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Determinants of adoption of improved forage technologies in crop–livestock mixed systems: evidence from the highlands of Ethiopia

B. GEBREMEDHIN[1], M.M. AHMED[2] AND S.K. EHUI[1]

[1]*International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia*
[2]*Purdue University, Lafayette, Indiana, USA*

Abstract

Inadequate feed and nutrition are major constraints to livestock production in sub-Saharan Africa. National and international research agencies, including the International Livestock Research Institute (ILRI), have developed several feed production and utilisation technologies. However, adoption of these technologies has so far been low. Identification of the major socioeconomic and policy factors influencing the adoption of improved feed technologies is required to help design policy and institutional interventions to improve adoption.

Using a panel data set from the crop–livestock mixed systems of the Ethiopian highlands, we found that household resource endowment, especially land and labour, and market integration and crop intensification were important factors encouraging adoption of an oats–vetch (*Avena sativa* and *Vicia villosa* ssp. *dasycarpa*, respectively) forage technology. Results imply that land-saving technologies such as high-yielding crop varieties or modern soil fertility management practices, the development of forage technologies that are complementary to food crops in land utilisation, and the development of livestock markets can enhance adoption of improved forage technologies.

Correspondence: B. Gebremedhin, International Livestock Research Institute, PO Box 5689, Addis Ababa, Ethiopia. E-mail: b.gebremedhin@cgiar.org

Introduction

Inadequate nutrition and feeding are major constraints to livestock production in sub-Saharan Africa (SSA). Feeds (usually based on fodder and grass) are either unavailable in sufficient quantities due to fluctuating weather conditions or are available but of such poor quality that they do not provide adequate nutrition. These constraints result in low milk and meat yields, high mortality of young stock, longer intercalving intervals and low animal weights (McIntire *et al*. 1992). Improved nutrition through adoption of sown forage and better crop residue management could substantially increase livestock productivity. National and international research agencies, including the International Livestock Research Institute (ILRI), have developed several feed production and utilisation technologies and strategies to address the problems of inadequate supply and poor quality of feeds. To date, adoption of these technologies has been slow, despite evidence of high returns where the technologies have been extended by extension and development agencies. These include fodder banks in west Africa (El Basha *et al*. 1999), alley farming in west Africa and Kenya (Jabbar *et al*. 1996), the napier grass and leguminous tree combination for dairy animal production in coastal and central Kenya (Staal *et al*. 2001) and oats–vetch (*Avena sativa* and *Vicia villosa* ssp. *dasycarpa*, respectively) intercrop in the highlands of Ethiopia (Darnhofer 1997). In the east African highlands, forage crops are not grown widely despite high animal stocking rates that should result in demand for fodder (Gryseels and Anderson 1983). Nevertheless, evidence is available showing that forage technologies display desirable agronomic characteristics such as high yields, contribute to improving soil condition and fertility, in the case of legumes, and increase milk yields of cows.

This paper examines factors that influence the adoption of forage crops. The conditions for successful introduction of forage technologies are explored and major socio-economic and policy factors affecting the adoption of forage and feed systems are identified. Empirical evidence is provided by modelling the adoption of oats–vetch intercrop in the mixed crop–livestock system of the Ethiopian highlands, where forage technologies are introduced in association with improved dairy production. In the process, conditions for successful interventions and policy options to encourage adoption are identified.

It is argued that the demand for forage and the opportunities for diffusion of forage technology may be poor if livestock production is for subsistence and if livestock productivity and response to improved technology are low. In addition, potential for adoption may be high where livestock productivity is high, where livestock respond to improved feed technology and where profitability is high due to market-oriented production systems, such as dairying in the highlands of Kenya, Ethiopia and Uganda. It is hypothesised that probability and intensity of adoption increase with the extent of market participation, household resource base, contact with extension workers and secure land tenure.

Potential for and constraints to forage introduction in African livestock systems

Advances in biological technology in livestock systems have been induced primarily by improving the yield of animal products/unit of feed or per unit of breeding stock (Hayami and Ruttan 1985). In this context, development and diffusion of improved feeding and supplementary feeding technologies are critical for improving livestock productivity.

Unlike residue management, and hay and silage making, adoption of forage legumes often involves introduction of a new crop into the farming system. Success of the introduction depends on how well the new crop fits into the existing system. The degree of crop–livestock interactions, the functioning of forage and livestock product markets and the extent of market participation of forage growers, and household resource availability are important factors for successful introduction of forage crops.

Depending on the degree of crop–livestock interactions, several farming system typologies can be identified. In livestock-specialised systems such as the pastoral systems of eastern Africa and the Fulani pastoral system of western Africa, the crop enterprise is not part of the household's production unit. Households in these systems are typically subsistence-oriented and based on seasonal milk production. The livestock herders are dependent on natural pastures and grazing areas, and to some extent the grazing of crop residues in crop systems after harvest. In these systems, adoption of improved forages is unlikely since livestock owners do not usually own land.

At the opposite extreme, there are crop-specialised farming systems where households predominantly produce crops but have limited livestock numbers, mainly small ruminants. In these systems, crop–livestock interaction is minimal. Typical examples are the savannah zones of western Africa. In this system, a necessary condition for adoption of forage is the availability of an external market for forage and animal products (McIntire and Debrah 1987). Therefore, adoption of forages in this system is also unlikely, unless institutional and marketing mechanisms are functioning to facilitate transactions of forage and feed products between crop producers and livestock owners.

The potential for existence of such markets may be strengthened by the increasing demand for livestock products in urban and peri-urban areas of sub-Saharan Africa. For instance, cattle finishing operations at Niamey, Niger, have created a demand for cowpea hay from farmers as far as 100 km from this urban market (Sanders *et al.* 1996). Forage markets are also well developed around the Nile Valley in Sudan near to urban centres. Thus, the adoption decision can be based solely on relative profitability of forage compared with other crops. However, in the Ethiopian highlands, the major constraint to adoption is the lack of transport infrastructure and the high transaction costs involved as distance from demand centres increases; this may erode the relative profitability of forage production.

In the typical mixed, crop–livestock farming system, the household has 2 integrated enterprises, namely, crop and livestock production (see Figure 1). Productivity of both enterprises is determined by biophysical environmental factors, such as rainfall and soil fertility, and by available technology such as improved forages, improved seeds, inorganic fertiliser, and soil fertility management and erosion control. The policy environment, including markets and factors affecting

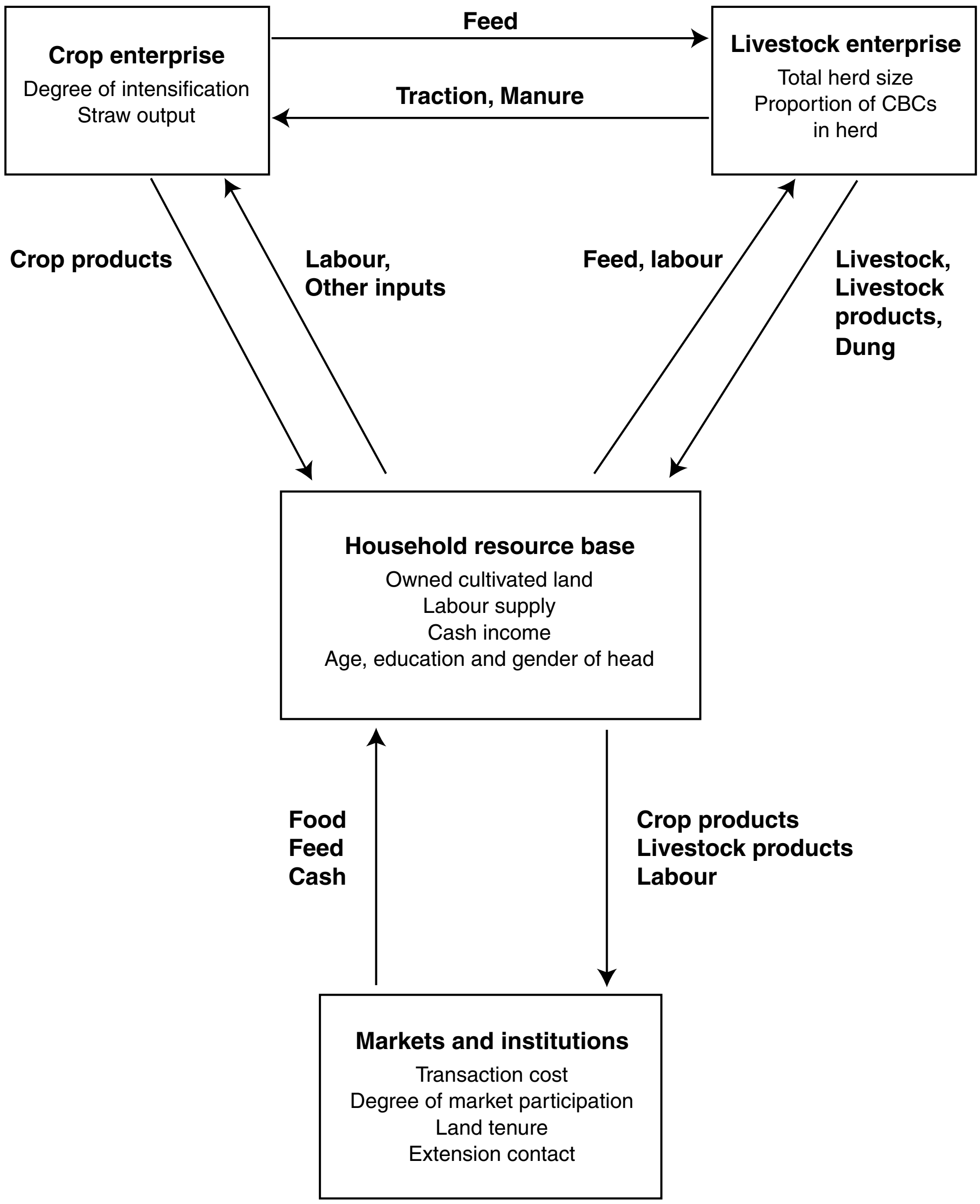


Figure 1. Crop-livestock interaction and factors affecting adoption of improved forages. CBCs are crossbred cows.

input and output prices, determines type and level of market exchange and the extent to which a household participates in market transactions. Where markets are narrow or non-existent and income incentives are limited, a household may resort to subsistence production.

In mixed systems, a household can grow and feed forages to their own animals without necessarily engaging in forage markets; accordingly, these systems have the highest potential for adoption of forages. Moreover, forages can be useful in these systems to support livestock during periods with low availability of crop residues and natural pastures (during the cropping season). In addition to contributing to livestock production, forage legumes contribute significantly to soil nitrogen and provide a break in cereal-dominated rotations (McIntire and Debrah 1987).

Such mixed crop–livestock farming dominates most smallholder systems of SSA. Most of these systems are characterised by high population densities and land scarcity, such as in the highlands of Ethiopia. The immediate response to population pressure is an expansion of cultivated area to maintain per capita crop output (Boserup 1965; Ruthenberg 1980; Sanders *et al.* 1996). Thus, livestock and crop activities may become competitive for land resources (McIntire *et al.* 1992). Although the demand for feed may increase under these conditions, competition with food crops is unfavourable to forage adoption, particularly because farmers tend to be unwilling to sacrifice food production to produce fodder for animals (McIntire *et al.* 1992).

Under what conditions will smallholder, mixed crop–livestock farmers be willing to allocate land to forage? In general, the potential for forage adoption is limited under subsistence-oriented livestock production as the economic incentives are low. However, the potential for adoption of forages can be high under market-oriented livestock production, such as dairying with crossbreds or improved breeds, and fattening of large and small ruminants. According to data collected from the Holetta area between 1993 and 1997, forage production, specifically oats–vetch intercrop, is much more common amongst farmers with dairy crossbred cows (authors, unpublished data). Since satisfying the subsistence food requirements of the household imposes a constraint on allocating land to forages, crop intensification through application of inorganic fertilisers may ease the competition for land between food and feed crops. By using inorganic fertilisers, a higher output can be produced from the same or a smaller land area, freeing land for on-farm forage production. For example, according to modelling results, area allocated to oats–vetch intercrop in Selale, Ethiopia increased substantially when fertiliser application for barley crops was introduced simultaneously (Darnhofer 1997). In southern Mali, *Lablab purpureus* and *Stylosanthes* spp. are being introduced successfully to farmers using chemical inputs on cotton and maize (Sanders *et al.* 1996). Apparently, market opportunities, price incentives and intensification encourage adoption of forages in mixed farming systems. In situations where population pressure is high and land is scarce, intensification in crop production appears to enforce livestock intensification.

Moreover, the theory of induced innovation proposes that farmers are responsive to the size of economic incentives provided by the new technology (Stevens and Jabara 1988). In the classical study of sowing of hybrid maize by farmers in the USA, Griliches (1957) demonstrated that rate of adoption by farmers of more productive hybrid seeds was largely a function of the increase in income obtainable. In the case of forage technologies, this is likely to be the case where adoption is associated with market-oriented dairying using high-yielding crossbreds.

Based on the above discussion, this study focuses on adoption of a forage technology by market-oriented dairy producers in a mixed farming system of the highlands of Ethiopia. Factors that affect forage adoption in a crop–livestock mixed system emanate from interactions amongst the system components and with its external environment (see Figure 1). To the extent that feed markets operate, purchased feed can compensate for feed shortages. Hence, the need to adopt improved forage technologies is affected by: both supply and demand factors for livestock feed; household capacity factors that determine the household's capability to integrate forage production into the farming system or purchase feed from the market; the extent of market integration of the household; institutional services such as extension; and the usual conditioning demographic factors. It is assumed that households in the study area face similar conditions in terms of access to communal grazing land.

Household resource base, especially land, the degree of intensification and participation in crop and livestock markets, and proximity to these markets are suggested as the principal factors explaining household adoption behaviour. Other institutional and socio-economic characteristics (such as tenure type), experience with crossbreds and dairying, and age, gender and education of the household head are amongst the factors affecting adoption of agricultural innovations (Feder *et al.* 1985).

The study area and data

The study area is located 40–70 km west of Addis Ababa, the capital of Ethiopia, in the vicinity of 2 small towns, namely, Holetta and Addis Alem. Altitude is about 2600 masl and average annual rainfall is around 1100 mm. The main rainy season, *mehr*, extends from June–September when more than 70% of the rain falls. The short rainy season, *belg*, extends from late February–May and is when farmers break and prepare the soil for the main crop season. Farmers in this area depend exclusively on rain-fed agriculture and most crops are grown in the main rainy season.

The farming system in this area is typically a mixed crop–livestock system. Farmers produce a wide range of cereal and legume crops on small parcels of land. Households may grow as many as 10 different crops. By area covered, the major crops are *teff*[1], wheat and barley. Other crops include field peas, oats, sorghum, linseed and rape seed. Besides crops, households keep a herd of animals, mainly consisting of dairy cows, oxen for ploughing, heifers, bulls, goats, sheep and chickens. Because of the dependency on animal traction for crop production, keeping at least one pair of oxen and a follower herd (heifers and bulls) for replacement is necessary despite the feed shortages.

Production is geared towards satisfying the household food requirements, as well as provision of feed in the form of straw and hay for livestock. The subsistence nature of the farming system is reflected in the limited dependency on the market for food supply. Medium and rich households, for example, purchase less than 2% of the *teff* and wheat needed for their consumption while poor households purchase a greater proportion of their *teff* and barley for consumption but produce most of their wheat. This indicates the uncertainty of depending on the market for food supplies or the limited availability of suitable, yet profitable, cash crops.

The Holetta area is one of the areas where crossbred cows were introduced to increase dairy production to meet the increasing demand of neighbouring urban areas and to improve farmers' incomes and nutrition. It is considered to have high dairy potential due to its agro-ecological conditions and market access to Addis Ababa. Farm households are organised into peasant associations, through which they are allocated usufruct rights (use rights) to farmland.

On-station research showed that properly fed dual-purpose (for milk production and traction) crossbred cows have the potential to substantially increase milk production and hence incomes over the use of local breeds, while maintaining work output and reproduction. Based on these positive on-station results, crossbred dairy cows were introduced on 14 farms in the Holetta area in 1993; 7 of the cows were for milk production only and 7 were for traction as well as milk production. In 1995, an additional 120 cows were introduced on a further 60 farms to test the economic and technical feasibility of dairy-draft technology on farmers' fields. A component of the crossbred cow technology is the production of oats–vetch forage. It was recommended that households devote up to 0.75 ha of land for improved forage production. Since adoption of the oats–vetch intercrop was limited to households with crossbred cows, the study focused only on this group.

Data used for this study are a subset of the data generated by the dairy-draft project; data collection in the project continued from 1993–1997. These data included information on: land use, labour allocation to different operations, draught power use and source, input use, output disposal, income, expenditure and price data. In addition, data were also collected on household resource endowments, cropping and livestock activities and demographic characteristics. The panel data used in this study consist of 212 observations.

Summary statistics for the variables used are presented in Table 1. Forage adoption was measured as the ratio of land area devoted by each household to improved forage production to the recommended land area for forage production. As expected, households varied substantially in area allocated to forage production (see Figure 2). Although about 60% were non-adopters (*i.e.,* planted no forage), about 56% of the adopters allocated 0.5 ha or less to oats–vetch. The average adopting household allocated 0.31 ha of land to the oats–vetch intercrop (only 41% of the recommended 0.75 ha). However, the adoption behaviour varied substantially with socio-economic characteristics of the households, such as wealth (see Table 2). During the 1995–97 period, adoption rates and area allocated to oats–vetch were highest in the medium-wealth class; about 50% of these households produced forages on an average area of 0.2 ha/household. Overall, in 1996, both indicators of adoption declined greatly in the 3 wealth classes; however, adoption regained momentum in 1997.

1 Teff is a cereal and its production is limited to Ethiopia. It is a staple food crop in north and central Ethiopia.

Table 1. Summary statistics for the socio-economic and resource base of sample households in the study area in 1997.

Variable	Adopters (n = 87)	Non-adopters (n = 125)	Entire sample (n = 212)
Area of oats–vetch forage cultivated (ha)	0.31	0.00	0.16
Proportion of forage cultivated to recommendation	0.41	0.00	0.22
Round trip distance to crop market (km)	9.56	10.10	9.82
Round trip distance to livestock market (km)	21.64	23.81	22.67
Quantity of straw output from all crops (t)**[1]	6.97	4.83	5.96
Land per adult equivalent (ha)**	0.52	0.39	0.46
Proportion of cultivated land owned	0.86	0.88	0.87
Proportion of cash income in total income***	0.56	0.46	0.51
Proportion of dairy income in cash income	0.37	0.33	0.35
Crop inputs per hectare (Ethiopian birr[2])*	319.10	409.33	371.38
Fertiliser nitrogen (kg/ha)	21.26	18.90	20.14
Labour supply capacity (adult equivalent)	2.56	2.71	2.63
Total herd size (tropical livestock units; TLU)	9.73	10.07	9.89
Number of CBC (crossbred cows; TLU)	4.48	4.22	4.36
Number of local breed cows (TLU)	5.25	6.16	5.68
Age of the household head (yr)	46.69	53.38	49.85
Adult equivalent size of the household	5.45	5.65	5.55
Proportion of illiterate heads of households**	0.24	0.50	0.36
Proportion of household who can read and write***	0.45	0.23	0.35
Proportion of male heads of households	0.93	0.88	0.91
Proportion of poor households	0.10	0.23	0.16
Proportion of medium-wealth households***	0.34	0.15	0.25

[1] Denote significant differences between adopters and non-adopters by 2-tailed t-test at the following significance levels: 10% (*), 5% (**) and 1% (***).
[2] US$ 1 = 8.50 Ethiopian Birr, in December 2002.
Source: Authors' computation from ILRI, Dairy-Draft Database.

Table 2. Distribution of adoption by initial wealth rankings of households.

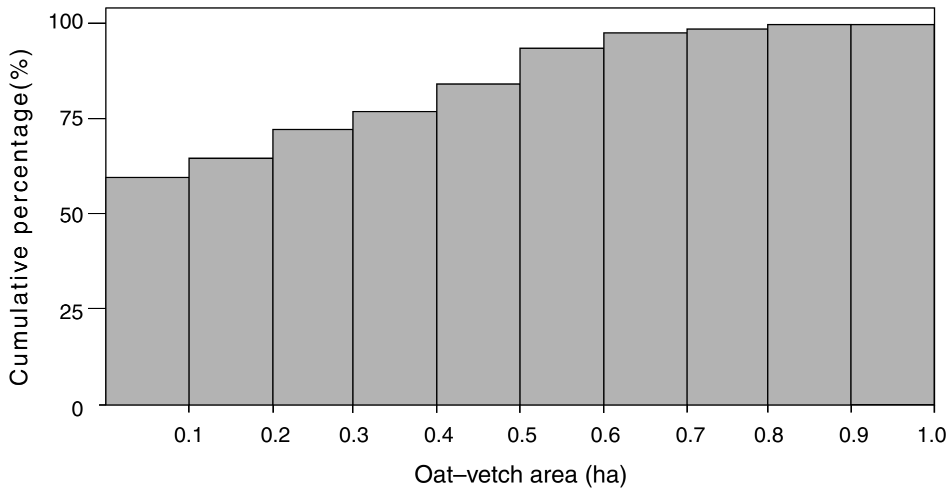
Year	Variable	Wealth level			
		Poor	Medium	Rich	Total
1995	Adopted forage (%)	38.5	58.8	24.3	35.8
	Oats–vetch area (ha)	0.174	0.223	0.128	0.161
1996	Adopted forage (%)	8.3	20.0	32.4	25.0
	Oats–vetch area (ha)	0.025	0.088	0.116	0.093
1997	Adopted forage (%)	33.3	71.4	50.0	52.7
	Oats–vetch area (ha)	0.098	0.281	0.130	0.163
1995–97	Adopted forage (%)	26.5	50.0	34.9	37.1
	Oats–vetch area (ha)	0.101	0.197	0.124	0.138

Source: Authors' computation from ILRI, Dairy-Draft Database.

Land, labour and livestock herds are amongst the critical resources that may affect household adoption behaviour. Area of cropped land per adult equivalent differs significantly between adopters and non-adopters; while the average area of cropped land per adult equivalent was slightly more than 0.5 ha amongst adopters, the corresponding value for non-adopting households was about 20% less. Adopting households produced significantly more straw than non-adopters (7 t *vs* 4.8 t). Labour supply capacity, assessed as the number of working age household members (14–60 years old), was similar for both groups. Although the average non-adopting household had slightly more livestock, particularly local breeds, the average adopting household tended to have slightly more crossbred cows (CBCs), although the difference was not statistically significant.

The degree of intensification of crop production was assessed from the cost of inputs (including seeds, fertiliser and herbicides used) and by the amount of nitrogen applied per hectare. Both groups applied similar quantities of fertiliser in terms of N/ha. However, given that average cultivated area was significantly greater for adopting households, total applied fertiliser nitrogen was greater in these households. Surprisingly, average

a) Entire sample.



b) Adopters of forage technology.

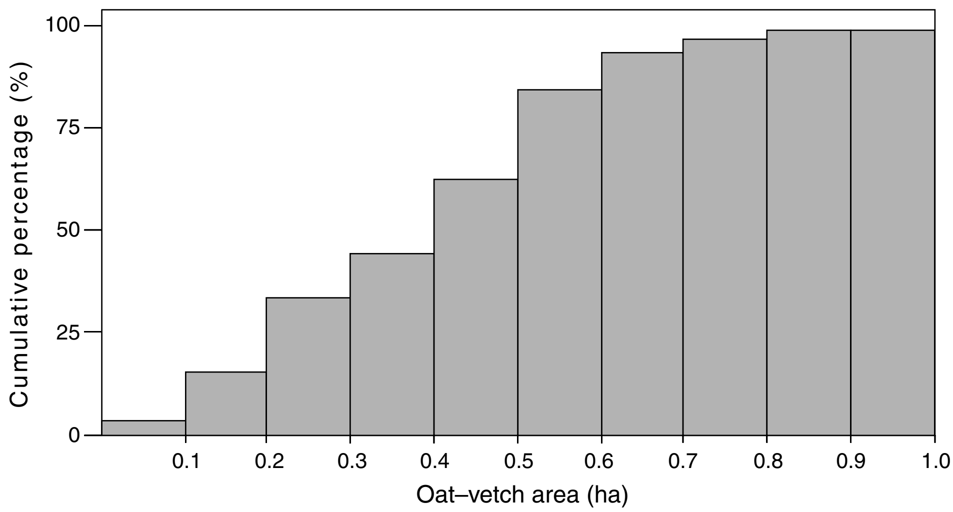


Figure 2. Observed cumulative distribution of area allocated to forage amongst: a) the entire sample; and b) adopters (1993–97).

cost of inputs per unit area of land was significantly higher for non-adopters than adopters. Given their relatively smaller land area per adult equivalent, non-adopters may have attempted to substitute land-saving inputs for land; this is consistent with the induced innovation hypothesis.

Adopters had a higher degree of market participation, assessed by the proportion of cash income to total income. However, both groups derived about 33% of their cash income from dairy sales. Proximity to markets usually encourages market participation by reducing transaction costs. However, in this case, both groups were located at similar distances from crop and livestock markets; livestock markets were further away than crop markets for both groups.

Adopting and non-adopting households shared similar household characteristics. However, adopters and non-adopters differed significantly in literacy and wealth characteristics; adopters were more literate and consisted of more medium-wealth households.

Empirical model and hypotheses

Empirical model

Time series, cross-sectional and panel data models have been the 3 basic types of model used in the study of adoption of technology (Besely and Case 1993). The main focus of time series models has been the aggregate diffusion process over time. As such, this type of model has been of limited use in explaining the relative influence of factors affecting the decision to adopt. Cross-sectional models either take a 'snapshot' of use by farmers of a given technology or depend on recall data. These models ignore the dynamic nature of the technology adoption process; moreover, in cases where the adoption process is incomplete, parameter estimates may be biased. However, if careful differentiation is made between the probability of adoption and the intensity of adoption, cross-sectional models can provide results that are indicative of important causal factors. Panel data models that are based on farm characteristics and adoption decisions over time have the potential to address the limitations of both time series and cross-sectional analyses.

Decisions of whether to adopt and how much to adopt, may be considered as joint or separate decisions. When the decisions are considered to be joint decisions, the Tobit model is appropriate for analysing the factors that affect the decision (Greene 1990). However, adoption and intensity of use decisions may not necessarily be made jointly. The decision to adopt may precede the decision on the intensity of use and the factors affecting each decision may be different. Such decision situations can be analysed using the two-part double-hurdle model (Cragg 1971). Hence, the choice between the double-hurdle model and the Tobit model is an empirical one. In this analysis, the double-hurdle formulation was compared with the Tobit model using the likelihood ratio test; the former was rejected in favour of the Tobit model.

In modelling technology adoption, interest is centred on both the discrete decision of whether to adopt and the continuous decision on intensity of adoption or how many resources to allocate to the new activity. Thus, the dependent variable cannot take values below zero and, since the sample usually includes non-adopters (households with zero values for intensity of adoption), the distribution of the dependent variable is censored. In this case, the ordinary least square estimator is inefficient and Tobit maximum likelihood estimation is required (McDonald and Moffitt 1980). Following McDonald and Moffitt (1980), the stochastic model underlying Tobit may be expressed as:

$$\begin{aligned} y_i &= X_i\beta + u_i \quad && \text{if } X_i\beta + u_i > 0 \\ &= 0 && \text{if } X_i\beta + u_i \le 0 \\ i &= 1,2, \ldots..N && \quad (1) \end{aligned}$$

where N is the number of observations, y_i is the dependent variable, X_i is a vector of independent variables, β is a vector of parameters to be estimated and $u_i \sim N(0,\sigma^2)$ is an independently distributed error term. The expected value of y in this model is given by:

$$Ey = X\,\beta\,F(z) + \sigma f(z) \qquad (2)$$

where $z = X\beta/\sigma$, $f(z)$ is the unit normal density and $F(z)$ is the cumulative normal distribution function.

Furthermore, the expected value of y for observations above the limit represented by $y^*$is given by:

$$Ey^* = x\beta + \sigma f(z)/F(z)$$

Hence, the basic relationship between the expected value of all observations, Ey, the expected value conditional upon being above the limit, Ey^*, and the probability of being above the limit, $F(z)$, is:

$$Ey = F(z)Ey^*.$$

McDonald and Moffitt (1980) showed that the effect of a change in the k[th] variable of X on the dependent variable, y, can be disaggregated into: (1) the change in y if it is above zero (adopters) weighted by the probability of being above zero [$F(z)$]; and (2) the change in the probability of being above the limit weighted by the expected value of y if above zero. That is:

$$\begin{aligned} \frac{\partial Ey}{\partial X_i} &= F(z)\left(\frac{\partial Ey^*}{\partial X_I}\right) + Ey^*\left(\frac{\partial F(z)}{\partial X_i}\right) \\ &= F(z)\beta_i\left[1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right] + \frac{f(z)\beta_i}{\sigma} \qquad (3) \end{aligned}$$

The relative magnitude of these two effects has important economic and policy implications, as it allows determination of both changes in the probability of being an adopter and changes in the intensity of adoption. The fraction of the mean total response due to a response above zero is given by:

$$\left[1 - z\frac{f(z)}{F(z)} - \frac{f(z)^2}{F(z)^2}\right]$$

Hypotheses

We hypothesised that the household feed supply factor (straw output) might detract from forage adoption through a substitution effect, or might enhance adoption if it was complementary to improved forage. Feed demand factors (degree of involvement in livestock production) were expected to enhance adoption. Crop intensification was expected to encourage adoption by freeing land for forage production. The effect of household capacity factors was ambiguous; owned cultivated land might increase the capacity of households to allocate land for forage production or detract from adoption through its effect on the supply of straw and crop residue. Similarly, higher household cash income might encourage adoption through its effect on household access to inputs or decrease adoption through its effect on household access to alternative feed sources. However, household labour supply was expected to enhance adoption through the availability of labour to meet the increased labour demand for forage production.

Amongst the market and institutional factors, transaction costs were expected to reduce adoption through their effects on the profitability of dairy operations. In contrast, proportion of cash income to total income, a measure of the degree of market participation of the household, was expected to enhance adoption. Secure land tenure should enhance adoption through its incentive effect on investment and contact with extension was expected to increase adoption since it is a source of technical information. While older household heads were expected to be less likely to adopt due to shorter planning horizons, household heads with higher levels of education were expected to show higher levels of adoption, as they might have better access to information. Furthermore, it was expected that female-headed households would be more likely to adopt forage technologies, since women might be more involved in dairy operations than men.

The following regression model was estimated to test the hypothesised effects:

Adoption = F (Cost of fertiliser and herbicides/ha, Nitrogen applied/ha, Land per adult equivalent, Household labour supply in adult days, Proportion of cash income to total income, Total cash income, Distance to crop market, Distance to livestock market, Straw output, Net livestock expenditure, Proportion of crossbred cows in total herd, Illiterate household head, Literate household head, Poor household, Medium-wealth household, Age of household head, Gender of household head).

Results and discussion

Results of the regression model are given in Table 3. The positive and significant relationship between adoption and land area per adult equivalent suggests that households with a larger land area per adult equivalent were more likely to adopt forages; moreover, it indicated that availability of land was an important factor for farmers considering whether to incorporate forage into their cropping systems. A 1% increase in the availability of land per adult equivalent increased forage adoption by 1.32% and the intensity of adoption (hectares of land allocated to forage) by 0.63%. Similarly, households with higher labour supply were more likely to allocate land to forage production, suggesting that forage production imposes an additional labour requirement on households. A 1% increase in household labour supply increased probability of forage adoption by 0.70% and intensity of adoption by 0.33%.

Other household resources include the capacity of the household to produce alternative feeds such as straw and crop residues. According to the Tobit results, the quantity of straw output encouraged forage adoption suggesting a complementary role for forage in supplementing other feed resources. In general, forages are important as adjuncts to crop residues and natural pastures, and may be used to fill feed gaps during periods of inadequate crop residues (McIntire and Debrah 1987). Even in the presence of abundant crop residues, forage crops, especially legumes, are needed to improve the utilisation of crop residues and straw. The positive and complementary association demonstrated by this study's results seems to support this role. Similarly, higher livestock expenditures (such as expenditure on salt, concentrates and veterinary services) encouraged forage adoption.

While total expenditure on crop inputs (including seed, fertiliser and herbicides/ha) reduced forage adoption, the amount of fertiliser nitrogen applied/ha encouraged adoption. In view of the significant impact of land supply on adoption intensity, these results indicate the potential of crop intensification to reduce land constraints

Table 3. Determinants of forage adoption, Tobit regression results[1].

Explanatory variable	Coefficient estimate[2]	t-value	Mean value	Total change or marginal value ($\delta y/\delta x_i$)	Change in probability above zero [$\delta F(z)/\delta x_i$]	Elasticity of probability[3]	Change in y above zero-value ($\delta y^*/\delta x_i$)	Elasticity of intensity[3]
Crop inputs cost per ha	–0.0020***	–3.8405	372.45	–0.0009	–0.0017	–1.4986	–0.0007	–0.7165
Fertiliser nitrogen applied per ha	0.0126***	2.6192	16.82	0.0053	0.0105	0.4191	0.0041	0.2004
Land per adult equivalent	1.4251***	5.4121	0.47	0.6033	1.1937	1.3251	0.4609	0.6335
Labor supply in adult days	0.1173***	3.2085	3.01	0.0497	0.0983	0.6987	0.0379	0.3341
Proportion of cash income to total income	0.9456***	3.0110	0.46	0.4003	0.7920	0.8605	0.3058	0.4114
Total cash income	–0.0001**	–2.3899	2997.25	–0.00004	–0.0001	–0.6036	0.0000	–0.2886
Round trip distance to nearest livestock market	–0.0156***	–2.6347	10.47	–0.0066	–0.0131	–0.3231	–0.0050	–0.1545
Round trip distance to nearest crop market	0.0091**	2.1427	22.83	0.0039	0.0076	0.4112	0.0029	0.1966
Straw output	0.0203**	2.3717	6.66	0.0086	0.0170	0.2677	0.0066	0.1280
Proportion of cash income from dairy	–0.0484	–0.2649	0.46	–0.0205	–0.0406	–0.0441	–0.0157	–0.0211
Net livestock expenditure	0.0005**	2.2804	340.89	0.0002	0.0004	0.3094	0.0001	0.1479
Proportion of crossbred cows in total herd	–0.0066	–0.0264	0.45	–0.0028	–0.0055	–0.0058	–0.0021	–0.0028
Proportion of land owned to total land	0.5155**	1.9899	0.89	0.2183	0.4318	0.9077	0.1667	0.4340
Experience with crossbred cows	0.0283	0.6788	2.22	0.0120	0.0237	0.1245	0.0092	0.0595
Illiterate[4]	0.0550	0.3795	0.33	0.0233	0.0461	0.0359	0.0178	0.0172
Read and write[4]	0.2850**	2.1047	0.38	0.1207	0.2387	0.2143	0.0922	0.1024
Poor[5]	0.2435	1.6386	0.16	0.1031	0.2040	0.0771	0.0787	0.0368
Medium wealth[5]	0.2289*	1.9316	0.24	0.0969	0.1917	0.1087	0.0740	0.0520
Age of household head	–0.0011	–0.3021	50.87	–0.0005	–0.0009	–0.1098	–0.0004	–0.0525
Male household head	0.0524	0.3711	0.89	0.0222	0.0439	0.0922	0.0169	0.0441
Constant	–1.6418***	–3.2762	1.00	–0.6951				
Sigma	0.4675	11.8949						

[1] Values used in the above computations are: $Z = -0.1933$; $f(z) = 0.3916$; $F(z) = 0.4234$; $f(z)/F(z) = 0.9249$; $[1-zf(z)/F(z)-f(z)^2/F(z)^2] = 0.3234$; $F(z)[1-zf(z)/F(z)-f(z)^2/F(z)^2] = 0.1369$; $F(z)\beta_i/\sigma = 0.2865$; $E(y) = 0.1448$; $E(y^*) = 0.3419$ and $\sigma = 0.4675$.
[2] *, **, *** indicate significance levels at 10%, 5% and 1%, respectively.
[3] Elasticities evaluated at the mean values of explanatory variables.
[4] Literacy dummies were compared with 'formal education' category.
[5] Wealth dummies were compared with 'rich' category.

along the qualitative dimension through productivity-increasing inputs; in contrast, because of population pressure it is difficult to increase quantity of land supplied.

Households with a higher proportion of cash income in total income were more likely to grow forage crops. The effects on probability and degree of adoption were also high. Higher proportion of cash income to total income reflects more involvement of the household in market-related activities including off-farm work and dairy. In such cases, the household economy is becoming more market-oriented. This enables the household to substitute land allocated for food crops to forage production while depending on the market for food supply. However, intensity of forage adoption is likely to increase initially with increase in proportion of cash income and then to decline as farming becomes more market-oriented. Therefore, it is not surprising that total cash income had a negative and significant impact on adoption. This was perhaps due to its effect on the capacity of households to purchase feed from the market.

However, impact of market integration on fodder adoption cannot be viewed without the impact of the transaction costs involved. In rural markets, the transaction costs are mostly associated with travel time and the opportunity costs of labour involved. In the regression results, distances to both livestock and crop markets had the expected associations with adoption, suggesting that markets are important factors in adoption of livestock technologies. While distance to livestock market detracted from forage adoption, distance to crop markets encouraged adoption. These results suggest that farm households are less likely to adopt forage when the profitability of livestock production is reduced due to higher transaction costs. High transaction costs in crop markets reduce the potential for substituting forage production with alternative feeds, such as concentrates that may be available in crop markets.

Amongst the institutional factors, land tenure security favoured forage adoption, supporting the hypothesis that tenure security encourages technology adoption. The elasticity estimates for the probability of adoption and degree of adoption were also high. This result is also consistent with the positive effect of land supply on forage adoption. However, experience with the crossbred cow extension service had an insignificant impact on adoption. This was probably due to the limited variability in experience of most of the households owning crossbred cows. Over time, households may adjust intensity of adoption as they accumulate experience with the nutritional needs of their herds.

Other socio-economic characteristics of the household affecting forage adoption included educational level of the household head and initial wealth of the household. Adoption was encouraged when the household head was literate or could read and write. Literacy is important in relation to access to information. In contrast, formal education was not positively associated with adoption, probably because it may increase the opportunity cost of labour. Similarly, households with medium wealth were more likely to adopt forage than poor or rich households. While poor households may be more risk-averse or lack the resources to adopt new technologies, rich households may be more inclined to participate in off-farm activities, such as trade. Age and gender of household head had no impact on forage adoption.

In summary, household resources (especially land and labour), integration in market-oriented activities and intensification of crop production are important factors encouraging adoption of forage technologies. Results of this study support our principal hypotheses that the potential for adoption of improved forage is high in mixed-farming systems where livestock productivity and response to improved feed technology are higher (with CBC), and where production is more market-oriented, such as in dairy systems. In these situations, the potential for adoption is high because of the possible complementarity between the regular cash income generated through dairying and the opportunity for intensification of crop production, which reinforces and improves both crop and livestock productivity. Factors affecting adoption also appear to be interrelated such that the effect of one factor may influence adoption through its impact on another factor. For instance, crop intensification through high levels of purchased inputs reduces land constraints and may lead to intensification of livestock production via improved feeding strategies. With sufficiently high crop productivity, land area devoted to subsistence crops is expected to decline, freeing land for forage production.

Conclusions and implications

This research shows conceptually that the potential for adoption of forages in mixed crop–livestock systems can be high due to the high level of opportunity for exploiting crop–livestock interactions and the potential of market-oriented livestock production such as dairying. However, typically, these systems are characterised by high population densities, which result in land scarcity, and land degradation, which results in low land productivity. In this case, competition with food crops affects adoption of forage unfavourably because farmers are generally unwilling to sacrifice food production to produce fodder for animals, especially in the context of subsistence farming.

Availability of cultivated land is a major determining factor for the adoption of forage technology, since the technology competes with food crops for land. On the other hand, intensification of crop production, such as use of modern soil fertility management techniques, encourages adoption. These results imply that the development and use by farmers of high-yielding crop varieties and intensive crop management practices can significantly enhance the adoption of improved forage technologies by releasing land for forage production. Intensification of crop production may also facilitate adoption of improved forage due to higher straw yields, since straw and forages are found to be complementary as feed inputs. Land scarcity in highly populated areas such as the highlands of east Africa also imply that forage technologies need to be land-saving and complementary to food crop in land utilisation.

Households with higher proportion of cash income that are closer to livestock markets are more likely to adopt the improved forage technology. Higher proportion of cash income implies that these households are better integrated into the market, either by the sale of crop and livestock products, or by involvement in off-farm activities. Distance to market constitutes the major component of transaction costs in the highlands of Ethiopia. These results imply that public interventions that are aimed at developing markets can contribute to the widespread adoption of forage technologies.

Land tenure security is positively associated with adoption of the forage technology, consistent with the hypothesis that secured property rights are essential for the adoption of improved or modern technologies. In the Ethiopian highlands, where farm households have only usufruct rights to land, institutional mechanisms to improve the land tenure security perception of farmers can improve the likelihood of adoption of forage technologies.

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