was much higher: $527/ton (Table 1). The price of fodder, cut green, was also obtained from the local market and estimated at $33/ton for *Desmodium*, and $75 for Napier grass, a popular animal feed in Western Kenya, especially for dairy cattle. The cost of the different technologies depended on the quantities and prices of the inputs used. The average fertilizer prices, obtained from local agrodealers during the time of study, were $461/ton for DAP and $395/ton for CAN and urea. Maize seed rate recommendations were 25 kg/ha. The price of IR-maize seed, not yet on the market during the study period, was estimated at $1.8/kg, slightly higher than the other improved maize seed ($1.7/kg), while the local maize seed price, as obtained from local agrodealers, was estimated at $0.7/kg. *Desmodium* seed is sold by local seed producers at $15.8/kg, while Napier grass cuttings are readily available at $1 for 1,000 cuttings. Finally, agricultural labor cost in the area was estimated at $0.92/day. Multiplying the seed rate with the price, results in the seed cost per ha (Table 1).

3. Results

3.1. Assessing the importance of the problem within the farming system

Secondary data indicate that Western Kenya is a densely populated area with a large proportion of poor people (Central Bureau of Statistics, 2003), where most households live on small land holdings (Odendo et al., 2001). The *Striga*-prone area forms a band around Lake Victoria, and has an estimated maize area of 246,000 ha (De Groote et al., 2008). It mostly coincides with the Moist Midaltitude agroecological zone (Hassan, Njoroge, et al., 1998). This zone is characterized by two rainy seasons, and rainfall increases with altitude, from 700 mm per annum by the lake shore to 1,800 mm in the highest areas farther inland. The mean annual temperature is 22°C, with an average minimum temperature of 13°C, and an average maximum of 30°C. Soils are mainly clay-loam and sandy-loam and of low fertility, since there is little volcanic or other young parent material (Jaetzold and Schmidt, 1983).

The population of this zone is estimated at 5.8 million people in 1.3 million households (De Groote et al., 2008), for an area of 16,000 km^2, resulting in a high density of 359 people/km^2. Maize is the dominant food crop, with a production of 231,000 tons on 166,000 hectares, with a yield of 1.34 tons/ha (Hassan, Onyango, et al., 1998; Otichillo and Sinange, 1991). Overall, there is a deficit of maize in the area, with an average production of 81 kg per person, compared to a national consumption average of 105 kg per person (Pingali, 2001). Total consumption in the zone was estimated at 387,000 tons, corresponding to a deficit of 155,000 annually (Mills et al., 1998). Only half of the farmers use fertilizer on their maize plots, but in small doses (less than 25 kg/ha on average), and less than half use improved maize varieties (De Groote et al., 2006).

The region's traditional cash crop sectors, based on cotton and sugarcane, are plagued by inefficient para-statals and companies, resulting in low farm gate prices and long delays in payments. Personal observations indicate that the region follows national trends that see the increasing importance of horticulture and livestock, especially dairy farming, as cash income sources.

Maize farmers in Western Kenya have consistently in the past identified *Striga*, stem borers, and declining soil fertility as their major constraints (Odendo et al., 2001). Based on farmers' estimates, yield losses due to *Striga* range from 35% to 72% (Hassan et al., 1994).

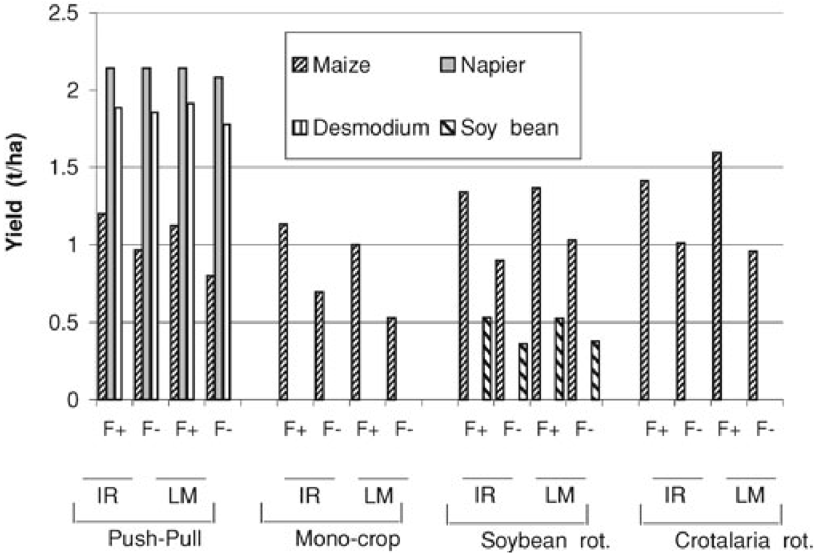

Fig. 2. Yields of the different treatments and crops.

Striga infestations increase with the continuous planting of cereals on the same plot, and with the declining soil fertility that weakens the host plant (Berner et al., 1995). Stem borers occur in all major agroecological zones of Kenya, and cause average crop losses of 13.5% country wide, and 16.6% in the Moist Midaltitude zone (De Groote, Bett, et al., 2004). Infestations of these pests can decimate individual maize fields, depriving rural families of their food supply and vital income. Finally, soil fertility depletion is increasingly being recognized as a fundamental biophysical root cause for declining food security in the smallholder farms of SSA (Sanchez and Jama, 2002; Vanlauwe et al., 2002). Soil nutrient mining and the resultant soil fertility decline occurs in most areas in Kenya, as observed by the negative balances for N, P, and K at the farm level (Smaling et al., 2002). Although organic inputs are essential soil amendments along with fertilizer, they alone cannot sustain crop production due to the limitations in their quality and availability (Vanlauwe and Giller, 2006).

The results of the PRAs conducted for this project (Odhiambo et al., 2007) confirmed that maize is the most important crop, for both food and cash. In most participating villages, *Striga*, stem borers, and low soil fertility were the major constraints faced by farmers. Moreover, livestock production was found to be important in all villages, suggesting a ready market for fodder crops such as Napier and *Desmodium*. In all sites, farmers were quite happy to try the new technologies, and many participated in the field days and evaluations.

3.2. Testing and evaluating the technologies on-farm

The effect of the different technologies on pest incidence, presented in detail elsewhere (Vanlauwe et al., 2008), indicate that the push-pull system significantly reduced *Striga* emergence and stem borer damage from the second season, while IR-maize reduced and delayed *Striga* emergence from the first season. Both technologies significantly reduced the seed bank at the end of the trial, while the reductions from the rotation crops were not significant. The various interventions did not, however, substantially affect various soil fertility-related parameters by the end of the trial.

The results also show that maize yields were substantially higher in the rotation crop systems, especially in the *Crotalaria* rotation (Fig. 2). But *Crotalaria* is a green manure and is, therefore, plowed under at the end of the season, and does not produce a marketable output. The soybean rotation does produce a high value output, but the soybean yields in the trials were rather low. Push-pull, with only 66% of the total cropped area in maize, barely increases maize yields in these trials but has a major advantage in that it produces fodder, which increases the value of the total output.

The results of the participatory evaluation, the details of which are presented elsewhere (De Groote et al., 2010), indicate that the farmers preferred most treatments to the control. Push-pull with IR-maize and fertilizer was the most preferred treatment, followed by the other push-pull treatments, the *Crotalaria* rotation and the soybean rotation (the last one especially with IR-maize and fertilizer). Within the mono-cropping system, IR-maize and fertilizer were preferred.

3.3. Economic analysis of different technologies, by season

Annual revenues from the different cropping systems were estimated by multiplying the yields with the output prices and adding up the revenues of the two seasons (Fig. 3). Push-pull clearly had the highest average revenue, $842/ha/year (over the two seasons), more than half of which came from the fodder crops, Napier grass ($319) and *Desmodium* ($123). Soybean rotations had the second highest revenue: $467/ha/year. The

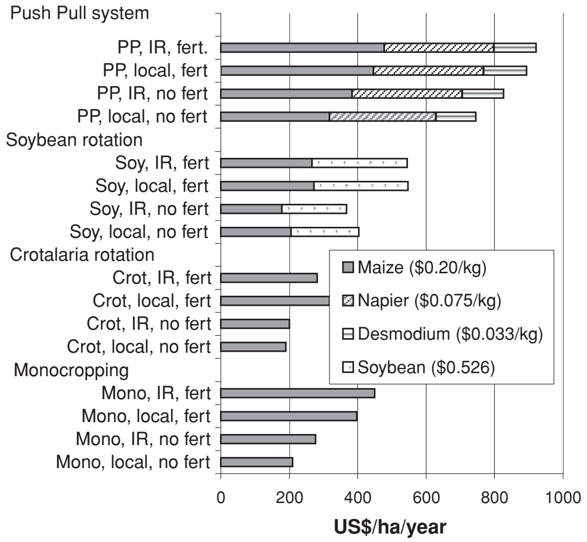

Fig. 3. Total revenue (US$/year) for the different treatments, over the two seasons, by crop (PP = push-pull, IR = imazapyr resistant, fert = fertilizer).

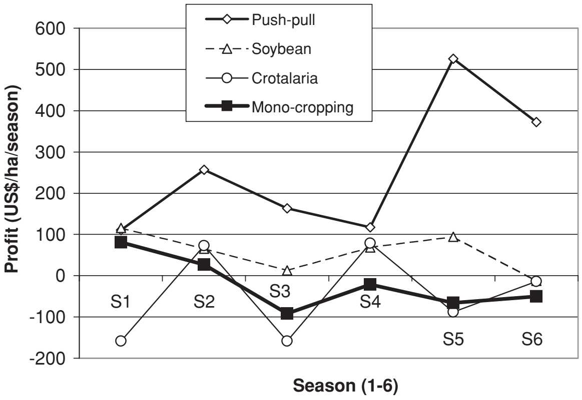

Fig. 5. Average profit of the different cropping systems, by season.

rotation clearly benefits from higher maize yields, but still half of its revenue comes from soybean. Although the latter has lower yields than maize, the difference is compensated for by its higher price. The *Crotalaria* rotation resulted in the highest maize yields, but its value did not compensate for the lack of marketable output in the green manure season, making it overall the cropping system with the lowest revenue: $248/ha/year. Maize monocropping with fertilizer, for both seasons, produced a higher revenue ($334/ha/year) than the *Crotalaria* rotation, but less than the other cropping systems.

The revenues of the different technologies were put in perspective by comparing them to their costs (Fig. 4). The results show that push-pull costs relatively more to establish: *Desmodium* seed and Napier cuttings have to be purchased, with the first one being more expensive. There are also the additional labor costs of planting and maintaining *Desmodium* within the maize rows and Napier grass around the plot. The total cost of establishing push-pull was, therefore, estimated at more than $350/ha, mostly from seed and labor (first bar in Fig. 4). In the later seasons, however, especially when *Desmodium* and Napier were well established, both labor and seed costs were substantially reduced, bringing the overall costs down to $200/ha. The cost of maize monocropping with fertilizer, on the other hand, was estimated at $240/ha. The soybean rotation was even more expensive, at $250/ha, because of the seed costs, while the *Crotalaria* rotation is slightly less expensive ($192/ha) mostly because of its lower seed cost.

Seasonal profits are calculated by deducting the costs from the revenues. Since the different cropping systems have different patterns over time, it is important to study the evolution of the profits over the six seasons (Fig. 5). Push-pull, with its high installation costs, only turned a small profit in the first season, but had the highest profit margin in all the other main seasons and the minor season. It suffered from drought in the third season, and was only well established in the fifth and sixth season.

Soybean rotation is clearly the second most profitable cropping system, albeit substantially below push-pull. It always performed equal to or better than the alternatives, except for push-pull. *Crotalaria* rotation made a profit in its maize seasons, but this could not make up for the lack of revenue, and consequent losses, in the green manure seasons. Maize monocropping, on

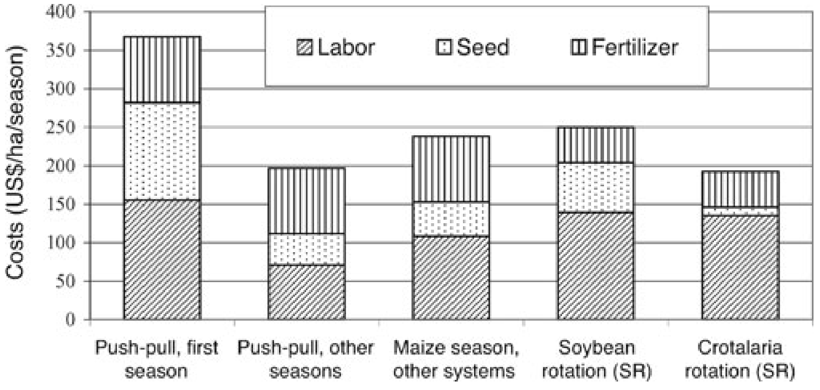

Fig. 4. Costs of the different cropping systems and technologies.

Table 2
Revenues, costs, and profits of different treatments

By	Cropping system	Maize variety	Fertilizer	First season (S1)			Other main seasons (S3, S5)			Minor season (S2, S4, S6)		
				Revenue	Cost	Profit	Revenue	Cost	Profit	Revenue	Cost	Profit
Treatment	Push-pull	IR	Yes	443	327	116	533	198	335	420	196	224
	Push-pull	Local	Yes	424	301	123	525	186	339	403	179	224
	Push-pull	IR	No	351	237	114	480	110	370	391	109	282
	Push-pull	Local	No	300	210	90	432	97	335	358	92	266
	Monocrop	IR	Yes	375	247	128	164	238	−74	215	241	−26
	Monocrop	Local	Yes	317	218	99	119	224	−104	213	223	−10
	Monocrop	IR	No	206	155	51	93	150	−57	147	152	−5
	Monocrop	Local	No	172	126	46	56	135	−80	116	133	−18
	Soybeans	IR	Yes	358	185	173	241	185	56	266	243	23
	Soybeans	Local	Yes	320	185	135	255	185	70	272	225	46
	Soybeans	IR	No	225	139	86	173	139	34	178	153	25
	Soybeans	Local	No	210	139	70	195	139	55	205	137	68
	Crotolaria	IR	Yes	0	181	−181	35	181	−146	281	255	27
	Crotolaria	Local	Yes	0	181	−181	35	181	−146	318	239	79
	Crotolaria	IR	No	0	135	−135	35	135	−100	201	166	35
	Crotolaria	Local	No	0	135	−135	35	135	−100	190	148	43
Cropping systems	Push-pull			379	269	111	492	148	345	393	144	249
	Soybeans						237	162	74	208	189	19
	Crotalaria						23	158	−135	251	199	52
	Monocrop						161	187	−25	200	188	12
Maize variety		IR-maize					228	186	42	298	225	73
		Local variety					210	177	34	223	136	87
Fertilizer			Yes				252	215	37	262	189	73
			No				186	147	39	259	172	87

the other hand, turned a profit in the first main season and in the minor seasons, but made a loss in the other two main seasons.

To compare the main features of the different systems, we synthesized their economic results for three different periods. The first season is treated separately, to distinguish the installation season for the push-pull system, while the other major seasons are combined to compare the main maize seasons for the different systems, and the minor seasons are combined to distinguish the legumes from the maize seasons (Table 2). It follows that push-pull, with its high installation costs, only turns a small profit in the first season, but has the highest profit margin in all the other main seasons ($345/ha) and in the minor season ($249/ha). Soybean rotation was clearly the second most profitable cropping system ($92/ha), while monocropping was often not profitable. Overall, neither IR-maize nor the use of fertilizer was more profitable than the control, monocropping.

3.4. Marginal analysis of multioutput technologies over time

To compare different systems with different income and cost streams at different time periods, the benefits were discounted and added, and the different treatments (combinations of technologies) were ranked in decreasing total discounted benefit or NPV (Table 3).

The results indicate that eight technologies were profitable. Evaluating the technologies from the bottom up, the first profitable technology was soybean rotation, with IR-maize but no fertilizer (ranked 8). It had a discounted profit (or NPV) of $198/ha over the six seasons, for a total discounted cost of $700, indicating that farmers could not receive much return on their investment here. However, the same technology with local maize (ranked 7) returned a much higher profit ($309/ha) at a slightly lower cost ($658), and was, therefore, more interesting. Therefore, this treatment (a combination of soybean rotation with local maize and no fertilizer) became the first economically interesting technology, and serves as the base level with which to compare the alternatives using multiperiod marginal analysis and DMRR.

The two soybean rotation combinations with fertilizer were more profitable than the base, but their DMRRs, the extra profit over the extra cost to obtain it, were low (2% and 14%). These DMRRs are generally considered too low a return to investment for farmers to justify a switch in technology, so these combinations are not likely to be adopted.

The next most profitable treatment is push-pull with IR-maize and fertilizer. It has a DMRR of 1.36 compared to the base and is, therefore, a worthwhile investment. Still, it is dominated by the next two push-pull treatments (those with local maize), which have higher benefits for lower costs. The most profitable treatment overall, push-pull with IR-maize and no fertilizer, has a DMRR of 1.13 over the lower treatment, which only differs in that it uses local maize. This is just above the 100% threshold, so it is not clear if farmers would switch to the IR-maize in this system.

To compare the investment costs of the different options, their marginal costs as compared to the control was calculated. The control, monocrop with local maize and no fertilizer, cost $628/ha over the six seasons (line 12 in Table 3). A similar

Table 3
Marginal rate of return (profits and costs discounted and added over the six seasons)

	Rank	Profit (discounted, US$/ha)		Cost	Marginal cost	MRR	Comments
		Mean	Standard deviation				
Treatments	1 Push-pull, IR, no fertilizer	1275	444	652		1.13	MRR low
	2 Push-pull, local maize, no fertilizer	1172	521	560			Dominating technology
	3 Push-pull, local maize, fertilizer	1098	444	983		2.43	MRR high
	4 Push-pull, IR, fertilizer	1082	505	1071		1.87	MRR low
	5 Soybeans, local maize, fertilizer	353	504	976		0.14	MRR low
	6 Soybeans, IR, fertilizer	317	385	1019		0.02	MRR low
	7 Soybeans, local maize, no fertilizer	309	383	658			Base level
	8 Soybeans, IR, no fertilizer	198	369	700			(First profitable treatment)
	9 Monocrop, IR, fertilizer	−41	258	1156			
	10 Monocrop, IR, no fertilizer	−46	190	728			
	11 Monocrop, local maize, fertilizer	−64	440	1058			
	12 Monocrop, local maize, no fertilizer	−97	423	628			
	13 Crotolaria, local maize, no fertilizer	−187	519	672			
	14 Crotolaria, IR, no fertilizer	−188	286	718			
	15 Crotolaria, local maize, fertilizer	−219	308	995			
	16 Crotolaria, IR, fertilizer	−335	415	1036			
Systems	Push-pull				−68		
	Soybean rotation				30		
	Crotalaria				43		
Technologies	IR-maize				99		
	Fertilizer				430		

push-pull system actually costs only $560/ha (line 2), a decrease of $68/ha. Clearly, the marginal cost of the alternative cropping systems, when added and discounted over the different seasons, were low: negative for push-pull, $30 for soybean rotation, and $43 for *Crotalaria*. These systems can, therefore, be considered quite affordable, although it should be noted that for push-pull most of the investment is needed in the first season, while for *Crotalaria* the return is not sufficient. The most expensive technologies are IR-maize seed which, over the six seasons, cost $99/ha more than the control, and fertilizer, at $430/ha more (Table 3). Within the different cropping systems, the switch to these technologies, based on a comparison of extra profit with extra costs, is rarely justified.

3.5. *Profit function*

A profit function was estimated with the discounted benefits as dependent variables, and the different technologies as independent variables (Table 4, short model). The basic model estimates the extra-discounted benefit, over six seasons, to push-pull at $1,218/ha, and the extra benefit to soybean rotation at $356/ha, both compared to the base, maize monocropping.

Since the cost of push-pull, discounted over the six seasons, is lower than the control, maize monocropping, and the marginal cost of the soybean rotation is only $30/ha, these technologies are highly profitable. None of the other technologies, *Crotalaria*, fertilizer, or IR-maize, had a significant effect on discounted profits.

To analyze if any of the improved inputs, IR-maize and fertilizer, would be profitable with a particular cropping system, cross-effects were introduced into the model (Table 4, long model). No cross-effects were, however, found to be statistically significant, indicating that, even within the different cropping systems, the use of IR-maize or fertilizer was not profitable in these trials.

Table 4
Profit function (dependent variable is the discounted profit over the six seasons, in US$/ha)

Variables	Short model		Long model with cross effects	
	Estimated coefficients	Std. error	Estimated coefficients	Std. error
Constant	−40	86	−90	124
Push-pull	1,218	99***	1292	175
Soybean rotation	356	99***	380	175
Crotalaria rotation	−170	99	−68	175
Fertilizer	−31	70	19	143
IR-maize	−13	70	37	143
Push-pull × IR-maize			6	202
Soybean × IR-maize			−111	202
Crotalaria × IR-maize			−96	202
Push-pull × fertilizer			−153	202
Soybean × fertilizer			62	202
Crotalaria × fertilizer			−109	202
Standard deviation regression	398		404	
R^2	0.62		0.63	
N	127		127	

4. Conclusion

The push-pull cropping system and, to a lesser extent, the soybean rotation, are highly profitable technologies for

Western Kenya. They provide good return for a relatively low investment, as compared to the seed- and fertilizer-based technologies, in particular the IR-maize seed and mineral fertilizer. Rotation with the green manure crop *Crotalaria* is clearly not economically interesting to farmers.

The push-pull system is not without problems, however. It requires high initial investment costs, in particular for *Desmodium* seed and labor. *Desmodium* seed is expensive, although farmers can now plant it using vines. The system also needs additional labor to plant and maintain the companion crops, which need careful attention during the establishment stages. During the early stages, it is also quite sensitive to drought. Once established, it is the most profitable technology among those tested here. This profitability does, however, not stem from the increase in maize yield, which is modest, especially since only 66% of the cropped area is in maize, but from the value of the fodder crops, Napier grass and *Desmodium*. This system is, therefore, only recommended in areas with sufficient livestock and a demand for fodder, resulting in the necessary price, a feature that was observed in the study areas as shown in our PRA results. Higher grain yields and economic benefits have been reported from farmers' fields in western Kenya, under different agro-ecologies (Khan, Amudavi, et al., 2008; Khan, Midega, et al., 2008).

The second most profitable technology system tested is maize rotated with the new promiscuous soybean varieties. Although the return is not as high as that for push-pull, the only investment needed is seed and starter fertilizer. While maize-soybean rotations are popular in many areas of the world, its adoption in Kenya is hampered by limited marketing opportunities (Chianu et al., 2009). The major potential production zones are situated in Western Kenya, where local demand centers around home consumption and cottage industries. Industrial demand, for oil production and animal feed, is located in the industrial areas around Nairobi and the coast, mostly supplied by imports. Efforts are, however, under way to promote soybean use in the home and in small industries to create enough stimulus to increase production to a level interesting to industrial marketing (Chianu et al., 2009).

These two new cropping systems provide a welcome improvement to the common low input/low output agricultural systems dominated by maize monocropping, with yields of around 0.5 ton/ha for local maize varieties without fertilizer, and slightly more than 1 ton/ha for the improved, IR-maize variety. Monocropping of maize is generally not profitable; it actually makes a small loss. Still, it is the most common mode of maize production in the area. Likely, the opportunity cost of labor for many rural households is lower than the labor cost used in this project. Many households also probably value maize produced on the farm more highly than its price on the local market. Home produced maize does not require transport and is shielded from price fluctuations.

While the other technologies tested do improve yield, the extra revenue does not generally justify the extra cost. The use of green manure is clearly not economical: the increase in maize yield after *Crotalaria* is small and is not compensated for by the loss of revenue during the *Crotalaria* season. While green manure technologies have been widely tested and promoted, the results presented here indicate that these technologies should be treated cautiously. They should not be promoted based on theoretical arguments or agronomic results, but only if empirical evidence of their economic viability is available. Given our results, that is, however, highly unlikely unless valued as an indigenous green vegetable for human consumption.

IR-maize was well appreciated by the farmers, highly effective against *Striga*, and had a substantially higher yield than the local variety. However, yields were still low compared to average yields in the area and other on-farm trials, influenced by a range of other factors. Therefore, in these trials, IR-maize was not profitable. However, in other trials in Western Kenya, under farmer-managed conditions, yields of IR-maize were high and its use was very profitable (De Groote et al., 2007). This was confirmed in yet another set of trials, where IR-maize outperformed push-pull and was more profitable (Woomer et al., 2008). The profitability of IR-maize, therefore, needs further research.

Fertilizer application in the trials generally increased maize yields, but again not enough to justify their costs. The poor management and low yields of the trials are clearly factors, and under those conditions fertilizer use was not economical. Another factor affecting the profitability of fertilizer use is the recommended dose, which is a high blanket recommendation for the country and is not based on empirical evidence of economically optimal use. However, the results presented here are in line with the studies of the Fertilizer Use Recommendation Project. This project tried to estimate maize response functions to fertilizer for each district in Kenya, and often found insignificant results. Unfortunately, the results were never synthesized and published.

While the trials were not set up to study the effect of drought, the different technologies clearly did not perform equally in dry versus wet seasons. Push-pull is particularly sensitive to drought, which influences the establishment of *Desmodium* and Napier grass. The IR maize varieties are more drought tolerant than other improved maize varieties, but not as much as some local varieties, and the herbicide can wash off under heavy rains (De Groote et al., 2007).

Given the good results for some cropping systems, and the poor results for others, more collaboration is needed between agronomists and economists to develop proper recommendations to help reduce pest and soil fertility problems in Africa. The experience of this particular project can help in the design of such projects. First, this type of research needs sufficient time, people, and resources. To study the long-term effects on pest problems and cropping systems, the six seasons of this project were generally adequate. However, long-term effects on soil fertility were still not observed, and these might need longer observation periods. The experimental sites need close supervision. Technicians need to be on-site for daily supervision and regular data collection, and the sites need to be easily accessible to the scientists of the different disciplines for regular visits and close follow-up.

Second, economic analysis contributes largely to the evaluation of these trials. This analysis, however, needs proper attention. Specific data need to be carefully collected, with special attention to labor data and the output of crops harvested at regular intervals or over a period of time. Further, appropriate models are needed. We have used the conventional NPV and added the novel DMRR, which allows for the elimination of technologies that are clearly dominated. While there is evidence that the classic one-period should be at least 50% for simple technologies and 100% for more complex ones, it is not clear if these thresholds hold for the multiperiod that DMRR suggests. However, if this type of analysis were consistently included in future research projects of this type, that information would soon be available.

Finally, the analysis presented here merely compares different options over three years, under researcher-managed conditions. It would be most interesting if the information collected in this project could be used to build optimization models, including soil fertility and pest control, for longer periods. Further research should also include risk analysis, and the performance of the different technologies under drought conditions, using methodologies developed for breeding drought tolerant maize varieties (Banziger et al., 2006). In the final stages of this research, as is standard in participatory research, the promising technologies should be evaluated under farmer-managed conditions. Under those conditions, the common practice of inviting volunteers or having farmer groups choose representatives to participate in the trials can lead to bias and overestimation of the benefits of the new technologies. To avoid this bias randomization of the participating farmers (Duflo et al., 2006) should be considered.

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