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Final

LIVESTOCK AND AGROFORESTRY IN PEASANT FARMS OF AFRICA
- ILLUSTRATIVE MODELING AND METHODOLOGY -

Edgar J. Ariza-Nino

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International Center for Research in Agroforestry
Nairobi, Kenya
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The University of Michigan
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INTRODUCTION

Background:

This paper grew out of a USAID grant to the Center for Research on Economic Development (C.R.E.D.) to assist the International Center for Research in Agroforestry (I.C.R.A.F.) in developing a livestock component for the microcomputer modeling program for use in ICRAF's diagnostic methodology for the economic appraisal of smallholder agroforestry systems in Africa.*

High priority is placed on including a livestock component since most promising agroforestry systems call for integration of trees, animals, and annual crops. In many cases a major rationale for introducing trees is to improve livestock productivity through the forage value of the tree. The aim is not only to increase output of animal products, but also to maintain the strength of draft animals through the dry season to be able to start land preparation earlier in the growing season, while the ground is still hard.

*I am indebted to Dirk Hoekstra, Dan Etherington, John Raintree, and Filemon Torres, all of ICRAF, for their valuable critiques and suggestions in preparing this report.

Agroforestry, Animal Production and the Farm Enterprise

Livestock Production in Africa is primarily concentrated in the semi-arid regions of the continent. It is also in these semi-arid regions where the urgency to promote tree planting is felt more strongly for both environmental and soil conservation purposes. The prevalence of tse-tse and trypanosomiasis in the areas favored with rainfall above 800 mm per year has effectively prevented cattle from being raised in those areas, except perhaps for a few dry months of the year. In the more humid regions of Africa the natural vegetation's exhuberance makes grass production practically impossible and costly, and increases the incidence of disease and parasites among cattle. Interest in the association of trees with livestock in an African milieu needs therefore focusing on the particular conditions of the semi-arid zones. The choice of tree species of potential use, for example, is therefore limited to those varieties able to prosper at low rainfall levels and able to survive dry spells of up to nine months.

The benefits to be derived from tree planting in semi-arid regions are multiple, but difficult to quantify with any precision. Environmental benefits have high priority among international experts, but the population affected locally need more practical considerations to be persuaded to plant trees on a regular basis.

Fuelwood production, for example, would receive a high regard in villages where women have to walk for several hours to obtain firewood. Forage production in the form of greene leaves or seed pods, would be favored by pastoralists and farmers struggling to feed their livestock during the dry season. Soil protection and fertility improvements are highly valued by farmers whose bare fields are gone with the Harmatan winds. Other benefits such as shade for people and for livestock, fruit production, aesthetic appeal, etc. might have special value in some circumstances. Timber production is not

a priority output, however. The market for specialty nuts and other tree products are similarly very limited.

The potential tree species with favorable prospects for the semi-arid zones of Africa are numerous: the legume family is well represented by several species which are drought resistant, prosper in soils of poor fertility, produce protein rich foliage palatable to livestock, fixes its own nitrogen in association with azobacter bacteria, and yields medium volumes of firewood every year. The Acacias, many of them indigenous to Africa, offer good examples of multiple purpose trees for dry climates. Neem trees, brought originally from the Indian subcontinent, are already well known in dry Africa. Prosopis from South America produce abundant forage when it can tap on good undergrown water supplies. Eucalyptus from Australia have been used in sand-dune stabilization projects thanks to its rapid growth pattern. Baobabs are of course the African multi-purpose tree par excellence.

Except in cases such as dune containment, trees are not likely to be planted as sole crop on a given terrain. Rather, we must view tree planting in semi-arid Africa in association with other land uses, be they livestock or agricultural. Prospects for pastoralists planting trees in the open range are negligible. Given the common property of the range resources, and the pattern of seasonal transhumance followed by pastoralist groups, it is unlikely that pastoralist would undertake tree planting since they would not be sure to enjoy the fruit of their labours.

More positive prospects exists for sedentarized farmers in Africa's semi-arid regions to engage in planting trees in or around their farm fields, particularly farmers who also include livestock activities among their operations. They are more likely than pastoralists, to appropriate the three main types of benefits from trees outlined above, namely fuelwood, forage, and soil fertility. They offer favorable targets for research and extension efforts in agroforestry in the semi-arid regions. Evidence of this is seen in

a recent survey of farming households in the Peanut Basin of Senegal which found remarkable disparities in millet and peanut yields among three villages surveyed. In the village with a high proportion of cattle and a conspicuous presence of acacia trees in the fields, yields were several times higher than those of two other villages where both trees and cattle were scarce. The authors concluded that the application of manure in the fields, and the soil protection and forage provided by the acacias were mainly responsible for the higher yields in the first village (Josserand and Ross, "Consumption Effects of Agricultural Policies - A Case Study in Senegal," CRED, 1982). Another CRED farming system survey in eastern Niger also found great advantages in yields from fields that benefit from fertilizing with manure from cattle and small ruminants (R. Thomas, "Stratification of Cattle Production in the Zinder Department of Niger," CRED, 1982). The essential point in these and other studies is the importance of livestock and agroforestry for the maintenance and improvement of soil fertility.

Farmers throughout the dry zones of Africa have been increasingly integrating cattle into their farm plans. Small ruminants have long been essential constituents of village farms. The last decade has witnessed a definite trend towards the introduction of oxen traction for transport and field activities, as well as cattle fattening during the dry season using mainly crop residues as forage. Expansion of farming into formerly grazing lands, increased sedentarization of pastoralists, and rising demand and prices for animal products in African cities will insure that the trend toward greater association of crops and cattle raising will continue over the coming years. The challenge for agroforestry is how to encourage farmers in dry areas to incorporate tree planting into their enterprises. To begin, one needs to determine whether the benefits to the farmers will indeed in the

long run compensate for the initial financial and labor effort required to establish the trees.

ECONOMIC APPRAISAL OF AGROFORESTRY

Establishing a plot of forage trees in a farm requires considerable expense and effort by the farmer: seedlings must be grown or purchased, transplanted, and provided with tender loving care during the first few months; labor for weeding, watering, fencing, guarding, and pruning must be diverted from other activities. Not until tow or three years later will the farmer begin to reap the benefits from those initial efforts. Considerable foresight is demanded of the farmer, and his expectation of benefits must be convincingly positive in order to justify embarking in such a long term strategy.

Moreover, introduction of a forage tree crop entails not merely a temporary reduction in farm income, but a thorough reorganization of farm activities. Thus, for example, when the eventual higher supply of forage becomes available, a larger number of animals will be kept at the farm, at perhaps higher levels of nutrition and productivity than before; this might entail shifting labor and other resources from crop to livestock production. On the other hand, the additional fertilizer available from manure will bring forth higher yields of both crops and forage.

A cautious farmer needs, therefore, to anticipate what sort of new farm organization to adopt once the forage tree crop is established and producing. Corresponding levels of revenues and costs for the new pattern of operations need also be estimated. Furthermore, the farmer must also decide some strategy to follow during the transition period between the current situation and when the tree crop is in full production.

Appraisal Strategy

To help the farmer in making the above set of decisions a tentative procedure involving several stages is suggested:

- First, a model of the existing farm enterprise is constructed, with its array of technical options for both crop and livestock production, resource endowments, limitations regarding family food consumption and farm credit, and the set of input costs and output prices faced by the farm.
- Second, the anticipated resource requirements for establishing the proposed forage tree crop in the first year, are introduced into the original farm model. A new plan of farm activities is then derived, indicating the adjustments the farmer should make in order to minimize the income loss brought about by the introduction of the forage tree.
- Third, similar annual farm plans are derived for the second, third,..., years of the forage tree crop, by making the appropriate changes in the input and output coefficients for the tree crop. For each year the model generates a farm plan incorporating the adjustments in the type and levels of all activities to make the most of the farm resources in that particular year.
- Fourth, the series of future annual farm net revenues is then discounted at an appropriate rate, to arrive at a single figure representing the overall economic worth of introducing forage trees, in present value terms. If that figure significantly exceeds the net present value of income from the current pattern of farm operations, the farmer is better off with the forage trees. Otherwise, he is not.
- Fifth, the farmer needs to determine the most advantageous size of the tree crop for the size of farm, the type of crop and livestock activities being carried out, and other circumstances particular to the farm or the household. A simple procedure is suggested to narrow down progressively the area of the tree crop within a reasonable level of approximation.

Stage I: Modeling the Agroforestry Farm

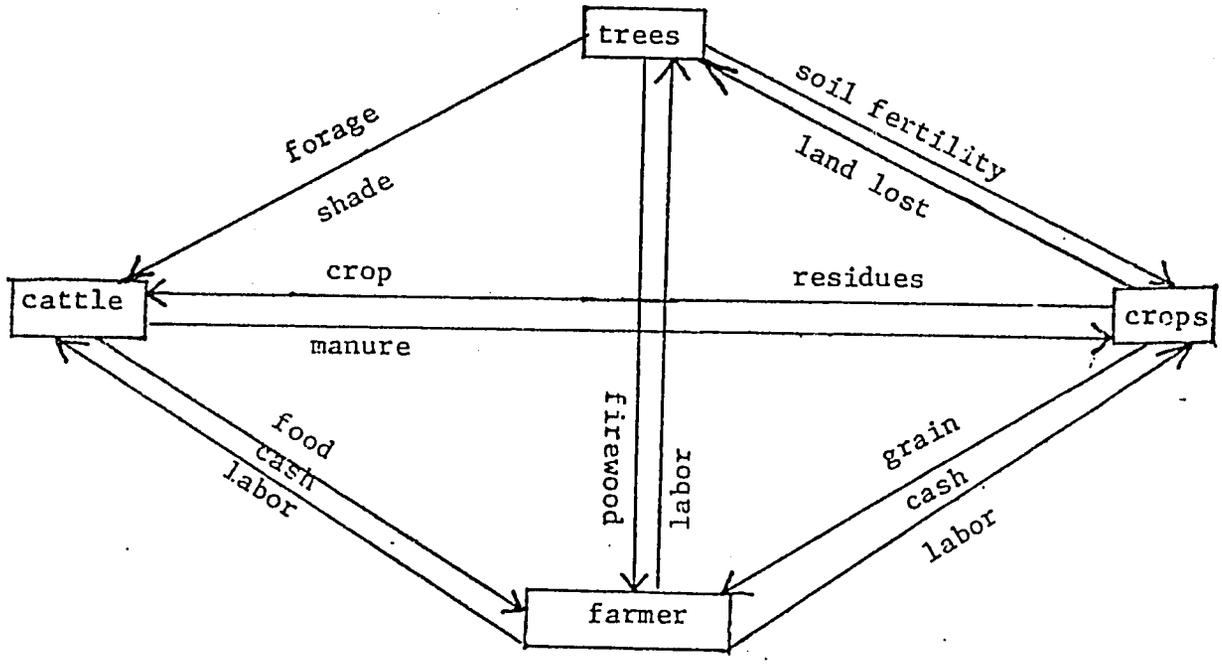
There has been in the past decade, increasing recognition by agricultural development specialists that traditional systems of introducing new varieties or new techniques are remarkably unsuccessful in peasant-type farming, particularly in Africa. The farming systems approach emphasizes the need to conceive and evaluate innovations within the context of the whole-farm enterprise, rather than separately on a crop by crop basis. Specifically, any new activity introduced in a peasant farm will necessarily involved a complex chain of trade-offs with the existing pattern of activities, the net effect of which are not easily foreseeable. A rather detailed knowledge of farm types in a given area is therefore needed in order to evaluate the impact of a potential new crop or new method.

In assessing the impact of tree planting in peasant farms of semi-arid African regions we need therefore to consider the whole range of changes in the operations of the farm enterprise. The diagram in Figure 1 might help to visualize these changes. For example, the introduction of a tree crop, say, Leucaena, will remove from cultivation cropland that otherwise could be used for grain production. After a couple of years, however, forage from the Leucaena will enable the farmer to feed additional livestock in his farm. Manure from the livestock when applied to the fields would enhance the fertility of the crop area, and the additional crop residues will further increase the forage available for livestock.

Monetary valuation of the products from the tree crop are extremely difficult in the above system. There are no market prices for tree branches, or for the improved soil characteristics. Firewood is easier to evaluate. To obtain a figure for the economic benefits from introduction of Leucaena in that farm, one must have the change in overall income for the entire

FIGURE 1

EXAMPLE OF AN AGRO-SYLVO-PASTORAL SYSTEM



enterprise, with and without the Leucaena. In such a way, prices are needed only for final products, for which there is a market, and obviates the problem of assessing prices and costs to intermediate products that are used within the farm.

Linear programming farm models have been widely used in farm management analysis in developing countries; their particular application to exploring potential consequences of introducing new products or technological packages has been amply reported by agricultural development practitioners. The use of programming models in combination with the increasing power, accessibility and portability of small computers is already enabling researchers to use these tools under tield conditions. It is thus now possible to obtain hypothetical results about the potential effects of changes in the farming system in a matter of hours, rather than the months or years that would require real-life experimentation.

There are however, certain caveats to the use of linear programming models, particularly concerning the underlying assumptions of linearity in the system, and that the farmer's main objective is the maximization of farm revenue, and the difficulties of accounting for risk and uncertainty considerations in the plan for a small peasant farm. Despite these shortcomings, farm linear programming models have demonstrated enough flexibility and usefulness in practical situations that their use is increasingly common in agricultural extension and development agencies.

Illustration: A Case Study from Southern Niger

In order to illustrate the proposed methodology a simplified version of a farm model has been formulated using actual data from a recently concluded study at the University of Michigan (R. Thomas-Peterhans, 1982) about livestock and cropping activities among farmers in a southern Niger village.

Whenever necessary these data has been supplemented with data from published or other well-informed sources. Table 1 lists the range of farm activities considered. These farm activities can be roughly grouped into: crop production, livestock production, and product selling.

Constraints

Eleven constraints are included in the farm model in order to maintain appropriate balances among inputs and outputs in the farm enterprise. Thus, animal traction hours required must not exceed those provided by a pair of oxen during the critical land preparation period (Constraint 1). Separate balances for millet, sorghum, cowpeas and peanuts are introduced to make explicit the yields and costs of production for each one of the cropping activities, and to transform their total production into revenue at the corresponding market prices (Constraints 2 through 5).

Since stover from millet and sorghum, as well as foliage from cowpeas and peanuts, can be fed to cattle, it becomes necessary to introduce separate balances for stalks (Constraint 5) and leaves (Constraint 6) to insure that their consumption does not exceed their respective levels of production within the farm. No outside sale or purchase of either stalks or leaves are contemplated for the moment. The converse relationship between crops and animals is also specified in Constraint 9: manure collected from the various types of livestock can be used in fertilizing crop fields to the limit of its availability.

Nutritionally adequate rations must be insured for all the types of livestock present in the farm. Constraints 10 and 11 are used to balance the overall livestock requirements of protein and energy with their respective supplies from the various feedstuffs available within the farm. Finally, the land

constraint merely insures that the area cultivated and grazed does not go beyond that within the family's control. Labor constraints throughout the year are omitted from this model despite their importance for farm management decisions because insufficient information was available for certain activities, and in order to emphasize the remaining input-output interactions among animals, trees, and crops.

Crop Production Activities

Farm fields in this particular southern Niger region consists of intercropping combinations of millet, sorghum, cowpeas, and peanuts. Distinctions are made between manured and unmanured fields, and within the manured fields between those plowed using animal traction and those worked with only normal labor.

Eight separate crop activities are identified in this area, following the farm management survey conducted in the village of Boukou, Zinder Department, Niger. Millet and peanuts are the predominant crops; ordinarily they are present together in the same fields, but often they also appear in combination with sorghum, peanuts, or both. Table 1 lists these crop combinations and their corresponding code names: UMSCP, for example, stands for unmanured fields with a millet, sorghuming; cowpeas and peanuts combination: MMSC describes a manured field of millet, sorghum, and cowpeas; and TMMSP denotes a manured field worked with oxen and planted with millet, sorghum, and peanuts. The last cropping activity, GARDEN, reflects the presence of small gardening patches around shallow water wells that farmers often have near their compounds. These small vegetable and sugarcane plots are intensely fertilized and cultivated all year round; accordingly, revenue per hectare of GARDEN is remarkably high -- 205,401 FCFA, but their size on average does not exceed one tenth of a hectare.

Finally, land that is not used for growing crops is set aside for cattle to graze, hence it contributes to fulfilling the nutrient requirements of livestock. Activity 22 in Table 1, GRAZE, denotes the area in hectares that the farmer allocates for grazing.

Table 2 presents the input-output relations among activities for each one of the eleven constraints described earlier. Cropping activities appear in the first few columns of the matrix. This matrix of coefficients is given in the standard linear programming format where inputs appear as positive numbers, while outputs are preceded by negative signs. Thus, in the first column corresponding to activity UMSCP, the -214 indicates a yield of 214 kilograms of millet, and -488 corresponds to a yield of 488 kilograms of stalks. The coefficient for land is a positive 1.0 because it takes one hectare of land to produce one hectare of UMSCP.

In a similar fashion, coefficients in the column for TMMSCP indicates that one hectare of manured millet-sorghum-cowpeas-peanuts worked with oxen requires 14.1 hours of a pair of oxen, one hectare of land, and one ton of manure; it in turn produces 499 kg of millet, 94 kg of sorghum, 28 kg of cowpeas, 204 kg of peanuts, 482 kg of stalks, and 332 kg of leaves.

Values in the objective function row reflect the contributions to farm revenue made by one unit of each activity. The value for the first column, UMSCP is -3180, i.e., one hectare requires a disbursement of 3180 FCFA in either seed, fertilizer, tools, or sprays. It does not reflect the cost of inputs produced within the farm, nor the value of outputs such as millet and sorghum.

Selling Activities

Revenue from crop producing activities is not realized until the farmer sells his production in the market. In this hypothetical example, the entire output from different crops are valued at market prices. No distinction is made here between internal household consumption and market sales, though in a more complete farm model such distinction can be readily incorporated.

Selling activities are defined for the four main crops, namely millet, sorghum, cowpeas, and peanuts, represented in Table 2 by the columns labeled SELL-M, SELL-S, SELL-C, and SELL-P. The coefficients in these columns have a simple pattern: they are zeros except for a 1.0 in the row corresponding to the product in question. Thus the 1.0 in SELL-M merely states the obvious fact that it takes one kilogram of millet to sell one kilogram of millet. The values in the objective function for the selling activities are merely the average prices received by farmers in the area, per kilogram of each product, during the crop year. That is, a kilogram of sorghum sold for an average of 55.25 FCFA, while a kilogram of peanuts brought in 134.5 FCFA on the average.

There are no selling activities for either stalks or leaves in this hypothetical example, although in fact there is a small but active trade in forage among farmers in the region. In this case study, the values of stalks and leaves are only realized if they are fed to cattle. Activities 20 and 21 in Table 1 translate the yields of stalks from millet and sorghum, and leaves from cowpeas and peanuts, into kilograms of STALKS and LEAVES fed to cattle as part of their ration.

Agroforestry Activities

Before livestock activities are brought into their example of an integrated farm in southern Niger, it is convenient at this point to introduce a hypothetical agroforestry activity, the principal subject of this exercise. Only one simple tree activity is postulated in this case, namely the planting, growing, and harvesting one hectare of *Leucaena leucocephala*. In the first year, establishing one hectare of *Leucaena* requires a net disbursement of 10,000 FCFA, the cost of seedlings, fencing, and protecting the young plants. On the other hand, the small trees only cover 40 percent of the area; the remaining 60 percent could be used for producing other crops. These particular facts are represented in the column LEUC-1 by the values .40 in the land row, and -10,000 in the objective function.

Column LEUC-2 represents the impact of the one hectare of Leucaena in the second year after planting. It is still too early to harvest any foliage, and there are no cash costs associated with this growing out period. Area coverage however has increased in the second year to 70 percent.

Finally, from the third year onwards, the Leucaena can be cut regularly for an annual yield estimated at 1,000 kg of dry matter of browse. The column for activity LEUC-3 depicts this situation: Area coverage is now complete at 100 percent, hence the value of 1.0 for land; the one ton yield of browse translates into a total of 100 kg of digestible protein and 2,000 megacalories of metabolizable energy (the values are negative since they are outputs from the Leucaena). There are neither cash expenses nor revenues attributed to the Leucaena; its economic value is realized only to the extent that the forage is fed to cattle and cattle brings in revenue, or because cattle contributes either manure and traction power that in turn increases revenue from cropping activity. No other value is given to other potential benefits from Leucaena such as improvement in soil fertility or firewood production.

TABLE 1

FARM ACTIVITIES IN SOUTHERN NIGER PEASANT FARM

Activity Code	Description and Unit
1 - UMSCP :	Unmanured millet-sorghum-cowpeas-peanuts. (ha)
2 - UMSC :	Unmanured millet-sorghum-cowpeas. (ha)
3 - UMP :	Unmanured millet-peanut. (ha)
4 - MMSCP :	Manured millet-sorghum-cowpeas-peanuts. (ha)
5 - MMSC :	Manured millet-sorghum-cowpeas. (ha)
6 - TMMSP :	Manured millet-sorghum-peanuts, with animal traction. (ha)
7 - TMMSCP:	Manured millet-sorghum-cowpeas-peanuts, with animal tractio
8 - GARDEN:	Gardening in bas-fond (vegetable, sugarcane). (ha)
9 - SELL-M:	Selling of millet. (kg)
10 - SELL-S:	Selling of sorghum. (kg)
11 - SELL-C:	Selling of cowpeas. (kg)
12 - SELL-P:	Selling of peanuts. (kg)
13 - SH-GO :	Sheep and goats. (animal units)
14 - OXEN :	Oxen for plowing. (pair)
15 - STEER :	Steer for dry-season fattening. (head)
16 - COWS :	Milk cows. (cow plus calf)
17 - LEUC-1:	Growing Leucaena, first year. (ha)
18 - LEUC-2:	Growing Leucaena, second year. (ha)
19 - LEUC-3:	Growing Leucaena, third year. (ha)
20 - STALKS:	Feeding millet and sorghum stalks to cattle. (kg)
21 - LEAVES:	Feeding cowpeas and peanut leaves to cattle. (kg)
22 - GRAZE :	Grazing land set aside to feed cattle. (ha)

Activity / Constraint	UMSCP	UMSC	UMP	MMSCP	MMSC	TMMSP	TMMSCP	GARDEN	SELL-M	SELL-S	SELL-C	SELL-P	SH-GO	OXEN	STEER	COWS	LEUC-1	LEUC-2	LEUC-3	STALKS	LEAVES	GRAZE	CONSTRAINT
Traction	0	0	0	0	0	32.1	14.1	0	0	0	0	0	0	-55	0	0	0	0	0	0	0	0	≤ 0
Millet	- 214	- 233	- 72	- 345	- 563	- 247	- 499	0	1.0	0	0	0	0	0	0	0	0	0	0	0	0	0	≤ 0
Sorghum	- 48	- 106	- 89	- 79	- 270	- 27	- 94	0	0	1.0	0	0	0	0	0	0	0	0	0	0	0	0	≤ 0
Cowpeas	- 48	- 8	0	- 58	- 42	0	- 28	0	0	0	1.0	0	0	0	0	0	0	0	0	0	0	0	≤ 0
Peanuts	- 77	0	- 205	- 151	0	- 138	- 204	0	0	0	0	1.0	0	0	0	0	0	0	0	0	0	0	≤ 0
Stalks	- 488	- 500	- 117	- 637	- 256	- 565	- 482	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	≤ 0
Leaves	- 208	0	- 228	- 312	0	- 414	- 332	0	0	0	0	0	0	0	0	0	0	0	0	0	1.0	0	≤ 0
Land	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0	0	0	0	0	0	0	0	0	.40	.70	1.0	0	0	1.0	≤ 6.7
Manure	0	0	0	1.0	1.0	1.0	1.0	0	0	0	0	0	0	-1.62	-.320	-.945	0	0	0	0	0	0	≤ 0
Protein	0	0	0	0	0	0	0	0	0	0	0	0	0	200	42	144	0	0	-100	-.017	-.080	- 5.0	≤ 0
Energy	0	0	0	0	0	0	0	0	0	0	0	0	0	7,560	1,452	4,905	0	0	-2000	-1.80	- 2.2	-1600	≤ 0
Objective Function	-3180	-3180	-3180	-3180	-3180	-5000	-5000	205,401	57.3	55.25	91.50	134.5	11,502	37.000	33,187	51,000	-10,000	0	0	0	0	0	Maximize

TABLE 2 : LINEAR PROGRAMMING MODEL MATRIX FOR INTEGRATED AGROFORESTRY PEASANT FARM IN SOUTHERN NIGER

Livestock Production Activities

No provisions are made for feeding small ruminants; sheep and goats are supposed to fend for themselves throughout the entire year. Cattle, on the other hand, are assumed to require feeding for most of the year, and provisions for their upkeep need be made in the farm plan. Steers for fattening are only kept during the dry season; oxen and cows stay in the farm through the year, but it is assumed that during three months they are able to fend for themselves, so that only nine months of feed supplies need arranging for.

Balancing feed supplies with the consumption requirements of farm livestock demands two distinct types of detailed information: quantitative estimates of nutrient requirements by each different kind of animal, and the nutrient content of each type of feed available in the farm. The following section will deal with the first of these concerns, followed by a section on the nutrient composition of feeds.

Nutritional Requirements

Only two nutrients are being considered in this exercise, namely protein and energy. Other nutrients might be of concern in certain circumstances, but these two are generally the most critical in growing beef cattle. There are many alternative systems for specifying energy requirements for cattle, from the forage units used by French animal nutritionists, starch equivalent units developed in Germany, to the net energy systems developed independently in California and in the United Kingdom. We will use here metabolizable energy (ME for short), as the common unity of energy for expressing both animal requirements and forage composition. Metabolizable energy measures are roughly equivalent to the Total Digestible Nutrients (TDN) unit popular in the United States, but it can also be converted into various other inter-

national energy nomerclatures. Metabolizable energy requirements are ordinarily expressed in megacalories – Mcal – per day per animal, while feed content is given in Mcal per kilogram of dry matter or per kilogram of feed.

Protein requirements for cattle are commonly given in kilograms of digestible protein per day. Protein content of feeds are given as a percentage on a 100 percent dry matter basis; this in turn can then be converted into actual kilograms of digestible protein per kilogram of dry matter, or of feed as is.

Ration formulation is easier to carry out when nutrient contents and ingredients are given on a 100 percent dry matter basis. Actual feed amounts can later be obtained from the dry matter values merely dividing by the proportion of dry matter content in the feed as is.

(a) Fattening Steers

The principal source of information regarding nutrient needs is the publication, "Nutrient Requirements of Beef Cattle" put out by the National Research Council of the United States National Academy of Sciences (1976 edition).

Separate tables of nutrient requirements are published for the various categories of beef cattle, depending on age, sex, and physiological status. Table 3 gives the nutrient requirements for growing-finishing steer calves and yearlings. Values are given for animals at different liveweights, and for alternative rates of daily weight gain. Thus, for example, a steer of 200 kg initial liveweight and growing at .5 kg per day, requires .35 kg of digestible protein and 12.1 megacalories of metabolizable energy per day. During the entire 120-day fattening period, the total protein requirement for such a steer is 42 kg of D.P., and the total metabolizable energy requirement amounts to 1452 megacalories. These are the figures which are used in the farm model described in Table 2.

TABLE 3

DAILY PROTEIN AND ENERGY REQUIREMENTS OF GROWING STEER CALVES AND YEARLINGS

Live Weight kg	Daily Gain kg	Daily Requirements		120-day Requirements	
		Digestible Protein kg	Metabolizable Energy Mcal	Digestible Protein kg	Metabolizable Energy Mcal
200	0	.17	7.0	20.4	840
200	.5	.35	12.1	42.0	1,452
200	.7	.39	13.0	46.8	1.560
200	.9	.40	13.3	48.0	1,596
250	0	.20	8.2	24.0	984
250	.7	.39	14.4	46.8	1,728
250	.9	.44	16.2	52.8	1,944
250	1.1	.48	17.0	57.6	2,040
300	0	.23	9.4	27.6	1,128
300	.9	.50	19.5	60.0	2,340

Estimated Requirements for working oxen (a)

Weight	Gain	Daily Requirements		270-day Requirements	
300	.3?	3.7	14.0	100	3.780

SOURCE: NRC, Nutrient Requirements of Beef Cattle. National Academy of Sciences, Washington, D.C. 1976.

NOTES: (a) Estimated from the above requirements for steers of 300 kg live-weight.

(b) Working Oxen

In the absence of tables of nutrient requirements for work oxen, their requirements were estimated using data for growing steers. A livesweight of 300 kg was assumed, and energy and protein requirements were taken as the average between maintenance and those for growing at .9 kg per day. Of course, their actual gain is much smaller than the midpoint because of their work in plowing and pulling carts. Thus, daily metabolizable energy requirements were taken at 14.0 Mcal, and digestible protein at .37 kg. For the year as a whole, provisions for a feeding period of only 270 days are thought necessary; in the remaining days it is assumed oxen can be grazed directly during the rainy season. Total protein requirements for a pair of exen are thus estimated at 200 kg of digestible protein; likewise, provisions for 7560 Mcal of metabolizable energy are needed in the animal farm plan.(see Table 2)

(c) Milking Cows

Daily protein and energy requirements of milking cows can be obtained from another NRC publication, Nutrient Requirements of Dairy Cattle, 1971. Nevertheless, these nutrient estimates are aimed at specialized dairy-breed cows producing relatively high volumes of milk. In the case of a milking cow in an African peasant farm, the breed will likely be Zebu, milk production will amount to only a couple of liters per day, and there will be a nursing calf to be fed at the same time. Under these circumstances it seems more appropriate to use the nutrient requirements for nursing beef cows, which appear in the NRC tables of Nutrient Requirements of Beef Cattle, 1976. Table 4 summarizes the pertinent nutrient values for a cow of 350 kg at different stages of lactation.

Total nutrient requirements for milking cows for the year were computed in the following fashion. Provisions are only made for 270 days; during the rest

TABLE 4

DAILY DIGESTIBLE PROTEIN AND METABOLIZABLE ENERGY REQUIREMENTS OF BEEF COWS NURSING CALVES

Stage of Lactation and Milking Ability	Live Weight kg	Daily Gain kg	Digestible Protein kg	Metabolizable Energy Mcal
Dry pregnant mature cow; middle third of pregnancy	350		.15	10.8
Dry pregnant mature cow; last third of pregnancy	350		.19	13.2
Nurisng cow; average milking ability (=5 kg/day); First 3-4 months post partum	350		.44	15.9
Nursing cow; superior milking ability (=10 k/day); First 3-4 months post partum	350		.65	21.0

SOURCE: NRC. Nutrient Requirements of Beef Cattle. National Academy of Sciences, Washington, D.C. 1976.

of the year it is assumed that the cow will graze unattended. During the first 120 days post partum the cow is assumed to have superior milking ability (10 kg of milk per day), followed by 150 days of average milking ability (5 kg of milk per day). Nutrient requirements for the entire 270-day period are weighted sums of the values given in Table 4. Thus for digestible protein we have:

$$120 * .65 + 150 * .44 = 144 \text{ kg Dig. Prot.}$$

and for metabolizable energy:

$$120 * 21.0 + 150 * 15.9 = 4905 \text{ Mcal ME.}$$

The resulting values are those entered in the farm plan model.

Nutrient Content of Feeds

Four main feeds are being considered as sources of nutrients for livestock (cattle) in the semi-arid peasant farm, namely

(a) - sorghum and millet stalks, left-over after harvest,

(b) - cowpea and peanut leaves,

(c) - browse from planted legume trees, specifically, leucaena leucocephala, and

(d) - grazing land.

Actual laboratory chemical analyses of these feeds can be made to determine their nutritional value. Alternatively, values from feed composition tables can be used. Unfortunately, information tables about nutrient composition of feeds found in sub-saharan Africa are not directly available, as it is the case for other parts of the world. Each forage species has its own peculiar nutrient composition; moreover, nutrient values vary considerably according to the part of the plant oncerned, the vegetative stage of the plant, the handling and storage of the feed, and other factors. Detailed

nutrient composition tables compiled from thousands of laboratory reports of proximate and in-viro analyses, are available for North American and Europe, Latin America and more recently the Middle East and Mediteranean countries.

For their exercise we shall adopt the nutrient values for the above feeds, as reported in the Arab and Middle East Tables of Feed Composition, published by the International Feed Institute of Utah State University, and the Arab Center for the Study of Arid Zones and Dry Lands (ACSAD) in Syria. This is a compendium of over 2500 feed entries with detailed information on proximate composition, digestible protein, total digestible nutrients, digestible energy, metabolizable energy, and net energy values, when used to feed cattle, as well as values for sheep, horses, camels, and chickens.

Tables 5 through 8 present digestible protein and metabolizable energy values for a few pertinent feeds to be found in the type of semi-arid farms one might encounter in Africa. Table 5, reports values for sorghum and millet stover; the diversity of these nutrient values in striking, as exemplified in the percent of digestible protein ranging from 0.6% for sorghum-aerial-part-sun-cured-mature-stage, to 3.1 percent reported for millet-aerial-part-sun cured. For metabolizable energy the variation is less, ranging from 1.70 to 1.92 Mcals of ME per kilogram of dry matter.

Under the circumstances, the values adopted for millet and sorghum stalks, taken combined, are arbitrarily selected to lie within the reported values. For digestible protein of millet-sorghum stover 1.7 percent of dry matter was chosen, while for metabolizable energy the value of 1.8 Mcal per kilogram of dry matter was adopted. Other researchers, using more pertinent information, may opt for different values in different circumstances.

In a similar vein, for cowpea and peanut leaves, rough averages of the values reported in Table 6 were adopted for the purposes of this exercise,

TABLE 5

DIGESTIBLE PROTEIN AND METABOLIZABLE ENERGY CONTENTS OF MILLET AND SORGHUM STOVER

Entry	Feed Description	Dry Matter %	Digestible Protein-Cattle % of D.M.	Metabolizable Energy-Cattle Mcal/kg D.M.
1975 & 1976	Sorghum vulgare, aerial part, sun cured, mature stage	95	0.6	1.79
2001 & 2002	Sorghum vulgare, aerial part, sun cured, mature	58	2.3	1.92
1977 & 1978	Sorghum vulgare, straw	91	0.7	1.79
1931 & 1932	Millet: Setaria spp., aerial part, fresh, 99 50 112 days	–	1.5	1.72
1935 & 1936	Millet: Setaria spp., aerial part, sun cured	92	3.1	1.70
1933 & 1934	Millet: Setaria spp., aerial part, fresh, post ripe		1.8	–

SOURCE: Arab and Middle East Tables of Feed Composition. International Feedstuffs Institute, Utah State University, Logan, Utah. 1979.

TABLE 6

DIGESTIBLE PROTEIN AND METABOLIZABLE ENERGY CONTENTS OF COWPEA AND PEANUT LEAVES

Entry	Feed Description	Dry Matter %	Digestible Protein-Cattle % of D.M.	Metabolizable Energy-Cattle Mcal/kg D.M.
0169 & 0170	Peanuts: Arachis hypogaea, aerial part, sun cured, mature	95	5.9	2.12
2403 & 2404	Cowpeas: Vigna unquiculata, aerial part, without seeds, fresh, mature	-	10.0	2.35

SOURCE: Arab and Middle East Tables of Feed Composition, International Feedstuffs Institute, Utah State University, Logan, Utah. 1979.

namely 8.0 percent of dry matter content of digestible protein, and 2.2 Mcal of metobolizable energy per kilogram of dry matter.

Nutrient values for Leucaena leucocephala were not obtained in the IFI Tables; instead, the values reported for Leucaena glauca were adopted and rounded to 10 percent of dry matter for digestible protein, and 2.00 Mcal of metabolizable energy per kilogram of dry matter. See Table 7.

One hectare of Leucaena is assumed to produce one ton of dry matter browse, beginning in the third year after establishment. This yield is merely a tentative guess, to be modified as more accurate information is available. In terms of nutrients, this yield is equivalent to 100 kilograms of digestible protein and 2000 Mcal of metabolizable energy per hectare, per year. These are the values used later in the farm plan model in Table 2.

Grazing land in semi-arid African rangelands have a multitude of grass and shrub species, but for simplicity's sake, in this exercise it is assumed that only two main grass species are present, namely Aristida mutabilis and Cenchaus biflorus. Nutrient values for these two species are reported in Table 8. The values finally adopted to represent a blend of grasses are merely midpoint values between those of the two species: digestible protein is taken at 0.5 percent of dry matter, and metabolizable energy at 1.6 Mcal per kilogram of dry matter.

Moreover, per hectare dry matter forage production for grazing land is assumed at one ton, but a better estimate must be used if information is available. Hence, each hectare of grazing land can contribute the equivalent of 5 kilograms of digestible protein and 1600 Mcal of metabolizable energy for the feeding of farm livestock. See Table 2.

TABLE 7

DIGESTIBLE PROTEIN AND METABOLIZABLE ENERGY CONTENTS OF BROWSE FROM SELECTED LEGUME TREES

Entry	Feed Description	Dry Matter %	Digestible Protein-Cattle % of D.M.	Metabolizable Energy-Cattle Mcal/kg D.M.
1239 & 1240	Leucaena glauca, aerial part, sun cured	95	9.8	2.06
(a)	Leucaena spp., browse dehydrated	94.3	12.3	2.73
(a)	Leucaena leucocephala, aerial part, fresh	27.4	16.7	2.72 (b)
(a)	Leucaena glauca, aerial part, fresh	22.3	22.0	--
0069 & 0070	Acacia tortilis, browse, fresh	--	5.6	1.87
0071 & 0072	Acacia tortilis, leaves, fresh	--	9.2	--
0057 & 0058	Acacia seyal, leaves, fresh	43	12.1	4.49
0075 & 0076	Acacia tortilis, pods with seeds, fresh--	--	15.7	--
0065 & 0066	Acacia seyal, pods, fresh, stem cured	96	13.6	3.20

SOURCE: Arab and Middle East Tables of Feed Composition, and Latin American Tables of Feed Composition.

NOTES: (a) From the Latin American Feed Tables, pp. 254-255.

(b) Value reported for sheep; no value given for cattle.

TABLE 8

DIGESTIBLE PROTEIN AND METABOLIZABLE ENERGY CONTENTS OF COMMON RANGELAND GRASSES

Entry	Feed Description	Dry Matter %	Digestible Protein-Cattle % of D.M.	Metabolizable Energy-Cattle Mcal/kg D.M.
0213 & 0214	Aristida mutabilis, aerial part, sun cured, late vegetative	96	0.9	1.48
0485 & 0486	Cenchrus biflorus, aerial part, fresh, post ripe	98	0.1	1.77(a)

SOURCES: Arab and Middle East Tables of Feed Composition. International Feedstuffs Institute, Utah State University, Logan, Utah. 1979. Tropical Feeds. Feed Inforamtion summaries and nutritive values, F.A.O., Rome. 1981.

NOTES: (a) From Tropical Feeds. Reference 281, for Zebu cattle.

Stage II: Annual Farm Plan Without Agroforestry

Once the agroforestry peasant farm has been modeled along the lines described in the previous stage, the next step is to verify if the recommended activity levels are compatible with the pattern of cropping and livestock activities observed in the area. This process of verification has to a great extent been carried out in the original study by R. Thomas (1983) that provides most of the input-output and price coefficients for crops and livestock. Rather, we concentrate our attention here in constrasting the situation with and without the agroforestry activity.

The set of recommended operations for a farm without Leucaena can be obtained by running the farm model depicted in Table 2 through a linear programming procedure using appropriate computing algorithms. An additional consideration was to solve the above farm management problem using the limited computing capacity available in microcomputers. In this particular case the linear programming package developed for the Hewlett Packard HP-85 microcomputer with 32 kilobytes of user memory was used. That program allows the user to specify upper and lower bounds for each activity without thereby increasing the size of the coefficient matrix. Thus, the solution to the situation when no Leucaena is present can be obtained by setting zero upper bounds for LEUC-1, LEUC-2, and LEUC-3. Moreover, gardening has been fixed at .1 hectares and the herd of sheep and goats is set to 15 animal units, to reflect the average situation observed in the zone.

Table 9 presents the results for the farm without Leucaena in the first column of numbers. The optimal arrangement consists of 5.5 hectares of unmanured millet-peanut combination (UMP), and 1.2 hectares of manured millet-sorghum-cowpea-peanuts (MMSCP). Output from these two crop combinations permits the farmer to sell 802 kg of millet, 585 kg of sorghum, 68 kg of cowpeas, and 1,310 kg of peanuts. In addition, the farmer produces 1,393 kg of millet-

TABLE 9

OPERATION PLANS FOR PEASANT FARM IN NIGER

Activity	Leucaena Level			
	None	1st Year	2nd Year	3rd Year
1 UMSCP				.6
2 UMSC				
3 UMP	5.5	5.2	5.0	3.2
4 MMSCP	1.2	1.1	1.0	1.9
5 MMSC				
6 TMMSP				
7 TMMSCP				
8 GARDEN	.1	.1	.1	.1
9 SELL-M	802	754	718	1,013
10 SELL-S	585	550	524	463
11 SELL-C	68	64	61	139
12 SELL-P	1,310	1,232	1,173	988
13 SHE-GOATS	15	15	15	15
14 OXEN				
15 STEERS	3.66	3.44	3.28	5.89
16 COWS				
17 LEUC-1		1.0		
18 LEUC-2			1.0	
19 LEUC-3				1.0
20 STALKS	1,393	1,310	1,248	1,877
21 LEAVES	1,626	1,529	1,456	1,446
22 GRAZE				
Revenue (FCFA)	553,951	522,406	516,247	599,712

sorghum stalks and 1,626 kg of cowpea-peanut leaves, which are sufficient to feed 3.66 steers. These activities, together with the .1 hectare of gardening and 15 animal unit equivalent of sheep and goats, provide a gross revenue to the farmer of 553,951 FCFA per year, for a farm of 6.7 total hectares.

Stage III: Annual Farm Plans With Agroforestry

In order to introduce Leucaena in the first year, a lower bound of 1.0 hectares of LEUC-1 was imposed on the model. A new solution emerges where crop area has been reduced to 5.2 hectares of UMP and 1.1 hectares of MMSCP for a total of 6.3 hectares of cultivated land; the remaining .4 hectares is now occupied by the small Leucaena trees. As a result, the volume of millet, sorghum, cowpeas, and peantus available for the market is reduced proprotionately, as well as the amount of stalks and leaves produced, which in turn reduces steers to 3.44 head (these fractional values are of course only indicative of the direction and magnitude of shifts in the optimal solution). The final outcome of the first year of introduction of one hectare of Leucaena in this farm is a drop in farm income to 522,406 FCFA. It is worth noting that only the levels of activities were affected in this case; the type of activities remains the same.

Year two of the Leucaena tree crop brings forth an even greater decline in farm revenue to 516,247 FCFA, despite the absence of establishment or maintenance cash costs. This outcome might appear peculiar unless one recalls that as the Leucaena trees grow they occupy a larger proportion of the land, hence they displace crop production by a larger factor. Now only 6.0 hectares are cropped in total; Leucaena covers the remaining .7 hectares of the farm. Steer production has declined to only 3.28 head.

Leucaena trees are assumed to begin production in year three and continue for five years until year seven. To derive the optimal farm plan in these

years, an upper bound of 1.0 hectares is specified for LEUC-3, while keeping LEUC-1 and LEUC-2 at zero levels. The result of increased availability of forage from the Leucaena trees is a doubling of the number of steers fattened to 5.89 head. Additional manure from the new steers allow the expansion of the manured crop combination MMSCP to 1.9 hectares. By contrast, the unmanured millet-peanut fields suffer a reduction to 3.2 hectares, from 5.5 hectares when there was no Leucaena. Curiously, a new unmanured activity, UMSCP, now enters in the optimal farm plan at a modest level of .6 hectares. Cropland now occupies 5.7 hectares of the 6.7 hectare farm, since the one hectare of Leucaena now covers the ground completely. Farm revenue in years three through seven has now increased to 599,712 FCFA per year.

Several additional points merit comment. Neither work oxen nor milking cows enter into the solution, with or without Leucaena. Steers evidently offer a more rewarding use of the forage resources being available at the farm. Needless to say, animal traction fields do not appear in the solution, despite their seemingly attractive yields; the value of the additional output does not compensate for the value of the forage consumed. All land in the farm is used for either crops or for the Leucaena; none is left fallow for grazing purposes. Finally, the predominant crop combination in the solutions is unmanured millet-peanut, which does in fact correspond to the mix most often observed in the zone.

Stage IV. Present Values With and Without Trees

Figure 2 presents graphically the financial consequences for this particular peasant farm of introducing one hectare of Leucaena in its operations. Had the farmer opted to continue without Leucaena, his income would have remained unchanged for the next seven years (in the absence of variations from other sources, an admitedly untenable supposition). By introducing Leucaena,

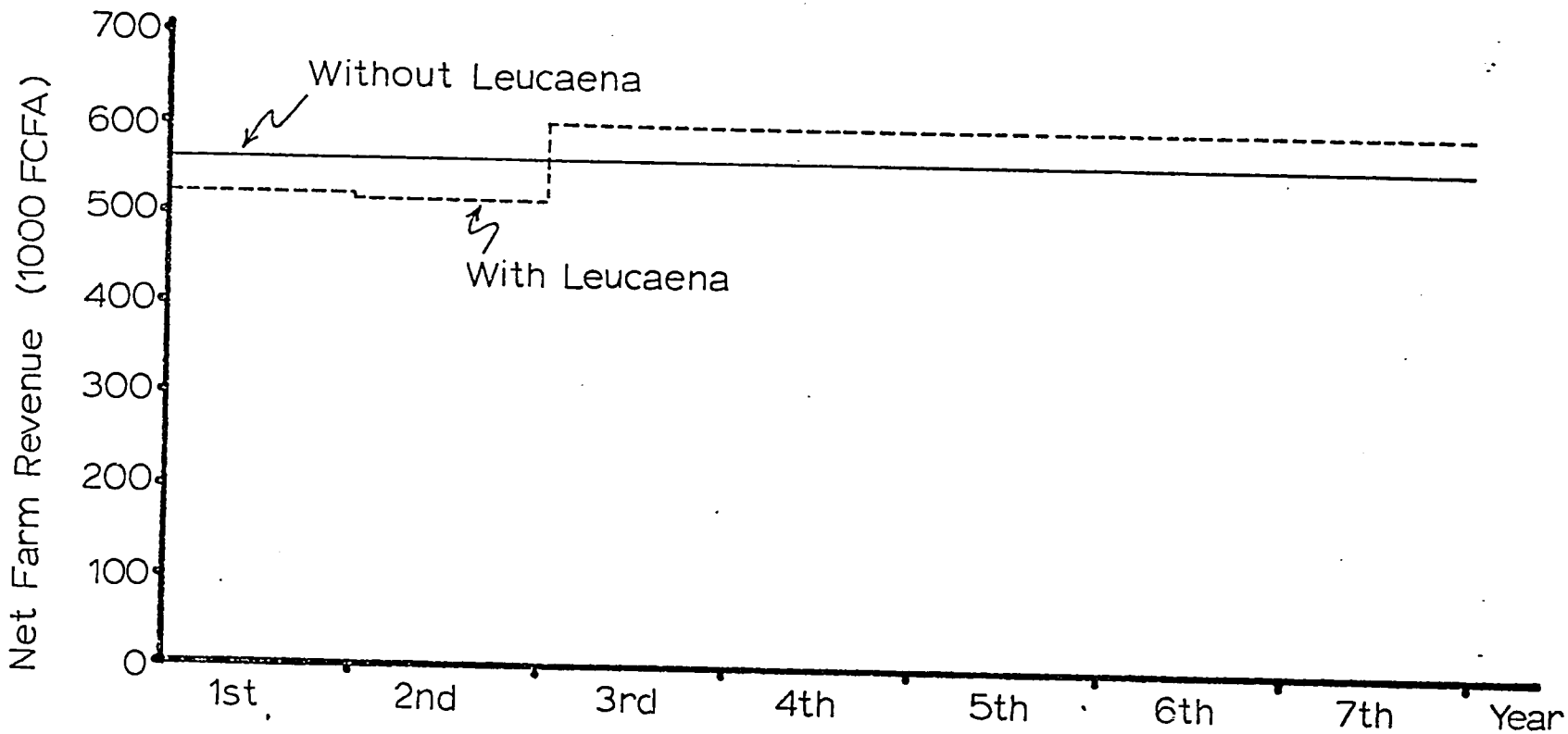
farm revenue suffers in the first year and even more in the second year, despite efforts by the farmer to reorganize the activities of the farms to minimize such an adverse income fall. On the other side, beginning in year three the farmer enjoys a considerably higher level of income. The question obviously arises: is the initial sacrifice for the first two years worth the additional revenue received subsequently?

The standard procedure to answer that question is discounting the series of annual incomes with and without the Leucaena trees, by a given discount rate, to reflect the time preference for income of the farm household. The resulting present values for the situations with and without Leucaena can be compared to arrive at an unambiguous choice for the situation with the higher present value over the period of reference.

In this hypothetical case, the introduction of one hectare of Leucaena results in a stream of income over a seven-year period of 3.058 million FCFA, when discounted at 10 percent per year. (See Table 10.) This value exceeds the present vlaue for the farm with no Leucaena, which amounts to 2.967 million FCFA over the same period. One concludes therefore that it is indeed financially worthwhile for the farmer to establish one hectare of Leucaena.

FIGURE 2

FARM REVENUE WITH AND WITHOUT LEUCAENA LEUCOCEPHALA.
PEASANT FARMER IN SOUTHERN NIGER.



Stage V: Determining How Many Trees

It is not sufficient to advise a farmer to establish a forage tree plot to complement his livestock diet. How big should that plot be is an essential part of the recommendation. A small plot may be highly profitable, while a large plot may actually reduce farm earnings. The size of the plot is critical in determining its overall profitability. This section develops a systematic procedure for arriving at an optimum plot size through a series of progressive approximations. An example using realistic whole farm data illustrates the method.

The Problem

In previous sections we have seen how a farmer will adapt the crop and livestock activities pattern to accomodate the requirements of establishing a tree crop plot. As the tree crop develops and matures, his farm operations will change accordingly to take best advantage of the resources at his disposal. The linear programming farm plan solution provides, if it is realistic, the best possible outcome for every year of the tree crop. The combination of farm plans for a series of years, keeping the tree crop at the same level, will give a sequence of best annual plans through the life of the tree crop. Discounting the revenue values in such a series by an appropriate rate, will yield the net present value of the stream of farm income over the entire period.

Thus, for any given level of the tree crop, it is possible to generate a unique net present value for the expected stream of annual farm earnings. Determining the most advantageous plot size for the tree crop, is a straight forward matter of finding the level at which the sum of net present values is maximized. This process is conceptually simple but operationally laborcous since each present value is the composite of a series of annual plans, each

of which has been generated by an optimal farm plan using the linear programming technique.

It merits emphasizing that the optimal tree crop plot size is unique for the particular conditions of the farm in question. Different combinations of resource endowments, technical options, marketing possibilities, or price schedules will result in different recommendations. There are no a priori rules of thumb to advise farmers on their level of tree plantings.

Illustration

A more-or-less realistic farm of the southern crop belt of Niger was modeled to illustrate the problem and the proposed approach. Data on crop and livestock activities were obtained from the earlier referenced study by R. Thomas (1982), and complemented with data on nutrient requirements and feed composition from standard reference tables (IFI, 1979; ARC, 1980; NRC, 1976). Hypothetical data for leucaena leucocephala was added: A substantial cost is incurred in purchasing and planting the seedlings the first year; browse production begins in the third year and continues till year seven at a constant level. Only 40 percent of the land is covered by the leucaena in the first year, 70 percent in the second, and full coverage occurs in the third. Livestock activities are limited by whatever feed is available in the farm from either crop residues, grazing land, and leucaena. Cropping activities include unmanured and manured fields, with and without animal traction, of millet, sorghum, cowpeas, and peanuts. Livestock activities include steer fattening, oxen for traction, milking cows, and sheep and goats. A total area of 6.7 hectares is available plus a small (0.1 ha) plot for intensive gardening. Labor constrains were deriyed non-binding and were therefore left out of consideration.

Approximation Procedure

Figure 1 presents graphically the sequence of results from introducing leucaena at various selected levels, by forcing the farm plan to include it in a series of eyars. This is easily accomplished by proper specification of upper and lower bounds for leucaena in the linear programming farm models for the corresponding years.

To begin, we must look at the situation of the farm without Leucaena. In such case the farm receives a constant 0.554 million FCFA per year, equivalent to 2.967 million FCFA in present value terms for the seven-year period, discounted at 10 percent per annum. Forcing a small area of Leucaeus (0.1 hectare) into the farm plan, has predictable results: farm revenue in the first year diminishes; it diminishes even further in the second year; but from the third through the seventh year farm revenue is superiod than before Leucaena was introduced. The sum of net present values for the seven-year period is now 2.976 million FCFA, a gain of nine thousand FCFA (in present value terms) for one tenth of a hectare of Leucaena. (See Table 1). From this first approximation we conclude that it pays the farmer to introduce Leucaena into his operations. But how much Leueaena remains to be determined.

As a second approximation, 3.0 hectares of Leucaena are postualted for the farm. Naturally, farm earnings in the first two years are considerably depressed, but the high earnings of the subsequent five years more than compensate for the earlier shortages. Overall, the present value of the seven-year period for 3.0 hectares of Leucaena is 3.018 million FCFA, slightly higher than for the case without Leucaena at all. In order to determine whether to increase the area of Leucaena even further we make the same exercise for 3.1 hectares of Leucaena, instead of 3.0. The new sum of net present values is now 3.010 million FCFA; in other words, increasing the area of Leucaena from 3.0 to 3.1 hectares resulted in a loss of income. We conclude

TABLE 10

FARM REVENUES AT VARIOUS LEVELS OF LEUCAENA LEUCOCEPHALA, AND THEIR PRESENT VALUE EQUIVALENTS[a]

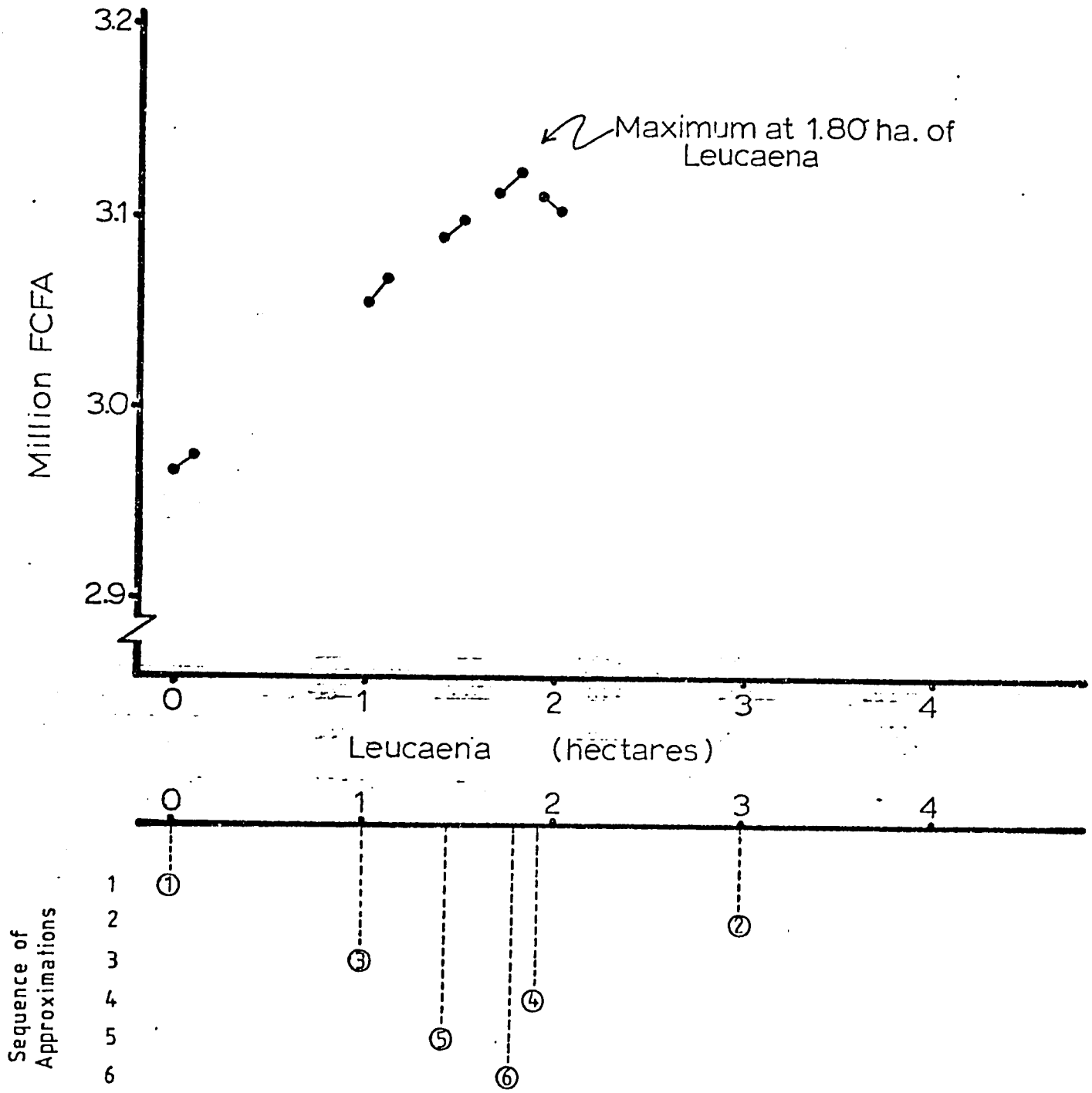
(million FCFA)

Year	Leucaena (hectares)					
	0.0	0.1	3.0	3.1	1.0	1.1
1	.554	.551	.459	.456	.522	.519
2	.554	.550	.441	.437	.516	.512
3	.554	.559	.626	.626	.600	.604
4	.554	.559	.626	.626	.600	.604
5	.554	.559	.626	.626	.600	.604
6	.554	.559	.626	.626	.600	.604
7	.554	.559	.626	.626	.600	.604
NPV	2.967	2.976	3.018	3.010	3.058	3.066

Year	Leucaena (hectares)					
	1.9	2.0	1.4	1.5	1.8	1.7
1	.494	.481	.510	.507	.497	.500
2	.482	.479	.501	.497	.486	.490
3	.633	.632	.617	.621	.634	.629
4	.633	.632	.617	.621	.634	.629
5	.633	.632	.617	.621	.634	.629
6	.633	.632	.617	.621	.634	.629
7	.633	.632	.617	.621	.634	.629
NPV	3.114	3.105	3.090	3.098	3.123	3.114

NOTES: (a) Sum of net present values computed for seven years at 10 percent discount rate.

FIGURE 3. SUM OF NET PRESENT VALUES OF FARM REVENUE AT VARIOUS LEVELS OF LEUCAENA, DURING SEVEN YEARS, DISCOUNTED AT 10% P.A.
(million FCFA)



that if the farmer must reduce the area in Leucaena his earnings will increase. Somewhere between zero and three hectares of Leucaena the farmer will realize maximum earnings.

The procedure continues in this iterative fashion. Next try is done at 1.0 and 1.1 hectares, and since revenue gets higher we increase the Leucaena area. Between 1.9 and 2.0 hectares the sum of present values diminishes; therefore the area must be reduced. Next we try 1.4 and 1.5 hectares and conclude that the optimal level must be higher. Finally, we reach the level of 1.8 hectares; any movement above or below which will reduce the present value of the seven-year earnings. We conclude that earnings are maximized at 1.8 hectares planted to Leucaena.

Conclusions

It is possible to determine the most advantageous area to be planted to a perennial tree crop for a particular set of farm conditions, through a process of successive approximations. The procedure uses the results of a linear programming farm model to generate optimum farm plans for each year, with their corresponding levels of earnings. The discounted sum of these annual revenues is the key criterion in deciding when to increase or reduce the area under the tree crop. The range of values containing the best level is progressively narrowed down, until a reasonable level of precision is reached.

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