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Improvement strategies for farming systems in the Eastern Highlands of Ethiopia

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ABSTRACT

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Eleven distinct farming systems were distinguished, based on selected indicators and locations. The indicators involve the resource basis, cropping pattern and intensity, and the major activities including off-farm work. Statistical tests were used to verify the differences. Accounting for the given constraints and for the interdependencies of the system's components, strategies are developed to improve their poor economic performance.

A linear programming model is used to evaluate the effects on farm performance of (a) reallocating the existing farm resources, and (b) introduction of improved technologies. The type of relationship among the elements of the farming system determines the overall outcome of any improvement effort. Groundnut and livestock production are highly competitive. A package of technological innovations is needed to achieve a major improvement on the smallest farms.

1. INTRODUCTION

In Ethiopia, as in many developing countries, the rate of population growth surpasses that of agriculture [2.9% and 2% per annum, respectively (CSA, 1986)]. The slow rate of agricultural growth is closely related to the structure and pattern of production. Smallholders, dominant in the high-

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lands, are the backbone of the Ethiopian economy, providing the largest portion of basic food supply for the urban population, raw materials for agro-industries and agricultural commodities for export.

Farming systems (FSs) in the Eastern Highlands of Ethiopia constitute complex production units involving a diversity of mixed crops and livestock in order to meet the multiple objectives of the household. The combination of these activities depends on environmental conditions, resource endowment and the management skills of the farmer. Understanding the interdependence of the elements of the farming system and maintaining the balance in the complex set of farmer's objectives are pertinent to outlining promising development strategies for such systems. Peasant farmers operate in different agro-climatic zones and under different socio-economic conditions, and are seldom confronted with identical constraints. Thus, they may not adopt the same innovations.

In this study a classification of the farming systems into homogeneous groups is proposed which allows the analysis of the existing farm organization and the interrelationships among the system's elements, and the evaluation of the effects of optimal allocation of farm resources and technological innovations in the region. The core objective of the study is to propose problem-specific innovations for some FSs, considering their effects on the whole system, their most limiting constraints and the interrelationship of the respective sub-systems.

The study was conducted in the Eastern Highlands of Ethiopia, part of the Hararghe Administrative Region. Agro-climatic zonation of the region is based on thermal zone (TZ) and length of growing periods (LGPs) (FAO, 1984). The study region was limited to altitudes greater than 1300 m above sea level (masl), and to a LGP of more than 180 days [1].

The study used data generated in a FS survey referring to the 1986 cropping season (Storck et al., 1991). The survey adopted a two-stage stratified sampling technique. For the first stage, based on information available, the study area was divided into two sub-regions: the eastern and the western sub-regions. In each sub-region, peasants' associations (PAs) in the different agro-climatic zones were stratified for random sampling. Secondly, the farmers in the selected PAs were randomly selected. In each PA, five farmers and their spouses were interviewed, bringing the sample size to 375, of which 369 were included in the analysis. A group discussion with older farmers, elected PA personnel and extension agents of the PA (if any) supplemented the information from individuals.

[1] Compared to the cropping calendar in this region, the established LGPs seem to be exaggerated.

TABLE 2.1

Steps for farming systems' classification

Step	Based on	Results
1. Selection of indicators	Literature review: Westphal, 1975 Ruthenberg, 1980 Shaner et al., 1982 Collinson, 1983 Upton, 1987 Fresco and Westphal, 1988	Land–labour ratio Share of major crops Cropping intensities Livestock units Market orientation Off-farm employment
2. Effect of altitude ranges (temperature zones)	Bartlett's test of homogeneity of variances H_0: $\vartheta_1^2 = \vartheta_2^2 = \ldots, = \vartheta_k^2$ ϑ_k^2: Variance of FS indicators (Snedecor, 1956; Winer, 1971)	Variances of all variables except share of large cereals in CA are different among the altitude ranges
	Tukey multiple range test H_0: $\bar{x}_1 = \bar{x}_2 = \ldots, = \bar{x}_k$ x_k: mean of FS indicators	Means of some of the variables are different among the altitude range
3. Effect of sub-regions East and West (different rainfall régimes)	*t*-Test based on separate sample variances H_0: $\bar{x}_1 = \bar{x}_2$ $\bar{x}_1$, $\bar{x}_2$: mean of FS indicators in each sub-region (Yamane, 1973; Kohout, 1974)	Means of all variables except land–labour ratio, livestock units; and shares of off-farm income are different between the two sub-regions

To be continued

TABLE 2.1 (continued)

Step	Based on	Results
4. Combined effects of altitude and sub-region	Analysis of variance; *F*-test; Tukey multiple range test (Snedecor, 1956; Winer, 1971; Kohout, 1974) cf. Tables 2.1 and 2.2	Low altitude (1301–1700 masl) East: oil crop zone West: coffee zone Medium altitude (1701–2600 masl) both sub-regions: large cereal zone High altitude (2200–2600 masl) East: off-farm activities prevail West: pulse zone
5. Separation of FS within the zones	Improving homogeneity	1. Size groups: Large cereal zone, small farms (< 0.5 ha CA) Large cereal zone, large farms 2. Growers and non-growers of leading crops in the respective zones

CA, cultivated area.

Some additional information was collected from the regional Ministry of Agriculture, and the Ministry of Coffee and Tea Development (MCTD). The information, relating to perennial crops and livestock, was complemented by survey results in the central highlands of Ethiopia (Gryseels and Anderson, 1983; Leithmann-Früh, 1983; Gryseels, 1988; Tesfaye, 1989; MCTD, 1990) and in the Hararghe highlands (Habtemariam, 1986; Risoud, 1987; Risoud et al., 1988; Verjux, 1988).

2. FARMING SYSTEMS CLASSIFICATION

A FS is an interaction of many components such as cropping, livestock and resources, which are influenced by the natural and economic environment. Table 2.1 gives a summary of procedures used to classify the FS in the study area. A selection of relevant indicators based on a review of

TABLE 2.2

Indicators of farming systems in the eastern sub-region

Altitude range (masl)	Land/ Labour (ha/ ME)	Live-stock (LU)	Share of cultivated area (%)				Inter-cropping index (%)	Market orien-tation	Share of off-farm income (%)
			Coffee	Large cereals	Pulses	Oil crops			
1301–1700	1.36 *	3.64 *	0.8	68	0	9.8 *	37	40	2.4
1701–2200	0.80	2.73	1.4	67	1	0.3	45	35	11.4
2201–2600	0.56	1.47	0.3	50	0	0.5	25	18	38 *
Total	0.94	2.92	1.1	66	1	3.1	41	36	10.3

ME, man equivalent.
LU, livestock unit, equivalent to an ox.
* Significantly different from means in the other zones at ⩽5% level.

TABLE 2.3

Indicators of farming systems in the western sub-region

Altitude range (masl)	Land/ Labour (ha/ ME)	Live-stock (LU)	Share of cultivated area (%)				Inter-cropping index (%)	Market orien-tation	Share of off-farm income (%)
			Coffee	Large cereals	Pulses	Oil crops			
1031–1700	0.98	2.95	6.4 *	54	1	0.4	25	68 *	5
1701–2200	0.87	2.41	0.7	68 *	4	0.0	37	32	10
2201–2600	0.63	2.43	0.1	54	14 *	0.5	30	30	15 *
Total	0.87	2.62	2.8	60	5	0.3	31	45	9

* Significantly different from means in the other zones at ⩽5% level.

literature was followed by applying statistical tests to analyze the effects of agro-ecological conditions on these indicators. The altitude ranges proposed by FAO (1984) were used as proxies for TZ and LGP, supplemented by a separation of the western and eastern sub-regions because of differences in their rainfall régime and magnitude.

The analysis helped to distinguish FSs in the different zones. Leading activities are used to characterize the systems. Based on the size of cultivated area (CA) and whether farmers grow the leading crop or not, eleven homogeneous FSs were identified. The main features of the systems in the different zones are given in Tables 2.2 and 2.3. Land scarcity prevails in the region, with land–labour ratios decreasing with altitudes; livestock activities are supplementary to crop production and mainly rely on by-products of annual crops. Cropping patterns change with altitude though large cereals generally play an important role; intercropping is widely practiced, especially in the eastern sub-region. Market orientation dominates the coffee zone. At high altitudes, off-farm employment substantially complements the incomes from the limited cultivated area. Details of the farm organisation, major constraints and problems, as well as economic result, were described elsewhere (Bezabih, 1991; Bezabih et al., 1991).

This paper focusses on finding strategies to improve the poor economic performance of the peasant farms, with due regard to the interdependencies of the systems' elements and constraints. To demonstrate different approaches, four FSs were selected for modelling, namely (a) the system with oil crops, (b) large farms of the large cereal zone in the East, (c) small farms of the large cereal zone in the West, and (d) the system with coffee.

3. FARM OPTIMIZATION UNDER CURRENT TECHNOLOGY

3.1. Optimization model

A linear programming (LP) model is used to evaluate: (a) the effect of reallocation of resources under normal conditions to arrive at a plan which can be used as a yardstick, and (b) the effects of improved practices on the system, accounting for interdependencies among the elements of the system. Annual and perennial crops, as well as livestock activities, are integrated in the optimization models.

The model comprises the following main components: the objective function, activities, and constraints. In developing optimization models for small farms, consideration of the farmers' objectives (food supply, cash generation, risk avoidance, etc.) is of paramount importance. Many authors have proposed different options to overcome the problem of multiple objectives in an optimization model (e.g. Hazell and Norton, 1986; Upton, 1987; Ellis, 1988).

In this study, risk aversion is assumed to play a major role in peasants' decision making. According to the field survey (Storck et al., 1990), and in line with other authors (Ellis, 1988), major risks are connected with: (a) extremely fluctuating weather conditions, resulting in a high variability of crop yields and market prices – to the extent of total crop failure in some FSs; (b) uncertain procurement of variable inputs; (c) animal diseases; (d) feed and water shortage for livestock production; and (e) government policies discouraging t'chat production.

The lack of time-series data prevented direct incorporation of stochastic variables into the optimizing model using, for example, a focus/loss approach (Boussard and Petit, 1967) or a quadratic variance/expected value, or MOTAD model, respectively (Anderson et al., 1977; Hazell and Norton, 1986). In addition, the authors feel that peasants' response to risk cannot be properly reflected by these approaches. On the other hand, given the limited information, neither a safety-first rule nor a utility function could be approximated (Fleischer and Robinson, 1985; Robinson et al., 1984). From the field survey, however, it was understood that peasants apply a range of risk-reducing practices (Sonka and Patrik, 1984; Stewart, 1991) which we tried to incorporate in different ways into the deterministic LP model.

By maximizing net cash income under the condition of satisfying the household subsistence requirements from crops grown, a major aspect of risk reduction was accounted for. In addition, cash crops with a short market risk (t'chat) [2] and crops grown during the extremely uncertain small rainy season were restricted to a level acceptable to the peasants in the area. Finally, sensitivity analysis was applied to test the stability of the solution if prices of cash crops decreased.

The activities could broadly be grouped into production, selling, purchasing and consumption activities (Annex 1). Production activities of annual crops procure yields for subistence or for sale, as well as by-products for animal feeding. Perennial crops allow for intercropping with annual crops. Pasture is limited by the access to common grazing land and is of minor importance for animal feeding. An oxen-keeping activity provides the necessary draught power capacity for ploughing; cow keeping provides milk for subsistence and sale, and heifers for herd replacement and for sale after replacement requirements are met. Production activities of annual crops do not contribute to the objective function (i.e. nearly zero cash variable cost), while perennial crops do so. Livestock activities contribute with their annual culling values and their (negative) purchase value, respec-

[2] *Catha edulis* (Celastraceae), a bush the leaves of which are chewed as a stimulant.

tively. Sale activities obtain open market prices, not affected by government policy. Purchase activities are incorporated only in case full subsistence is infeasible, as, for example, in off-farm-oriented FSs with very small land resources. Consumption activities assure a given level of consumption without influencing the objective function.

Coffee and t'chat are the most widely grown perennial crops with high variation of areas of the former compared to the latter. Three activities of the perennial crops were specified: existing coffee (OCF) and t'chat (TCH1 and TCH2) and new coffee (NCF). For existing coffee and t'chat, zonal average annual cash returns per ha were used as their contributions to the objective function. Since the decision to establish new coffee is affected by future changes and has to account for the time value of money, an investment analysis was prepared to determine the annuity which can be used appropriately as the average annual contribution to the objective function. The determination of annuity [3] of expected returns implies an assessment of the economic life of a coffee plant and of the optimum year of its replacement (16 years).

The objective function is maximized, subject to several constraints such as land, labour, draught power and other interrelated constraints, and to subsistence requirements. The rows in the optimization model represent the constraints and reflect the type of relationship (complementary, supplementary and competitive) between the activities, depending on the sign of the input coefficients in the same row. The area transfer constraint limits the intercropping of annual crops with perennial crops.

Balancing constraints are used to balance the deliveries (−) and the requirements (+) in a particular row. The subsistence requirements in terms of food crops and milk were incorporated in the model as minimum constraints.

3.2. Comparison of the existing and optimum plans

The poor performance of the peasant farm calls for an investigation of the means to improve the situation. One possible way is by reallocating farm resources without assuming any technological innovation. To this end, for the selected farming systems, the actual farm plans under normal conditions were prepared by substituting the actual crop yields of the reference year on which the budgets were based by yields the respondents would expect under normal weather conditions. These yields were also

[3] $A_t = \text{NPV} * \text{CRF}_t$; $\text{NPV} = \Sigma\, \text{CB}_t / q^t$; $q = 1 + i$ and i = discount rate (%); CB = cash balance; CRF = capital recovery factor $= q^t(i)/q^t - 1$; t = year after planting.

used as coefficients in the optimization models. The effect of reallocation of resources can only be assessed if the same technical and objective coefficients are assumed for the actual and optimal farm plans.

The FSs in the oil crops zone, in the large cereal zone and in the coffee zone were selected for optimization. In the model for the oil crops zone, groundnut is included as a sole crop, belg [4] crops are absent and the coefficients of the objective function for t'chat are low.

The model for larger farms of the large cereal zone in the East included small cereals (belg and mehar) [4] which increased the number of feasible activities. To account for the risk of failure, the maximum area that could be allocated to belg crops is limited to 25% of the CA. According to experience in the eastern sub-region, belg crops can be planted only during half of the seasons as rain does not always allow timely land preparation. Due to lack of rain after sowing, in some years a substantial yield is not obtained. A maximum rate of 25% is chosen to approximate to these conditions.

The small farms of the large cereal zone in the West were selected to represent a system with extremely scarce land resources. It regards all possible ways of allocating the extremely limited CA. The prevalence of the belg maize activity, and the possibility of interplanting sweet potato when maize is maturing, as well as the possibility of growing pulses (sole), are some of the specific characteristics of this model. A maximum of 60% of the maize area can be transferred for relaying.

The coffee zone was selected for optimization due to the prevalence of coffee. In this zone the option of multiple cropping is limited. Existing coffee and new coffee cultivation allows intercropping with annual crops.

The optimum combination of activities for the oil crop zone and for the large farms of the large cereal zone entails intensification by intercropping in such a way that 60% of the CA is intercropped in both systems (Table 3.1). Due to the twofold advantage of large cereals, food and feed supply, the area allocated to MSHAI is more than doubled. In the oil crop zone, groundnut cultivation is a competitive activity. In the large cereal zone, however, belg barley followed by teff is competitive as it allows the improvement of land use intensity. Efficient use of resources implies a reduction of the t'chat area by about 40% in the large cereal zone.

The optimum plan for the small farms of the large cereal zone in the West shows a cropping pattern with emphasis on intensification through relay cropping. As land shortage is a severe constraint, its most efficient allocation requires double cropping whenever possible (Table 3.1). The

[4] Belg and mehar refer to the short and long rainy seasons, respectively.

TABLE 3.1

Comparison of actual and optimal farm plans

Sub-region	East				West			
Leading crop	Oil crops		Large cereals				Coffee	
Size			large		small			
	Actual	Optimal	Actual	Optimal	Actual	Optimal	Actual	Optimal
Crops (ha)								
Maize	0.21	–	0.10	–	0.11 [a]	0.32 [a]	0.10 [a]	–
Sorghum	0.40	–	0.23	–	0.14	–	0.12	–
Sweet potato	0.01	–	0.04	–	0.02	0.19	0.05	–
Barley	–	–	0.03 [b]	0.29 [a]	0.04 [a]	0.13 [a]	–	–
Teff	–	–	0.04	0.29	0.04	–	–	–
Wheat	–	–	0.04	–	–	–	–	–
Field peas	–	–	–	–	0.02	0.13	–	–
Groundnut	0.34	0.58	–	–	–	–	0.01	–
MSHAI [c]	0.39	0.86	0.35	0.71	0.12	–	0.21	0.40
T'chat, sole	0.13	0.07	0.06	0.13	0.02	0.04	0.03	0.06
T'chat, intercropped	0.05	0.09	0.22	0.04	0.03	0.01	0.05	0.02
Coffee, sole	–	–	–	–	–	–	0.11	0.40
Coffee intercropped	–	–	–	–	–	–	0.11	0.17
Animals (head)								
Ox	0.97	1.03	0.45	0.33	0.20	0.04	0.30	0.27
Cow + follower	1.41	1.25	1.47	1.76	0.97	1.10	1.20	1.00

[a] Belg (short rainy season) crop.
[b] Partly belg crop.
[c] Intercropping of maize, sorghum and haricot beans.

area under belg maize has been increased, mainly because of the possibility of interplanting with sweet potato, a security crop. The small farms increase the non-ox cattle and heavily compete with others for common pasture.

The coffee growers, however, should give more emphasis to the establishment of new coffee while still maintaining the existing t'chat and coffee plants, and assuring about 70% of the food supply from their own production. Here, too, sole cropping is not economical.

Under normal price and yield conditions, the actual combination of activities would yield more gross margin (GM) and net farm cash income compared with the budgets based on actual yields in all systems. Reallocation of farm resources improves the farm performance in all systems with coffee growers benefiting most and the small farms in the large cereal zone

TABLE 3.2

Comparison of GM and net cash income of the two plans (EB)

Sub-region	East						West					
Leading crop	Oil crops			Large cereals						Coffee		
Size				large			small					
	Actual	Optimal	CH	Actual	Optimal	CH	Actual	Optimal	CH	Actual	Optimal	CH
GM, crops	922	1282	39	800	1007	26	351	432	23	844	1546	83
GM, animal	375	350	−7	328	405	23	210	216	3	251	230	−8
GM, total	1298	1632	26	1128	1412	25	561	648	16	1095	1776	62
GM, crops per LBF	688	957	39	588	740	26	308	379	23	721	1321	83
GM, crops per CA	576	801	39	684	861	26	702	864	23	804	1472	83
GM, total per AE	258	324	25	229	287	25	124	143	15	224	363	62
Net farm cash income	585	925	58	451	743	65	59	98	66	432	1104	156

GM, gross margin (gross income minus direct costs).
EB, Ethiopean currency (official rate: 2.07 EB = US$1.00).
CH, ratio of optimal minus actual to actual (in %).
LBF, labour force involved in farming (ME).
AE, adult equivalent.

TABLE 3.3

Shadow prices of some resources (EB per unit)

Sub-region	East	West		
Leading crop	Oil crops	Large cereals		Coffee
Size		large	small	
Cultivated area (ha)	910.00	1006.00	1013.00	972.00
Pasture area (ha)	149.00	166.00	134.00	144.00
T'chat area (ha)			600.00	643.00
Old coffee area (ha)				657.00
New coffee area (ha)				1316.00
TRFR1 (ha)	376.00	442.00	451.00	460.00
TRFR2 (ha)		710.00	480.00	
TRFR3 (ha)			637.00	424.00
TRFR4 (ha)				424.00
Oxen-day in April (pair)	6.00	3.00	3.00	4.00
Manure (q)	0.50	6.00		
Metabolic energy (kcal)	80	90	70	80

TRFR, area transfer for intercropping with t'chat (TRFR1), with old coffee (TRFR3), with new coffee (TRFR4), and for second crop (TRFR2).
q, metric quintal = 100 kg.
kcal, kilocalorie = 1000 cal
1 cal = 4.1868J (def).

least. The improvements are more pronounced in terms of cash income than in terms of GM (Table 3.2).

In all systems, land entails high opportunity cost (shadow price) (Table 3.3). The transfer of land to intercropping, or to second crops, is also limiting in most of the systems, indicating that a less restrictive limitation of belg crops and an extension of perennial crops would allow increased cash income. In the coffee zone, the limitation of new coffee areas has the highest opportunity cost. Livestock feed limitation is also common.

3.3. *Sensitivity tests*

The decision concerning an establishment of coffee is highly sensitive to future changes in prices and yields. The world coffee price fluctuates heavily and tends to decline; likewise, yields may not reach the expected level. Therefore, the stability of the proposed farm plan was assessed by parametrizing the annual return from coffee (due to price or yield reduction) downwards.

The optimum cropping plan remains stable even under very low coffee prices or yields. The proposed optimum plan is the same even if returns fall by 40%. But this would lead to a significant reduction in income from farm production; the effect is more pronounced in cash terms than in gross margins.

4. IMPROVEMENT POSSIBILITIES FOR SOME FARMING SYSTEMS

In this section, the effects of technological innovations are illustrated for (i) systems with oil crops, and (ii) small farms of the large cereal zones in the West. These cases are suitable for elucidating how the knowledge of FS classification and resource use optimization can be used for selection of technical innovations which are promising and adequate for improving the performance of the FS. The productivity of resources, as indicated by their shadow prices and by high gross margins per unit, can serve as major indicators of activities which deserve special emphasis.

In the oil crops zone, the competitive relationship between groundnut and livestock production is strong as animals depend on the cereal crops for feed. This relationship, together with the farmers' attitudes towards risk, should receive due attention. The system with oil crops was selected to demonstrate the consideration of such interrelationships for improving the FS.

Two different, but interdependent, improvement options are considered in this zone: (a) increasing the gross margin per ha of the groundnut, mainly by promoting its yield, and (b) the introduction of improved fodder crops to relax the dependence of animals on feed from grain crops, thus enabling increased groundnut production.

Based on adaptation trials made by Verjux (1988), a mixture of *Sorghum almum* (grass) and *Dolichos lablab* (legume) was selected as an appropriate technology. Since uncertain information about the outcomes is an inherent feature of technical innovations, this aspect has been accounted for by parametrization techniques. Parametrization allows the determination of relevant break-even points and provides a discussion basis with plant scientists about the feasibility of the assumed levels of yields.

The improved farm model leads to an increased herd size and a higher integration of the system into the marketing system while 80% of household food requirements still would be supplied from its own production. Table 4.1 shows the competitive nature of groundnut (GN) and livestock production, the latter being expressed in terms of area allocated to improved fodder crops (FD). The groundnuts should yield at least 780 EB of GM, and the FD should yield at least 5000 kg of dry matter (DM) in order to be competitive.

At lower productivity levels, emphasis is given to the production of a mixture of large cereals as its combined food and feed supply advantage

TABLE 4.1

Competitiveness of groundnut and livestock production

GM, groundnut (EB/ha)	Improved fodder (DM in kg/ha)											
	6653		6000		5750		5500		5000		4000	
	Area (ha) under ...											
	GN	FD	GN	FD	GN	FD	GN	FD	GN	FD	GN	FD
768	–	0.340	–	0.313	–	0.330	–	0.349	–	–	–	–
960	0.422	0.380	0.380	0.421	0.362	0.440	0.578	0.224	0.744	0.072	0.582	–
1056	0.558	0.387	0.869	0.076	0.866	0.079	0.863	0.083	0.854	0.091	0.750	0.092
1152	0.558	0.387	0.869	0.076	0.866	0.079	0.863	0.083	0.854	0.091	0.832	0.114

GM, gross margin (EB/ha) of groundnut (GN).
DM, dry matter (kg/ha) of fodder crops (FD).

offsets the relative advantages of the two competing activities. When the GM per ha of groundnut is fixed at 960 EB, various levels of the two activities can be obtained depending on the productivity of the fodder crops. Three ranges can be distinguished:

(1) At a high productivity of fodder crops (5750–6653 kg per ha), groundnut production is expanded at the expense of fodder crops with a similar herd size.

(2) At a medium level of fodder crop productivity (5000 to 5750 kg per ha), its area decreases from a maximum to a minimum and the groundnut area, in contrast, rises to its peak. Here, the productivity of the groundnut offsets the declining productivity of the fodder crops, resulting in a reduction of herd size (Table 4.2).

TABLE 4.2

Improved optimal farm plan at different productivities of GN and FD

Activities	GM	960	960	960	960	1056	1056	1056	1056	1152	1152	1152	1152
	DM	6653	6000	5750	5500	6653	6000	5750	5500	6653	6000	5750	5500
Groundnut (ha)		0.42	0.38	0.36	0.58	0.56	0.87	0.87	0.86	0.56	0.87	0.87	0.86
T'chat, sole (ha)		0.08	0.08	0.08	0.08								
T'chat, intercropped (ha)		0.12	0.12	0.12	0.12								
MSHAI [a] (ha)		0.60	0.60	0.60	0.60	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Fodder (ha)		0.38	0.42	0.44	0.22	0.39	0.08	0.08	0.08	0.39	0.08	0.08	0.08
Oxen (pair)		0.51	0.51	0.51	0.51	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Cow + follower (head)		3.30	3.30	3.30	0.21	3.30	1.30	1.30	1.30	3.30	1.30	1.30	1.30

[a] Intercropping of maize, sorghum and haricot beans.

TABLE 4.3

Income from the different levels of improvement (EB)

GM, groundnut (EB/ha)	Improved fodder (DM in kg/ha)											
	6653		6000		5750		5500		5000		4000	
	Cash [a]	GM	Cash [a]	GM	Cash [a]	GM	Cash [a]	GM	Cash [a]	GM	Cash [a]	GM
768	1013	1686	986	1659	974	1646	960	1633	941	1617	941	1617
960	1065	1724	1025	1685	1007	1667	989	1644	981	1633	973	1632
1056	1115	1772	1074	1725	1071	1721	0167	1718	1058	1709	1035	1688
1152	1169	1826	1158	1808	1154	1805	1150	1800	1140	1791	1113	1765

[a] Net farm cash income.

(3) At a yield level lower than 5000 kg of DM, fodder crops are no more competitive and livestock heavily competes with groundnut production.

With further increment in the productivity of groundnuts above 960 EB of GM per ha, the productivity of the fodder crops should be very high in order to be competitive.

The income from these technological innovations indicates that the best return in terms of both cash and GM is achieved with high productivities of the two activities (Table 4.3). At medium yield levels, differences in GM are rather small. To increase the GM substantially over the level of the

TABLE 4.4

Optimum farm plan under different improvement options for small farms of the large cereal zone, western sub-region

Activities	Optimum plan	Improved plan with improvement option					
		HYV	EMV	MCC	FD	SCB	Integrated
Barley, belg (ha)	0.13	0.13	0.11	0.13	0.13	0.26	–
Field pea [a] (ha)	0.13	0.13	0.11	0.13	0.13	0.26	–
T'chat, sole (ha)	0.04	0.04	0.04	0.06	0.04	0.04	0.07
T'chat, intercropped (ha)	0.01	0.01	0.01	0.02	0.01	0.01	0.03
Maize, belg (ha)	0.32	0.32	0.34	0.31	0.14	0.22	0.38
Sweet potato [a] (ha)	0.19	0.19	0.2	0.19	0.08	0.13	0.23
Oxen (pair)	0.04	0.04	0.04	0.04	0.11	0.09	0.01
Cow + follower (head)	1.1	1.1	1.12	1.05	2.0	0.99	1.31
Fodder crop (ha)	–	–	–	–	0.21	–	0.04

HYV, high yielding variety (10% more yield than the current average). EMV, early maturing variety of maize. MCC, more cash crop (up to 0.2 ha of the CA for t'chat). FD, improve fodder crop (DM = 6653 kg/ha) and maximum of two cows. SCB, more area under small cereals, belg (upto 50% of the CA). Integrated, combination of EMV, MCC, IFD and SCB.

[a] Crops grown on belg crop area.

TABLE 4.5

Farm revenues under different improvement options (EB)

Activities	Optimum plan	Improve plan with improvement option					
		HYV	EMV	MCC	FD	SCB	Integrated
GM crops	432	469	522	470	287	463	523
GM animals	216	216	218	206	401	208	249
GM total	648	685	739	677	688	671	771
Net farm cash income	98	150	204	138	136	125	242

HYV, EMV, MCC, FD and SCB as defined earlier.

basic plan, high-yielding varieties of fodder crops and groundnuts are required.

The small farms of the large cereal zone in the West have been selected to elaborate the effect of integrated improvement efforts on the very small farms. The basic limitation in this FS is the farm size itself. Nevertheless, the analysis of the optimum farm plan indicates that the return from the limited land resource can be improved mainly by increasing the intensity of its use. Cropping methods are transformed through various methods of intensification, particularly multiple cropping, permanent land use and the introduction of high yielding varieties and crops maturing earlier than the traditional ones (Fresco and Westphal, 1988). Several areas of technological innovation have been analyzed (Tables 4.4 and 4.5):

(1) High-yielding varieties that can increase the current yield of annual crops by 10% would improve the GM by about 9% and the net cash farm income by 53%, without changes in the cropping pattern.

(2) Introduction of an early maturing maize variety that can be harvested early enough to allow a full second crop in the same season. The marginal productivity of a transfer of land from belg to the following crop is high (Table 3.3), showing the feasibility of this innovation. It would extend the relay cropping to full double-cropping. Consequently, the GM and the net farm cash income of the family would increase by 21% and 108%, respectively.

(3) Allowing an expansion of cash crop production would nearly double the area allocated to t'chat production at the expense of the maize area, resulting in increased cereal purchases. This change would increase the GM from crop production by about 9% and the net cash farm income by 41%.

(4) An introduction of improved fodder crops into the small farms to improve the livestock subsystem would lead to an allocation of some area to fodder crops and help to extend cow keeping and milk sales. It would, however, increase farmers' dependency on the market for subsistence. By

this means, the farm returns in terms of GM and net cash could increase by 6.2% and 39%, respectively.

(5) The shadow price of limiting the barley area during the short rainy season indicates the advantage of expanding the area under this crop. Compared to the basic plan, expansion of the area up to 50% of the CA would result in 7% more GM and 28% more net cash income from cropping activities.

(6) Finally, an integrated implementation of the above technologies has been assessed except for the case of the high yielding varieties. The effects of such a package of improvements is found to be better than any one-sided effort. It would result in an increased net cash income (+147%) and in about 21% additional total GM compared with the basic plan. T'chat has become competitive along with maize, followed by sweet potato and livestock; barley followed by peas has lost its competitiveness and is excluded.

5. CONCLUSIONS

Efforts to improve the poor performance of smallholder farms have to take into account fully the repercussions of any changes in resource allocation and in implementing innovations on the whole farming system. However, due attention should be given to the objectives of the farm household and to prevailing external restrictions.

Identifying homogeneous farming systems, and using models for optimization of allocative efficiency and for assessing the effects of innovation on the system's components and its economic results, can

- prevent researchers and extension officers from following only one-sided promotion of some elements of the system;
- guide research and extension activities towards promising strategies for solving the peasants' problems; and
- enhance the general understanding of the development process in peasant agriculture acting under different agro-ecological conditions.

Models should be elaborated on a thorough knowledge of the prevailing chances, constraints and objectives of the respective FS, and should in their very structure reflect real conditions. In this sense, the proposed approach of a deterministic linear model has its own shortcomings regarding, for instance

- inadequate reflection of uncertain weather conditions;
- Inadequate incorporation of peasants' responses to actual weather conditions;
- inadequate accounting for long-term effects of drought periods on herd development.

ANNEX 1

General Skeleton Matrix

	Production activities						
	Annual Crops	Perennial crops	Inter-cropping	Past-ure	Oxen	Cow + follower	Donkey
Activities (units)	X_A (ha)	X_K (ha)	X_I (ha)	X_F (ha)	X_{OX} (pair)	X_H (head)	X_U (head)
Objective function (EB)		$+Q_K$			$+V_{OX}$	$+V_H$	$-V_U$
Cultivated area (ha)	1_A	1_K					
Pasture area (ha)				1_F			
Perennial crops area (ha)		1_K					
Area transfer (ha)		$-j_K$	1_I				
Labour (man-day)	w_{tA}	w_{tK}	w_{tI}				
Draught power (ox-day)	d_{tA}				$-d_{tOX}$		
Ox-max. (pair)					1_{OX}		
Ox-replacement (pair)					r_{1OX}	$-r_{2H}$	
Heifer transfer (head)						$-z_H$	
Balances							
Yield (q)	$-y_A$		$-y_I$				
Milk (l)						$-m_H$	
Manure (q)	n_A	n_K			$-n_{OX}$	$-n_H$	$-n_U$
Feed							
ME (Mcal)	$-e_A$		$-e_I$	$-e_F$	e_{OX}	e_H	e_U
DCP (kg)	$-g_A$		$-g_I$	$-g_F$	g_{OX}	g_H	g_U
Subsistence requirement							
Food crops (q)							
Milk (l)							

List of codes used in the skeleton matrix. The subscripts show the requirements of (+) or the deliveries by (−) the activities whose codes have been indicated. These are:

A = Type of annual crops (sole or intercropped)	A = {A: 1,..., n_1}
BC = Type of crops purchased	BC = {BC: 1,..., n_2}
BM = Purchase of milk	BM = {BM: 1}
CR = Consumption requirement for food crops	CR = {CR: 1,..., n_2]
F = Pasture	F = {F: 1}
H = Cow plus follower	H = {H: 1}
HF = Sales of heifer	HF = {HF: 1}
I = Combination of annual and perennial crops	I = {I: 1,..., m_1}
K = Type of perennial crops	K = {K: 1,..., m_2}
MR = Consumption requirement for milk	MR = {MR: 1}
OX = Oxen	OX = {OX: 1}
SC = Type of crops sold	SM = {SM: 1}
SM = Sales of milk	SM = {SM: 1}
U = Donkey	U = {U: 1}

Coefficients

(1) Objective function

Q = Average/ annuity income from existing/new perennial crops area.

V = Average annual income (+) or cost (−) per respective animal activity.

P = Selling (+) or purchasing (−) prices for the respective activities.

Sales			Purchases		Consumption		RHS
Food crops	Milk	Heifer	Food crops	Milk	Food crops	Milk	
X_{SC}	X_{SM}	X_{HF}	X_{BC}	X_{BM}	X_{CR}	X_{MR}	
$+P_{SC}$	$+P_{SM}$	$+P_{HF}$	$-P_{BC}$	$-P_{BM}$			
							$\leqslant$ CA
							$\leqslant$ PAS
							$\leqslant$ PCA
							$\leqslant 0$
							$\leqslant W_t$
							$\leqslant 0$
							$\leqslant$ OXM
							$\leqslant 0$
		1_{HF}					$\leqslant 0$
1_{SC}			-1_{BC}		1_{CR}		$\leqslant 0$
	1_{SM}			-1_{BM}		1_{MR}	$\leqslant 0$
							$\leqslant 0$
							$\leqslant 0$
							$\leqslant 0$
					1_{CR}		$\geqslant$ SRC
						1_{MR}	$\geqslant$ SRM

(2) Technical coefficients. If the coefficient is 1, then it has been indicated in the matrix. Others:

w_t = Labour requirement per ha of the respective activity in period t, $t = \{t: 1, \ldots, 13\}$.
d_t = Draught oxen power requirement (+) or supply (−) per unit of the activity in period t.
m = milk supply per unit activity.
n = Manure requirement/supply per unit of the respective activity.
e = Energy production (non-grain only) or requirement per unit of the respective activity in the form of metabolic energy, ME (Mcal).
g = Protein production (non-grain only) or requirement per unit of the respective activity in the form of digestible crude protein, DCP.
j = Share of intercropping area in perennial crops.
r_1 = Pair of oxen to be replaced each year.
r_2 = Pair of male calf delivered by a cow each year.
y = Yield of annual crops.
z = Net supply of heifer for sale.

(3) RHS (capacities)

CA = Cultivated area.
PAS = Pasture area.
PCA = Area for perennial crops.
W_t = Labour force for farming in period t.
OXM = Maximum oxen pair available.
SRC = Minimum subsistence requirement for crops.
SRM = Minimum subsistence requirement for milk.

To tackle these aspects further research and data are needed.

The FS approach to improve farm performance should not encourage the overlooking of the uniqueness of each and every peasant household, which has its own chances, problems, objectives and constraints. Extension for peasant development should ultimately strive to teach farmers how to understand and to change their own systems. FS models will help to meet this requirement but cannot be a substitute for it.

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