Agricultural Systems 103 (2010) 233–244

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Participatory evaluation of integrated pest and soil fertility management options using ordered categorical data analysis

Hugo De Groote [a,*], Esther Rutto [a], George Odhiambo [b], Fred Kanampiu [a], Zeyaur Khan [c], Richard Coe [d], Bernard Vanlauwe [e]

[a] International Maize and Wheat Improvement Centre (CIMMYT), P.O. Box 1041-00621, Nairobi, Kenya
[b] Maseno University, P.O. Box Private Bag Maseno, Kenya
[c] International Centre for Insect Physiology and Ecology, P.O. Box 30772, Nairobi, Kenya
[d] World Agroforestry Centre (ICRAF), P.O. Box 30677, Nairobi, Kenya
[e] Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (TSBF-CIAT), P.O. Box 30677, Nairobi, Kenya

This paper is dedicated to the memory of Esther Rutto, a valued friend and colleague.

ARTICLE INFO

Article history:
Received 22 January 2009
Received in revised form 16 September 2009
Accepted 1 December 2009
Available online 15 January 2010

Keywords:
Maize
Imidazolinone-resistant maize
Ordinal regression
Participatory evaluation
Striga
Stem borer

ABSTRACT

Maize is becoming the major food crop around Lake Victoria. Major constraints to its production are *Striga*, stem borer, and declining soil fertility. Innovative integrated technologies have been developed: the 'push–pull' system (intercropping with *Desmodium* and surrounded by Napier grass), soybean and *Crotalaria* rotations, and imidazolinone-resistant (IR) maize seed.

In 12 demonstration trials in four villages in Siaya and Vihiga districts (Kenya) and two villages in Busia (Uganda) in 2003 and 2004, 504 farmers evaluated all cropping systems and a mono-cropped continuous maize, each cropped with IR or local maize, and supplemented or not with fertilizer, totaling 16 treatments. Farmers evaluated all treatments for yield, resistance to *Striga* and stem borer, improvement of soil fertility, and provided an overall evaluation score, using an ordered scale of 1 (very poor) to 5 (very good). Data were analyzed using ordinal regression, estimating log odds ratios.

The results show significant preferences for all treatments over the control. Push–pull with IR and fertilizer had the highest log odds ratio (2.93), so the odds of farmers preferring this treatment are 18.7 times the odds that farmers prefer the control. The odds ratios for the other push–pull combinations were generally highest (9–15), followed by the rotation systems with *Crotalaria* (3.5–7.0), and soybeans, especially with IR maize and fertilizer (odds ratio of 5.7). In mono-cropping systems, IR maize was only appreciated in combination with fertilizer, and then only in 2004. Push–pull and *Crotalaria* were more appreciated in 2004 than in 2003. Farmers in Vihiga had a stronger preference for push–pull, and those in Busia for soybean rotations.

Significant differences among farmers were observed, but the effects were small. Women appreciated push–pull more than men, while other technologies were gender-neutral. Older farmers were more likely to prefer push–pull and *Crotalaria* with fertilizer. Livestock ownership was not found to have an effect on technology preferences. Measured yield, stem borer and *Striga* infestation all had significant but small effects, although their inclusion did not eliminate the treatment effects, indicating that other factors are still important. OLS of the scores for different criteria on the overall score shows yield to be the most important criterion (coefficient of 0.40), followed by soil fertility enhancement (0.25) and *Striga* resistance (0.13). Labor saving (0.09) and stem borer resistance (0.03) are relatively minor criteria.

This research shows that scoring and analysis with ordinal regression is a convenient way to solicit and analyze farmers' preferences for new technologies, with wide applicability in farming systems and participatory research. Its application here shows that farmers like the new technologies, especially push–pull, but that there are substantial differences between years, sites and farmers. The use of this method can be very helpful to define and focus further research and formulate specific and targeted recommendations for agricultural extension.

1. Introduction

Sub-Saharan Africa's rapid population growth, combined with a stagnating agricultural productivity, has led to a decrease in food

* Corresponding author. Tel.: +254 722 4604; fax: +254 722 4601.
E-mail address: h.degroote@cgiar.org (H. De Groote).

0308-521X/$ - see front matter © 2010 Published by Elsevier Ltd.
doi:10.1016/j.agsy.2009.12.005

production per capita. It is now the only region in the world where both the number and the proportion of malnourished children has been consistently rising in recent years (Rosegrant et al., 2001). Throughout most of eastern and southern Africa, maize (*Zea mays* L.) is the dominant food staple (Byerlee and Eicher, 1997) and, therefore, improving its productivity is essential to reversing the per capita food decline. Maize in the region is primarily grown by small-scale farmers, using limited inputs and almost no irrigation, resulting in average yields of only 1.6 tons/ha (FAO, 2007).

The Lake Victoria basin is characterized by a very high population density and small land holdings. The major constraints in maize production, as identified by farmers in the area, are *Striga hermonthica* (L.) Benth, a parasitic weed of sorghum and maize, stem borers (*Chilo partellus* Swinhoe (Lepidoptera: Crambidae) and *Busseola fusca* Fuller), and declining soil fertility (Odendo et al., 2001). *Striga*, also known as witch weed, is an obligatory root parasite and a serious constraint to cereal production in Western Kenya. Throughout Africa, it is estimated that it affects more than 6 million ha of maize (De Groote et al., 2008), with crop losses estimated at between 30% and 50% of the potential yield (De Groote et al., 2007). *Striga* infestations increase with the continuous planting of cereals on the same plot, and with the declining soil fertility that weakens the host plant and makes it more susceptible to *Striga* attack (Berner et al., 1995). Over the years, *Striga*-infested areas have developed high levels of *Striga* seeds in the soil with only a few breaking dormancy each season when stimulated by crop root exudates. In Kenya, an estimated 200,000 ha of land are infested with *Striga* (76% of farmland in Western Kenya). Yield losses due to *Striga* range from 35% to 72% (Hassan et al., 1994) causing an estimated crop loss valued at about US$53 million .

Large maize-growing areas in the developing countries face serious problems of insect infestation, in particular stem borers. In Kenya alone, crop losses due to stem borers are estimated at 13.5% of their potential harvest (De Groote 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 sub-Saharan Africa (Sanchez and Jama, 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).

A number of technologies have been developed to alleviate these constraints, including the push–pull technology for the stem borer and *Striga* control, imidazolinone-resistant (IR) maize for *Striga* control, and cereal–legume rotations for enhancing the soil fertility status and reducing *Striga* incidence. In the push–pull strategy, developed by the International Centre of Insect Physiology and Ecology (ICIPE) and partners, maize is intercropped with a stem borer moth-repellent plant, *Desmodium uncinatum* (Jacq.) (push), while an attractant host plant, Napier grass, *Pennisetum purpureum* (Schumach) (pull), is planted as a trap plant for stem borers around this intercrop (Khan et al., 2000). Volatiles produced by the *Desmodium* repel the host-seeking moths, while those produced by the Napier grass are attractive to them. *Desmodium* also significantly suppresses *Striga* (Khan et al., 2006).

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). Seed can, therefore, be coated with the herbicide, which is absorbed by the crop roots. Over time, the herbicide is exuded and kills attaching or attached *Striga* seedlings, as well as its nearby non-germinated *Striga* seeds in the soil (Kanampiu et al., 2002b). This low-dose seed coating provides good control of *Striga* (De Groote et al., 2007), especially in the early growth stages (Kanampiu et al., 2002a), the period when most of the damage is done (Berner et al., 1995).

Soil fertility problems can be addressed by the rotation of cereals with fast-growing nitrogen-fixing herbaceous legumes such as *Mucuna* spp. or *Crotalaria* spp. (Versteeg et al., 1998). While productivity has been shown to increase substantially after a herbaceous fallow phase (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 so far 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 N fixed is removed with the grains.

Scientists at IITA in Nigeria have developed dual purpose soybean varieties which produce large amounts of leafy biomass without compromising grain yields (Sanginga et al., 2003). These soybean varieties were bred for promiscuity or the ability to establish symbiosis with the native *Bradyrhizobium* spp., thus eliminating 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., 2000; Gacheru and Rao, 2001; Gacheru et al., 1999; Sanginga et al., 2003).

Given the interactions between soil-borne pests and soil fertility status, a new Integrated Pest and Soil Fertility management (IPSFM) paradigm is emerging that aims to simultaneously 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). There is an urgent need to target critical cereal production constraints, such as *Striga*, stem borer and soil fertility-related problems, in a holistic way, following a systems approach, and to explore which set of options farming communities facing these constraints prefer.

Therefore, a collaborative project was initiated in the Lake Victoria basin of Kenya and Uganda in 2003 by ICIPE, CIMMYT, TSBF-CIAT, the Kenya Agricultural Research Institute (KARI), and the Ugandan National Agricultural Research Organisation (NARO), to test and evaluate with farmers and other stakeholders the technologies these organizations have been developing: push–pull, IR maize, and rotation crops. The project followed a three-stage approach. First, Participatory Rural Appraisals (PRA) were conducted in selected communities to engage in discussions with farmers. The main objectives were to gauge farmers' constraints in maize production, to discuss if the technologies developed fit their farming system, to check their interest in conducting participatory trials, and to agree on which technologies should be incorporated in those trials. In the second phase, demonstration trials were organized with selected technologies and combinations, in farmers' fields but researcher managed, to demonstrate and evaluate them. In the third phase, farmers conducted their own trials, adopting the technologies they liked, and adapting and combining them in their own way.

In this paper, we present the results of the farmers' evaluations of the demonstration trials, with specific objectives: (i) to evaluate various best-bet IPSFM options in a participatory, gender-sensitive manner; (ii) to evaluate the factors and farmer characteristics that influence the preference for particular technologies; and (iii) to demonstrate and evaluate the use of ordinal regression in farming systems research, in particular the participatory evaluation of new technologies and IPSFM options. The results of the Participatory Rural Appraisals, and formal agronomic and economic analysis of the trials are reported elsewhere (Odhiambo et al., 2007; Vanlauwe et al., 2008).

2. Methodology

2.1. Quantitative analysis of farmers' evaluations

A convenient and popular method for farmers to evaluate proposed or demonstrated technologies is to rank them in order of preference. Unfortunately, when applying this method in a systematic way, several problems arise. First, it is hard for farmers and other participants to rank more than a small number of options. Where a large number of technologies, such as new varieties or combinations of technologies (crop management, fertilizer and varieties, in this case) are involved, ranking all options is cumbersome. Secondly, while ranking provides a relative appreciation of the different technologies, it does not provide the most important information: if the technologies are acceptable or not. Thirdly, although appropriate quantitative methods for the analysis of ranking have been developed, they are not available in standard software, and they have high data requirements.

Because of these problems, the alternative of scoring is becoming increasingly popular, and has been used in evaluating agroforestry options (Franzel, 2001) and maize varieties (Bellon et al., 2006; De Groote et al., 2002). In scoring, also called rating, farmers evaluate new technologies on a limited scale, for example by giving them an evaluation of "very poor", "poor", "average", "good" or "very good". Often, these evaluations are given a numeric score, from 1 (very poor) to 5 (very good). For convenience, many scientists treat these scores as continuous variables, calculate the mean score for each technology, and compare those means using standard statistical tools. Unfortunately, this type of analysis is based on assumptions that are hard to justify, in particular that the numeric distance between scores have a meaning: for example that two scores of 3 (average) would have the same value of one score of 2 (poor) and one score of 4 (good), although this cannot be derived from what the farmers said. Farmers gave their evaluations in different categories, which are clearly ordered, but which are not measured on an interval scale.

Therefore, these scores should be treated and analyzed as the ordered categorical data that they are (Coe, 2002; Train, 2003, pp. 163–167). Unfortunately, this approach, although popular in other fields, is rarely used in agricultural research. Likely factors are the difficulty of analysis and interpretation, but also, in our experience, the rather slow adoption rate of appropriate technologies by agricultural scientists. Fortunately, modern software makes the analysis fairly straight forward and with some effort, as will be shown in this paper, the results can be conveniently interpreted.

2.2. Theoretical model

Instead of assuming the scores are measured on an interval scale, the data can also be analyzed based on less restrictive assumptions, in particular that the scores represent an order of the responses, leading to ordered-response models (Maddala, 1983, p. 46). In these models it is assumed that scores represent ordered segments of a utility distribution. Respondents score a treatment of a trial in a particular ordered category, driven by a latent, unobserved variable U, which represents utility or indicates a general appreciation of the new technologies. Instead of this latent variable U, we observe the scores y, a variable that falls in one of J ordered categories, in our case from 1 (very poor) to 5 (very good). The scores are then linked to the latent variables through the cut-off points k_1 to k_{J-1}, as follows:

$$\begin{aligned} y &= 1 \quad \text{if } U < k_1, \\ y &= 2 \quad \text{if } k_1 \leqslant U < k_2, \\ &\cdot \\ &\cdot \\ y &= J \quad \text{if } k_{J-1} \leqslant U. \end{aligned} \tag{1}$$

The scores represent an order: their values of y are ordinal numbers and should not be used in quantitative analysis such as the calculation of arithmetic means or standard regression methods. The values of the latent variable U, on the other hand, represent quantities and can be analyzed using standard quantitative methods such as the linear model (Train, 2003):

$$U_i = \boldsymbol{\beta}'\boldsymbol{x_i} + \varepsilon_{\boldsymbol{i}}, \tag{2}$$

where U_i represents the utility of individual i, $\boldsymbol{x_i}$ is a set of variables influencing the i's utility and choice, $\boldsymbol{\beta}$ is a vector of parameters to be estimated and ε_i is the error term. For ease of notation, and since all variables relate to individual i, the subscript is dropped in the rest of this section.

The probability of the scores y can now be derived from this model. The probability of the first outcome, given a set of independent variables $\boldsymbol{x}$, becomes:

$$P(y = 1) = P(U < k_1) = P(\varepsilon < k_1 - \boldsymbol{\beta}'\boldsymbol{x}), \tag{3}$$

while the probability of the second outcome is:

$$P(y = 2) = P(k_1 < U < k_2) = P(k_1 < \boldsymbol{\beta}'\boldsymbol{x} + \varepsilon < k_2) = P(\varepsilon < k_2 - \boldsymbol{\beta}'\boldsymbol{x}) - P(\varepsilon < k_1 - \boldsymbol{\beta}'\boldsymbol{x}), \tag{4}$$

and so forth (Train, 2003).

To estimate these probabilities from survey data, a distribution function for the error term ε needs to be assumed. The logistic distribution is often used because of its convenient closed-form cumulative distribution function (cdf):

$$P(\boldsymbol{X} < \boldsymbol{x}) = 1/(1 + e^{-\boldsymbol{x}}) = e^{\boldsymbol{x}}/(1 + e^{\boldsymbol{x}}), \tag{5}$$

The probability for the lowest score can now be derived from the cdf as:

$$P(y = 1) = P(\varepsilon < k_1 - \boldsymbol{\beta}'\boldsymbol{x}) = \frac{e^{k_l - \boldsymbol{\beta}'\boldsymbol{x}}}{1 + e^{k_1 - \boldsymbol{\beta}'\boldsymbol{x}}}, \tag{6}$$

that for the second one as

$$\begin{aligned} P(y = 2) &= P(\varepsilon < k_2 - \boldsymbol{\beta}'\boldsymbol{x}) - P(\varepsilon < k_1 - \boldsymbol{\beta}'\boldsymbol{x}_2) \\ &= \frac{e^{k_2 - \boldsymbol{\beta}'\boldsymbol{x}}}{1 + e^{k_2 - \boldsymbol{\beta}'\boldsymbol{x}}} - \frac{e^{k_l - \boldsymbol{\beta}'\boldsymbol{x}}}{1 + e^{k_1 - \boldsymbol{\beta}'\boldsymbol{x}}}, \end{aligned} \tag{7}$$

and so forth. The log-likelihood function can then be constructed by multiplying the logs of the probabilities for the different outcomes. Maximum likelihood estimation provides estimates for both the coefficients $\boldsymbol{\beta}$, which give the impact of the explanatory variables on people's opinions, as well as for the cut-off points k_i. from which the probabilities of the different outcomes can be derived. This model is called the ordered logit model (Train, 2003; Greene, 1991, pp. 703–705).

While the coefficients quantify the effect of the explanatory variables on people's preferences, the interpretation of the coefficients is somewhat cumbersome in the above formulation, but much easier if we consider the odds of the cumulative probabilities. First, the cumulative probability of a score j is defined as the probability of a score to be equal or less than j, and this can be derived directly from the logistic cdf (Eq. (4)) as:

$$P(y \leqslant j) = \frac{e^{k_j - \boldsymbol{\beta}'\boldsymbol{x}}}{1 + e^{k_j - \boldsymbol{\beta}'\boldsymbol{x}}}. \tag{8}$$

Second, the odds of an event a to occur is the probability it occurs over the probability it does not, mathematically $P(a)/(1-P(a))$. The odds of obtaining a 6 when throwing a dice, for example, are 1/5, while the probability of that event is 1/6. For the ordered-response model, the odds for the lowest score to occur is $P(y=1)/(1-P(y=1))$, for the second score $P(y=2)/(1-P(y=2))$, and so forth. Finally, the cumulative odds are the odds that a score y falls at or below a certain level j, or $\frac{P(y\leqslant j)}{1-P(y\leqslant j)}$. This cumulative odds ratio can be derived from Eq. (7) as:

$$\frac{P(y\leqslant j)}{1-P(y\leqslant j)} = \frac{e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}}{1+e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}} \Big/ \left(1-\frac{e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}}{1+e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}}\right) = \frac{e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}}{1+e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}} \Big/ \left(\frac{1}{1+e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}}\right) = e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}} \quad (9)$$

It follows that the logarithm of the cumulative odds, the log odds, is a linear function of the independent variables:

$$Ln\left(\frac{P(y\leqslant j)}{1-P(y\leqslant j)}\right) = \ln(e^{k_j-\boldsymbol{\beta}'\boldsymbol{x}}) = k_j - \boldsymbol{\beta}'\boldsymbol{x}. \quad (10)$$

Now we are interested in the effects of the variables $\boldsymbol{x}$. For a change of $\boldsymbol{x}$ from $\boldsymbol{x}_1$ to $\boldsymbol{x}_2$, we have a log odds ratio of:

$$Ln\left(\frac{P(y\leqslant j|\boldsymbol{X}=\boldsymbol{x}_2)/1-P(y\leqslant j|\boldsymbol{X}=\boldsymbol{x}_2)}{P(y\leqslant j|\boldsymbol{X}=\boldsymbol{x}_1)/1-P(y\leqslant j|\boldsymbol{X}=\boldsymbol{x}_1)}\right) = -\boldsymbol{\beta}'(\boldsymbol{x}_2-\boldsymbol{x}_1) \quad (11)$$

This ratio of odds is independent of j. The model is, therefore, referred to as a 'proportional odds' model (McCullagh, 1980). The odds in favor of a high score ($y > j$) versus a low score ($y \leqslant j$) are in the same proportion for two different $\boldsymbol{x}$ values, whatever the value of j. Now the interpretation of the coefficient $\boldsymbol{\beta}$ becomes clear: it is the change in the log odds ratio for a unit change in the explanatory variable $\boldsymbol{x}$. Note that the coefficient is independent of the different classes y. If the predictor $\boldsymbol{x}$ is a binary variable, such as a variety or new technology, the coefficient $\boldsymbol{\beta}$ represents the change in the log odds, mathematically: the log of the ratio of the odds of that variety having a high score rather than low to the odds of the control having a high score rather than low. This ratio is called the log odds ratio and its exponent, e^{β_i}, represents the odds that one technology is rated higher over the same odds for another technology (Bellon et al., 2006). It should be noted that the proportional odds assumption is an assumption of the model chosen here, and not a necessary property of this type of data. More advanced models have been developed to relax the assumptions (Ananth and Kleinbaum, 1997), although they are harder to use and lack the ease of interpretation.

2.3. Site selection

The target zone for the technologies in this study is the East African *S. hermonthica* zone, situated around Lake Victoria. Previous studies showed that in Kenya it forms a band around Lake Victoria, from the shore to up to 1600 m (De Groote et al., 2008). A study in Tanzania (Mbwaga and Obilana, 1993) indicated a similar situation south of the lake, while key informants in Uganda indicated *Striga* presence east of the lake, but not to the west (Baguma and Bigirwa, 1994). Based on secondary data and field visits, representative areas and villages in each of the three collaborating countries were purposely selected. Two districts were selected in Kenya (Siaya and Vihiga) and Tanzania (Musingwi and Sengerema) and one in Uganda (Busia), based on heavy *Striga* infestation, stem borer and poor soil fertility, accessibility to scientists, and having areas with good, as well as poor, market access (Fig. 1). In each of the districts, four sites were purposely selected for the PRAs, which took place from December, 2002 to March, 2003. During group discussions, usually with men and women separately, participants explained the constraints they face as farmers, their ma-

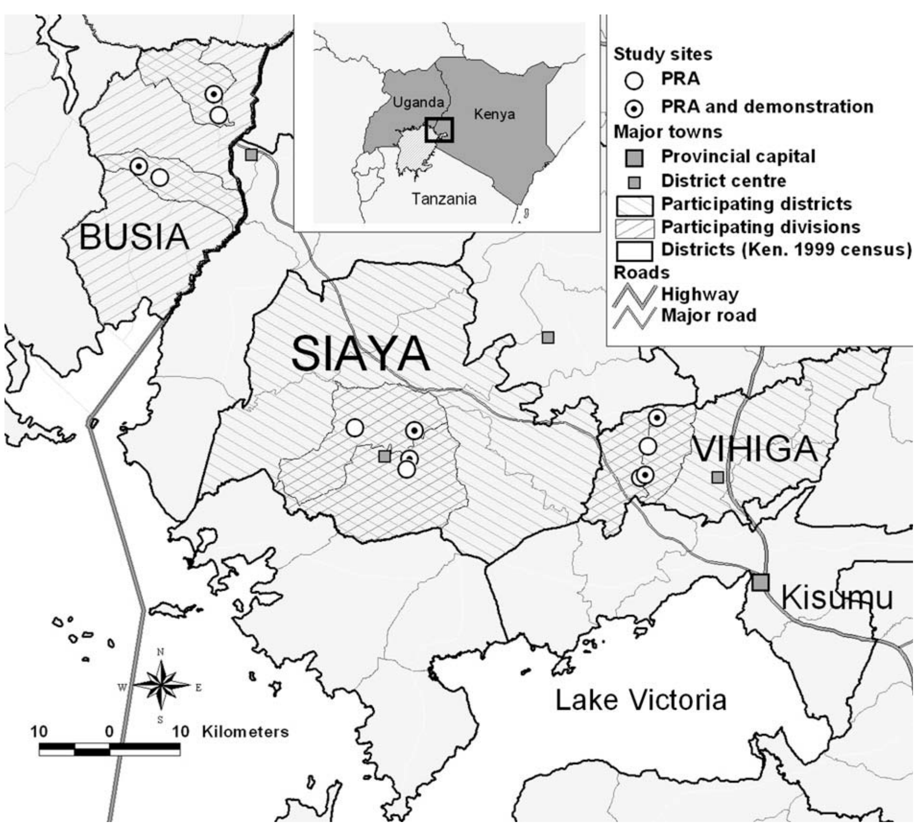

Fig. 1. Map of the study area, PRA and demonstration sites.

jor pest problems, the criteria they use to select maize varieties and cropping systems, the wealth categories they observe, and they discussed with the scientists the options of participatory trials (Odhiambo et al., 2007).

Based on the results, two representative villages were purposely selected for participatory trials in each district: Angorom and Kubo West in Busia (Uganda); Ngoya and Nyalgunga in Siaya, and Ebulonga and Ematsuli in Vihiga (Kenya). In each village, two farmers were selected who belonged to the medium wealth category, were willing to cooperate and were acceptable to the majority of the community. The farms had to have the following characteristics: medium to low soil fertility, medium to heavy *Striga* infestation, an open and large enough surface area to accommodate all 16 treatments, low inputs of organic and mineral inputs in the past, gently sloping fields which were not too far from the homestead. Visits were made to several households by scientists together with the extension staff and discussions were held with the farmers to discover the suitability of the fields based on the above criteria. During these visits, information was collected on topsoil texture, topsoil color and erosion features, while observing the slope and growth of crops for soil fertility indicators and *Striga* pressure. In Kenya, two fields were selected in each of Nyalgunga and Ngoya in Siaya while, due to the small land size, the demonstrations were spread over six farmers' fields in Vihiga. In Uganda, two fields were selected in each of Kubo West and Angorom.

The project also conducted PRAs in three villages in each of the districts of Misungwi and Sengerema in the Mwanza region of Tanzania. In each of the districts, again, two villages were selected for participatory trials. Unfortunately, the rains failed for two consecutive seasons in Tanzania, so these sites were not included for this analysis.

2.4. Demonstration trials

After consultation with the farmers during the PRAs, three cropping systems were selected for the trials to address the farmers' major constraints (*Striga*, stem borers and low soil fertility): push–pull (PP), soybean–maize (SOY) rotation, and *Crotalaria*-maize (CRT) rotation, to be compared to the control, maize mono-crop (MON). Further, each of the four cropping systems was combined with two fertilizer options: once with fertilizer (+F) and once without (−F). Moreover, each of these combinations was tested with two maize varieties: a local variety and imidazolinone-resistant (IR) maize. The four cropping systems, in combination with two fertilizer and two variety options, resulted in a total of 16 treatments.

In each of the six villages, the trial was replicated once, and the initial phase of the project went over four seasons, starting with the long rains of 2003 (April–August) until the short rains of 2004. For the push–pull treatments, the Napier and Desmodium were established in the first season, and maize planted in all seasons. For the treatments involving rotations, the legumes were planted during each of the long rainy seasons, and maize in each of the short rainy seasons (September–December). In the control plots, maize was planted in all seasons. In Uganda, the project only obtained government permission to introduce IR maize into the trials in 2004. During 2003, another improved variety was substituted for IR maize, Longe I.

Visits were made to these sites and farmers were asked to indicate the level of *Striga* in each of their fields (low, medium or high). During the maize-growing season, the fields were visited to confirm infestation levels through visual observation. Based on this feedback, two farmers' fields with high *Striga* pressure and relatively low soil fertility status were selected in each of the villages in Siaya, while in Vihiga, due to the small area of most fields, four fields were selected in Ematsuli and six in Ebulonga. The overall design was a randomized complete block design (RCBD) with four replications in each district. In Siaya, in each of the farmers' fields, a trial was laid out using a split-plot arrangement with the 'cropping system' as the main plot factor and 'variety' and 'fertilizer' as subplot factors. The plot size was 10.5 m by 10 m. The 'cropping system' factor had four levels: maize mono-crop, maize-Desmodium push–pull intercrop, dual purpose soybean (variety TGX-1448-2E)-maize rotation, and *Crotalaria ochroleuca*-maize rotation. The 'variety' factor had two levels: IR maize and local maize. (In Kenya, Msamaria, an open-pollinated local variety was used). The 'fertilizer' factor had two levels: with and without fertilizer application. In Vihiga, a similar design was allocated randomly between the various farmers' fields selected, thereby ensuring that each of the fields accommodated eight experimental units in Ematsuli and four or eight units in Ebulonga. One replicate was allocated to one field in Siaya and two or three fields in Vihiga.

2.5. Farmers' evaluations

In each site, farmers were invited to observe the 16 treatments of the trial at the end of the maize season, and score them. This scoring is clearly more of a snap-shot than a full evaluation, since observations were not taken during the season, and should conservatively be interpreted as a preliminary screening of different pest control and soil fertility options. The scoring took place at the end of each short rainy season, the season when maize was planted in all treatments. Each village followed the same procedure. During the initial meeting, both farmers and scientists introduced themselves, and the purpose of the visit was discussed. A review of the various treatments was presented to the farmers and other participants, such as extension and NGO officers. Farmers listed and ranked the criteria they would use to evaluate the different treatments. Farmers in all villages used *Striga* resistance, stem borer resistance, soil fertility enhancement, yield, and labor saving as criteria to evaluate the different treatments. Two villages in Kenya (Ngoya and Nyalgunga) also added crop vigor, fodder supply, and the ability to reduce soil erosion. Farmers were asked to give an overall evaluation score for each treatment.

Next, each farmer was supplied with an evaluation form consisting of a short section of farmers' characteristics, an evaluation table, and some final questions about their interest in participating in the project. Before going to the field, farmers filled in the first section, indicating their age, gender, level of education, and experience, as well as wealth indicators such as the size of their farm, area under maize, and number of livestock owned. Next, they were invited to visit the trial for the evaluation. At the site, they filled in the evaluation table, consisting of a row for each treatment and a column for each criterion they had mentioned. Farmers then scored each treatment for each criterion, using a scale of 1 (very poor) to 5 (very good), and gave an overall score for each treatment. Then, farmers selected the top three or four treatments they would like to try in their own fields. They were asked to make any suggestions and, after the individual evaluations, the farmers and scientists regrouped to discuss their preferences. This was the chance for farmers to discuss broader issues with scientists and extension staff.

In this paper, these farmers' evaluations are analyzed, using data collected at the end of the short rainy seasons when maize was grown in all plots. For Kenya, the evaluations from both 2003 and 2004 were included, but for Uganda, where the 2003 trials did not yet include IR maize, only the 2004 data were included. In the first year in Kenya, 142 farmers participated, on average 18 women and 18 men per site. An effort was made to involve more farmers, especially women, leading to a total of 323 farmers in the second year (on average 28 women and 26 men per site). In Uganda, 60 farmers (20 women and 40 men) participated in the evaluation during the 2004 short rains. Approximately three quarters of the participating farmers evaluated the trials in both years.

Parallel with the farmers' evaluations, scientists made their observations and reported in more detail elsewhere (Vanlauwe et al., 2008). At 6, 8, and 10 weeks after planting, the number of emerged *Striga* plants were counted in the central six rows (45 m^2), corrected for maize stand and converted to *Striga* plants m^{-2}. In the same plot, the number of maize plants damaged by stem borer were counted and converted to a percentage of the plants damaged. At harvest, the maize yield was obtained from the net plot area of 45 m^2 and adjusted for moisture content.

2.6. Empirical model

Since the scores or ratings used in the farmers' evaluations are ordered categorical data, the appropriate analysis is ordinal regression (Coe, 2002), equivalent to the proportional odds model. This model estimates the log odds ratio, or the log of the ratio of the odds of that treatment having a high score rather than low to the odds of the control having a high score rather than low.

First, the following simple model was estimated:

$$\log\left(\frac{P(Y \leqslant j)}{1 - P(Y \leqslant j)}\right) = k_j + \boldsymbol{\beta}'\boldsymbol{x} + \boldsymbol{\lambda}'\boldsymbol{s} + \boldsymbol{\mu}'\boldsymbol{f} \qquad (12)$$

The dependent variable Y_i is the overall evaluation score of farmer i, using a score from 1 (very poor) to 5 (very good), while the explanatory variables consist of three vectors of binary variables or dummies, to capture the different technologies ($\boldsymbol{x}$), the time periods and sites ($\boldsymbol{s}$), and the different participants ($\boldsymbol{f}$). For each of these groups, the categories are linear combinations of one another and, therefore, one category has to be omitted for each group. The first vector $\boldsymbol{x}$ consists of a dummy for each of the 16 different technologies, except for the control (mono-cropping with local maize without fertilizer). The second vector $\boldsymbol{\lambda}$ has a dummy for one time period (2004, with 2003 as the base) and for two sites (Siaya and Vihiga, with Busia being the base). The fourth vector $\boldsymbol{f}$ includes a binary variable for each participant except one, to capture the correlation of evaluations of the same farmer for different technologies. The estimation of this basic model provides log odds ratios for the different technologies compared to the control, while controlling for year, site and farmer effect.

To analyze if differences exist in appreciation for particular technologies between years and sites, cross effects are introduced in the following model:

$$\log\left(\frac{P(Y \leqslant j)}{1 - P(Y \leqslant j)}\right) = k_j + \boldsymbol{\beta}'\boldsymbol{x} + \boldsymbol{\lambda}'\boldsymbol{s} + \boldsymbol{s}'\boldsymbol{A_{sx}}\boldsymbol{x} + \boldsymbol{\mu}'\boldsymbol{f} \qquad (13)$$

The matrix $\boldsymbol{A_{sx}}$ has a column for each of the site and year variables in vector $\boldsymbol{s}$, and a row for each of the treatments in vector $\boldsymbol{x}$, and each element represents a cross effect of the year or site with that particular treatment. In this model, the coefficients $\boldsymbol{\beta}$ are to be interpreted as the log odds ratios for the different technologies for the base year (2003) in the base site (Busia), while the cross effects are for the differences in log odds ratios between the different years and sites. Alternatively, these effects can be broken down into contributions due to system, variety, fertilizer and their interactions. Details of the estimation have not been included here as it did not aid interpretation.

The actual log odds ratios for the different technologies in 2004, for example, are found by adding the cross effects for 2004 to the basic log odds ratios $\boldsymbol{\beta}$.

The effect of participant characteristics $\boldsymbol{z}$ was evaluated by a similar model:

$$\log\left(\frac{P(y \leqslant j)}{1 - P(Y \leqslant j}\right) = k_j + \boldsymbol{\beta}'\boldsymbol{x} + \boldsymbol{\lambda}'\boldsymbol{s} + \boldsymbol{\gamma}'\boldsymbol{z} + \boldsymbol{z}'\boldsymbol{A_{zx}}\boldsymbol{x} + \boldsymbol{\mu}'\boldsymbol{f} \qquad (14)$$

If the characteristic is a binary variable, "female" for example, the cross effect is interpreted as the change in log odds ratio between the two groups, men and women. If the characteristic is continuous, the cross effects represent the change in the log odds ratio due to a change of one unit of the farmer characteristic.

The effect of the technical performance of the different technologies on farmer evaluation, finally, was analyzed by including the measured grain yield (tons/ha), stem borer infestation (% of infested plants) *Striga* emergence (plants/m^2), and time of emergence (days after planting), in the basic model of Eq. (12).

The relative importance of the different criteria in technology evaluation was estimated by regressing the overall score of each treatment on the scores of the five criteria that were used in all sites: *Striga* resistance, stem borer resistance, soil fertility enhancement, labor saving and yield. Assuming the scores on the different criteria represent sections of the same utility function, a linear regression model is appropriate. This model was estimated using Ordinary Least Squares (OLS), so the coefficients of each of the criteria can be interpreted as their relative importance or weight towards the overall evaluation score.

3. Results

3.1. Identifying farmers' constraints

The results of the PRAs, the full analysis of which is presented elsewhere (Odhiambo et al., 2007) showed that in most participating villages, *Striga*, stem borers and low soil fertility are indeed major constraints faced by farmers. In Kenya and Tanzania, livestock production is important and there is a potential market for fodder crops such as Napier and Desmodium. In the Ugandan villages, however, farmers have fewer livestock units. During group discussions, the farmers explained that they considered sufficient production of maize to feed the family, and land and livestock ownership as major indicators of wealth. In all sites, the farmers were quite happy to try the new technologies, and many participated in the field days and evaluations.

3.2. Summary of the biophysical results

The biophysical results of the trials are reported in detail elsewhere (Vanlauwe et al., 2008). However, it is important to understand the main results and to compare the scientists' observations with the farmers' evaluations. First, *Striga* emergence and stemborer damage were significantly lower under the push–pull system than under all other systems from the second season onwards. Second, IR maize reduced and delayed *Striga* emergence from the first cropping season, while differences in *Striga* emergence and stem borer damage between the other systems were not significantly different. Under IR maize, the *Striga* seed bank was significantly lower than under local maize for all cropping systems, particularly with the push–pull system. After five cropping seasons, the *Striga* seed bank was significantly lower in in the push–pull system than in the mono-cropping system.

Maize yields were found to vary between seasons, districts, and cropping systems (Fig. 2). Yields in the push–pull system were higher than the mono-cropped yields after two seasons and in the absence of mid-season drought stress. Both maize and soybean responded significantly to fertilizer application for both districts and for most seasons. The various interventions did not substantially affect various soil fertility-related parameters after five seasons. The rotational systems may need a longer timeframe to reduce the *Striga* seed bank and show significant improvements in soil fertility status.

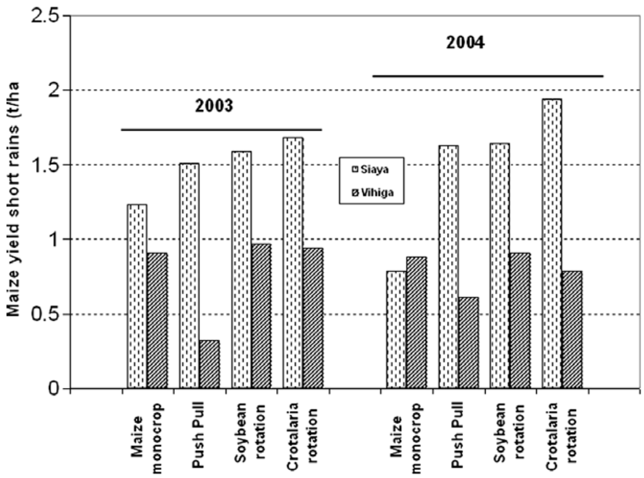

Fig. 2. Maize yields under the different treatments (short rains of 2003 and 2004).

3.3. Analyzing farmers' evaluations of different cropping systems and technologies

To analyze the farmers' evaluations of these technologies, the simple ordinal regression model of Eq. (12) was first estimated. The dependent variable is the overall evaluation, and the independent variables are the different treatments, the year, the sites and the farmers themselves. Farmers' specific evaluations on resistance to *Striga* and stemborers, and improving yields and soil fertility, were also analyzed the same way, although these results are not presented here in the interest of brevity. The estimated coefficients for the treatments (Table 1) represent the log odds ratio that the treatment is preferred to the control or baseline, here the monocropping of the local maize variety without fertilizer. The coefficients on the individual farmer effects are not presented here to save space.

The results show a significant preference of the participating farmers for all treatments over the control. Moreover, the treatments of the push–pull cropping system are clearly preferred. The combination of the new technologies, push–pull with IR and fertilizer, came out best, with an estimated coefficient or log odds ratio of 2.93. The exponent of its coefficient, the odds ratio, is 18.7, so the odds of farmers preferring the first treatment are 19 times the odds that the farmers prefer the control. The odds ratios for the other push–pull combinations ranged from 9 to 15 (Table 1).

After the push–pull cropping system, the rotation systems were preferred. *Crotalaria* was the preferred rotation crop, with farmers preferring it to the control with an odds ratio of 3.5–7.0. Within the soybean group, IR maize with fertilizer stood out (5.7). Preferences for IR maize and fertilizer were also significant in the mono-cropping system. Finally, the coefficients on years show that the different treatments received a much higher appreciation in 2004, which had substantially higher rainfall (Vanlauwe et al., 2008). Note that the evaluations were done at the harvest of the maize crop, so the farmers did not observe the rotation crops directly, only their effect on the maize crop. Moreover, in 2004, three push–pull treatments were not evaluated.

The significance levels α in the Table are presented for individual tests (5%, 1%, and 0.1%). Adjusting the significance level for the multiple tests in this regression, the Bonferoni test, leads to critical level of $\alpha/18$ (0.277%, 0.056% and 0.0056%). Since the p-levels of the coefficients of the different tests are all very small they are also significant at the adjusted levels. Because of convention, only the single test is presented in the tables.

An alternative model, with effects broken down into contributions due to system, variety, fertilizer and their interactions, was also estimated. However, almost all effects and cross-effects were significant, which brings the interpretation of the results close to

Table 1
Overall appreciation of the technologies through estimation of the proportional odds regression model (model 1: dependent variable is the overall farmer evaluation score, from Uganda and Kenya, 2003 and 2004; independent variables are the different technologies, year and site).

Components of treatment			Estimated coefficient (log odds ratio)	Standard error	Exponent of coefficient (e^{β_i} or odds ratio)
Cropping System	Maize variety	Fertilizer			
Push–pull	IR[a]	Yes	2.93***	0.134	18.7
Intercrop	IR	No	2.73***	0.135	15.3
	Local	Yes	2.22***	0.133	9.2
	Local	No	2.40***	0.126	11.0
Soybean–maize rotation	IR	Yes	1.73***	0.122	5.7
	IR	No	0.75***	0.121	2.1
	Local	Yes	1.03***	0.121	2.8
	Local	No	0.96***	0.121	2.6
Crotal aria–maize rotation	IR	Yes	1.78***	0.122	5.9
	IR	No	1.26***	0.121	3.5
	Local	Yes	1.94***	0.123	7.0
	Local	No	1.81***	0.122	6.1
Mono-crop	IR	Yes	0.56***	0.121	1.8
	IR	No	0.55***	0.121	1.7
	Local	Yes	0.62***	0.121	1.9
	Local	No	0.00.		1.0
Year	2004		2.49***	0.694	12.1
Site	Vihiga		−0.33	0.675	0.7
	Siaya		−0.47	0.64	0.6
	Log likelihood		18948.62		
Goodness of fit	X^2		2859.96		
	N		7033		

* Significant at 5%.
** Significant at 1%.
*** Significant at 0.1%.
[a] IR: imazapyr-resistant.

an appreciation of the 16 combinations of the different factors, which are identical to the 16 treatments. Therefore, the results were not included here.

3.4. Analyzing the difference in farmers' evaluations between years and sites

The differences in appreciation between sites and seasons can by analyzed by including binary variables for evaluations belonging to those particular groups, and their cross effects in the proportional odds model (Eq. (13)). In such a model, the direct effects of the treatments represent the log odds ratio, or the log of the ratio of the odds that the participants not in that category (dummy = 0) prefer that treatment over the odds that they prefer the control. The coefficients of the cross effects (dummy = 1) then represent the change in the log odds, or the log odds ratio, between those in the category and the others, in the preference for the specific technology compared to the control.

This analysis was first used to compare the two years, by including a vector of cross effects for farmers' evaluations from the year 2004 (Eq. (13)). The coefficients $\boldsymbol{\beta}$ now represent the direct effect of farmer appreciation of the different technologies as log odds ratios, at the 2003 evaluations (Table 2, model 2). The results show that, in 2003, all treatments were significantly more appreciated than the control. Moreover, except for those with the mono-cropping system, all cross effects with 2004 were also positive and significant, indicating that these treatments were more appreciated in 2004 than in 2003. The farmers' actual appreciation of these technologies in 2004 can be found by adding the two coefficients. The log odds ratio for the top treatment, push–pull with fertilizer and IR, was 2.08 in 2003, and the cross-effect for 2004 was 1.38, so the log odds ratio for 2004 can be calculated at 3.47. This means that the odds ratio for this technology to be more appreciated over the control was 8:1 in 2003, but 32:1 in 2004.

The results show positive and significant cross effects for 2004 for all push–pull combinations, indicating that this technology was more appreciated in 2004 than in 2003. Similarly, the *Crotalaria* intercrop was more appreciated in 2004 than in 2003. The cross effects were not significant for the soybean rotations though, indicating that there was no difference between farmer appreciation for this cropping system between 2003 and 2004. The IR maize in the mono-crop was only appreciated in combination with fertilizer, and then only in 2004. Fertilizer in the mono-crop was appreciated in both years, although the effects were small (odds of 1.7:1 in 2004 and 1.9:1 in 2003).

The differences in farmers' evaluations of technologies between sites were analyzed in a similar manner (Eq. (13)). Since there were three sites, first there is the set of coefficients on the technologies $\boldsymbol{\beta}$, representing the farmers' evaluations in the omitted site Busia (Table 2, model 3), then two sets of cross effects for the other sites, Siaya and Vihiga (columns 6 and 8). The farmers' evaluations in the last two sites are found by adding the cross effects to the direct effects. This analysis shows substantial differences in farmer appreciation of the new technologies between the sites. The farmers in Busia, for example, gave the soybean rotations with IR maize a better score than the push–pull with IR maize, with a log odds ratio of 2.77 vs. 1.44 (treatments with fertilizer). This indicates that the odds of the soybean with IR maize and fertilizer to be preferred over the odds of the control to be preferred are 15:1, while those of the similar push–pull treatment are only 4:1. The cross effects of treatments with the dummy for Siaya are almost all significant, indicating substantial differences in farmer appreciation with Busia. In particular, farmers in Siaya liked the push–pull system much better than those at the other sites, as well as the *Crotalaria* rotation with fertilizer. Adding up the direct and cross effects results in the log odds ratio for the preference of the different technologies in Siaya over the control. Farmers in Siaya appreciated the new technologies most; the technology most preferred (push–pull with IR maize and fertilizer), has a log odds ratio of

Table 2
Farmers' evaluation of technologies by year and sites, analyzed through cross effects with binary variables in ordinal regression model.

Components of treatment			Model 2: year		Model 3: sites			Model 4: age	
Cropping system	Maize variety	Fertilizer	2003 (direct)	2004 (cross effect)	Busia (base)	Siaya (cross effect)	Vihiga (cross effect)	Direct effect	Age (cross effect)
Push–pull	IR	Yes	2.08***	1.38***	1.44*	3.75*	−0.40	1.32*	0.05*
	IR	No	1.68***	1.83***	1.23*	3.80*	−0.83*	1.75**	0.04**
	Local	Yes	1.59***	1.03***	0.50	3.63*	0.05	0.85	0.04**
	Local	No	1.74***	1.00***	0.05	3.80***	2.14***	1.69**	0.02*
Maize–Soybean	IR	Yes	1.82***	−0.11	2.70*	0.09	−2.01***	2.10***	−0.01
	IR	No	0.76***	−0.03	1.38*	0.27	−1.66***	0.21	0.01
	Local	Yes	1.27***	−0.35	0.27	1.40***	0.56	−0.14	0.02
	Local	No	0.62**	0.49	1.70*	−0.45	−1.08**	0.70	0.01
Maize–crotalaria	IR	Yes	1.23***	0.81**	−0.80*	3.31*	2.92***	1.42**	0.01
	IR	No	1.36***	−0.18	2.18*	−0.34	−1.44***	1.39**	0.00
	Local	Yes	1.16***	1.13***	−0.65	3.48***	2.86***	1.17*	0.03*
	Local	No	1.27***	0.79**	2.12*	0.81*	−1.24	2.41***	0.00
Mono-crop	IR	Yes	0.11	0.64*	0.48	0.76*	−0.51	0.40	0.01
	IR	No	0.05	0.73	2.55*	−1.48*	−2.95***	0.71	0.00
	Local	Yes	0.54*	0.11	−0.05	0.94*	0.76*	0.31	0.01
	Local	No	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Year	2003		−2.09**		−2.492*	0		0.00	0.05*
Site	Vihiga		−0.46		−0.893			4.66	0.04
	Siaya		−0.49		0.337			3.79	0.04
Age	Years							−0.11	0.02*
Goodness of fit			1879					1132	
	Log likelihood		6		17806			1	
	X^2		3012		4003			2046	
	N		7033		7033			4300	

5.18, indicating it is 178 times more likely to be preferred. Similarly, the cross-effects with Vihiga indicate substantial differences: push–pull and soybean rotations with IR maize, for example are less preferred here than in the base group, Busia.

3.5. Analyzing the effect of farmer characteristics

Next, the method was used to analyze the effect of farmer characteristics on their appreciation of technology, in particular the effects of gender and age (Eq. (14)). Gender is a categorical variable, so the analysis is similar to the previous, with a binary variable for female and a cross-effect of each technology with this variable. To save space, the full results are not presented here. The coefficient on female was not significant, indicating that women overall did not rate technologies differently from men or use a different scale. There were, however, substantial differences between the two groups in evaluating the different technologies. All cross effects for push–pull technologies are significant, large and positive, indicating that women appreciate this cropping system substantially more than men. The cross effects of the maize soybean rotation treatments are not significant, indicating that this is a gender-neutral technology, as are IR maize and fertilizer.

Next, the effect of continuous farmer characteristics on preferences for different technologies was analyzed, using cross effects with Eq. (14). The effect of age on farmer preferences was found to be small, but positive and significant, on the appreciation of push–pull, in all combinations (Table 2, model 4). This indicates that older farmers are more likely to prefer push–pull. Similarly, there was a small, positive effect of age on the preference for *Crotalaria* with fertilizer combinations.

To analyze if wealthier farmers have different preferences for technologies from poorer farmers, the model was estimated with cross effects for wealth indicators, in particular farm size and livestock ownership. Farm size had a significant negative effect on the preference for three of the four push–pull technologies, indicating that the proposed technologies are more appreciated by small-scale farmers and, similarly, the *Crotalaria* treatments with fertilizer were more preferred by smaller-scale farmers. These effects, however, were all very small. Another wealth indicator, number of livestock owned, was not found to have any significant effect on the farmers' appreciation of the technologies.

3.6. Estimating the importance of different criteria

To analyze how the different selection criteria influence the overall evaluation score, the overall score was regressed on the scores of the different criteria. The coefficients then represent an estimate of the importance of the individual criteria in the overall evaluation (Table 3). The coefficients on all criteria are significant and positive, but differ substantially in size. By far the most important criterion is yield, with a coefficient of 0.40. In other words, when all other criteria are equal and when the score of a treatment for yield increases by 1, its overall score increases on average by 0.40. The two other important criteria are soil fertility enhancement (0.25) and *Striga* resistance (0.13). Labor saving (0.09) and stem borer resistance (0.03) only make small contributions to the overall evaluation and can be considered as relatively minor criteria.

Table 3
Decomposition of overall evaluation for different treatment, by OLS regression on the scores for different criteria (all scores going from 1 = very poor, to 5 = very good).

Variables	Estimated coefficient	Standard error
Constant	0.45	0.04***
Yield	0.40	0.01***
Soil fertility enhancement	0.25	0.01***
Striga resistance	0.13	0.01***
Labor saving	0.09	0.01***
Stem borer resistance	0.03	0.01**
R^2	0.58	
N	5848	

* Significant at 5%.
** Significant at 1%.
*** Significant at 0.1%.

3.7. Effect of the technology's performance on farmers' evaluations

Of major interest to the interaction between farmers and scientists is the effect of the technologies' performance, according to the scientists' criteria, on the farmers' evaluations. Therefore, maize yield, stem borer infestation, *Striga* infestation and the timing of *Striga* emergence were regressed on the farmers' overall evaluation (Table 4). The effect of soil fertility improvement was not measured since soil analysis for each plot would have been prohibitively expensive. Also, yield data from Uganda were not available.

The results of the regression show that the effects of the four performance variables are all highly significant, although relatively small. The coefficients again indicate a change in odds ratio, but now for one unit change of the performance variables. The major result, however, is that including these variables has little effect on the different evaluation of the technologies, indicating that other factors still play a major roll in farmers' evaluations. It should also be noted that farmers' evaluations of the yield of different treatments is not particularly good. While treatments with a higher yield do, on average, receive a better evaluation for yield, there is a wide variation, and farmers often rate treatments with lower yield higher.

4. Discussion

4.1. Participatory evaluation of best-bet IPSFM technologies

Analysis of the participatory evaluation, showed that the different treatments received a much higher appreciation in 2004 and that appreciation of different technologies varied between the sites. The evaluations were done at the harvest of the maize crop, so the farmers did not observe the rotation crops directly, only their effect on the maize crop. Moreover, in 2004, three push–pull treatments were not evaluated.

The results show positive and significant cross effects for 2004 for all push–pull combinations, indicating that this technology was more appreciated in 2004 than in 2003. Similarly, the *Crotalaria* intercrop was more appreciated in 2004 than in 2003. The cross effects were not significant for the soybean rotations though, indicating that there was no difference between farmer appreciation for this cropping system between 2003 and 2004. The IR maize in the mono-crop was only appreciated in combination with fertilizer, and then only in 2004. Fertilizer in the mono-crop was appreciated in both years, although the effects were small (odds of 1.7:1 in 2004 and 1.9:1 in 2003). Technologies like push–pull and *Crotalaria* registered better effects on the agroecosystem from the second season (2004), suggesting residual effects of technology and also the effect of established companion crops in the push–pull system. Similarly, stemborer infestation was generally higher in 2004 then 2003 and so the effect of technologies was more evident (Vanlauwe et al., 2008) which could partly explain the results, although one has also to take into account that the rains were better in 2004.

Moreover, the results of the evaluation show how maize production systems with intercropping or rotation with legumes are

Table 4
Effect of actual yield, and observed stem borer and *Striga* infestations on farmers' overall evaluation.

Variables	Cropping system	Maize variety	Fertilizer	Short model		Long model	
				Estimate	Standard error	Estimate	Standard error
Maize yield (tons/ha)				1.57	0.08***	1.80	0.10***
Stem borer infestation (% of plants)				−0.24	0.01***	0.01	0.02
Striga infestation (plants/m2)				−0.09	0.02***	−0.02	0.02
Striga emergence (days after planting)				0.10	0.02***		0.03***
Treatment	Push–pull	IR	Yes			2.57	0.19***
		IR	No			2.48	0.18***
		Local	Yes			2.41	0.17***
		Local	No			2.91	0.16***
	Maize–Soybean	IR	Yes			1.10	0.14***
		IR	No			0.67	0.14***
		Local	Yes			0.88	0.15***
		Local	No			0.75	0.13***
	Maize–crotalaria	IR	Yes			1.48	0.15***
		IR	No			0.68	0.14***
		Local	Yes			1.88	0.14***
		Local	No			1.94	0.13***
	Mono-crop	IR	Yes			0.20	0.14
		IR	No			0.53	0.14***
		Local	Yes			0.24	0.14
		Local	No			0.00	
Year (2004)						2.62	0.70***
Site (Siaya)						0.24	0.69
−2 Log likelihood				16,142***		18,754***	
Chi-square				2612***		3286***	
N				6016		6016	
Farmers				405		405	

well appreciated by farmers. Push–pull is understandably more appreciated in the second season, since *Desmodium* and Napier grass take time to establish. The technology also offers additional benefits, beyond *Striga* and stemborer control, to the farmers thereby making it more attractive (Khan et al., 2008). Further, there are substantial differences between sites, which need to be taken into account. Several factors can play a role, in particular soil type, Vihiga sites were more sandy than the others for example, and altitude: Busia at 1200 m and Siaya at 1300 m are much lower than Vihiga at 1500 m, and receive less rainfall.

4.2. Analysis of the factors influencing farmers' appreciation

The analytical method used here, combining scoring and ordinal regression, reveals the effect of farmer characteristics on their appreciation of new technologies, which, as was shown here, is particularly useful in gender and poverty analysis. The technologies demonstrated here were either more appreciated by women and poorer farmers, or neutral. Among wealth indicators, only land ownership had an effect, although this is a rather crude indicator. Combined indices could be looked into. Livestock ownership, somewhat surprisingly, had no effect on appreciation of the rotation or intercropping technologies. Since these technologies produce substantial amounts of feed, they were expected to be more interesting to livestock owners.

4.3. Evaluation of the use of scores and ordinal regression in participatory research

Scoring was found to be a convenient and time-efficient alternative to ranking in participatory evaluation of new technologies, with wide applications for farming systems research. Clearly, sufficient time is invested in explaining the method to farmers and other participants, and participants need to be guided through the first exercise. Still, it was found that 20% of the farmers were likely to have reversed the scoring scale or mixed scoring with ranking: they gave a score of "1" to their first choice of technologies, and a score of "2" to the second choice. Such inconsistencies need to be clarified on the spot, by screening the questionnaire. Alternative methods include the use of alphabetical instead of numerical scores (VG for "very good", G for "good", and so forth), or checking the scores in appropriate boxes. The last option, however, requires substantially more space on the questionnaire, which was here limited to one page.

Ordinal regression was found to be a convenient tool to analyze these scores with standard statistical software. Again, it takes some effort at first but, once accustomed, the analysis and interpretation is straight forward. In particular, the ordinal regression allows for the analysis of factors influencing farmers' preferences, which is particularly useful for gender and poverty analysis. However, the large number of treatments ($4 \times 2 \times 2$), over two years and at three sites does generate a large number of coefficients and cross effects, especially when analyzing the effect of farmer characteristics. Thus, it becomes tedious to go through all the options. Therefore, it would be preferable to specify clearly the hypotheses at the beginning of the study, so they can be tested in a more straightforward manner.

All statistical analysis procedures involve making assumptions about the nature of the data. The stronger the assumptions made, the more information can be extracted from the data and the stronger the inferences that can be made. However the validity of these inferences depends on the assumptions being reasonable. Choosing a method is therefore a question of balancing information gains through making strong assumptions and losses from making inappropriate assumptions. Alternative methods for this type of score data include: (i) treating the score as a continuous, interval measure, simple but difficult to justify, making assumptions which rarely seem reasonable; (ii) dichotomizing the data, reducing each score to two levels, either $> j$ or $< j$ for a fixed j, which makes fewer assumptions but involves ignoring much information; and (iii) treating the data as multinomial, with each possible score having its own level of response, which makes few assumptions but ignores the ordinal nature of the data and typically makes results hard to interpret. Because of the problems with the alternative methods, the ordinal regression is the most common. Key assumptions here are of proportional odds, the nature of the linear part of the model and the nature of the link function. Methods have been developed to examine these assumptions (Agresti, 2002), and more advance models have been developed to relax them (Ananth and Kleinbaum, 1997).

Decomposition of the overall evaluation of the treatments over the separate selection criteria showed that, as expected, maize yield is the most important criterion in evaluating cropping systems. Although very important, its weight is substantially less than that which breeders usually give it in their selection index. The two other important criteria, that should always be included in the analysis, are soil fertility enhancement and *Striga* resistance. While significant, the criteria of labor saving and stem borer resistance only make small contributions to the overall evaluation and can be considered as relatively minor criteria. However, labor saving might not be fully appreciated when the evaluation is only done at harvest. Also, stemborer infestation levels were generally low, between 1 and 10% of plants, except in Siaya where they reached 15% in the short rainy season of 2004 in some of the treatments (Vanlauwe et al., 2008). The use of overall evaluation and its decomposition is particularly important for farming systems research, since it allows the farmers to set their own evaluation criteria.

In this study, the method of scores and ordinal regression was only used in centrally located, researcher-managed trials, and only at the end of the maize season. Clearly, this can be improved substantially by having farmers observe the trials more frequently over the season. The next phase of the research is to have farmers experiment with the new technologies, and adapt and mix them in their fields. It is likely that the method of capturing farmers' preferences and appreciation will need to be adapted and tested in these new environments. This will also provide them with a better evaluation of labor requirements. Also, the use of randomized trials, in which not only the treatments but also the evaluating farmers are randomized, should be considered. Such randomized social experiments are receiving increasing attention in development research (Duflo et al., 2006), but are not common in agriculture.

5. Conclusions

The main objectives of this study were participatory evaluation of new technologies, analysis of the factors that influence farmers' appreciation, and evaluating the use of scores and its analysis using ordinal regression in farming systems and participatory research. The results show that all treatments are preferred by the participating farmers over the control, but the four push–pull treatments clearly stood out. The most preferred treatment was the combination of the new technologies, push–pull with IR and fertilizer. The next most preferred group was the maize-*Crotalaria* rotation, followed by soybean rotation. Within the soybean group, IR maize with fertilizer stood out; within the mono-crop, both IR maize and fertilizer were preferred. IR maize was only appreciated in combination with fertilizer, and then only in 2004. The analysis showed substantial differences in farmers' evaluations between the years and the sites. The push–pull and *Crotalaria* systems, for example, were more appreciated in 2004, but there was no difference for the soybean rotation between the years. Further, farmers in Busia liked the push–pull, but only with IR maize, while those in Siaya like the push–pull system much better. In Vihiga, the preference for push–pull and soybean rotation was clearly less pronounced.

The analysis showed substantial differences according to farmer characteristics such as gender, age, and land size. Overall, women do not rate technologies on a different scale than men, but they do clearly prefer push–pull and soybean rotations more than men, while there is no gender difference for maize–soybean rotations and within the mono-cropping system. Generally, age has little effect on the appreciation of different technologies; only the preference for push–pull with IR maize increases with age. Farm size, on the other hand, had a substantial negative effect on the preference for push–pull technologies, indicating that they are particularly appreciated by small-scale farmers.

The results of this study show how scoring is a convenient alternative to ranking in participatory evaluation of new technologies. Moreover, this study shows that there is no reason to treat scores as continuous variables. Ordinal regression provides a convenient tool to analyze these data with standard statistical software. However, in this study the method was only used in centrally located trials and will need to be adapted to the next phase of this research, where farmers are adapting and combining the technologies in their individual fields.

This method of farmer's evaluating new technologies, using their own criteria, and analyzing the results in the way presented here, has wide applicability in farming systems research. Farmers can use their own criteria, depending on their specific systems, to score the technologies and these scores can be conveniently, while rigorously, analyzed using ordinal regression. The analysis then helps to focus further research and extension. The analysis of the different options in integrated pest management and soil fertility tested in the trials presented here, show clearly how particular options are widely appreciated (push–pull) and others much less (*Crotalaria),* while other options are only appreciated in particular combinations (IR-maize with fertilizer). Moreover, the evaluation helps to understand the acceptability of different technologies by different groups, and ensure they fit their specific demands. This is particularly useful for gender and poverty analysis, as indicated here by the acceptability of tested technologies by women and small holder farmers. The use of this method can be very helpful to define and focus further research and formulate specific and targeted recommendations for agricultural extension.

Acknowledgments

The authors would like to thank the Crop Protection Program of the Department for International Development (DFID) for funding this research. The technical support of the research technicians Dickens Nyagol and Laban Nyambega, and of the CIMMYT support staff in Nairobi is highly appreciated. We also thank Kathy Sinclair for editing this manuscript.

References

Agresti, A., 2002. Categorical Data Analysis, Second ed. Wiley, New York.
Altieri, M.A., Nicholls, C.I., 2003. Soil fertility management and insect pests: harmonizing soil and plant health in agroecosystems. Soil and Tillage Research 72, 203–211.
Ananth, C.V., Kleinbaum, D.G., 1997. Regression models for ordinal responses: a review of methods and applications. International Journal of Epidemiology 26, 1323–1333.
Baguma, S.D., Bigirwa, G., 1994. Occurance of Striga Species in Western Uganda, African Crop Science, Vol. 1. African Crop Science Society, pp. 222–223.
Bellon, M.R., Adato, M., Becerril, J., Mindek, D., 2006. Poor farmers' perceived benefits from different types of maize germplasm: the case of creolization in lowland tropical Mexico. World Development 34, 113–129.
Berner, D.K., Kling, J.G., Singh, B.B., 1995. Striga research and control: a perspective from Africa. Plant Disease 79, 652–660.
Byerlee, D., Eicher, C.K., 1997. Introduction: Africa's food crisis. In: Byerlee, D., Eicher, C.K. (Eds.), Africa's Emerging Maize Revolution. Lynne Rienner Pulbishers, Boulder, Colorado, pp. 3–8.

Carsky, R.J., Berner, D.K., Oyewole, B.D., Dashiell, K., Schulz, S., 2000. Reduction of *Striga hermonthica* parasitism on maize using soybean rotation. International Journal of Pest Management 46, 115–120.

Coe, R., 2002. Analyzing ranking and rating data from participatory on-farm trials. In: Bellon, M.R., Reeves, J. (Eds.), Quantitative Analysis of Data from Participatory Methods in Plant Breeding. CIMMYT, Mexico, DF, pp. 46–65.

De Groote, H., Wangare, L., Kanampiu, F., 2007. Evaluating the use of herbicide-coated imidazolinone-resistant (IR) maize seeds to control Striga in farmers' fields in Kenya. Crop Protection 26, 1496–1506.

De Groote, H., Siambi, M., Friesen, D., Diallo, A., 2002. Identifying farmers' preferences for new maize varieties in Eastern Africa. In: Bellon, M.R., Reeves, J. (Eds.), Quantitative Analysis of Data from Participatory Methods in Plant Breeding. CIMMYT, Mexico, DF, pp. 82–102.

De Groote, H., Bett, C., Okuro, J.O., Odendo, M., Mose, L., Wekesa, E., 2004. Direct estimation of maize crop losses due to stemborers in Kenya, preliminary results from 2000 and 2001. In: Friesen, D.K., Palmer, A.F.E. (Eds.), Integrated Approaches to Higher Maize Productivity in the New Millennium. Proceedings of the 7th Eastern and Southern Africa Regional Maize Conference. CIMMYT, Mexico, DF, pp. 401–406

De Groote, H., Wangare, L., Kanampiu, F., Odendo, M., Diallo, A., Karaya, H., Friesen, D., 2008. Potential for herbicide resistant maize seed for Striga control in Africa. Agricultural Systems 97, 83–94.

Duflo, E., Glennerster, R., Kremer, M., 2006. Using Randomization in Development Economics Research: A Toolkit. BREAD Working Paper 136. Bureau for Research and Economic Analysis of Development.

FAO, 2007. FAO Statistical Databases (FAOSTAT). Food and Agriculture Organization (FAO) (verified 07.01.07).

Franzel, S. 2001. Use of an indigenous board game, 'bao', for assessing farmers' preferences among alternative agricultural technologies. In: Peters, G.H., Prabhu, P. (Eds.), Tomorrow's Agriculture: Incentives, Institutions, Infrastructure and Innovations. Proceedings of the 24th International Conference of Agricultural Economists, 13–18 August 2000, Berlin, Ashgate, Aldershot, pp. 416–424.

Gacheru, E., Rao, M.R., 2001. Managing Striga infestation on maize using organic and inorganic nutrient sources in western Kenya. International Journal of Pest Management 47, 233–239.

Gacheru, E., Rao, M.R., Jama, B., Niang, A., 1999. The potential of agroforestry to control Striga and increase maize yields in Sub-Saharan Africa. In: Maize Production Technology for the Future: Challenges and Opportunities, Proceedings of the Sixth Eastern and Southern Africa Regional Maize Conference, 21–25 September, 1998. CIMMYT (International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organization), Addis Ababa, Ethiopia, pp. 180–184.

Greene, W.H., 1991. Econometric Analysis. Mcmillan Publishing Company, New York.

Hassan, R., Ransom, J.K., Ojiem, J., 1994. The spatial distribution and farmers' strategies to control Striga in maize: survey results from Kenya. In: Jewell, D.C., et al. (Eds.), Maize Research for Stress Environments, Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference, Held at Harare, Zimbabwe, 28 March-1 April, 1994. CIMMYT, Mexico DF, pp. 250–254

Ibewiro, B., Sanginga, N., Vanlauwe, B., Merckx, R., 2000. Nitrogen contributions from decomposing cover crop residues to maize in a tropical derived savanna. Nutrient Cycling in Agroecosystems 57, 131–140.

Kanampiu, F., Ransom, J., Gressel, J., Jewell, D., Friesen, D., Grimanelli, D., Hoisington, D., 2002a. Appropriateness of biotechnology to African agriculture. Plant Cell, Tissue and Organic Culture 69, 105–110.

Kanampiu, F.K., Ransom, J.K., Friesen, D., Gressel, J., 2002b. Imazapyr and pyrithiobac movement in soil and from maize seed coats to control Striga in legume intercropping. Crop Protection 21, 611–619.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K., Gressel, J., 2003. Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls *Striga* spp, and increases yields in several African countries. Crop Protection 22, 697–706.

Khan, Z.R., Pickett, J.A., Van den Berg, J., Wadhams, L.J., Woodcock, C.M., 2000. Exploiting chemical ecology and species diversity: stemborer and Striga control for maize and sorghum in Africa. Pest Management Science 56, 957–962.

Khan, Z.R., Pickett, J.A., Wadhams, L.J., Hassanali, A., Midega, C.A.O., 2006. Combined control of Striga hermonthica and stemborers by maize–*Desmodium* spp., intercrops. Crop Protection 25, 989–995.

Khan, Z.R., Amudavi, D.M., Midega, C.A.O., Wanyama, J.M., Pickett, J.A., 2008. Farmers' perceptions of a 'push–pull' technology for control of cereal stemborers and Striga weed in western Kenya. Crop Protection 27, 976–987.

Maddala, G.S., 1983. Limited-dependent and Qualitative Variables in Econometrics. Cambridge University Press, New York.

Mbwaga, A.M., Obilana, A.T., 1993. Distribution and host specificity of *Striga asiatica* and *S. hermonthica* on cereals in Tanzania: a preliminary study. International Journal of Pest Management 39, 449–451.

McCullagh, P., 1980. Regression models for ordinal data. Journal of the Royal Statistical Society. Series B (Methodological) 42, 109–142.

Odendo, M., De Groote, H., Odongo, O.M., 2001. Assessment of farmers' preferences and constraints to maize production in the moist midaltitude zone of western Kenya. In: African Crop Science Conference Proceedings of the 5th International ACS Conference, Lagos, Nigeria, 21–26 October, 2001, vol. 5. ACSA, ed., African Crop Science Association, Kampala, pp. 769–775

Odhiambo, G., De Groote, H., Khan, Z., Kikafunda, J., Nyagol, D., Rwiza, I., Kanampiu, F., Vanlauwe, B., 2007. Participatory Assessment of Striga, Stemborer and Soil Fertility Problems in the Lake Victoria Basin. Unpublished Manuscript, Nairobi.

Rosegrant, M.W., Paisner, M.S., Meijer, S., Witcover, J., 2001. 2020 Global Food Outlook Trends, Alternatives, and Choices International Food Policy Research Institute (IFPRI), Washington, DC.

Sanchez, P.A., Jama, B.A., 2002. Soil fertility replenishment takes off in East and Southern Africa. In Vanlauwe, B., et al. (Eds.), Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice. CABI, Wallingford, UK, pp. 23–46.

Sanginga, N., Okogun, J., Vanlauwe, B., Dashiell, K., 2002. The contribution of nitrogen by promiscuous soybeans to maize based cropping the moist savanna of Nigeria. Plant and Soil 241, 223–231.

Sanginga, N., Dashiell, K.E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R.J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B.B., Chikoye, D., Keatinge, D., Ortiz, R., 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. Agriculture, Ecosystems & Environment 100, 305–314.

Smaling, E.A.M., Stoorvogel, J.J., de Jager, A. 2002. Decision making on integrated nutrient management through the eyes of the scientist, the land-user and the policy maker. In: Vanlauwe, B., et al. [Eds.], Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CABI, Wallingford, UK. pp. 265–284.

Train, K.E., 2003. Discrete Choice Methods with Simulation. Cambridge University Press.

Vanlauwe, B., Giller, K.E., 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystems & Environment 116, 34–46.

Vanlauwe, B., Bationo, A., Carsky, R.J., Diels, J., Sanginga, N., Schulz, S., 2003. Enhancing the contribution of legumes and biological nitrogen fixation in cropping systems: experiences from West Africa. Grain legumes and green manures of soil fertility in Southern Africa: taking stock of progress. In: Proceedings of a SoilFertNet Meeting, 8–11 October 2002, Vumba, Zimbabwe, pp. 3–13.

Vanlauwe, B., Kanampiu, F., Odhiambo, G., De Groote, H., Wadhams, L.J., Khan, Z.R., 2008. Integrated management of *Striga hermonthica*, stemborers, and declining soil fertility in western Kenya. Field Crops Research 107, 102–115.

Versteeg, M.N., Amadji, F., Eteka, A., Gogan, A., Koudokpon, V., 1998. Farmers' adoptability of Mucuna fallowing and agroforestry technologies in the coastal savanna of Benin. Agricultural Systems 56, 269–287.