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Benefits of Integration of Cereals and Forage Legumes With and Without Crossbred Cows in Mixed Farms: An *ex ante* Analysis for Highland Ethiopia[+]

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Abstract

Poverty, low crop and animal productivity and large-scale resource degradation are major problems in the agriculture sector in the East African highlands. Among others, integration of forage legumes in cereal based cropping systems has been proposed as a promising strategy to improve the sustainability of smallholder farming systems through increased crop and livestock productivity and better soil management. Using experimental data from Ethiopia and elsewhere in the region, linear programming models have been used to determine the economic impacts of cereal-forage legume inter-cropping with and without crossbred cows for a typical highland mixed farm. An important feature of the model was that the benefits of inter-cropping in terms of nitrogen fixation and the better nutrition of animals were accounted for. Model results demonstrate that the introduction of forage legumes with cereals changes cropping pattern significantly, but does not significantly change the use pattern of principal farm resources, labor and ox power. Introduction of cereal-forage legume inter-cropping significantly increases gross margin and cash income, and the introduction of crossbred cows enhances these returns even further. Inter-cropping also significantly increases the share of livestock in farm and cash income when crossbred cows are included. Sensitivity analyses show that the improved technologies remain more profitable than current practices even when there is a substantial decrease in price of outputs. The results indicate that the improved production technologies should be widely tested under actual farm conditions under farmer management through on-farm research and extension. Benefits of inter-cropping in terms of weed control and control of soil erosion should be quantified in future research.

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Key words: Cereals, forage legumes, inter-crop, profitability, Africa, Ethiopia

Background and Objectives

Poverty, low crop and animal productivity and large scale resource degradation are major problems in sub-Saharan Africa and achieving sustainable increases in agricultural production from an increasingly fragile ecosystem is a major concern for scientists and policy makers alike. High human and animal population densities in some areas, and the consequent increasing demand for food and feeds have led to permanent cultivation of more land, reduction of grazing and forest lands to expand crop production, and disappearance of traditional practices that formerly allowed land to rejuvenate. Large-scale resource degradation indicated by soil erosion, nutrient depletion, deforestation and decline of pasturelands is common in the region. Nutrient balances, or the difference between nutrient inputs and harvests, are negative for many production systems. Organic and inorganic fertilizer use is well below the amount necessary to prevent nutrient mining. Fertilisers and good quality feeds are in short supply and access to available fertilisers and feeds is poor because of widespread poverty and lack of credit (Mohamed Saleem and Fitzhugh, 1995; Larson and Frisvold, 1996). Nutrients available from communal grazing and crop residues are of poor quality and insufficient for more than that required for maintenance of animals particularly in the dry season when cattle and small ruminants may lose up to 20% of their body weight (Bekele, 1991; Getachew and Hailu, 1992). Therefore, fertilizers and commercial feeds will not be adequate to solve these problems of smallholder farmers in the region in the near future.

New and innovative crop, livestock and soil management strategies for efficient cycling of nutrients among crops, animals and soil are crucial for the sustained increase of productivity of low-input mixed farming systems that dominate in the region. Integration of forage legumes in cereal based cropping systems is one such strategy. Experiments have shown that forage legumes enhance soil fertility, increase crop yields, improve yields and nutritive values of crop residues, sustain feed production during the dry season, suppress weeds, and combat erosion (Nnadi and Haque, 1988; Humphreys, 1994; Peoples *et al.*, 1995). Nitrogen fixing legumes may offer an economically attractive and ecologically sound means of reducing external inputs and improving the quality and quantity of internal resources for improving crop and livestock productivity. A substantial amount of experimental work has been done in Ethiopia and elsewhere in the region on the technical feasibility of integrating forage legumes with cereals (Abate *et al*., 1992; Abiye *et al*., 1995; Umunna *et al*., 1995). However, there are few examples of successful adoption of this technology by smallholders. One possible reason is that little is known about the economic benefits and constraints for such integration in real farm conditions. Assessment of profitability, resource requirements and constraints are likely to be helpful in developing strategies for diffusion of the technology to smallholders.

The objectives of this paper are to (a) assess the economic benefits of cereal-forage legumes integration with and without crossbred cows, (b) assess the impacts of cereal-forage legume integration on the demand for farm resources and their productivity. It is hypothesised that available land, labor and capital resources of the farmers will be a major determinant of whether such integration will be profitable and desirable for the smallholders. The assessment was done with data from the highlands of Ethiopia where agriculture faces fairly similar problems as elsewhere in the region, so the findings would be expected to be applicable to similar production systems and environments in the region and elsewhere.

Methodology and Data

A linear programming (LP) model was constructed to assess *ex ante* the impact of introducing forage legumes and improved dairy cows into the existing farming system. LP is widely used for *ex ante* evaluation of technologies before costly testing on farmers' fields. An increase in income can be considered as a major incentive to adopt a new technology and linear programming is an appropriate tool for maximization of income subject to resource and other constraints (Dillon and Hardaker, 1993).

The following general form of the LP model was used:

Maximize $Z = \Sigma C_j X_j$; $j = 1,\ldots N$;

subject to:

$\Sigma a_{ij} X_j \leq R_i$; $i= 1, \ldots, M$; $j= 1,\ldots,N$;

$R_i \geq 0$, $a_{ij} \geq 0$, $X_j \geq 0$; $j= 1,\ldots,N$;

where:

Z = aggregate cash income, that is, gross return less variable costs and value of home consumption,
C_j = cash income for j-th activity over variable cost and value of home consumption,
N = the number of possible activities,
X_j = level of j-th activity,
R_i = the quantity available of the i-th resource,
a_{ij} = i-th input required per unit of the j-th activity or technical coefficient,
M = the number of resources/constraints.

Four models or farm plans were constructed:

Base Plan: This plan approximated the existing situation so that it could be used as a basis for comparison with plans that represented changes in the system. It included teff, wheat, sorghum, maize, barley, horse beans, chick peas and rough peas, all sole cropped. Livestock activities included oxen, dairy cows and their repalcements, small ruminants and donkeys.

Improved Plan 1 (IP1): This plan maximized farm cash income with existing resources and practices, except that three inter-crops, i.e. wheat-clover with fertilizer, maize-lablab broadcast without fertilizer and sorghum-lablab broadcast without fertilizer, were introduced to provide improved feed for existing livestock.

Improved Plan 2 (IP2): It was the same as IP1 but the local cow was replaced by a crossbred dairy cow to maximize farm cash income.

Improved Plan 3 (IP3): In addition to the crops included in IP2 the following inter-crops were included: maize-lablab and sorghum-lablab broadcast with fertilizer, maize-lablab row planted with and without fertilizer, sorghum-lablab row planted with and without fertilizer.

The activities and constraints used in the models are briefly presented below. The models were constructed for a typical Ethiopian central highland farm.

Activities

Crop activities: Crop activities included in various models were mentioned earlier. Inclusion of the inter-crops in the models was based on the availability of experimental data. Experimental yields for the inter-crops were adjusted downward by 10% in order to take into account the difference between extra care taken by researchers on small experimental plots and the real farm conditions.

One of the functions of forage legumes is to improve soil fertility and improve yield of the subsequent crops. Since a single year model was constructed, any residual fertility effect of current year cropping could not be directly captured. Instead it was assumed that an increase in the soil nutrient status in the given year is an output of the system, in addition to the harvested grain and straw, whereas a decrease in soil nutrient (a negative nutrient balance) is a cost (Farrell and Capalbo, 1986; Jabbar *et al*., 1994). From various experiments, forage legumes (lablab, clover, and vetch) inter-cropped with cereals were found to leave 30-60 kg N per hectare in their root systems which might be available for uptake by the next crop. So in this study, in addition to the relevant grain and straw output , an inter-crop was assumed to produce 45 kg N per hectare for the benefit of the next crop, and this was valued at the market price of nitrogen fertiliser.

Livestock activities: Farmers in highland Ethiopia maintain livestock for draft power and milk. In mixed farms, livestock often provide up to 80% of farm cash income (Gryseels, 1988; Omiti, 1995). Based on previous surveys, it was assumed that a representative farm had a pair of oxen, one local zebu cow, one sheep and one donkey. The introduction of forage legumes with cereals would increase fodder production of better quality, which in the long run might change herd size and composition and feed allocation among different categories of animals. Since the plans were constructed for a single year, it was assumed that in the Base Plan and IP1, farmers would keep both livestock numbers and herd composition unchanged, and any improvement in output due to improved feed would come through higher productivity of existing animals. It was further assumed that under IP2 and IP3, farmers would replace the local cow with a crossbred cow by using the sale value of the local cow as well as borrowing. Currently the Smallholder Dairy Development Project in the country is giving a crossbred cow on a loan of Birr 3000 (Birr 6.64= 1US$) without interest but the farmer has to insure the cow by paying a premium of Birr 84. The loan is to be repaid in three years. Since livestock is a multiperiod enterprise, returns were annualised under a range of assumptions, based on surveys and experimental results, on the economic life, feed requirements, weight gain, milk yield, fertility and mortality of different categories of animals under the base and the improved plans (Menale Kassie, 1997).

Consumption, purchase and sale activities: Small farmers in the highlands put emphasis on subsistence food and feed production. When requirements for subsistence are met, they often generate income by selling the available surplus to buy some items, which they do not produce enough for subsistence. Therefore, consumption, purchase and sale were included as separate activities to balance production and utilisation. Average prices of various products over 18 months (January 1995-June 1996) were used in order to capture seasonal variations in prices. Purchase prices for grains were assigned 5 Birr higher per 100 kg than selling prices to reflect transaction and marketing costs (Gordon *et al*., 1995).

Resource Supplies or Constraints

Amount of scarce farm resources and other constraints, such as subsistence food requirements; determine the optimum allocation of resources to various activities. The resources currently available on the farm were used to derive the restrictions for each plan. The major constraints specified in the model include land, human labor, ox power, working capital, and subsistence food and feed requirements.

Crop land (ha) : The total arable land was constrained to be less than or equal to 1.75 ha based on the mean farm size in the area. No arable land is left under compulsory fallow for fertility management.

Pasture land (ha): Because of the prevailing land tenure system and cultural practice, there is no private pasture land in the study area but households have access to available communal pasture land and other common access grazing areas such as road sides. Assuming that each household in a village or locality has access to a proportion of the communal and common access pasture land, it was assumed that a typical farm would have access to an equivalent of 0.45 ha of grazing land giving 4500 kg dry matter production per ha ((Bekele, 1991). However, the available consumable forage produced annually from such pasture land was assumed to be 50% of gross production because of cattle selectivity and trampling, use by wildlife and loss due to fire (Houerou and Hoste, 1977).

Human Labor (person hours) : Six critical labor periods of two months each were identified for agricultural production on the basis of important farm operations. There are several religious holidays in each labor period during which farmers do not work in the field. These days were identified and excluded from the labor supply estimates. Farmers in the study area on average worked six hours per day in crop activities. The major labor input required by livestock was for herding by children whose opportunity cost was assumed to be zero in the cropping activities (Getachew and Hailu, 1992; Bezabih, 1991). Labor was not a constraint for any other livestock related activity.

Ox power (pair hours): For land preparation, three oxen labor periods with different intensity of demand were identified. Threshing of grain crops were done by oxen as well as by other livestock; occasionally neighbors' animals also were exchanged. This task is generally performed during slack periods when oxen do not have competing work such as tillage. For this reason no constraint of oxen for threshing was assumed.

Working capital : Working capital to meet operating expenses, for example to buy fertilisers, seeds, pesticides, or hired labour, is one of the most important restrictions on small farms (Sisay, 1983; Getachew and Hailu, 1992). The maximum available working capital was assumed to be equivalent to the amount of cash income generated by each plan.

Minimum subsistence consumption: This constraint was designed to more or less reproduce the current production and consumption patterns in which producers give emphasis to the production of some commodities for home consumption. An average household had 5.07 adult equivalents. Based on Gryseels (1988), 200 kg of cereals, 50 kg of pulses, 30 kg milk, and 500 kg of dung for fuel were assumed as average annual subsistence requirements per adult equivalent. It was assumed that the household consumed the grains produced from crops to meet its subsistence requirements in the same ratio as the average cropping pattern and the resulting production. For example, the total amount of cereals consumed might come from one or more cereals depending on the optimal cropping pattern. It was also assumed that in the short run the amount of food required for home consumption would not change as a result of introduction of forage legumes with cereals so that any gains from increased production would be reflected in higher cash income.

Feed demand and supply : Livestock feed was provided by crop residues, aftermath grazing, and from natural pastures. In the case of cereal-forage legume inter-crops, additional feed was available from forage legumes. Livestock required crude protein (CP), metabolizable energy (ME) and dry matter (DM) and they were required for maintenance and other productive functions. The feed demands of total livestock herd of the household were calculated as a function of total number of livestock, their classes, functions and weights (Gryseels, 1988; Hailemariam, 1995; Menale Kassie, 1997). Any surplus feed was sold while any deficit was met by purchase.

Crop, nitrogen, milk, and manure output balances: These constraints were included in order to ensure that grain and nitrogen yields from crop production, and milk and manure from livestock were transferred to the subsistence balance, and sale and purchase equations as appropriate. Also, straw and pasture outputs were transferred to the livestock activities, and sale and purchase equations, as appropriate.

Validation of Base Model Outcome

The purpose of the base model was to examine whether existing resources were allocated efficiently among possible current activities, and then to use this as a base to compare the results of introduction of cereal-forage legume inter-crops and other improvements. In order to test whether the solution obtained from the base model was representative of the current production practices found in survey results, i.e. to validate the results of the base model, the following quantitative tests suggested by Hazell and Norton (1986) were applied to the level of use of land, human labor and ox power, and to output levels.

Mean Absolute Deviation (MAD):

$$MAD = \frac{\sum_{i=1}^{N} | X_i^p - X_i^a |}{N}$$

Where X_i^p is the predicted value of a variable X_i, X_i^a is the actual value of a variable X_i, and N is the number of observation of the variable being evaluated.

Percentage Absolute Deviation (PAD): defined as MAD in percentage terms, i.e,

$$PAD = \left(\sum_{i=1}^{N} \frac{|X_i^p - X_i^a|}{|X_i^a|} \right) . \left(\frac{1}{N} \right) x\ 100$$

The components are as defined above. Small values of MAD and PAD are indictors of a desirable model fit.

Theil's index:

$$T = \frac{\left[\frac{1}{N} . \sum_{i=1}^{N} (X_i^p - X_i^a)^2 \right]^{\frac{1}{2}}}{\left[\frac{1}{N} . \sum_{i=1}^{N} (X_i^p)^2 \right]^{\frac{1}{2}} + \left[\frac{1}{N} . \sum_{i=1}^{N} (X_i^a)^2 \right]^{\frac{1}{2}}}$$

The symbols are as defined above. The Theil's index equals zero when predicted and actual values of X are equal for all i=1,..,N, and implies a perfect fit. The closer the index is to zero, the better the correspondence between predicted and actual values.

Correlation coefficient (r): measures the degree of association between predicted and actual values, and is defined as:

$$r = \frac{\sum_{i=1}^{N} (X_i^p - \overline{X}^p).(X_i^a - \overline{X}^a)}{\sqrt{\sum_{i=1}^{N} \left(X_i^p - \overline{X}^p \right)^2 \ \sum_{i=1}^{N} \left(X_i^a - \overline{X}^a \right)^2}}$$

It is advisable to use a multiple rather than a single criteria for validation of model outcome. Generally, a PAD value of less than 10%, Theil’s Index close to zero and correlation close to one are good indicators of the validity of the test results. A PAD value of over 15% indicate the need to re-examine the model (Hazell and Norton, 1986).

Risk and Sensitivity Analyses

The plans were developed on the basis of fixed input-output coefficients and prices but this might not be the case in the real world. Many of the coefficients used in the model, particularly price of inputs and outputs, may vary in a largely unpredictable way. The impacts of such variation on the stability of model results can be examined with sensitivity analysis which involves changes to model coefficients within reasonable bounds of the original estimate and is often used to determine if the original ranking of alternatives is affected (Dillion and Hardaker, 1993). Risks also play a major role in the adoption of a technology. Although direct incorporation of risk in the models was not possible due to data limitations, maximization of cash income after satisfaction of household subsistence requirements could be considered an indirect mechanism for taking into account some aspects of risk as this was a common strategy that farmers used as a means of risk management. To take into account other sources of risks such as market, weather, price changes etc.; sensitivity analyses were applied to test the stability of the model results. The sensitivity of the results was tested to account for two sets of changes : (a) 30% decrease in the prices of all outputs in the Base Plan, and IP1 and IP2. This was the lower bound average price observed during the 18-month period indicating seasonal fluctuation. (b) 100% increase in the price of fertilizer in IP3 as fertilizer was more extensively used in this plan. Currently fertilizer price is low due to subsidy but the extent of subsidy is expected to be reduced in the future leading to increases in price.

Data Sources

Technical coefficients with respect to traditional and proposed inter-crops were developed on the basis of farm survey results and on-station and a few researcher-cum-farmer managed experiments conducted mostly in Ethiopia by the International Livestock Research Institute and the Ethiopian Institute of Agricultural Research. Some published results from experiments conducted elsewhere were also used in order to fill gaps or validate the Ethiopian results. Socioeconomic data including prices were derived from previous surveys conducted by the International Livestock Research Institute, the Institute of Agricultural Research and the Ministry of Agriculture and from supplementary surveys conducted to update, validate or fill gaps in available data. Since farmers in Ethiopia have not yet adopted cereal-forage legume integration, relevant data based on actual practice was not available. Therefore, the estimated impacts were of an *ex ante* nature.

Results and Discussion

The Base Model Outcome

The results obtained from the application of different validation criteria to the base Model outcome are summarized in Table 1. In this study, most test statistics are well within the range that indicate good model fit except in the case of the PAD values for cropland allocation and crop output. In reality, all the major crops and their outputs had PAD values less than 5% but because of small magnitude of area and output of some minor crops, small changes led to PAD values higher than 15%, which in turn contributed to the high overall PAD values. If the values for the minor crops are ignored, overall, the outcome of the Base Model could be considered representative of actual practices, so the results could be used to perform experiments to evaluate the effects of changes in the current production system.

Outcomes of Improved Models

Land and labor use patterns: Compared to the Base Plan (Table 2), there was significant change in land uses patterns after the introduction of forage legume inter-crops. Land devoted to maize increased markedly due to the combined effects of higher grain yield, higher quantity and quality of stover production, and because it demanded little cash working capital. The area allocated to other crops was influenced to a great extent by the need to satisfy subsistence requirements.

Overall labor use increased at most 2.4% in the improved plans compared to the Base Plan. Also, in five out of six labor periods, there was only marginal change in labor use. In one period the improved plans used up to 30% more labor than the Base Plan, yet there was unused labor in that period. Ox power requirement in the improved plans decreased up to 14% because of reduced area allocated to teff, which requires high ox power input particularly for tillage.

Feed demand and utilization: The quality of feed is one of the determinants of the dry matter intake of livestock. As the quality of the feed increases animals can satisfy their requirements at intakes lower than with poor quality feed resources. In the Base Model, livestock consumed all the available feed dry matter but under IP1, IP2 and IP3 respectively 81, 88 and 89% of available feed dry matter were used by livestock (Table 3). This decrease in dry matter intake under the improved plans resulted from the increased ME and CP content of feed in the improved situations. Decreased consumption by livestock allowed sale of some straw/stover to earn cash. In IP2 and IP3, a higher proportion of available feed was utilized than in the Base Plan as the former systems include crossbred cows.

Farm Income: The introduction of forage legume inter-crops has increased farm cash income by 247, 393 and 553% in IP1, IP2 and IP3, respectively compared to the Base Plan (Table 4). These percentage increases are apparently high because cash income in the Base plan is very low. The introduction of a crossbred cow in IP2 increased cash income by 42% compared to IP1 without the crossbred cow. This value can be increased to 98% once the credit has been repaid. Cereal-forage legume inter-crops planted in rows with fertilizer increased crop yields and further enhanced cash income. If the value of nitrogen fixed by the cereal-legume inter-crops were ignored, the extent of cash income in the improved plans would be much less.

The economic impact of cereal-forage legume inter-cropping is most pronounced with the introduction of a crossbred cow, because the cow converts straw and better quality forage legumes into higher value products. The share of livestock in gross farm return increased from about 36% with zebu cattle in the Base Plan and IP1 to 59% and 53% in IP2 and IP3 respectively, both having a crossbred dairy cow. Similarly, the shares of livestock in gross margin and cash income were significantly higher in IP2 and IP3 in spite of the fact that introduction of the crossbred cow dramatically increased variable cost. Although shares of livestock in gross margin and cash income in IP3 were lower than those in IP2, absolute values of gross margin and cash income in IP3 were higher because of higher output and gross return.

In addition to higher income, the introduction of crossbred cows may also help to mitigate the risks and uncertainties of income from crop enterprises and reduce the time lag between expenditures on inputs and receipt of revenues. Although these impacts are not incorporated explicitly in the models, experiences from India (Thorve and Galgalikar, 1985) indicate that dairying with crossbred cows may provide more evenly distributed income throughout the year and be less subjected to unstable income from crop yield variation due to weather

Resource productivity and returns to resources: Integration of forge legumes with cereals substantially increased average returns to farm resources compared to the Base Plan (Table 5). Since human labor and oxen power are the main household resources employed in production, gross margin is a good measure of return to family resources. The estimated gross margin per person day (Birr 7.95) in the Base Plan is about the same as the prevailing wage rate in the peak season in the study area. Returns to labor can be increased by nearly 70% with cereal-legume inter-crop and crossbred cow production. Average rate of return to working capital is high (Table 5) because of the very low level of use of purchased variable inputs, particularly in the Base Plan.

The estimated marginal value productivities (MVPs) of the resources available to the farm household give an indication of the importance of different resources in the production process. For example, the MVP of cropland under different plans indicates the extent of additional income that could be generated per ha by increasing the size of the farm. Higher MVP indicates higher degree of scarcity of that resource for increasing income. Zero MVP indicates that the resource in question is still underutilized. The results of this study indicate that after the introduction of forage legume inter-crops the marginal productivities of human labor and ox power remain zero because neither of these resources are fully used for production under existing or improved plans. On the other hand, the MVP of land is positive as expected because overall productivity and profitability have increased after the introduction of inter-crops and can be further increased by increasing the size of the farm. Given the scarcity of land under increasing rural population, inter-cropping of forage legumes with cereals may be an option to intensify land use. This is likely to increase the value of land (and therefore land rental rates where rental is allowed or practiced).

The higher MVP of pasture in the base plan compared to the improved plans indicates that communal pasture is currently an important feed source, both in quality and quantity (Table 5). The marginal value productivity of pastureland decreases in the improved plans in relation to the Base Plan because of an increase in feed availability from inter-cropping. An increase of MVP of pasture in IP2 and IP3 compared to IP1 is consistent with the higher demand for feed for crossbred cows than for local cows.

The MVP of working capital under different plans indicates that it becomes an increasingly important constraint for the improved plans, as more cash is required with more commercial inputs.

Sensitivity Analyses

The effects of a 30% reduction in the prices of all the products in the Base Plan and IP1 and IP2 were examined. The results indicate a lowering of the cash income for all the plans (Table 6). The relative drop in cash income is greatest for the Base Plan (49%) followed by IP1 (22%) and the least for IP2 (6%). The resulting farm incomes remain higher and more stable for the improved plans than the Base Plan. The land use pattern and the sources of cash income in the improved plans remain similar to those before price reduction. Among improved plans, IP2 remains the most profitable. This shows the potential of the crossbred cow to moderate the impact of decreased output prices on cash income.

The effect of raising fertiliser prices by 100% in IP3 was only a 3% reduction in cash income. However, the cropping pattern changed drastically from the optimal plan before price rise (Table 2). Maize-lablab and sorghum-lablab planted in rows with fertilizer in IP1 and IP2 (Table 2) were replaced by the same inter-crops without fertilizer. Compared to the optimal plan before rise (Table 2), there were also a substantial increase in the area under maize-lablab and a decrease in the area under teff, barley and horsebean. These changes indicate that a substantial rise in fertiliser price relative to output prices may require major adjustment in cropping pattern in order to keep income stable. A good price information service would be required if farmers were to plan properly under volatile price regime.

Conclusions and Recommendations

The results show that integration of forage legumes with cereals can contribute to the sustainability of smallholder farms by improving resource productivity and enhanced cash income compared to the present practice of the farmers without forage legumes. The impacts were estimated primarily on the basis of on-station experimental data. The positive impacts therefore provide a basis for validation of experimental results under real farm conditions under farmer management through on-farm research and extension. Currently availability of forage seeds is a major constraint for farmers before they can test and then use them extensively. Therefore, efforts should be made by national organisations to produce and supply seeds alongside the on-farm research and extension program.

Among the benefits of cereal-legume inter-cropping, higher and better quality fodder, enhanced animal productivity and enhanced soil fertility were accounted for in the present study. Other important contributions, e.g. erosion and weed control, were not measured due to lack of appropriate data. These additional contributions may positively influence adoption of the technology. Hence efforts should be made to quantify these benefits in future on-station and on-farm investigations.

The impacts of improved practices were measured on the basis of single year plans in which flow of input and output of multi-year enterprises were annualized. However, forage legumes have carryover impact on the farming system, which need to be measured directly. In the long run, improved cropping and feed production strategies may also lead to a change in household consumption pattern and herd size and composition. Therefore efforts should be made to monitor these changes through on-farm research, and model the impacts of these changes over time in a more holistic manner to account for the dynamic aspects of the technology.

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Table 1 Summary statistics for validation of the Base Model outcomes

	Validation statistics

Criteria	MAD	PAD	Theil's Index	r
Cropland Allocation (ha)	0.01	14.8	0.01	0.99
Human Labor(Person-days)	0.62	2.1	0.01	0.99
Ox Power(Pair-days)	0.37	3.0	0.01	0.99
Crop Production (Kg)	10.9	14.7	0.02	0.99

MAD = Mean Absolute Deviation
PAD = Percentage Absolute Deviation
r = Correlation between actual and predicted values

Table 2 Optimal cropping pattern under different farm plans (ha)

Particulars	Base plan	IP1	IP2	IP3
Teff	0.96	0.66	0.66	0.66
Sole wheat	0.43	0.00	0.00	0.00
Sole sorghum	0.04	0.00	0.00	0.00
Sole maize	0.04	0.00	0.00	0.00
Barley	0.04	0.00	0.00	0.03
Horse beans	0.08	0.03	0.05	0.08
Chick peas	0.08	0.08	0.08	0.08
Rough peas	0.08	0.08	0.08	0.08
Wheat-clover**	-	0.30	0.30	0.30
Broadcast maize-lablab*	-	0.56	0.55	0.00
Broadcast maize-lablab**	-	-	-	0.00
Broadcast sorghum-lablab*	-	0.04	0.04	0.00
Broadcast sorghum-lablab**	-	-	-	0.00
Row maize-lablab*	-	-	-	0.00
Row maize-lablab**	-	-	-	0.49
Row sorghum-lablab*	-	-	-	0.00
Row sorghum-lablab**	-	-	-	0.02

* Without fertilizer. ** with fertilizer.
(-) = Indicates the crop is not included in the model.
(0.0) = Indicates the crop is included in the model but not chosen in the optimal plan.

Table 3 Feed availability and utilization by livestock in different plans (kg DM)

Items	Farm plans			
	Base plan	IP1	IP2	IP3
Available Dry Matter	4396	5212	9990	9990
Predicted intake	4319	4238	8839	8884
Percent utilized	98	81	88	89

Table 4 Share of livestock in annual farm income in different plans

Particulars	Base Plan	IP1	IP2	IP3
Gross return (Birr)	5023	6206	8026	8982
% from livestock	37	35	59	53
Variable Cost (Birr)	660	536	1587	1698
% for livestock	5	6	68	64
Gross margin (Birr)	4363	5670	6439	7284
% from livestock	41	38	57	51
Cash Income (Birr)	528	1831	2601	3447
% from livestock	59	36	84	64

Table 5 Average and marginal returns to farm resources in different plans

Particulars	Base Plan	IP1	IP2	IP3
A. Gross Margin:				
Per ha	2493	3240	3679	4162
Per person-day	7.95	10.33	11.73	13.27
Per unit of working capital	9.94	12.92	14.67	16.59
B. Cash Income:				
Per ha	302	1046	1486	1970
Per person-day	0.96	3.34	4.74	6.28
Per unit of working capital	1.20	4.17	5.92	7.85
C. MVP of resources				
Crop land (Birr/ha)	1757	3059	3236	4661
Pasture land (Birr/ha)	419	300	328	330
Human labor (Birr/person day)	0	0	0	0
Ox power (Birr/pair day)	0	0	0	0
Working capital (Birr/Birr)	0.33	0.99	1.10	2.56

Table 6 Effect of 30% reduction in output prices on cash income (Birr) in selected plans

Plans	Before reduction	After reduction	Change	% change
Base Plan	528	271	-257	-49
IP1	1831	1428	-403	-22
IP2	2601	2453	-148	-6