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Ex ante assessment of dual-purpose sweet potato in the crop–livestock system of western Kenya: A minimum-data approach

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ABSTRACT

Mixed crop–livestock systems have a crucial role to play in meeting the agricultural production challenges of smallholder farmers in sub-Saharan Africa. Sweet potato is seen as a potential remedial crop for these farmers because of its high productivity and low input requirements, while its usefulness for both food and feed (dual-purpose) make it attractive in areas where land availability is declining. In this paper, we develop and apply a 'minimum-data' methodology to assess *ex ante* the economic viability of adopting dual-purpose sweet potato in Vihiga district, western Kenya. The methodology uses and integrates available socio-economic and bio-physical data on farmers' land use allocation, production, and input and output use. Spatially heterogeneous characteristics of the current system regarding resources and productivity are analyzed to assess the profitability of substituting dual-purpose sweet potato for other crops currently grown for food and feed. Results indicate that a substantial number of farmers in the study area could benefit economically from adopting dual-purpose sweet potato. Depending on assumptions made, the adoption rate, expressed as the percentage of the total land under adopting farms, is between 55% and 80%. The analysis shows that the adoption rate is likely to vary positively with the average total yield of dual-purpose sweet potato, the harvest index (the ratio between tuber and fodder yields), the price of milk, and the nutritional value of available fodder. This study demonstrates the usefulness of the minimum-data methodology and provides evidence to support the hypothesis that dissemination of the dual-purpose sweet potato could help improve the livelihoods of smallholder farmers operating in mixed crop–livestock systems in east Africa.

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1. Introduction

The rapid increase in human population in sub-Saharan Africa is increasing the demand for food and livestock products. Given the substantial barriers to food importation in the region, particularly in isolated rural areas facing high transport costs, the production growth required to feed rural populations will have to be met largely by increased output per unit of land. This increasing demand causes an intensification of the smallholder production systems on which a large proportion of rural populations in sub-Saharan Africa depend (Kuyvenhoven et al., 2004; Sachs and McArthur, 2005). Typically, smallholder systems are characterized by continuous cropping with few external nutrient inputs and removal of field crop residues for feeding livestock with limited recycling of nutrients and organic matter back into the soil. The resulting depletion of soil nutrients and organic matter is threatening the sustainability of many agricultural systems (Smaling et al., 1992; Stoorvogel et al., 1993; Lynam et al., 1998; Sanchez et al., 1997; Place et al., 2003). Typically, the systems on these small farms involve crops and livestock, and researchers have been investigating how soil degradation can be addressed in these mixed crop–livestock systems (Shepherd and Soule, 1998; Nyaata et al., 2000; Thornton and Herrero, 2001; Thornton et al., 2003; Waithaka et al., 2005). In sub-Saharan Africa alone, an estimated 444 million people (70% of the total human population) depend on these systems (Thornton et al., 2003). In addition, smallholder dairy farmers, representing up to 70% of households in some high-potential areas of Kenya, are grazing their animals less and depend increasingly on cut-and-carry fodders (zero-grazing systems). There is a clear need for a better understanding of mixed crop–livestock systems and assessing the possibilities of new technologies to enhance sustainability.

There is a need for timely *ex ante* impact assessment studies to support research priority setting as well as policy decision making (Thornton et al., 2003). However, the diverse socio-economic and bio-physical conditions of mixed smallholder systems in

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sub-Saharan Africa and other parts of the world make *ex ante* assessment with data-intensive models extremely costly in time and other resources (Thornton and Herrero, 2001; Herrero et al., 2007). Thus, the development and application of feasible methods for *ex ante* evaluation of technologies are needed (Shepherd and Soule, 1998; Stoorvogel and Antle, 2001; Thornton and Herrero, 2001; Thornton et al., 2003; Waithaka et al., 2005; Antle and Valdivia, 2006; Herrero et al., 2007). Thornton et al. (2003) summarize a number of different approaches to impact assessment for crop–livestock systems with strengths and weaknesses. Each approach tends to be specific for the type of information to be generated, the availability of resources, skills and baseline data and generally requires an integration of several models, analytical tools and participatory elements. They conclude it is necessary to take a broad, integrated look at the systems themselves and the processes going on within them. With the lack of one generic crop–livestock model, mixtures of 'hard' and 'soft' models are possible (Thornton and Herrero, 2001). In addition, there are indications that donors and institutions may not always want complex impact assessments but rapid, low-cost tools might be more appropriate (Thornton et al., 2003).

In this paper, we present and apply a methodology to assess *ex ante* the economic feasibility of adopting dual-purpose sweet potato (*Ipomoea batatas*) in Vihiga district, western Kenya. The proposed methodology, which is based on the minimum-data (MD) approach described by Antle and Valdivia (2006), uses available data to characterize the distributions of returns to both actual and potential alternative technologies and associated management practices in the farm population, and then uses those distributions to assess the economic feasibility of farmers' adopting the alternative practices. In contrast to analyses based on conventional 'representative farm' models that cannot realistically assess potential adoption rates, this methodology provides an estimate of the rate of adoption of a new technology in a heterogeneous farm population. The aim of this study is to use the MD approach to assess the economic feasibility of dual-purpose sweet potato varieties as a first step in assessing prospective pathways out of poverty for smallholder farmers. The longer-term goal is to determine the potential for adoption of this technology over larger regions with conditions similar to the study area.

Sweet potato is widely seen as a potential remedial crop for tropical smallholder farmers because of its high productivity and low input requirements, while its usefulness for both food and feed (dual-purpose) make it attractive in resource-poor areas where land availability is declining (Karachi and Dzowela, 1990; Woolfe, 1992; Leon-Velarde et al., 1996; Leon-Velarde, 2000; Nyaata et al., 2000; Larbi et al., 2007). In addition, the high nutrient content of the vines can improve the diet of livestock and quality of manure (Nyaata et al., 2000). According to FAO statistics (FAOSTAT, 2008), Kenya's national average (tuber) yield of sweet potato in 2004 stood at 9.4 ton/ha which is low compared to the potential of 50 ton/ha under experimental conditions (Carey et al., 1999). The Kenya Agricultural Research Institute (KARI) and the International Potato Center (CIP) are undertaking screening work which aims at obtaining dual-purpose sweet potato accessions that have comparative advantage over local varieties, optimizing yields from both roots for food and leaves and vines for fodder with zero or minimal additional input costs. Dual-purpose sweet potato allows a low number of toppings, which enables spreading of fodder availability over the year, without significantly affecting root yields (Tupus, 1983; Arteaga, 1997; Leon-Velarde, 2000). Age at harvest has been shown to be an important management factor that affects the fodder and tuber yields and quality (An et al., 2003). Optimal methods and frequency of defoliation must be developed and put in practice to avoid interfering with regeneration that can lead to reduced root yields and decreased starch content (Ruiz et al., 1980). Although currently sweet potato is not one of the major crops in Vihiga district (Salasya, 2005) it is an important crop grown typically by women for tubers, which are mainly used as food, and to a limited extent for leaves and vines which are a supplementary source of fodder for livestock.

2. Study area

Vihiga district in western Kenya lies between 1300 and 1500 m above sea level and covers an area of 563 km^2 of which 419 km^2 is arable land (CBS, 2001) (Fig. 1, 0°10′N 34°50′E). Vihiga district is broadly representative of other areas of the east African highlands found in Uganda, Ethiopia, and Madagascar in terms of soils, climate, technology, and production potential (Soule and Shepherd, 2000). The district's high-potential agricultural area is predominantly located in the 'upper midland one' agro-ecological zone (Jaetzold and Schmidt, 1983) with well drained nitisols that support the growing of various cash and food crops (Waithaka et al., 2006). Soil fertility is low due to continuous cropping without sufficient replenishment and leaching over the years (AFRENA, 1998; Salasya et al., 1998). Nitrogen and phosphorus are the main limiting nutrients for food crops (Shepherd et al., 1997; Soule and Shepherd, 2000). The area receives adequate bimodal rainfall that ranges from 1800 to 2000 mm per year. The heavier long rains fall from March to June and short rains fall between September and December. Temperatures are moderate and range from 14 to 32 °C with limited diurnal variations.

In 1999 Vihiga district had a total population of 500,000 with a population growth rate of 2.2% (CBS, 2001). Recent poverty mapping in Kenya places Vihiga among the poorest districts in the country (CBS, 2003). Most households in Vihiga show a maize deficit of 200–400 kg per year, which is equivalent to shortage in 6–10 months each year (Waithaka et al., 2005). The shortage is aggravated by the increasing conflicts among food, cash, and fodder crops as farm sizes continue to decline. This has greatly reduced available fodder with hardly enough to feed livestock all year round. With high poverty levels, farmers do not use high-return inputs such as certified seeds, fertilizers, disease and pest control measures, and rotations, but are limited to low-input and low-return enterprises (Waithaka et al., 2006, 2007). The average household has 4.7 persons living on a 0.5 ha farm creating a high pressure on agriculture.

About 60% of Vihiga population falls below the poverty line of 1 US$ per person per day (CBS, 2003) with an average total income of 56 Kenyan Shillings (KSh) per household per day (1 US$ was equivalent to KSh 77 in mid-2005). Households obtain 65% of their income from off-farm sources in the form of wages and remittances (Waithaka et al., 2006). A high proportion of farm income is obtained from milk sales. In an effort to enhance household income and food security, farmers in the district appear to pursue risk management strategies, such as matching (i.e. the tendency of a household to produce much of the food it consumes to avoid market risk) and diversification, and hence grow many crops on their small land holdings.

The main food crops are maize, beans, sorghum, groundnuts, bananas, and a variety of vegetables and the main cash crop is tea. The predominant livestock is local Zebu, which is mainly used for dairy production. Most farmers practice zero grazing and grow Napier grass (*Pennisetum purpureum)* for fodder, which competes with high value crops in the small holdings. With investments in transportation infrastructure, the area could have improved market opportunities as most farms are within 50 km of the large urban centers of Kakamega and Kisumu with more than 500,000 people each (CBS, 2001).

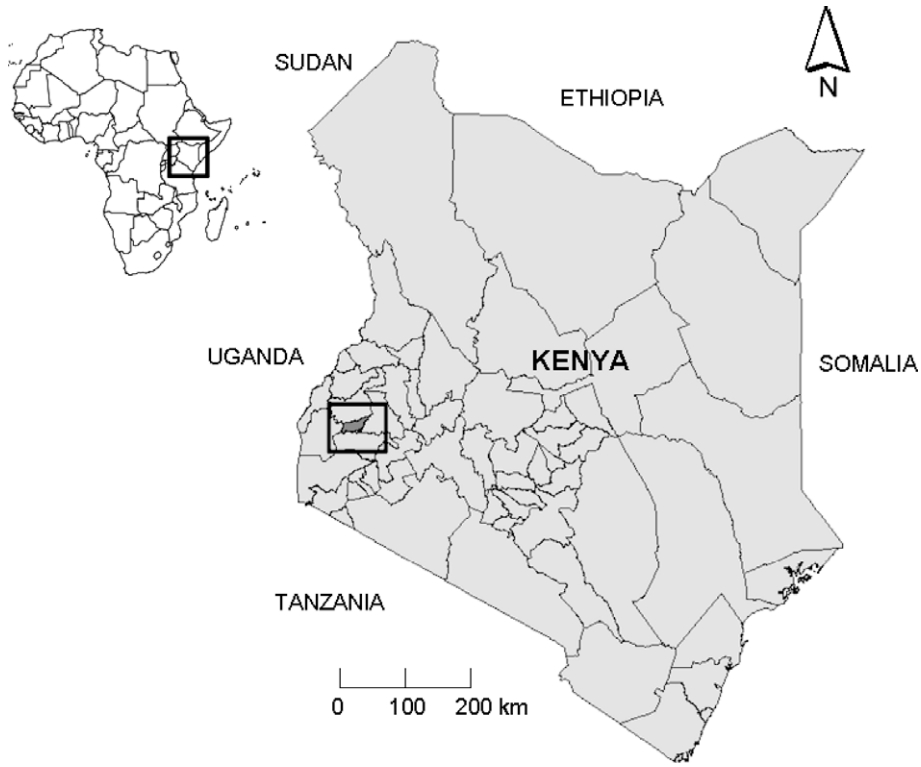

Fig. 1. Location of the study area, Vihiga district in western Kenya.

3. Materials and methods

3.1. Data sources

The data used in this study originate from the PROSAM project, 'systems prototyping and impact assessment for sustainable alternatives in mixed farming systems in high-potential areas of east Africa' (Waithaka et al., 2005), that aimed to assess natural resource management interventions that promote sustainability of prototype farming systems and to develop and disseminate methodologies that can be used in subsequent initiatives within the region. Farm data for Vihiga district were collected in 2000 and 2002 (Waithaka et al., 2002; Salasya, 2005; Herrero et al., 2007). For this analysis, a selection of 119 farms was extracted from the database for which complete data on inputs, outputs, and farm management were available (Table 1). Data used in this study include quantities and prices of inputs (such as seeds, labor, fertilizer, and manure) and outputs (crop yields and land areas). These data are used to calculate net returns for the different cropping systems in each farm. The prices of inputs and outputs are based on a survey of 10 markets in western Kenya in mid-2005. The average annual price is used in the analysis. The majority of the farms have a maize–bean intercrop as basic food crop system (Table 1). More than half of the farms have Napier grass which is used as cut-and-carry animal feed. Bananas, sweet potatoes (non dual-purpose varieties, mainly for tuber production), vegetables, and annual crops that are grown heterogeneously across farms and occupy very small land units are grouped for this analysis under one activity called mixed crops. Crops such as tea, sugar cane, and woodlots are treated as fixed activities (i.e. not convertible into dual-purpose sweet potato) and thus are not included in the analysis.

Table 1
Key characteristics for the 119 farms from the PROSAM project used for the analysis in Vihiga district

Number of farms			119
Number of cropping seasons[a]			207
Number of farms having livestock			112
Total cultivated area (ha/season/farm)			0.35 (0.31)
Tropical livestock units[b] (TLU/farm)			1.69 (1.18)
Milk production (l/day)			2.7 (2.8)
Lactation length (days)			261 (23)
Cropping system	Maize–beans	Napier grass	Mixed
% of farms growing crop	80.9	56.3	61.3
Number of cropping seasons[c]	154	112	110
Area (ha/season/farm)	0.24 (0.21)	0.15 (0.18)	0.17 (0.16)
Crop yield (kg/ha)	1512 (1269)	33,321 (22,945)	4265 (2818)
Net returns (KSh/ha)	13,428 (16,902)	21,197 (23,280)	26,188 (21,042)

Mean values with standard deviations in parentheses where applicable.
[a] Total of observed cropping seasons in dataset. 89 farms have two cropping seasons and 29 have one.
[b] 1 TLU = 250 kg of body weight.
[c] Total number of cropping seasons where crop is observed.

3.2. Modeling approach

3.2.1. Minimum-data (MD) approach

A number of researchers have utilized bio-physical and economic models with site-specific data to implement an *ex ante* assessment of alternative agricultural systems (Antle and Capalbo, 2001; Thornton et al., 2003; Stoorvogel et al., 2004; Tré and Lowenberg-Deboer, 2005; Waithaka et al., 2006; van Ittersum et al., 2006; Herrero et al., 2007). However, spatially-explicit integrated assessment models require highly detailed data that are rarely available, particularly for *ex ante* assessments. Antle and Valdivia (2006) developed a minimum-data (MD) approach for *ex ante* assessment of the adoption of practices that can be implemented with the kinds of bio-physical and economic data that are available in most parts of the world. This approach provides an estimate of the rate of adoption of alternative practices based on their economic feasibility, i.e., on the differences in returns between the observed

practices and the alternative practices. This method provides a preliminary basis on which to assess adoption potential. Antle and Valdivia (2006) argue that this approach can be implemented at low cost in a timely manner to provide a good first-order estimate of adoption potential that can be used to support informed decision making by researchers and policy decision makers. It is acknowledged that actual adoption and household decision making is influenced by numerous other factors besides economic feasibility. In some cases, researchers may choose to carry out additional, more detailed analysis if sufficient time and other resources are available.

3.2.2. Economic model

To illustrate the MD approach, consider a farmer's choice between the baseline or observed production system without dual-purpose sweet potato, and the alternative system that includes dual-purpose sweet potato. The choice of practice in each time period is based on the maximisation of expected returns:

$$R = P_m Q_m - C_m + \sum_i ((P_i HI_i + B_i(1 - HI_i))Y_i - C_i)A_i \quad (1)$$

where i indexes the crops, P_i is the product price, B_i is the by-product price, HI_i is the harvest index (the harvest index is defined as crop yield divided by total yield), Y_i is the total yield (output of product and by-product) per ha, C_i is the cost of production per ha, A_i is the area, and the m subscript indicates the price (P), quantity (Q) and cost (C) for milk production, including the value of fodder produced and fed on the farm. The activities in the baseline production system are a maize–bean intercrop, Napier grass, a mixed crops system and milk. When dual-purpose sweet potato is added to the system, land is re-allocated from the other crops to dual-purpose sweet potato, and some additional milk production is obtained due to the change in fodder quality and quantity. The decision to adopt the dual-purpose sweet potato is based on the change in expected returns, defined as

$$\Delta R = P_m \Delta Q_m - \Delta C_m + \sum_i ((P_i HI_i + B_i(1 - HI_i))Y_i - \Delta C_i)\Delta A_i \quad (2)$$

Thus, the farmer adopts if $\Delta R > 0$ and does not adopt otherwise.

In a simple 'representative farm' analysis, typical or average values of costs and returns would be used to evaluate whether the alternative practice was likely to be profitable. The significant limitation of that type of analysis is that it is difficult to generalize the analysis to represent the population, particularly where there is a substantial degree of heterogeneity in the farm population, both in bio-physical conditions affecting crop and livestock productivity, and in economic conditions associated with variations in farm management ability and farm location in relation to markets and other infrastructure. The MD methodology is designed to take spatial heterogeneity into account by using the available data to represent the bio-physical and economic heterogeneity in the population. For example, Antle and Valdivia (2006) discuss using mean estimates of costs and returns together with yield variability as a proxy for farm heterogeneity. Alternatively, if farm survey data are available, as they are in the Vihiga data described above, then the observed variation in the data sample can be used to represent the heterogeneity in the population. Accordingly, the analysis presented below utilizes the survey data and a simple model of livestock production to calculate ΔR for each farm in the sample, determines whether each sampled farm would adopt the dual-purpose sweet potato based on economic feasibility, and then aggregates across all farms in the sample to obtain an adoption rate.

The economics literature discusses various factors that may inhibit adoption of new technologies, including risk, financial constraints, transaction costs, and learning and other adjustment costs. All of these factors can be interpreted as increasing the cost and thus lowering the benefits of adoption. Thus, if estimates of such costs were available, they could be included in the analysis. However, in most cases these costs vary substantially among farms and data are not available to quantify them. Accordingly, as we carry out the adoption analysis without incorporating possible costs of adoption, it may be prudent to interpret the resulting adoption rates as an upper bound estimate, with actual adoption rates possibly lower if there are substantial unobserved costs of adoption.

To implement the analysis using Eq. (2), we need to specify the changes in land allocated to the crops (the terms ΔA_i), and the effect of the increase in fodder quantity and quality on milk production (ΔQ_m). The input applications per hectare in the cropping systems and dairy management other than fodder are assumed not to change, so ΔC_i is set equal to zero and ΔC_m is equal to the value of the change in fodder fed to livestock. In a more detailed economic model, the farmer's decisions to re-allocate land among crops could be determined within the model. However, in the MD approach, we utilize other information to determine land allocation. In this application, we utilize information about livestock feed requirements to construct possible scenarios for land re-allocation.

3.2.3. Land re-allocation and feeding strategies

As mentioned above, in order to adopt the dual-purpose sweet potato farmers must re-allocate some land from the three crops of the base system to the dual-purpose sweet potato. In the analysis presented here, land is re-allocated according to different feeding strategies. Besides some grazing, animal feed in the base system is mainly Napier grass (cut-and-carry) and fodder from maize–beans and mixed crops (thinnings, leaves, and stover). We analyze the substitution of some of the land allocated to those crops with dual-purpose sweet potato. The basic model setup assumes a conservative dry matter (DM) requirement, based on the observed number of livestock (TLU) on each farm and an estimate of the average daily dry matter intake for the study area of 6.25 kg DM per TLU per day from the literature (Euroconsult, 1989; Schlecht, 1995; Ayantunde, 1998; Vlaming et al., 2005). Feeding strategies, i.e. fractions of feed coming from the different feed resources, can be varied and analyzed within the basic model setup.

The total amount of DM currently available in the base system for feeding in each farm and each season (DM_{tot} in kg per farm per season) is calculated by adding the amounts of DM per crop (DM_i) as follows:

$$DM_i = A_i Y_i (1 - HI_i) DMf_i$$
$$\text{If } DM_i < DMT_i \text{ then } DM_i = DMT_i$$
$$DM_{tot} = \sum_i DM_i \quad (3)$$

where DMf_i is the dry matter fraction of fodder from crop i (Table 2). DMT_i is the minimum amount of fodder available from the ith crop, to account for the fact that even in cases of crop failure some dry matter will be produced (observed DMT_i is 440 kg/ha for the maize–bean intercrop and 335 kg/ha for the mixed system). It is implicitly assumed that all crop by-products, reflected by the harvest index and total yield, can be used as feed in different forms over the season (cut-and-carry, thinnings, leaves, vines, and pods during the season, crop residues left in the field after harvest or crop failure).

We introduce an alternative feeding strategy with fractions of the total DM requirement coming from the different existing sources of feed plus the by-products from dual-purpose sweet potato. Land areas for the different crops are re-allocated according to:

$$Aalt_i = \frac{DM_{tot}\ Falt_i}{Y_i(1 - HI_i)DMf_i} \quad (4)$$

Table 2
Properties of animal feed resources

	Dry matter fraction (fodder)[A]	Energy (consumption by animals)[A,B] MJ/kg DM	Crude protein[A,B] g/kg DM	Harvest index[A,C,D,E] crop yield/total yield
Napier grass	0.17	8.2	128	0.9
Maize–beans[a]	0.61	7.4	133	0.44
Mixed[a]	0.21	6.3	121	0.46
DP sweet potato	0.33	9.0	234	0.27

Data sources: [A] NUTMON (De Jager et al., 1998); [B]Abate et al. (1984);[C] Tittonell et al.(2005), [D] Mwanga et al. (2006), [E]Ndolo et al. (2007).
[a] Values are weighted averages on the basis of the observed mixture of individual crops

where $Aalt_i$ is the area under crop i according to the alternative feeding strategy, and $Falt_i$ is the contribution (fraction) of crop i in the alternative system to the total amount of DM available from the base system. We assume that land areas from the three crops in the current system will not increase after re-allocation in the alternative system. We also assume that the total area per farm and per season does not increase, so the area under the three crops of the base system must decrease. Given this constraint, it is also possible to vary the areas of the three base crops. In the scenarios presented below, we either reduce all three crops equally, or hold fixed the maize–bean area and reduce the other two crops equally, based on the idea that maize–bean is used as a subsistence crop for household consumption. For the base system, we use the observed total yield data (Y_i) per farm and per season from the available dataset. Because dual-purpose sweet potato is not part of the current system we have no data on farmers' yields for the study area. Instead we draw yields from a normal distribution of a set of yield data for dual-purpose sweet potato from field trials at nearby locations with similar conditions in western Kenya and eastern Uganda (Table 3).

The net returns of the current system are calculated with the actual farm data on land allocation, productivity, and prices of inputs and outputs. As with yields, we can not calculate net returns for dual-purpose sweet potato in the alternative system from the survey data. Instead, we draw net returns for dual-purpose sweet potato from a distribution for which the mean net returns per ha (μ_S) depend on the average total yield Y_S, the harvest index (HI_S), the average cost of production (C_S) observed for the sweet potato varieties currently in use, and the values of tuber (P_S) and fodder (B_S) according to the following equation:

$$\mu_S = (P_S HI_S + B_S(1 - HI_S) - C_S)Y_S \tag{5}$$

The sweet potato tuber price is set at the observed average value of 3.6 KSh/kg, and the average cost of production is set at the observed value of 0.0538 KSh/kg. The price for sweet potato fodder is estimated on the basis of prices of fodder with comparable feeding characteristics and set at 1.5 KSh/kg. Following the arguments in Antle and Valdivia (2006), we assume that the coefficient of variation (CV) in net returns of dual-purpose sweet potato is equal to the CV of the total yield, so the variance in returns to sweet potato can be calculated accordingly. In the survey data we observe a very low correlation between the returns to sweet potato and other crops, so in simulating net returns for dual-purpose sweet potato we assume the correlation with other crops is zero.

3.2.4. Milk production

An alternative feeding strategy including dual-purpose sweet potato in the system not only brings about a change in quantities of different feed resources, but might also change the nutritional quality. Cows can increase their milk output with stall-fed higher quality diets based on high-yielding forages without using additional land (Herrero et al., 2007). In general, the nutritional value of feed for livestock is determined by its dry matter content, crude protein (CP), and fiber, digestibility and voluntary intake of nutrients (Abate et al., 1984). The basic model setup is based on a conservative dry matter requirement and we only take into account the possible benefits of an increased crude protein content of the feed. Based on local data (Kitale, western Kenya) and on lactation performance with different feeding strategies, Nyambati et al. (2003) found the following empirical relationship between an increased crude protein content (by adding supplements to Napier grass) and additional milk production:

$$\Delta Q_m = 0.0024\ \Delta\ CP\ (\text{g day}^{-1})\text{days season}^{-1} \tag{6}$$

The additional milk production due to the alternative feeding strategy results in an increase in net returns. The average price of milk at the time of data collection was 24.98 KSh/l (Waithaka et al., 2002). In the analysis we assess the effects of changes in milk price on adoption rates.

3.2.5. Analysis

In the next section we use the MD model described above to assess the economic viability of adopting dual-purpose sweet potato in the Vihiga study area. We specifically analyze the effects of changing parameters in the model that influence net returns and thus adoption rates. The effects of introducing different varieties of dual-purpose sweet potato cultivars are analyzed by varying the harvest index. The value of sweet potato fodder is uncertain and may change as a result of adoption of sweet potato. Therefore we check whether changes in its value have major consequences for the adoption rates. Finally, alternative feeding strategies with different feed fractions from different sources based on a conservative dry matter requirement are tested.

4. Results

The MD model, by its construction, approximates the observed distributions of yields and returns to crop and livestock production. Because dual-purpose sweet potato varieties are not currently

Table 3
Overview of on-farm trials for dual-purpose sweet potato (standard deviations between parentheses)

Variety	SPK004 (orange fleshed, dual-purpose variety)
Number of observations	37
Locations	Uganda: Mtwapa (3), Wakiso (6), Mpigi (9), and Nakasongola (6); Kenya: Busia (6) and Kakamega (7)
Total yield (ton/ha/season)	22.7 (10.4)
Tuber yield (ton/ha/season)	8.0 (3.7)
Harvest index	0.27 (0.07)

Data sources: Ndolo et al. (2007) and Mwanga et al. (2006).

available to farmers, we cannot validate the model's *ex ante* predictions of dual-purpose sweet potato adoption by comparing them to observed adoption rates. However, as we explain below (see Fig. 5), we can compare predicted rates of adoption of dual-purpose sweet potato to the sweet potato varieties currently in use, assuming that the dual-purpose sweet potato is not fed to livestock. This experiment confirms that, in the absence of feed benefits associated with the dual-purpose sweet potato, adoption rates would be similar to the observed allocation of cropland to conventional sweet potato.

4.1. Sensitivity to sweet potato yield and number of livestock

As with any *ex ante* study, there is substantial uncertainty in the parameters of the model, so we subject a number of the key parameters to sensitivity analysis. As a first step, a sensitivity analysis was conducted to examine the effects of changing the average total yield of dual-purpose sweet potato over a plausible range centered on the observed average total yield of 22.7 ton/ha/season (Table 3). As described in the methodology, the model assumes a conservative dry matter (DM) requirement based on the observed number of livestock (TLU) on each farm, so we also consider the effects of increasing the observed number of livestock by 50%. Adoption rates are calculated in two ways: as the percentage of the total farm land area under adopting farms and as the percentage of the total land area under the crop.

The results in Fig. 2 show that with the lowest average yield, farms representing 55% of the total land area would adopt the system with dual-purpose sweet potato under the specified feeding strategy (in this case, 25% of the feeding requirement has to come from dual-purpose sweet potato), and about 62% of the total land area would need to be converted to dual-purpose sweet potato. The number of farms adopting increases with the average total yield, but the area under dual-purpose sweet potato declines because of the fixed feeding strategy. With a high average total yield of 40 ton/ha, the adoption rate increases to about 82%, but only about 8% of the total farm land would be converted to dual-purpose sweet potato.

Increasing the number of TLU per farm to 150% of the observed value increases both adoption rates and land area converted. The total feeding requirement per farm increases and the amounts of dry matter farmers have to get from their crops increases accordingly. Because the model uses this dry matter requirement and a fixed feeding strategy to reallocate the land, total land areas converted to dual-purpose sweet potato need to increase, as do adoption rates.

4.2. Harvest index

Dual-purpose sweet potato cultivars are selected based on the harvest index. The effect of different harvest indices reflecting different varieties was tested with the same feeding strategy as the previous analysis. The average yields for dual-purpose sweet potato are drawn from the observed distribution (Table 3) and net returns are calculated with Eq. (5). The range of harvest indices tested (0.15–0.55) is consistent with the variation observed in the production data of Ndolo et al. (2007) and Mwanga et al. (2006). The results in Fig. 3 show that high harvest indices present an 8.5% higher adoption rate and a 7.5% increase in area converted into dual-purpose sweet potato compared to lower harvest indices. There is a higher adoption when there is relatively more tuber yield because tubers have a higher value than fodder (Eq. (5)).

In Fig. 4 the effect of increasing the price of fodder is illustrated. Up to a value of 2 KSh/kg, adoption rates still slightly increase with a higher harvest index. The curve starts leveling off at the highest value of 4 KSh/kg for fodder, which is now higher than the value of tubers (3.6 KSh/kg). From this analysis it is difficult to define the optimal harvest index at which adoption rates are highest: Depending on the values of tuber and fodder, adoption rates only fluctuate slightly with a change in harvest index. In general, this result would argue for the selection and breeding of sweet potato varieties that are high yielding in general or have increased fodder without compromising tuber yield. Still, following the analysis

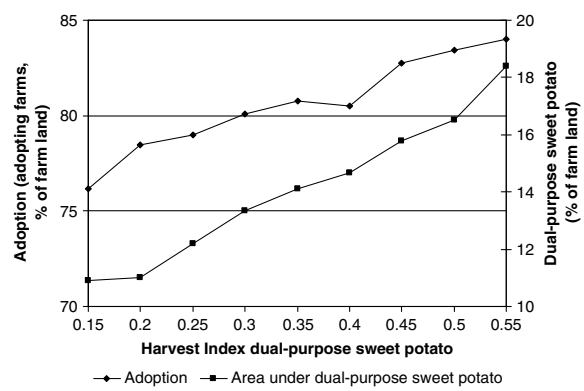

Fig. 3. Changes in adoption rate and land area converted into dual-purpose sweet potato with a varying harvest index.

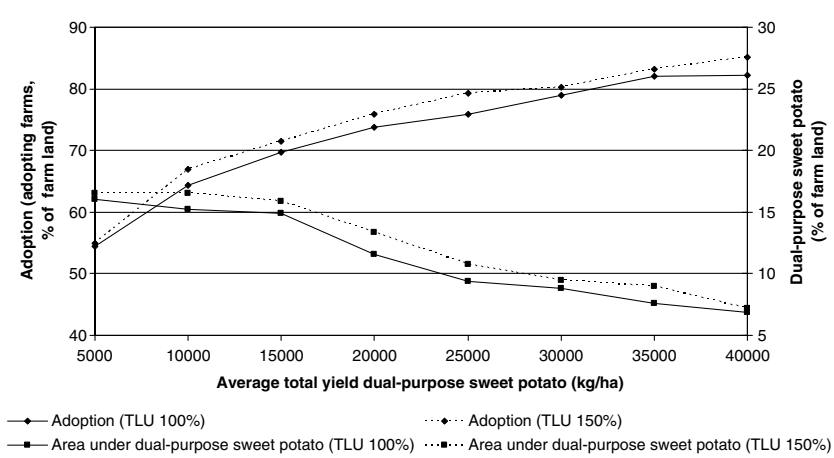

Fig. 2. Effect of average total yield and TLU per farm on adoption of dual-purpose sweet potato.

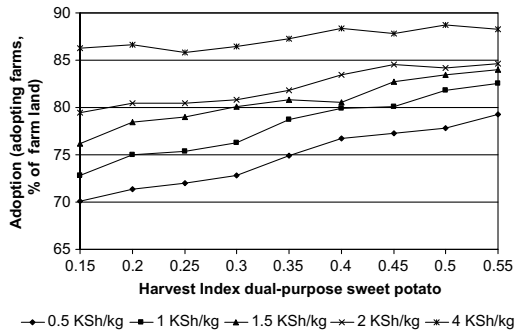

Fig. 4. Effect of harvest index and value of dual-purpose sweet potato fodder on adoption rate.

with the current prices of tuber and fodder, adoption rates are highest with the highest harvest index.

4.3. Feeding strategies

Alternative fractions of feed from different sources based on a conservative dry matter requirement (current system with actual TLU) were tested (Fig. 5), assuming that the remainder of the dry matter requirement is equally distributed over the other three feed sources (maize–beans, Napier grass, and mixed crops). Increasing the fraction of feed from dual-purpose sweet potato increases the adoption rate and area under dual-purpose sweet potato. The rate of increase in adoption decreases as the fraction increases, but the total area converted increases at an increasing rate because more farms adopt and adopting farms allocate more land to dual-purpose sweet potato. The changes in feed quality (crude protein content) and additional milk production are plotted on the secondary axis. By increasing dual-purpose sweet potato in feed, the feed quality in terms of crude protein increases and thus causes an increase in milk production (Eq. (6)).

In the analysis the price of milk is set at the observed value of 25 KSh/l. For a feeding strategy with 25% of the requirements coming from each of the four crops, the adoption rate is 78%. Analysis shows that the adoption rate is not sensitive to the milk price; a milk price increase of 40% results in a 1% increase in the adoption rate.

For the feeding strategies analyzed in Fig. 5, all crops are converted into dual-purpose sweet potato in equal proportions.

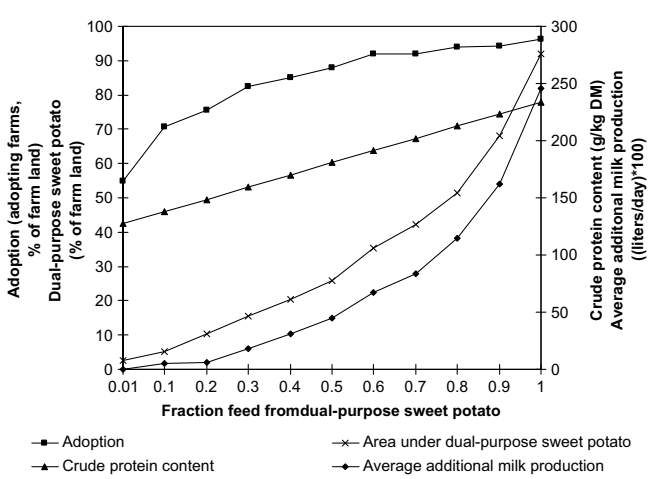

Fig. 5. Effect of changing feed fraction when other crops are converted into dual-purpose sweet potato in equal proportions.

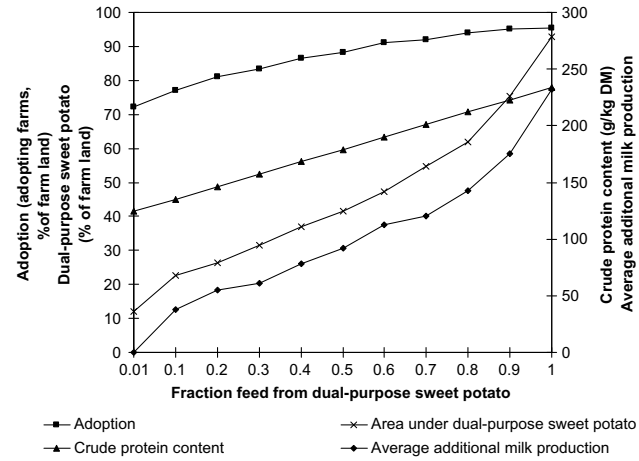

Fig. 6. Effect of changing feed fraction when land allocated to maize–beans is fixed.

Although 65% of household income is from off-farm sources and a large share of food is purchased, farmers in the study area appear to grow the maize–beans crop for food security, suggesting that the introduction of dual-purpose sweet potato might not induce farmers to grow less maize–beans. In Fig. 6 the area under maize–beans in the current system is fixed, with the remainder of the feed requirement coming from Napier grass and the mixed system (equally distributed). The same patterns as in Fig. 5 can be observed, but adoption rates and land areas converted are generally higher with small fractions of dual-purpose sweet potato. When maize–beans is allowed to be converted (Fig. 5), the land taken from this system can account for a larger proportion of the dry matter requirement because there is a relatively large area under maize–beans (Table 1). When the maize–beans system is fixed, and there is little or no Napier grass and/or mixed crops, dual-purpose sweet potato must account for more of the dry matter requirement, hence larger areas are needed. For the same reasons, additional milk production is slightly higher for low fractions of dual-purpose sweet potato when the maize–beans system is fixed.

5. Discussion

As mentioned earlier, the MD methodology utilized here is based on economic feasibility (expected profitability). Other factors that have been found to be important in technology adoption are not taken into consideration. Participatory work in the study area indicated that even when farmers are aware of the potential benefits of alternative technology options, they have different risk attitudes and are constrained by market failure and the heavy burden of providing for many people who depend solely on small farms (Waithaka et al., 2006). In another study for Togo and Benin, Wendland and Sills (2008) also found that household preferences, resource endowments, and risk and uncertainty affect household decisions about adoption of soybeans. They also refer to the importance of intra-household dynamics and experience with the crop. In a general review of adoption of soil fertility replenishment technologies in southern Africa, Ajayi et al. (2007) found that farmer uptake of technologies depends on several factors that can be grouped into broad categories: technology-specific (e.g. soil type and management regime), household-specific (e.g. farmer perceptions, resource endowment, and household size), policy and institutions context within which the technologies are disseminated (inputs and output prices, land tenure and property rights), and geo-spatial (performance of species across different bio-physical conditions, location of village). Therefore, the adoption rates based

on economic feasibility alone should be interpreted as providing an upper bound on likely adoption rates. Some of the additional information required to take other factors into consideration could be gathered in more intensive community- and household-level surveys (e.g. Kristjanson et al., 2001; Waithaka et al., 2006). In addition, to boost real adoption, constraints that hinder technology uptake such as inadequate information about crop management (e.g. methods and frequency of foliation), post harvest practices and availability of planting material must be dealt with. It is also assumed that strains identified to optimally produce fresh roots and forage will have other suitable characteristics, such as taste, shape, color and texture, which are important in determining acceptability of varieties.

The analysis in this study takes prices as given, and thus requires the assumption that changes in the supply of sweet potato or feed will not substantially affect the supply–demand balance in the region. As long as sweet potato remains largely a subsistence crop, and feed markets are not well-developed, this assumption is reasonable. If widespread adoption of the dual-purpose sweet potato did increase supply and thus lower prices, this would reduce to some degree the incentive to adopt. To address this possibility, the adoption analysis presented in this paper could be linked to an analysis of regional sweet potato and feed markets. In such an analysis, the estimated rate of adoption would be used to shift the regional supply of sweet potato and fodder, and the effect on the market equilibrium prices would be determined by the interaction of supply and demand.

It is implicitly assumed in the methodology that all crop by-products, reflected by the harvest index and total yield (Eqs. (3) and (4)), are used as feed in different forms over the season. Variation in availability of feed over the season is not considered nor the fact that some crop by-products are left on the field (as fertilizer or erosion control) or used as fuel, especially in lower income farms (Soule and Shepherd, 2000). Only farm-produced feed is taken into account for this analysis, although in the study area moderate amounts of feed are purchased and often supplemented with concentrates (Herrero et al., 2007).

The basic setup of the methodology proposed does not allow the assessment or modeling of changes in crop management strategies (e.g. intercropping, leaf stripping, post harvest handling, manure application, and agroforestry practices) and the effects on crop and residue yields and quality and livestock production. Effects of feeding strategies on manure quantity and quality and the longer term effects on nutrient return to the production system (increased soil fertility and crop yields) also are not taken into account.

The main reasons why adoption of dual-purpose sweet potato is economically viable for a relatively large percentage of farms appear to be the relatively high yields, net returns and crude protein content of the fodder which increases milk production and income. Average crop yield of dual-purpose sweet potato is 8 ton/ha compared with 1.5 and 4.3 ton/ha for maize–beans and the mixed crops, respectively. The average fodder yield for dual-purpose sweet potato amounts to 14.6 ton/ha compared to 3.4 for maize–beans and 9.3 ton/ha for the mixed crops. Average net returns for dual-purpose sweet potato are 56,806 KSh/ha compared to 13,428 for maize–beans and 26,188 KSh/ha for the mixed crops. The researchers who collected the dual-purpose sweet potato yield data from on farm field trials in the region (Mwanga et al., 2006; Ndolo et al., 2007) suggest that the yields they observed are higher than most farmers would achieve because crop management and soil conditions would be less favorable than in the trial sites. The sensitivity analysis (Fig. 2) shows that if the average total yield was reduced from the experimental mean value of 22.7 to a lower value of 10 ton/ha, this would result in a decrease in adoption rate from 78% to 65%.

Feeding strategies are based on a conservative dry matter requirement for the current amount of livestock and a simple empirical relationship based on a single study in western Kenya to reflect gains in milk production by improved feed quality (Eq. (6)). We recognize that a more detailed model could be developed. Still, additional milk yields ranging from 0.14 to 0.94 l/day (Figs. 5 and 6) compare favorably with more detailed feeding studies and modeling exercises in the east African region (Muinga et al., 1993, 1995; Muia et al., 2000; Methu et al., 2001; Bwire and Wiktorsson, 2002; Romney et al., 2003). A comprehensive study involving livestock modeling and more detailed information on the effects of feeding strategies and feed quality on livestock production could be useful to confirm the potential gains in livestock nutrition and milk yield due to adoption of dual-purpose sweet potato. An integration of a livestock model (e.g. RUMINANT (Herrero et al., 2002) or LIFE-SIM (Leon-Velarde et al., 2006)) into the methodology is planned, to obtain more accurate numbers on the effects of feeding strategies on feed quality, intake, livestock performance and milk yield. However, including more complex models in the methodology requires additional regionally-specific data for validation and calibration, which are often not available (arguing for the minimum-data approach proposed).

The proposed methodology was developed and applied based on an available dataset for the specific study area. To be able to scale up results to a wider region or to areas with similar conditions, the use of crop growth simulation models could be assessed to simulate differences in productivity levels if suitable soils and climate data and adequate data to estimate genetic parameters are available.

6. Conclusions

The development and application of relatively simple and reliable methods for *ex ante* evaluation of technology changes at the household and system levels are needed to provide timely assessments of the potential impacts of alternative technologies and policies. In this paper a minimum-data methodology was proposed to assess the economic viability of adopting dual-purpose sweet potato as a food-feed crop in the mixed crop–livestock systems of western Kenya. The methodology uses available data to characterize the distributions of returns to both actual and potential alternative technologies in the farm population, and then uses those distributions to assess the economic feasibility of farmers' adopting the alternative practices. A sensitivity analysis showed that even if average total yields from dual-purpose sweet potato were low (5 ton/ha), a majority of farms would benefit from adoption due to the value of both tubers and fodder produced. With the average total yield obtained in field experiments (23 ton/ha), the adoption rate was estimated to be about 78%, with about 10% of farmland planted to dual-purpose sweet potato. Higher average total yields could result in an adoption rate over 80%.

An optimal harvest index for selecting dual-purpose cultivars would depend on the ratio between the price of tuber and fodder. For the current dataset, the value of tuber is more than twice that of fodder, and economic viability of adoption increases with higher harvest indexes (varieties that have a higher tuber yield). In general this result would argue for the selection and breeding of sweet potato varieties with higher total yields or that have increased fodder without compromising tuber yield. Improved agronomic practices to increase total yields should be promoted. In addition, because factors other than yield will influence actual adoption, researchers and rural extension agents should involve farmers from the early stages of the screening and dissemination process.

Despite the limitations of the methodology, this study yielded insights into the way the inclusion of dual-purpose sweet potato

in the agricultural system could assist in improving the livelihoods of smallholder farmers operating in the mixed crop–livestock systems in east Africa. The minimum-data approach offers a flexible framework for evaluating innovations and new technologies using scarce data of resource-poor countries in sub-Saharan Africa and other parts of the world. It allows a rapid integrative analysis for timely advice to policymakers and for exploration of technology options.

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