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Agroforestry options for Ghana - Land use planning with integrated bio-physical and multiple objective models. Part 2.

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6 Economic Evaluation of Agroforestry Interventions[1]

The Agroforestry unit (AFU) of the ministry of food and agriculture in Ghana has collated experimental and socio-economic economic data and reduced it to a uniform set of budget information on both traditional food crops and Agroforestry practices. The comparative performance of this set of alternative systems of land use was evaluated using "incremental cost benefit analysis". Changes in costs and benefits over the lifetime of an investment are compared with a basic costs and benefits from traditional land use practices. Regrettably this evaluation was done at a real discount rate of twenty percent. Whilst this may have been a treasury rule for appraising public expenditure it is not satisfactory from the stand point of would be adopters of Agroforestry practices (WBA).

We will demonstrate that the accounting practice was not sufficiently refined from the standpoint of the WBA. A twenty percent real discount rate leads to erroneous conclusions and does not properly represent the time preference of small scale farmers.

The most damaging result was that the analysis **as read** showed that Agroforestry interventions will not be adopted by small holder farmers for the reason of **poor financial performance** and therefore needed financial incentives (public subsidy) to promote adoption and achieve environmental benefits.

On the contrary, interpreted properly the same data shows that **Agroforestry systems** have superior financial performance over traditional bush fallow emphasising the urgent need for Agroforestry intervention. Without the detail contained in systems models financial appraisal can not explain non adoption by West African Farmers. The systems models developed in the following chapter reveal sufficient reasons for non adoption which are certainly not rooted in poor financial performance expressed by NPV or B/C.

6.1 Accounting Practice

A unit of account has to be adopted to conduct a comparative systems analysis. Because of the unstable market values and rampant inflation three equally plausible approaches to valuation are used by economists.:-
A) National average prices for each year corrected for inflation.
B) Constant prices using base year relative values.
C) Constant prices using final year relative values.

The future course of inflation can not be predicted [2]. Base year relative values are chosen because price series are difficult to obtain and the final year is well into the future with most woody species i.e. not available at the time of analysis.

6.2 Financial performance measures

There are four common financial performance measures using discounted[3] cash flow techniques to appraise Agroforestry practice. Discounting is essential to enable the comparison between systems to be made at the same point in time. Net present value of the user net benefit stream would appear to be the logical guide to system choice.

1). Net Present Value (NPV): -places a capital value on the expected lifetime performance of an investment. Defined as the sum of discounted Benefits minus the sum of discounted Costs and identical

[1] Intervention is defined to be a publicly funded subsidy targeted to induce a change in farming practice which will benefit society in general.
[2] The fall in the world price of oil is ample testament to this fact.
[3] Discounting:- a procedure to convert the value of a sum of money expected at some future date (year = t) to an equivalent present value (year = 0) generally the procedure weights the present and near future more heavily than the distant future. At high discount rates the distant future has little or no weight.

with the sum of the discounted **net benefit stream**. The criterion for making the investment is :- NPV>0. In a comparison of resource productivity the system maximizing net present value of the resource base to the users would be a suitable criterion.

2). Benefit Cost Ratio(B/C): -An efficiency measure using a ratio rather than a difference expressed as the sum of discounted benefit divided by the sum of discounted costs. The criterion B/C>1 is the same as NPV>0 and could serve equally well as a criterion.

3). Equivalent Annual Income (EAI) or (Annuity): - used to compare perennial crops with annual cropping systems. The ranking based on the magnitude of the annuity should also correspond to NPV. $EAI=NPV[r(1+r)^n] / [(1+r)^n-1]$ where r is the real discount rate and n the cycle length of the system. An implicit assumption is that a similar project could be refinanced at the terminal date and render the same performance so that the equivalent annual income stream could be maintained in perpetuity.

4). Internal Rate of Return (IRR):- a measure of efficiency in the utilisation of capital by the system. Defined as that rate of discount which will make the NPV=0 or B/C=1. The criterion is to proceed if the IRR exceeds the market rate of interest and the associated risks are acceptable. A sign change in the net benefit stream is required in order to produce a result.

6.3 Computability of the IRR

There is no simple algebraic expression for the IRR it is generally found by iterative or graphical procedures. The measure computes easily when investments are front loaded in cost and there is only one sign change in the benefit stream. The measure has the problem of interpreting multiple roots when there is more than one change of sign.

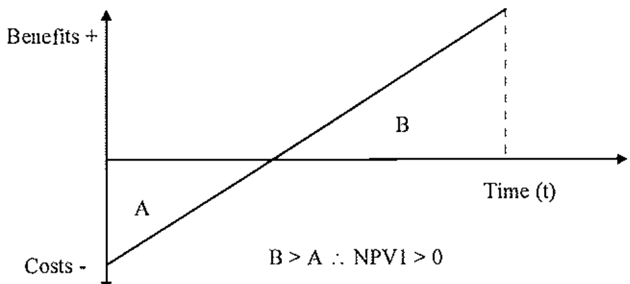

Figure 26: Conventional Cash Flow - front loaded costs.

Annual time steps are not fine enough for farming systems comparisons. A sustainable system with positive net benefits in all annual accounting periods i.e. no sign change in the net benefit stream has a finite positive NPV but no IRR. The accounting has to be practiced on a time step less than annual in order to express the time interval between investment and reward.

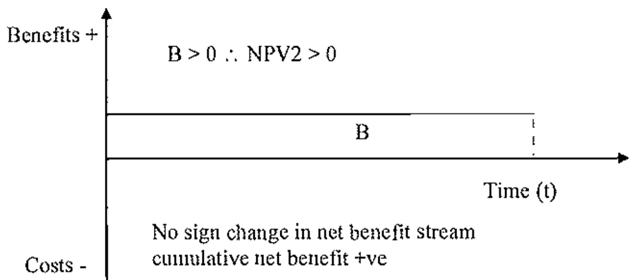

Figure 27: Traditional Cropping system with sustainable net output.

A traditional system with annual net benefits under persistent environmental degradation with a predicted sign change from positive to negative in the net benefit stream may have the property of increasing NPV with increasing discount rate. In practice such a system would be abandoned long before a negative cash flow.

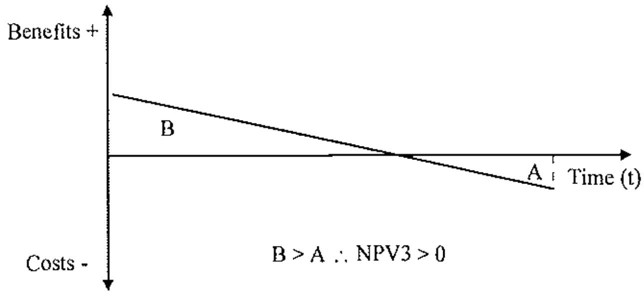

Figure 28: Unsustainable traditional cropping system with long term decline in yield.

The value of the cumulative discounted net benefit stream from year 0 to the terminal year t is the net present value. How heavily we discount the future is crucial to investment decisions we make. Using zero discount rate will not express the obvious time preference of decision makers, too high a value undervalues future benefits of environmental improvement or future restoration costs.

Figure 29 shows that NPV1 from figure 26 will discount to zero with IRR= 15%. What is disturbing is the fact that the NPV 3 for unsustainable farming practice increases with increasing discount rate and out performs sustainable farming systems at real discount rates around five percent.

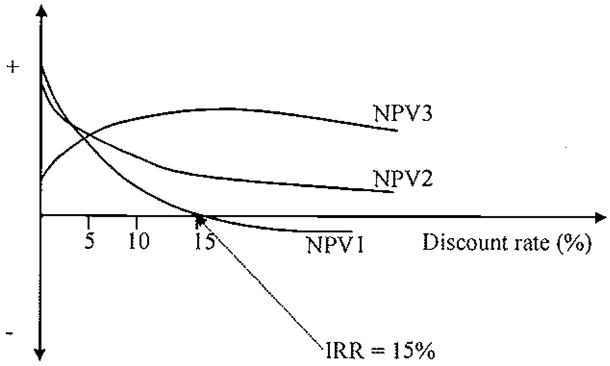

Figure 29: Discounting NPV.

We are able to dismiss IRR as not a suitable criterion for annual data on the grounds that it may not exist for crucial comparisons to be made. The criteria that we can use are all highly sensitive to the choice of discount rate.

Net present value and benefit cost ratio and equivalent annual value can function in the circumstances

The **real social discount rate** for most countries is of the order of two to three percent and five percent real discount serves as an upper limit.[4]

Although it is a common procedure for extension evaluations is to look at the financial performance of incremental input required by a new technology and to charge as an opportunity cost the output lost from the displaced traditional technology. Some skill is to required to decide upon the appropriate definition of traditional technology displaced.

Financial appraisal procedures are appropriate to Governments and large scale Plantation Owners (state, corporate or private) choosing between alternative investments. Arguably the government can adopt a uniform social discount rate to decide which interventions should be funded. The Plantation owners may be concerned with efficiency in the utilisation of capital. The answer as to which is the appropriate criterion depends on circumstances according to C.J.Price[5] who also concedes that linear programming is necessary to resolve complex decision problems.

The argument in favour of these financial performance measures is that they designed to take care of the time distribution of inputs and outputs by using the **annual discounted cash flow** approach. The problem with their use as comparative system performance measure is that they may give the wrong ranking from the standpoint of the **(WBA)** if the annual time step is too long and the differentiation between purchased inputs requiring currency units and family labour inputs which do not is unrecognised.

6.4 Choice of Comparator Systems

Experimental protocol requires the testing of control plots alongside treated plots, the analogy in systems analysis is that we require comparator systems to judge whether or not Agroforestry practices can deliver real improvement over some benchmark or comparator system.

Verbal reports and Field experimental data shows that site productivity yield per unit area and consequently yield per labour hour is falling with time. Soil losses are also continue at some average annual percentage rate under traditional practice compared with the stabilising effects on yield and reduction in soil loss, deriving from Agroforestry practices. Agroforestry also provides a flow of utilisable biomass for mulch, fodder and fuel often with a bonus of edible and marketable fruit.

Comparator systems used in the internal reports are generally continuous mono cropping of a staple food crop considered to be relevant to the particular agroecological zone. Such a control fails in its purpose when it does not properly represent relevant local practice. Indeed the argument for a good control may be best local practice. If it can be shown that an intervention has significant and persistent gains over best local practice then the intervention has a good chance of spontaneous local adoption.

[4] Sharma et al made a detailed analysis with regard to social Forestry in India J. Ag. Econ. 42(1) 1991
[5] Price C.J (1989)P202 *Forest Economics*

The traditional system of shifting cultivation mines fertility by successive cropping without adequate fertilisation. The natural capital value embodied in soil fertility is then restored by a long fallow. Such a system is sustainable in the long run (50-100 years) provided that the regenerative fallow is of sufficient duration which implies an upper limit to food crop intensity and carrying capacity in the system as a whole.

Financial models being applied in the Agroforestry Unit in 1996 account for the annual percentage loss in yield in the benefit stream but do not charge for this depreciation of the fertility status of the soil. This accounting practice arises presumably because natural regeneration takes place at zero input cost to the cultivators and alternative hectares are available at no cost to the cultivator other than the initial land clearance which is charged as a cost. Such a system of accounting would be appropriate if there were an infinite reservoir of land to provide replacement plots as and when required. The minimum period for full restoration of fertility varies by soil type and agroclimatic zone (i.e. is site specific) and seems to vary between ten and twenty five years.

A system comparison including bush fallow technologies must take into account the fallowing process and include both the cropped area and the area under fallow. A soil nutrient balance model accounting for NPK would go some way towards solving the problem of accounting for fertility loss and there is a market in NPK to establish a valuation.

Economic theory suggests that the value of a capital asset is measurable through the income stream which it generates. The first tenet of accounting practice is that the value of capital must be maintained constant, in other words the rule of 'weak sustainability'[6] must be applied. The **NPV** of any sustainable yield level can serve as a benchmark valuation. Systems could be compared on the **NPV** generated from sustainable use. Unfortunately few of the current systems of land use are demonstrating long term sustainability. The **NPV** of a rotation under a **sustainability rule** can repeat in perpetuity. The **NPV** under secular decline does not appear on the surface to repeat indefinitely and consequently is deficient as a measure of asset value unless depreciation can be charged..

In examining the comparative analysis applied in working papers of the Agroforestry Unit, the information on the control or baseline performance of traditional farming systems is insufficient for the purpose intended and this was reported to be general throughout Agroforestry research institutions in Africa.[7]

6.5 System information

The budget information base provided for systems comparisons is reduced to a statement of the following categories on a per hectare basis :-
(1) initial cost (land clearance in bush fallow)
(2) recurrent input cost (seed, fertiliser, sacks and hand tools)
(3) net output [calculated as the monetary value of harvested yield (kg)x(unit value) adjusted for losses and costs associated with harvesting, processing, and marketing.]

Labour time is charged at constant rates in all cases according to age and gender whether or not it is hired or family.

[6] Weak sustainability in environmental accounting allows man made capital to compensate for loss of natural capital. Hence charging depreciation for loss in fertility is necessary accounting practice.
[7] Bayliss Smith et al (1993) Final Report p28 R4592 (OFI-FRP), EMC X-0175 (NRI).

Table 16: Summary Data on Traditional Bush Fallow Constant 1991 Prices.

Forest	yield losses	2 crops p.a.	years	unit	cd/ha
B1.Maize	50% intensity	initial inv	1	ha	(12,000)
sequential	9.1%	recurrent	1:10	ha	(82,000)
long term	6.7%	net output	1:10	ha	186,912
Transition	yield losses	2 crops p.a.	years	unit	cd/ha
B2.Maize	50% intensity	initial inv	1	ha	(7,500)
sequential	8.2%	recurrent	1:10	ha	(71,500)
long term	6.7%	net output	1:10	ha	129,408
Savannah	yield losses	1 crop p.a.	years	unit	cd/ha
B3Sorghum & millet mixture	50% intensity	initial inv	1	ha	(4,000)
sequential[8]	7.9%	recurrent	1:10	ha	(30,500)
long term[9]	6.5%	net outputs	1:10	ha	74,090

The projected financial consequences of long term productivity decline arising from annual percentage losses in sequential crop yields are captured by expressing net output as a function of yield per hectare. These annual percentage losses in yield implicitly value loss of soil and soil fertility.

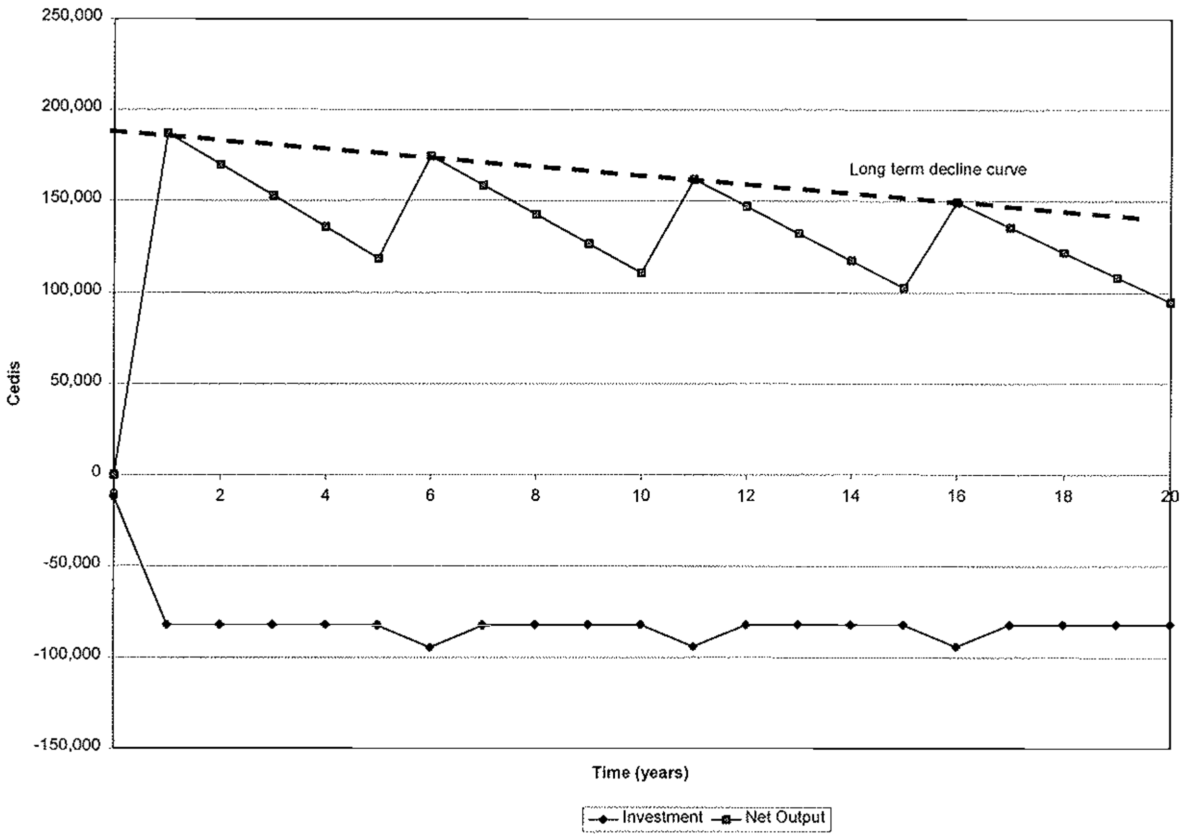

Figure 30: Time-series of forest maize.

The long term loss reflects the productivity gap on a 5 year fallow cycle. An arbitrary cut off of either ten or twenty years was applied to the budget data depending on the nature of the crop. Traditional food crops B1-B3 are budgeted over ten years of successive cropping. Budgets are constructed at 100% intensity and then multiplied by cropping intensity to express the performance per hectare of system as operated.

8 annual soil loss plus annual fertility loss

9 productivity gap between cycles

Table 17: Summary Data on New Agroforestry practices Constant 1991 Prices.

Forest		years	cd/ha
B5 Hedgerow	Initial investment	1	(190,000)
associated crop long term loss	Recurrent inputs	2:10	(29,250)
-net eventual stability	Net Outputs	4:10	40,495
Savannah		years	cd/ha
B6Farm trees	Initial investment	1	(8,000)
associated crop long term loss	Recurrent inputs	1:3	(16,500)
1.9%	net outputs	11:20	88,760
B7 Fodder bank		years	cd/ha
	Initial Investment	1	180,000
associated crop long term loss	Recurrent inputs	1:10	10,000
1.9%	net outputs	4:10	83,865
Transition		years	cd/ha
B8 woody fallow	Initial investment	1&6	(185,000)
associated food crop long term loss	Recurrent inputs	1:10	(12,000)
1.9%	Net outputs	5&10	662,475
Savannah		years	cd/ha
B9 Cashew fully stocked	Initial investment	1	(32,000)
associated food crop long term loss	Recurrent inputs	1:4	(39,000)
1.9%	Net outputs	5:20	69,000

Hedgerows B5, Fodder Banks B7 and improved Woody Fallow B8 are also budgeted over 10 years. Farm trees B6 and Orchard trees B9 are budgeted over twenty years without consideration of optimal rotation length. Net outputs are presented as a stream of annual values dating from the time when they first come on stream thus neglecting surge, senescence and the issue of optimal rotation lengths in woody species.

A budget for yams was presented in the original study. Since yams are grown on a fresh site every year, this information can only be used for comparison with the first year performance of some composite system growing yams in year one and, thus, are not included in this study. Livestaking of yams has potential for tree crop establishment like taungya.

6.6 Choice of Discount Rate

The use of monetary units creates a problem for analysts in the context of rampant inflation. The method we recommend of using constant relative values (i.e. **real values**) abstracts the argument of system performance from the inflationary context. The use of base year relatives in currency units, grain equivalent units or energy units will result in the same ranking. The use of 1991 base year pricing also means that there is a one to one correspondence between physical and financial performance.

The use of constant (**real**) values for a projected stream of costs and benefits requires a **real discount rate** to express the time preference of the **WBA**. The difference between real rates and money rates is explained below. The existence of an institutionally declared **treasury discount rate** does not absolve the analyst from the task of choosing a proper rate of discount. Those who account for public expenditure will be required to look at incremental cost benefit relating to the use of public funds. The systems under performance testing are using mainly private resources of family labour and own land. The procedure adopted has to evaluate land use practices from the point of view of the **WBA** using own private resources and then determine whether or not intervention is justified to induce changes in the behaviour of the adopters.

6.7 Financial measures of system performance

The use of a high real discount rate of twenty percent in the AFU evaluation of Agroforestry interventions may have been imposed to reflect the opportunity cost of capital or shortage of public funds for intervention. This does not satisfactorily deal with the problem of capital shortage and leads to erroneous conclusions regarding the relative merits of interventions.

The existence of high money rates of interest in periods of high inflation is only to be expected. Real rates of interest may even be negative for short periods. There is a normal expected relationship between positive money rate of interest (m) and a positive real rate of interest (r) for any given rate of inflation (i), when conditions are less volatile[10].

It is expected that the **real rate of interest** be closely associated but not necessarily identical with the **rate of time preference** of society at large in an equilibrium situation. Equilibrium here is envisaged to mean a dynamic equilibrium in the sense that people adapt to the rate of inflation they live with. Individual **WBA's** may have different time preference rates varying around the social rate of time preference. Time preference legitimately expresses the opportunity cost of capital in that present money can be invested now until a future date and earn a rate of return based upon the average long term real rate of return on capital . Those who have studied the subject of long term rates of return find that they are inevitably less than five percent. For those without alternative investment opportunities personal reflection on mortality inevitably weights the present more than the future.

6.8 Real cash constraints

Lack of currency as a means of payment does not necessarily imply a high rate of time preference. The timing of receipt and delivery of physical goods may well differ from dates of settlement in cash. The modelling of cash flow should become a significant component in the design of the farming system when the means of payment is a physical constraint. People can and do resort to barter if shortage of cash is severe.

Models of cash flow must be expressed on a finer time step than one year (e.g. monthly) for small scale household decision making subject to seasonal fluctuations. A physical constraint for cash carrying forward unspent balances is a useful planning tool. The physical constraint can then be relaxed by the farmers informal or formal credit arrangements regarding settlement dates made well in advance of the event. Better credit terms can always be obtained by prior negotiation. The strictures of a cash constraint in a linear programming model will provide vital evidence of the marginal value productivity of money internal to the farm business. The existence of off farm investment opportunities can take care of the opportunity cost outside the business. The marginal value productivity of cash will in turn influence a potential borrowers attitude towards risk bearing. The amount one may be prepared to borrow is necessarily a multiple objective problem.

6.9 Other Criteria for System selection

Financial performance criteria are one dimensional, based on the present value of income expected in the future. The reduction of a future sum of money to its mathematical expectation (arithmetic mean value) requires the **WBA** to be risk indifferent. From what we know of traditional small scale producers their behaviour is likely to be both risk averse and satisficing. This requires a model of the risk return trade off and additional constraints or a procedure like lexicographic[11] goal programming to express satisficing behaviour.[12]

Comparisons of value productivity per hectare derive from a presumption that land is the limiting factor. All factors may be limiting but some are more limiting than others. In traditional hand labour technologies it is more likely that human labour is seasonally the most limiting factor.

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[10] $(1+r)(1+i)=(1+m)$ hence $r=[(1+m)/(1+i)]-1$ This requires a rational normality of $m>i$ for positive r.

[11] Lexicographic signifies an order of priorities in the pursuit of goals which can be associated with the lexicon or alphabet A before B before C etc.

[12] A term coined by management scientist Herbert Simon. Satisficing implies that the decision maker wishes to attain a preset goal or target performance level which is consistent with the pursuit of other goals simultaneously. This contrasts sharply with maximization of a single i.e. one dimensional objective like profit.

In comparisons of farm system performance from the **standpoint of adopters**, Twumasi Ankrah used partial efficiency indicators in the use of land, labour and working capital on the basis that these are more relevant and easily understood and the would be adopter can select his or her own criteria from a set of partial efficiency measures.

6.9.1 Partial efficiency measures of system performance

1) net cedis income per hectare
2) net cedis income per man day
3) net cedis income per cedis spent on variable capital inputs
4) labour efficiency in food production expressed as KGs maize/man day

The main difficulty with this approach is identifying which is the most relevant criterion in what circumstances? The decision maker has to know **a priori** which is the most limiting factor and when it is appropriate. This is precisely the information which the decision support analyst can derive from the output of a linear programming model.

All four of the above criteria ignore the question of **risk and preferences** of the farmers and their future expectations. History is not necessarily the best guide to the future when planning under uncertainty. In the selection of a smallholder investment portfolio for labour and working capital, safety first and/or a risk return trade off based on **robust systems models** provides a viable and more realistic methodology for decision support. The system solution ensures that the enterprises dovetail together in a mutually supporting set of interactions. Decision making in the real world is inevitably based on multiple criteria and there is scope to develop PRA dialogue with farmers and their advisors to fine tune the preference weighting in such decision support models.

6.10 Tastes Preferences and Property rights.

There may be reasons outside the scope of financial analysis why intervention may fail to be adopted. This is where issues of security, tastes and preferences must be taken over in a multicriterion approach. For example in food security and property rights issues. Food security may require that the household provide for subsistence in case the market is too volatile to rely upon for purchases of staple foods. This can be built into a system model in different ways. Insecure property rights may limit investment in woody species bearing in mind that a property right is only as secure as is the duty of all others to recognise that right.

The property rights system has to evolve and guarantee that investors in Agroforestry interventions and their heirs and successors individually or collectively, have secure rights to the eventual benefit stream. The choice of fruit /nut trees in cropping land stems not from a dietary imperative but recognised individual usufruct rights in planted fruit trees. Investors choose to sell rather than eat and the financial reward may be less than that from timber species. Reluctance to invest in timber species with superior financial performance can be explain where property rights in indigenous timber species are less secure and may have been alienated by previous government grants of timber concessions without formal restoration. Expropriation of indigenous cultivators property rights remains unfinished business over most of the tropical zones of the earth and is a major contributory factor to bad land management.

6.11 Bush Fallow Rotation and Sustainability Requirements

Under the specific Ghanaian examples there are long term productivity declines without fertiliser. The productive potential exhausted by **m** years of the cropping sequence is not fully recovered in the **n** years fallow period. Instead of practicing alternate husbandry on the cropped area and the fallow operational efficiency dictates that farmers cultivate **m** plots one in each year of the cropping cycle clearing the minimum area of bush each year. This limits the amount of the initial investment , evens the flow of income and spatially distributes the risk. The initial land clearance is a significant item in the forest zone budget but diminishes with the climatic effects on regeneration. Savanna zone clearance costs are only one third of forest zone costs due to lower wage rates and a fifty per cent reduction in labour requirements. Shorter fallows result in reduced clearance costs. There are two routes to sustainability one is to reduce the cropping intensity and maintain regular short cycles with slightly longer fallows the other is to let the land degenerate under short cycles and then abandon to a long fallow for recovery. Either way the system can work effectively. Stability under short cycles is preferable in NPV terms.

Let the rate of productivity decline in sequential cropping be of the order of **X%** p.a. The fertility gain under fallow currently leaves a productivity gap **G %** at the commencement of the next cycle. Let the gap divided by the years in fallow be
Z% p.a. = G%/ n. This implies that the regenerative power of the fallow is
Y% p.a. = X% p.a.-Z% p.a.

Sustainability requires that length of the fallow has to be arranged such that:-
n Y> m X <u>or</u> n/m> X/Y

Sustainability requires:-
n/(p-n)>X/Y

The cycle period is **p = n+m.** Let the proportion of land under fallow be **F** and the proportion under food crops be **C** . Sustainability translates into the idea that the proportion of land under fallow treatment **F** must exceed the proportion under food crops **C** whenever **Y<X.** The cropping intensity rule for sustainability can be written :-

C< Y/(X+Y)

6.11.1 Example from the forest zone in Ghana

SEQUENTIAL YIELD LOSS X=9.1% p.a.
REGENERATIVE GAP G=6.7%
years in fallow n=5
productivity gap Z=6.7/5 = 1.34% p.a.
regenerative power of fallow Y= X-Z = 7.76%
Critical cropping intensity C=Y/(X+Y) = 0.4602

For any given sequential **rate of loss X** and **regenerative gap G** which has occurred as in the above ten year rotation, there is a reduction in cropping intensity which can theoretically compensate.

Table 18: Forest Maize SUSTAINABLE ROTATIONS C<0.4602

crop years m	fallow years n	rotation years p	land value lower 000 cedis	land value upper 000 cedis	Cropping intensity C
2	3	5	723	1351	0.40
<u>4</u>	<u>5</u>	<u>9</u>	<u>679</u>	<u>1350</u>	<u>0.44</u>
5	*5*	*10*	*351*	*1004**	*0.50**
5	6	11	623	1303	0.45

* The 10 year rotation is unsustainable on present evidence.

Correcting for unsustainability 351K lower value is reduced to 337K on an irregular cycle of eighty years (6x5 crop years 5x5 short fallow 1x25 long fallow, cropping intensity 0.375) This difference emerges because there is no value attributable to fallow other than that captured through food crops.

6.12 Land Use Value under sustainable use with short fallows

The sustainable annuity of figure 27 derives from a regular cycle with cropping intensity below the critical value. Let y_0 be the initial yield level , the sequential drop in yield $\Delta = y_0x$ where **x=X%/100**. The four years (m) sequential crop yields form a series $y_0 + (y_0 - \Delta) + (y_0 - 2\Delta) + (y_0 - 3\Delta)$. Substituting y_0x for Δ, the average yield over m cropped hectares is y_0 **(1-3x/2)**. The average yield over the **m+n** cropped hectares over the full cyle is **C** y_0 **(1-3x/2)** giving rise to an annuity.

On full cost recovery a capital value is placed on the cultivation rights

PV=C [P_n y_0(1-3x/2)-R]/r

Where P_n is the net revenue per kg of harvested yield, **R** is the required cost recovery rate for recurrent annual input cost and initial investment and **r** the real discount rate.

The Recurrent input cost includes a significant family labour element. If we reduce cost recovery to purchased inputs only (Π) the capital value of cultivation rights would rise to **C [P_n y_0(1-3x/2)-Π]/r.** [13]

6.13 Land Value under short / medium term unsustainable land use

The Capital value of cultivation rights under short/medium term unsustainable practice is slightly more cumbersome to evaluate. The same process are involved but instead of a perpetual annuity we have a declining annuity series because of the yield gap **G%** recurring at the end of each cycle. Cultivation will be abandoned into a **long fallow** when recurrent costs can not be recovered by a sufficient margin.

This represents a practical limit to the extent of mining fertility. One must emphasise that the system is sustainable in the long run but the next long cycle is beyond the remaining life span of most adults. Irregular cycling patterns can emerge for a host of different reasons. Indeed the use of the long fallow for tree crops lies at the heart of good agroforestry practice. There are good alternatives to natural regeneration in the long fallow and current evaluation of traditional practice ignores food from the wild and the products of long fallows under natural regeneration.

Using the **m*=5** , **n*=5** under decline the following pattern emerges with a cropping intensity of **0.5** in the short fallows.

Table 19: diminishing annuities .

series	avge yield over five years	equivalent annuity	years	year of NPV
1	y_0 (1-2x)	P_n y_0 (1-2x)-R	1-5	0
2	y_0 (1-g-2x)	P_n y_0 (1-g-2x)-R	6-10	5
3	y_0 (1-2g- 2x)	P_n y_0 (1-2g-2x)-R	11-15	10
4	y_0 (1-3g-2x)	P_n y_0 (1-3g-2x)-R	16-20	15
5	y_0 (1-4g-2x)	P_n y_0 (1-4g-2x)-R	21-25	20
6	y_0 (1-5g-2x)	P_n y_0 (1-5g-2x)-R	26-30	25

The equivalent annuities for the five sequentially cropped years are based on net revenue from average yields less recurrent input costs. Whilst the annuity remains positive and **R** is recovered by an acceptable margin, each series has a positive **NPV** at the onset of each series, calculated by rearranging the annuity formula 3. The NPV's for each series is then discounted back to a common origin at time zero and summed. The question then is how do we interpret the collective **NPV** for the period of short fallows upto economic exhaustion of staple food cropping potential? Do we charge for the run down of fertility or increase the period of evaluation? The addition of a long fallow makes a long irregular cycle in the pattern of land use which is then sustainable. Increasing the period with no cost and no benefit will not affect the magnitude of the discounted cash flow computed at 100% intensity. The effect of including the long fallow is to reduce cropping intensity and derive estimates of sustainable **NPV per hectare** and the effective carrying capacity of the system.

[13] The present value of a perpetual annuity A is A/r where r is the discount rate since the discount factors form a geometric progression θ $[1+\theta+\theta^2+\theta^3+.....\theta^{n-1}]$with common ratio $\theta = 1/(1+r)$ and for any positive r, $0<\theta<1$ hence the bracketed series converges to a finite sum $1/(1-\theta)$ and $\theta/(1-\theta)$ reduces to 1/r.

Table 20: short cycle and long cycle sustainable values.

system m=5 n=6	sequential loss X%	productivity gap G%	critical C to sustain	short cycle value 000	Long cycle years 5[(2q-1)+5]	Long cycle value 000	**C long cycle**
forest maize	9.1	6.7	0.46	623	80 m=5 n=5 q=6	337	0.37
transition maize	8.2	6.5	0.46	320	70 m=5 n=5 q=5	135	0.35
savanna sorghum/ millet	7.9	6.5	0.46	283	90 m=5 n=5 q=7	180	0.39

q is the number of cropping cycles before abandonment to a long fallow

The object lesson is that **NPV** can be computed for alternative land use practices including apparent degradation in irregular patterns of use but it must be done on a sustainable basis. The key elements in the value of natural capital being held constant. In a food and energy system this amounts to use value measures on a sustainable yield basis.

On the performance indicated above the observed tendency to shorter cropping sequence, shorter fallows and larger plot size is a rational response on the part of farmers. The shorter the crop years **m** the smaller the number of plots compensated by increase in average size where land is abundant relative to labour. The impact of shorter fallows is a change in vegetation type. Woody trees give way to perennial shrubs which are likely to be shallow rooted with implications for fertility restoration but providing an immediate benefit in reduced labour input for land clearance.

Objective data[14] on the **sensitivity of degradation rates**[15] **X** and **fertility restoration rates Y** to changes in rotation length is not immediately available although subjective participatory techniques may lead to adequate site specific judgement. Alternatively models of soil and water and nutrient processes under fallowing regimes are required to complement the current models of soil, tree and crop interactions e.g. WaNuLCAS [16]to facilitate simulation of restoration of fertility. Although existing models like the Century model developed at the University of Colorado may be well suited to studying fallows, research workers tend to focus on rangelands or tree /food crop interactions. It is difficult to get precise estimates of **X** and **Y** because of random disturbances above ground and the multitude of interacting processes below ground.

6.14 Performance Standards and the Adoptability of Interventions.

Spontaneous adoptabiliy of any innovation is critically dependent on the ability of farmers to cash in on a superior economic performance. **CIMMYT (1988)** places the required rate of return in the range **(50-100)%**. The upper end of the range is required for entirely new technologies.

One must pause for reflection on what is meant by rate of return in this context There is a world of difference between a **B/ C** ratio in the range of **(1.5-2 .0)** and an **IRR** in the range **(50%-100%)**. The case for **B/C** ratios of this order of magnitude is well understood. The requirement of an **IRR** of **50%-100%** frankly is not achievable in any open competitive process except in the short term.

The **CIMMYT** methodology specifically looks at the marginal rate of return **MRR** which is the ratio of incremental net benefit **(ΔB - ΔC)** to incremental cost of purchased inputs ΔC like new a new maize variety and or fertiliser . In this context the calculation is :- **(ΔB - ΔC) / ΔC = (ΔB/ΔC) -1**

[14] experimental measurement as distinct from model output

[15] Analysis of experimental yield data provides the rate of change in yield loss under sequential cropping by site and crop.

[16] The WaNuLCAS model is being used by Wye and ICRAF Indonesia to study below ground tree crop interactions Maize/Peltophorum hedgerow intercrop

6.15 Financial performance of tree/crop interactions

1. **80:20 crop/ hedgerow** The combination is fixed and calculated as a weighted average of NPV's at 80% and 20% intensity. There is the question of **interaction between trees and crops** which influences the rate of loss of fertility and consequently yield and net output. Similarly there may also be significant effects on soil loss so it is impossible to infer what the performance of any other crop-hedgerow interaction would be from this data.

Kang (1985)reported that Maize/Leuceana alley crop yields stabilised at 2t/ha Maize lower than originally expected but demonstrates that long term sustainable yields without fertiliser can be achieved.

Fertilisers at full rate in the first year and half rate for five years in Forest Zone Maize /Leucana alley cropping experiments reported by the AFU may well be the appropriate technique for rehabilitating nutrient depleted soils. A period of six years would appear to be necessary to stabilise yields.

Table 21: The effect of discount rate on economic performance measures.

system (intensity)	NPV@5%	NPV@20%
*forest maize (100)	715.8E3	327.4
forest hedgerow (100)	-132.3E3	-196.2
crop/hedge (80:20)	1.1E6	296.4E3
system (intensity)	B/C@5%	**B/C@20%**
*forest maize (100)	1.68	**1.78**
forest hedgerow (100)	0.75	**0.36**
crop/hedge (80:20)	1.72	**1.41**

*Forest maize without fertilizer is only sustainable at cropping intensities below 46% which reduces NPV and equivalent annual value pro rata but leaves B/C ratio unchanged.

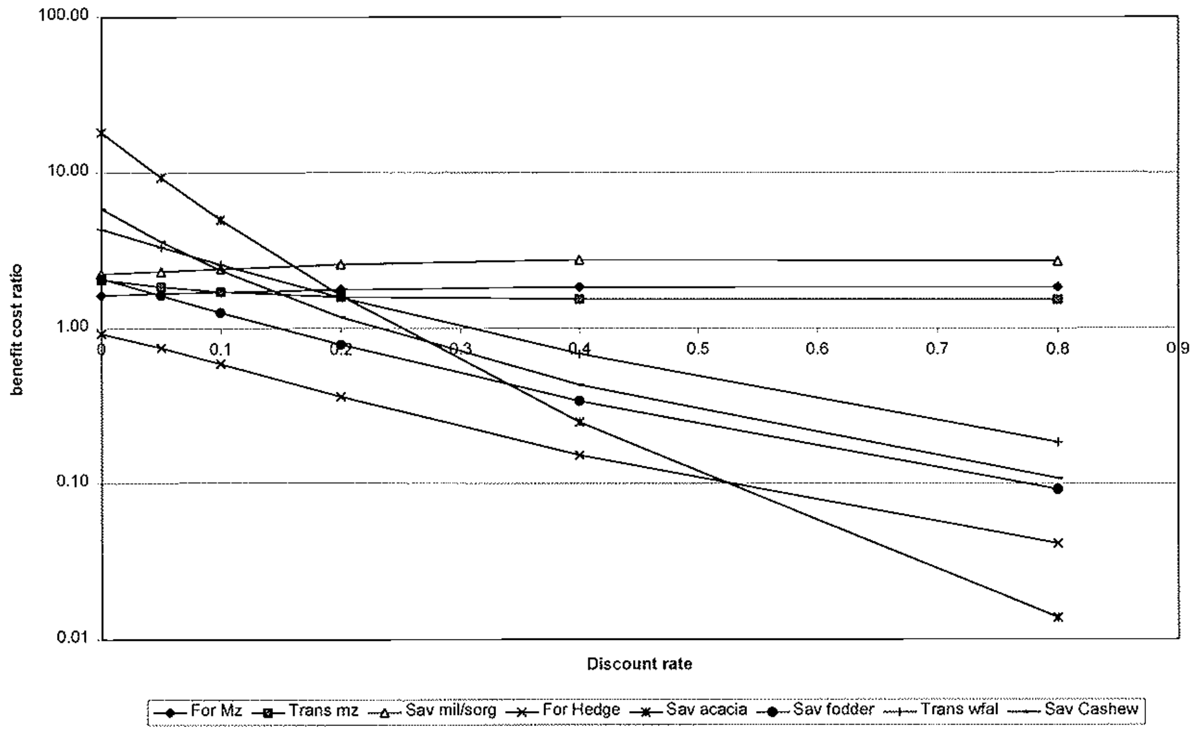

Figure 31: Benefit cost ratios comparing traditional systems with interventions at a range of real discount rates.

Figure 31 shows how a 20% real discount rate has made all agroforestry practice inferior to unsustainable agricultural practice.

7 Farm systems modelling

7.1 The Modelling Environment

Linear programming is an applied mathematical technique for finding optimal solutions to planning problems. Linear optimisation consists of trying to find the optimal value (maximal or minimal value, depending on the problem) of a linear function of a certain number (n) of variables, given a set of m linear constraints on these variables (equalities or inequalities). The LP framework allows a planner to select from a wide range of activities. Objectives for the planning process commonly include maximising returns from or minimising costs of an enterprise.

Before we can get to grips with optimal resource allocation we have to define the purpose i.e. state the objective. The objective function has to have measurable units. If more of these units is better we maximize if less is better we minimize. An objective simply has a direction of improvement. What we must know is the number of units of our objective we get from each unit of activity. These are our objective coefficients.

We take an inventory of the resources we have. The quantities of fixed resources represent physical constraints to the level of input into all activities competing for the use of the resources. The information we require before we can set up the problem is the resource requirements per unit of activity i.e. input output coefficients. The process of building up the model defines the information we require in order to provide a solution.

The generic linear program can be described thus:

Minimise/Maximise $c_1x_1 + c_2x_2 + ... + c_nx_n$ (Objective function)

Subject to:

1st constraint:	$a_{1,1}x_1+$	$a_{1,2}x_2+$	.... +	$a_{1,n}x_n <=$	b_1
2nd constraint:	$a_{2,1}x_1+$	$a_{2,2}x_2+$	.... +	$a_{2,n}x_n <=$	b_2
...	...	...	...	...	...
m-th constraint:	$a_{m,1}x_1+$	$a_{m,2}x_2+$	.... +	$a_{m,n}x_n <=$	b_m
Non-negativity:	$x_1 \geq >0$	$x_2 \geq >0$ ...		$x_n \geq >0$	

Where a_{ij} are the constraint coefficients of the activity i in the j^{th} constraint, x_i the activity levels of activity i, b_i the resource availability or constraint limits and c_i the objective coefficients.

Any generic model should exist independently from the data, which gives rise to the model output simulating system performance. Dash associates software Xpress MP provides an environment which enables the user to flex the model to meet changing circumstances and make the necessary structural changes and scale changes required in a move from the individual farm to a group of farms and an aggregate of groups.

In the process of developing these system models of agroforestry practice there is data which is deemed to be representative of an ecozone and data which is specific to an individual farm household. The data base has been used as the major source of information on local farming practice in the ecozones and furnishes family specific data which was valid at the time of recording in summer and autumn of 1996.

The information from the surveys was enhanced and validated by the participants at the workshop held at IRNR Kumasi in July-August 1997. These models represent the outcome of that workshop supplemented by additional information from the literature and subjective judgement with regard to missing information.

The spreadsheet data driving the models at the point of publication must be regarded as a template which the user must scrutinise and validate before interpreting the results. The output is a logical consequence of the input. The user may accept the values contained in the spreadsheet as DEFAULT values appropriate to the ecozone represented.

7.1.1 The key logic to LP modelling

Linear programming is concerned with making the best choice between a set of decision variables given that the system is bounded by the constraints and driven by an objective. Figure 32 shows a conceptual system where the decision maker can choose between growing maize or cassava (both measured in hectares). The farming system is bounded by the physical constraints of land and labour, which are in finite supply. Thus, any choice which can be made must not exceed the use of these resources (i.e. be below the line on the graph). The set of possible solutions is represented by the feasible solution space (shaded area in Figure 32).

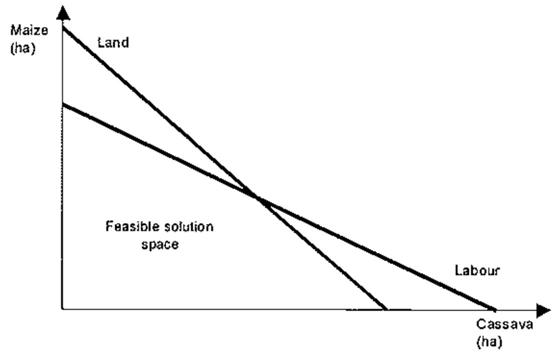

Figure 32: A two dimensional representation of the LP logic.

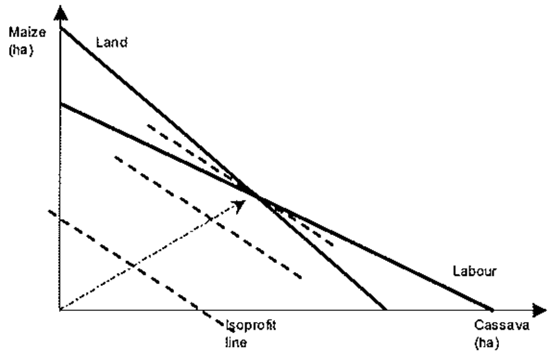

Figure 33: Conceptual model showing maximisation of isoprofit line.

The only remaining question to be answered is where best to be positioned within the feasible solution space. This is dictated by the objective of the enterprise and the relative value of each decision variable (activity) in terms of the objective. In the case of maximising profit, the optimal point would lie at the tangential point of an isoprofit line to the feasible solution space, which represents the farthest possible point from the origin. Any point on an isoprofit line will yield equal profit but have differing levels of decision variables. The gradient of the isoprofit line is given by the relative values (objective coefficients) of the decision variables. This logic is identical when more decision variables are added – each variable adds another dimension to the solution space hypervolume.

7.2 Modelling Agroforestry practice in Northern Ghana

Economic logic dictates that efficient allocation of time is based on equi-marginal marginal value productivity (MVP). These values are individual and imputable in so far as scarce time is being spent on non market activities[17]. Drawing a picture of the seasonality in the MVP of labour time in the Agroforestry systems models depends upon the constraints in supply induced by competing activities.

Most of the individual family models involve the hire of labour. Some have surplus labour to offer. The demography of village populations demonstrates the extent of labour surplus or shortage. Human kind inevitably finds market based solutions to labour shortages even when no surplus cash is available. The existence, evolution and prevalence of variants of the share tenancy demonstrates this.

Limits to the system are placed on land, capital and, importantly, labour. Optimal deployment of these scarce resources is a priority for sustainable development. Land-use decisions are not made through an analysis of single factors: minimising risk, improving food security, involvement in the community, fulfilling cultural obligations, concerns about income, dietary taste preferences, and perceptions of sustainability may all have swaying and varying influences.

[17] Personal, domestic, social and cultural activities are included.

The household-level model is based on generalised constraint equations which represent the systems' behaviour and linkages (Figure 34). The linked database of input parameters facilitates the shift from generalised model to the site specific. The AOG survey of existing practice reveals that farming systems are more diverse and complex than were originally envisaged.

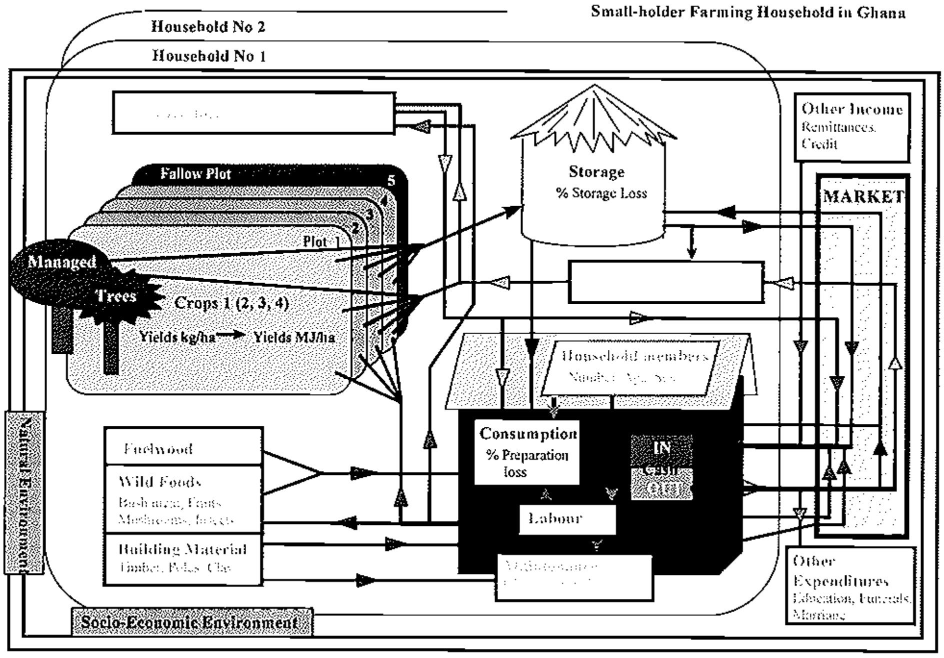

Figure 34: The physical links of the household with its productive enterprises and the market

7.3 *The farm-level models*

At the representative farm level, objectives may be set in relation to net income, security, family employment and borrowing. Constraints are set in relation to the endowment of land, household size and composition, stocks and balances. The agroecological zone is primarily determined by rainfall, its distribution and associated temperature. A secondary classification may be necessary where the location of certain crops and their yield levels are strongly correlated with the distribution of certain soils and their drainage characteristics. Thus, a classification of agricultural areas is made such that a similar range of enterprises is open to all who occupy and farm within that zone and soil classification.

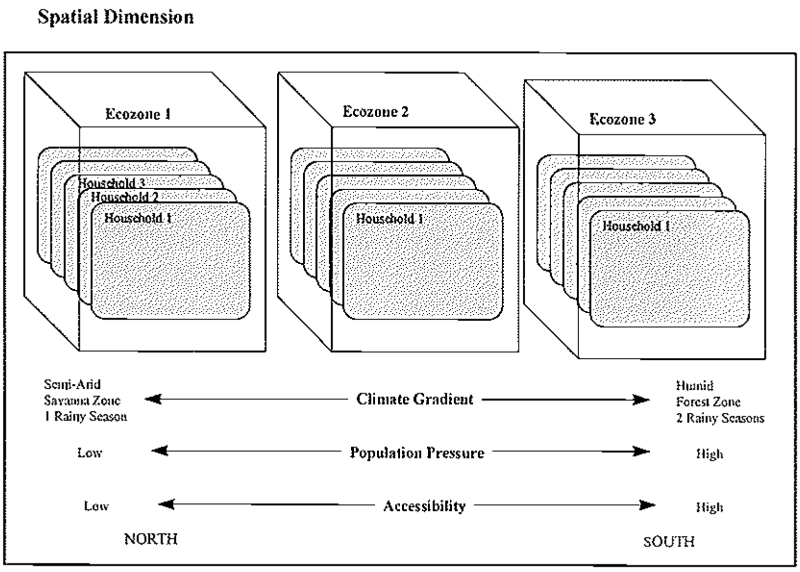

Figure 35: Households which are segregated in space are influenced by different physical and socio-economic parameters

Households and their farms are segregated in space. This space is not uniform but varies according to numerous parameters such as soil, climate, relative location to water resources and transport routes etc. In Ghana, the most prominent factors of change from south to north are the climatic gradient and the relative market accessibility. Other important factors, influencing farm management choice, are variation in soil fertility and population densities. Cultural factors such as household member role allocation also influence the farm management. The use of female labour varies from region to region (Sarris & Shams 1991). Levels of collective family and individual farming activity also seem to deviate substantially between different areas (Amanor 1994, Norton 1990).

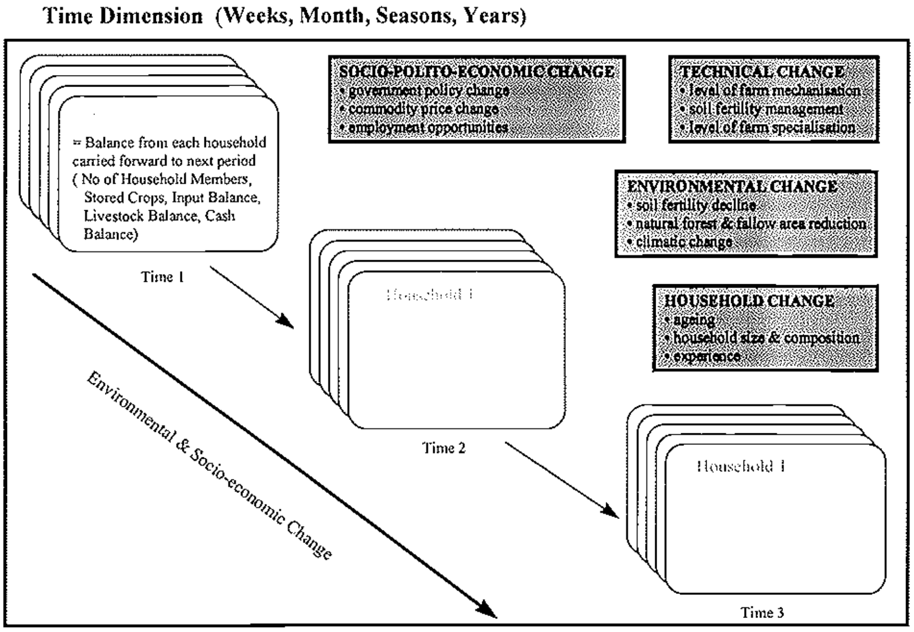

Figure 36: Change over time manifests itself in different forms, all influencing the household decision making process

Time brings change at different levels of the farming system. The household itself changes in size and composition as a result of birth, death and migration. Furthermore, the members of the household under go a process of ageing which influences their consumption patterns, labour capabilities and experience. Environmental factors can vary independently of farmers' actions and as a result of them. Climate varies seasonally and from one year to the next, with rainfall being most important in tropical farming systems. Other factors such as soil fertility and the state of fallow and natural vegetation can be brought under more direct control. Government intervention and large scale commercial farms have become increasingly prominent which often overrule a farmers' control. Change in commodity price offered by the local, urban or international markets and change in availability of employment outside the farm will further influence the farming system. Dynamic adaptation in farm management also occurs as a result of own experimentation, new information and better technology.

The consumption and labour components are adjusted according to household size and composition. Individual members of the household participate in different activities under different contracts. Allowances are made for intercropping practices and the household's reliance on wild resources for fuel, foods and building material. Labour allocation takes account of requirements of labour for household maintenance and food preparation as well as leisure and production activities.

Equation 1: Monthly commodity inventory (including losses).

```
INVN(v=1:mxv,m=1:mxm,n=1:mxn): -loss*INV(v,m,n)- STW(v,m,n) +DRW(v,m,n) +INV(v,m+1,n) =0
```

The mathematical modelling was carried out using Dash Associates' Xpress MP optimisation software. The key to successful modelling of these complex systems is being able to capture the multi-dimensionality of natural systems. This process has been facilitated by the software which can declare multi-dimensional variables. Demand for labour varies within the agricultural year. Peak demands also vary for different crops and husbandry technologies as identified in the timelines elicited at the workshop.

This information is captured by dis-aggregating the model into monthly sub-models. Labour utilisation and supply are calculated each month. Balancing constraints are used to tie the months together such that spare resources (stocks) are transferred to the following month as an opening balance of supply. Newly available resources are added to the stock and the new monthly calculations begun (Equation 1).

In essence, there are two parts to the modelling process: a command and control code matrix and a data sheet of input parameters. The structure of these are presented in tables 1 and 2. Table 1 shows the 20 variable groups – complexity in the models is introduced by allocating more than one dimension and multiple choices within a dimension. Table 2 defines the data structure tables, which make up the input parameters for the model. Some of the data are averaged for an agroecological zone (e.g. crop yield parameters). Other data (HMEM and LAND) are recorded for individual households thus capturing the variability in household size, composition and plot number/size. Thus, each household has a data sheet which comprise some zonal data and some specific data. The command matrix remains the same, however, allowing multiple runs to be carried out without needing to change the command code.

Table 22: The variable groups in the model, their units and dimensions.

Variable	Description	Units	Dimension		
			1	2	3
ALLEY	Area permanently cropped i.e. taken out of bush fallow	Ha			
ALY	Alley annual cropping activities	Ha	Plot	Annual crops	
HH	Household composition	No.	Working gender[1]		
FD	Field days of labour	Day	Month	Working gender	Plot
MD	Marketing days	Day	Month	Working gender	
GDH	Hunting days	Day	Month	Working gender	
GDF	Gathering fungi days	Day	Month	Working gender	
BC	Bush clearing	Ha			
AC	Annual cropping activities	Ha	Plot	Annual crops	
C	Perennial cropping activities	Ha	Plot	Perennial crops	
LST	Livestock activities	No.	Livestock type		
PRD	Non-crop commodities	Kg	Month	Other commodities	
INV	Inventory of commodities (adjusted for loss)	Kg	Month	Crop products	
DRW	Draw commodities	Kg	Month	Crop products	
STW	Stow commodities	Kg	Month	Crop products	
EAT	Eat commodities	Kg	Month	Commodities	
BUY	Buy commodities	Kg	Month	Commodities	
SELL	Sell commodities	Kg	Month	Commodities	
WG	Work off-farm	Day	Month	Working gender	
HG	Hired work on-farm	Day	Month	Working gender	

[1] 'working' gender consists of male and female adults and children over 8 years old.

Separating out the data from the command matrix allows the data to be compressed in an easily understandable format, improving the ability to check for data errors and missing information. Constraint equations are entered capturing the physical, social and environmental processes highlighted in Figure 34. These equations are entered in a generic format and can be dimensioned according to time, plots, and crop commodities (etc.) as necessary. This process of dimensioning the variables and constraints greatly reduces the modelling effort in capturing complex systems.

Table 23: Data sheet components and their dimensions.

Table Name	Description	Units	Dimension 1	2	3
ALL	Pruning, mulching timber harvest	Kg	Month		
WOOD	Timber yield	Kg	Month		
ALLDEX	Secular decline in yield in alleys		Plot	Annual crop	
UTILS	Commodity information, sell price, buy price, energy content, protein content	Varies	Utilities	Commodities	
PCL	Perennial crop labour requirements	Days	Plot	Month	Perennial crop
ACRL	Annual crop labour requirements	Days	Month	Annual crop	
ACY	Annual crop yields	Kg	Annual crops		
PCY	Perennial crop yields	Kg	Plot	Perennial crop	
YLDEX	Rotational yield index by age of plot indexed by plot number k		Plot	Annual crop	
PRDEX	Seasonal commodity price index		Month	Commodity	
AHVST	Annual crop harvest		Month	Annual crop	
HVST	Perennial crop harvest		Plot	Month	Perennial crop
OFFTK	Livestock yields, hunting and gathering	Kg	Other products	Non-crop activities	
TKOFF	Commodity takeoff by month	Kg	Month	Other products	
LAND	Land area managed by household	Ha	Year	Plot	
LIVE	Number of different livestock	No	Livestock		
HOURS	Distance reduction in field work hours	Hours/ visit	Plot		
T	Gender adjustments for loads, wages, hiring, hunting and gathering	Varies	5	Gender	
HMEM	Household composition	No	Gender	Age classes	
WHOE	World Health Organisation energy requirements	MJ/day	Gender	Age classes	
WHOP	W.H.O. protein requirements	g/day	Gender	Age classes	
OV	Opening valuation of crop commodity in inventory	Kg	Crop products		

7.3.1 Multi-Year Modelling.-

Multi-year modelling is facilitated by Xpress as it is relatively simple to add the necessary extra dimension to the decision variables. In addition, suitable transfer activities must be added to pass resources and commodities from one year to the next. This process is identical to that described for the monthly balance equations. Figure 37shows the progression of plots through time. Rotational constraints are added to the model to allow for the passage of time. In particular, the incidence of perennial crops which are harvested in the second or third year have to be carefully represented within the model structure.

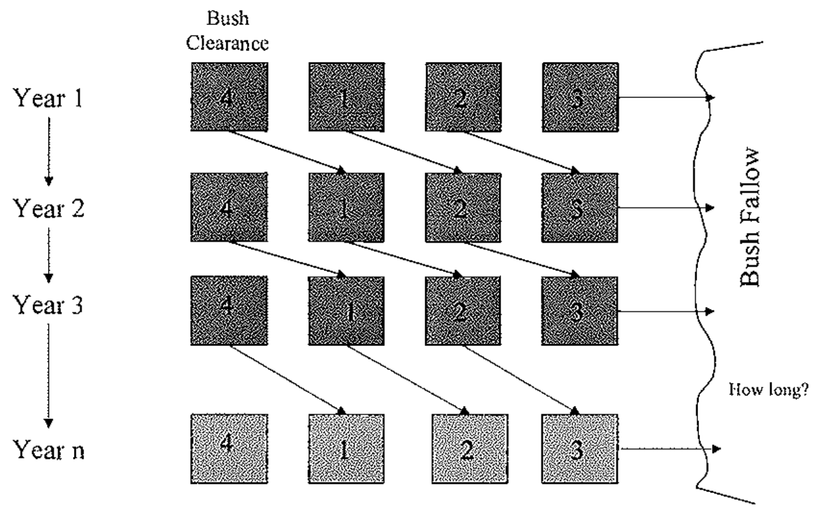

Figure 37: Conceptual framework to model bush-fallow system

7.3.2 Inflation, pricing and discounting:

The economy of Ghana is undergoing structural reform and the price system is volatile. When annual inflation is above twenty percent and rates of discount of thirty percent are suggested, refuge may be sought in constant relative prices or maize grain equivalent pricing or day wage equivalent pricing.

Constant relative pricing with a real discount rate is the approach adopted, but the models can be easily adjusted to another set of accounting principles.

Constant relative prices are made to fluctuate through a seasonal cycle, by multiplying with a systematic seasonal price index. Subjective judgement can be applied to make one month (or group of months) in the year as base and express the remaining months relative to the base. It is usual to have the lowest prices sometime after and highest prices prior to harvest. A good choice of base is midway between lowest and highest price periods rather than midway through relatively rapid transition over the harvest period.

7.3.3 Food security, taste preferences and dietary specification:

No model of subsistence farming can be considered adequate unless it demonstrates the ability to provide the observable diversity in the diet. This was achieved by two simple rules, which serve the twin purposes of diversity and security. Firstly, no more than thirty percent of the dietary energy can be supplied by any one staple food[18] and secondly purchases of all staple food is limited to less than ten percent of minimum dietary energy requirement. Reliance on the market as a source of food is severely limited to guarantee security of supply.

Balance in the diet is achieved by simultaneous expression of energy and protein requirements with strict upper and lower bounds. The monthly amounts required lie between 30 and 40 days supply of the WHO daily dietary energy and protein needs.

Equation 2: Dietary requirements and maximums.

```
!Maximum energy intake
MXE(v=1:mxv,m=1:mxm):SUM(u=1:mxu)utils(3,u)*EAT(v,m,u)< 40*MJ
!Minimum energy intake
 MINE(v=1:mxv,m=1:mxm):SUM(u=1:mxu)utils(3,u)*EAT(v,m,u)> 30*MJ
!Minimum Protein intake
 MINP(v=1:mxv,m=1:mxm):SUM(u=1:mxu)utils(4,u)*EAT(v,m,u)>30*CP
!Maximum protein intake
 MXP(v=1:mxv,m=1:mxm):SUM(u=1:mxu)utils(4,u)*EAT(v,m,u)< 40*CP
```

Crop yields are quoted as kilograms of marketable produce in the least processed state. Dietary concentration of energy and protein as purchased is adjusted downwards to take account of cooking and preparation losses since nutritional values foods are quoted per gram of edible portion rather than per gram as purchased.[19] The culinary need for fresh green leafy vegetables was assumed to be easily met from the plots and the bush without assigning extra land and labour and has not been built into this particular model.

7.3.4 Crop yields for annuals and perennials:

One of the significant features of hand labour systems is the relatively long period over which harvesting takes place with certain notable exceptions. Annual cereal crops of maize and sorghum can be harvested over a period of several weeks with seed heads been taken as and when required. When a mature crop is at risk from seed dispersal, damage by wind, rain or pests then it is harvested quickly e.g. cow pea.

Perennial Crops may have an extended harvesting period. Roots and tubers may store better in the ground rather than lifted to deteriorate in store[20]. Because of prolonged harvest periods the selling prices of plantain[21], cassava and cocoyam are distributed over time. The revenue raised from the sale of a crop depends on the month when it is sold.

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[18] Staples identified were maize, cassava, plantain and coco-yam.

[19] A knowledge of local processing and cooking techniques is important to get crude estimates of processing and cooking losses. The same commodity can be consumed in a variety of different ways with significantly different preparation losses. In this case a weighted average may be used. Cassava may be processed as gari for storage in the home and to reduce the transport burden.

[20] This is particularly the case with Cassava

[21] Plantains usually flower sequentially yielding large bunches at intervals. There is some discretion as to the best time of harvesting.

The simultaneous nature of the solution maximises net revenue on the expected values of yield and price. There is a planned distribution of harvesting, buying and selling. The expected variability in yields and prices associated with the plan is derived from a knowledge of the variance-covariance properties of prices and yields. The simplest assumptions to make are that the crops are independent random variables in respect of yield due to the fact that pathogens are usually species specific. Selling prices are negatively correlated with yield accepting the proposition of elementary economic theory that demand curves have a negative slope. In the absence of the required historical data set, a synthetic one is created which uses the mean absolute deviation (MAD) of expected net revenue as the measure of variability in financial outcome.

The model therefore requires the bi-variate simulation of yields and prices with the correlation coefficient as the means of transmitting covariance effects between prices and yields. Bi-variate pairs of deviates from a suitable[22] statistical distribution are generated with a correlation coefficient (-0.5). Negative co-variance is a risk reducing phenomenon which allows low yields to be partially offset by higher prices and vice versa and determines the sign on the correlation coefficient.

7.3.5 Secular decline in yields:

The survey data depicts a considerable range of expected crop yields. The method of reporting on mixed crop plots is to attribute the yield to the proportion of the surface area occupied by the crop. The traditional farming system is based on soil nutrient extraction followed by a period of recovery. The secular decline in yield from continuous cropping is subjectively estimated based on historic experience and there is supporting evidence from field experiments. In the model the expected yield for any crop is based on two components the expected yield from a virgin plot multiplied by a yield index which scales the yield according to the number of years the plot has been cropped in order to represent the secular decline.[23]

7.3.6 The Interaction of Food from the Wild (FFW) with the local labour market.

With prevailing prices of bushmeat, honey[24] and fungi relative to the price of other protein rich foods and sweeteners there is prima facie evidence of marked preference for such items in the diet. Consequently the seasonality and the proportion of labour time spent by whom is of significance to marginal value productivity in the labour market. The evidence points to FFW as a welcome alternative means of subsistence to complement or substitute for Agroforestry activity.

There is a presumed gender bias in that men traditionally hunt and women gather. Honey is hunted rather than gathered in that the traditional techniques are dangerous involving the use of fire. Children are involved in FFW as part of their indigenous cultural development.

The regional Agroforestry models demonstrate that these activities are competitive and that farm labour will be hired in order to release family members to engage in such activity over a wide range of productivity of the FFW activity.

7.4 Risk aversion and multiple criteria decision making (MCDM)

Traditional economic appraisal use as a method of evaluation both NPV (net present value) and IRR (internal rate of return) criteria. The problem encountered here is that such appraisal methods do not take account of the context in which the farmer is operating.

The question of risk is ignored. The results are only applicable to a capital constrained plantation owner who is indifferent to the risks involved in the production system. In order to solve the problem we need evidence about the variability of crop yields. Any written record will be variety specific and relate to measured yields on research farms. The chances of such historical records being of the right variety, soil type etc. under the same management and climate is remote.

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[22] A distribution with the required shape in probability density function.

[23] The extent of recovery of fertility can be related to the length of fallow period and any special treatment of the fallow.

[24] Honey has considerable medical significance see Holt Wilson 1996

Decisions have to be made in the absence of complete information. In such circumstances we must rely on subjective judgement (i.e. the personal strength of belief of the decision maker about future outcomes). Subjective probability judgements enable the rational decision maker to get on with the business of decision making. The best we can do in planning is make sure that our actions are consistent with our beliefs.

When we accept the idea that a decision maker has more than one criterion for what is best, it is no longer a simple matter to find the best solution to a resource allocation problem. Linear programming is the ideal tool for finding the maximum or minimum for a single objective, usually cost minimisation or profit maximisation. If our decision maker is interested in more profit and less risk, these two objectives can be seen to be in conflict in the risk efficient set (i.e.) substitution or trade off along the risk efficiency frontier, more of one implies less of the other and vice versa.

Financial risk has a lower priority than food security which is built in as part of the constraint set. The Mean Absolute Deviation in net cash income is a proxy measure for the standard deviation in net cash income and is easily accommodated within the linear programming framework. The standard textbook risk return trade-off is between expected returns and variance (or Standard deviation). In our particular case we are minimising a Mean of the Total Absolute Deviation (MOTAD) as a proxy measure for the associated risk for a given target level of Expectation (mean net cash income). This Mean Absolute Deviation (MAD) is related to the standard deviation thus:

Equation 3: The relationship of MAD to the standard deviation.

$$\sigma = MAD \bullet \left(\sqrt{\frac{\pi}{2}} \right)$$

$$\therefore \quad \sigma = 1.253 \bullet MAD$$

Risk efficiency was defined as the minimum variability for a given level of expectation. Usually, this is achieved by parametric linear programming, commencing with the target of maximum expectation, whilst minimising the mean absolute deviation (MAD); then iteratively subtracting the "allowable decrease" from the binding constraint of the target level of expectation and resolving for minimum MAD until the procedure terminates with zero activity and zero MAD. For this project, however, this process would have been too time consuming. Thus the two endpoints for the axes were selected at maximum target expectation and zero expectation. It was possible to use zero expectation because of the subsistence targets which are built into the constraint set force the farmer to carryout productive enterprise even when no cash income is made.

The following stage in the process is termed compromise programming, i.e. finding the optimal compromise between the two conflicting objectives (assuming that a tradeoff between them can be made). In simple terms, this is minimising levels of disappointment from some theoretical ideal point. This is built into the constraint set by incorporating targets for the criteria to be compromised – the right-hand-side target levels being set at the aspiration levels. The problem is solved to minimise deviations from that ideal.

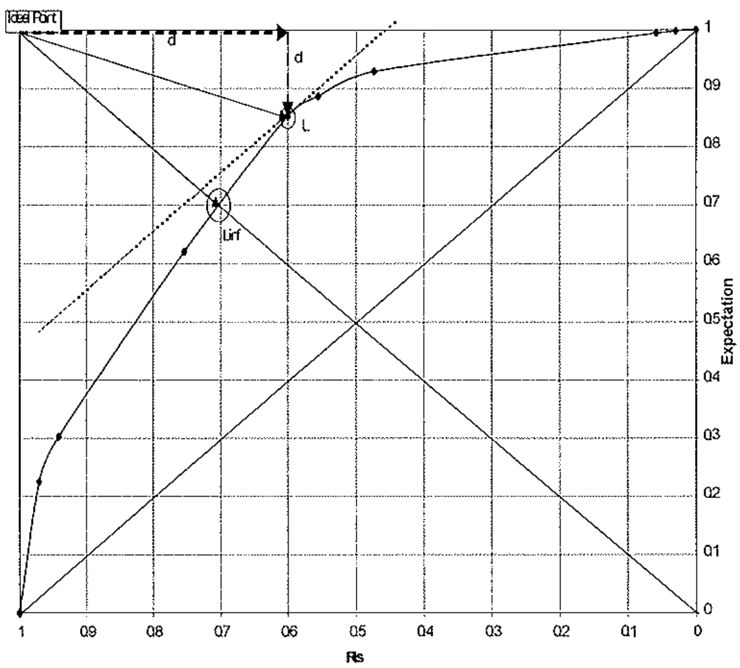

Figure 38: Example normalised risk efficiency frontier to show the logic for compromise programming.

Direct solution using L1 and L∞ metrics identifies the locus of operation for risk averse decision makers. The relevant scaling is between zero expectation and maximum expectation. The mean absolute deviation is computed at both these points to provide the necessary scaling coefficients for the L1 and L∞ solutions. The ideal solution (1,1) is identified as that with maximum expectation and minimum MAD which is infeasible in that such a point lies outside the risk efficiency frontier diagonally opposed to the nadir (0,0). The best outcome in each dimension is assigned the value of unity and the worst outcome is assigned a value of zero. Any solution has a devotional score in each dimension proportional to its distance from the best outcome on a normalised (0-1) scale. This appears to be the most cost effective way of effecting the compromise and identifying extremes of the risk efficient set in Expectation/ MAD space.

Persons who are "risk indifferent" by definition will go for a solution, which maximises an expectation like profit a single criterion objective will satisfy these people. It is generally believed that persons are risk averse. If the risk reduction goal is equally weighted with increasing expectation goal persons who are weakly risk averse will go for a solution delivered by the L1 metric. As the importance of the risk aversion objective increases they will move to the L2 solution point and ultimately to the L∞ solution point if the person is seriously risk averse. All risk averse persons have their optimum in the "compromise set", i.e. the section of the risk efficiency frontier which lies between L1 and L∞ solutions. Between these limits we have the range of compromised solutions appropriate for all risk averse persons.

7.5 Coping with non-tradable conflicting objectives

7.5.1 Lexicographic goal programming

Thus far we have assumed that the decision maker is a single individual. Utility functions are unique to the individual. But even this individual may make choices which can not be explained by relative weight changes. Not all values are tradable. We have made the assumption that risk averse persons are willing to sacrifice some expectation in order to reduce risk and that this sacrifice increases their personal satisfaction. We can explain their choice as being rational in the context of a utility maximizing model.

Any problem can be analysed and reduced to the bare essentials, however we as analysts or advisors may be confronted with decisions or choices which are difficult to understand. For example, some decision makers are making choices which do not reflect tradable values or they refuse to carry out a trade-off. It may be that some people are prepared to make heroic sacrifices rather than trade their principles and values.

In both public and private sector decision making, we are to a certain extent governed by the will of the majority. There are complex decision processes in all walks of life. Managers often have to take goals and values as expressions of the collective will of the board room communicated through a chief executive acting in response to a group of directors or management committees members appointed by secretaries of state.

One way forward is to place goals in an order of priority and solve for them in sequence, a technique, called "Lexicographic" Goal Programming.

Lexicographic simply implies that goals and values can be placed in a hierarchical order (sequence) like the letters in the alphabet (lexicon) and that in searching for what is the best solution we satisfy higher order priorities before lower order priorities. The goals are satisfied in a pre-emptive manner which denies the possibility of trade. The most important consideration and difference from compromise programming are that in this case, a hierarchy for the goals is selected and, thus, not allow any trade off between them. So, goal 1 is infinitely important than goal 2 and must be satisfied before goal 2; goal 2 is vastly more important than goal 3; and so on, such:

Goal 1 >> goal 2 >> goal 3 >> ... >> goal *n*.

(where >> signifies the hierarchical relationship and no trade off allowable).

A goal is represented by an equality constraint with deviational variables + N and - P together with a corresponding objective statement regarding the direction in which deviations are to be minimised.

This methodology is thought to be particularly useful for multi level resource use planning. It is supposed that there is a natural hierarchy from the International level, down through National and Regional levels to Local District and Individual levels. Hence, goals and priorities can be transmitted in the order in which they are to be achieved. People in government believe that constraints from above have to be met before we can get down to solving individual priorities. Laws can be made which fix the order of priority. Ultimately we come down to the rights and freedoms of the individual to do what he or she wills with the resources at his or her disposal and the willingness to obey the law of the land and or the "Ten Commandments". Another name for this type of approach is pre-emptive goal programming. This is because the weights involved are infinite, signifying that there is no relative price at which achievement at a higher level is to be traded for achievement at a lower level.

A sequential linear method can be applied to find lexicographic solutions. Such:
The Sequential Linear Method (Algorithm)

$\Im$ 0	defines the feasible solution set
X	is the set of decision variables(activity levels)
N	Deviational variable for underachievement
P	Deviational variable for overachievement

Start: Take the highest priority goal (i) from the list of outstanding goals. If the desired outcome would allow P > 0 then minimise N (alternative if the desired outcome would allow N > 0 then minimise P)

Objective	Min N (or P depending on context)
subject to	$f_i(X) + N - P = T_i$
and	$X \in \Im \quad i = 0, 1, 2, 3, 4, \ldots, n$

If the objective function is non zero stop - otherwise continue until the list is exhausted. If the objective is still non zero change direction and deviational variable[25].

Augment the feasible set $\Im 0$ with equation $f_i(X) - P_i = T_i$ (the deviational variable is the opposite type to the one used in the objective). This completes the feasible set $\Im i$ to ensure compliance with the priority goal. Delete the goal from the list and go to start.

In essence, this process sequentially reduces the feasible solution set such that when no more objectives can be met we are left with a manageable enterprise plan which gives a prescription for how to best satisfy the hierarchy of goals as defined.

7.6 Village or District level of Aggregation.

Once the models have been validated for the logic of their responses, they are applied to the evaluation of agroforestry options at different levels of aggregation, Household level, Village or District and Regional levels. This requires maps, demographic data and sample survey data for which the clusters in each ecozone act as a representative sample.

On the strong assumption that we have a random sample of families from the agro-ecological zones the limits to labour supply can be imputed, using the theory of diminishing marginal labour productivity. This can be tested against the known population densities. From a highly constrained apparently logical deployment of land and labour resources aimed at maximising net revenue subject to subsistence targets being met, constraints are sequentially relaxed in pursuit of additional goals and freedoms. The models have a subtle architecture which facilitates expression of observable phenomena and gives logical cause to the particular effects we wish to study in support of the decision making process.

[25] Romero, 1991, chapter 2 – Handbook of Critical Issues in Goal Programming, Pergammon, Oxford.

The District area, less water area, less areas unsuitable for cultivation, less developed lands under roads or urban settlement, less designated forest reserves, and plantations is taken to be bush fallow and cropping lands. Such mapping sets upper limits to the bush fallow area.

Demographic data defines the population base to which the sample survey can be raised. Scaling the farming families output constrained by their individual circumstances and contrasting with the output from farming with the available land area and labour force as a large scale enterprise will indicate the level of aggregation bias.

Aggregation bias in scaling up linear models is due to the relaxation of individual constraints so that the aggregate potential is greater than that of the sum of individuals. Historical evidence on forced collectivisation points to the reverse, that productivity declines, due to the lack of incentive and managerial skill in collective enterprise. Naturally evolved large scale enterprise with skilled management may be able to overcome disadvantages of scale.

7.6.1 The Aggregate Regional Model Northern Ghana

The aggregate cultivated area on the fifty family holdings is 240 hectares out of 840 hectares on an average four year cycle with ten years fallow. With 426 persons this represents a carrying capacity of 52 persons per kilometer square. This system is employing 291 adult equivalents. Such models of farming systems can be scaled using population census data to make estimates of the regional agricultural activity where land and labour are the only significant inputs to the farming systems. A cursory examination of the regional population densities shows that the carrying capacity of the northern region system is more than double the population density of 20.9 persons per kilometer square. Brong- ahafo has only 29.8 persons per kilometer square with higher rainfall and a major and minor season. It is the forest zone of Asante with 83.6 persons per kilometer square where carrying capacity could be an issue. However the existence of large regional trading centres with extensive urban areas and incomes derived from non agricultural activities implies that they are not totally dependent on the local farming surplus.

7.7 Multi-tiered modelling for policy planning.-

The proposed multi-tiered modelling framework (see Figure 39) sets out the farm family objectives and the resource constraints under which small-holders operate thereby, allowing the user to define alternative farm plans, simulate them, aggregate and test the hypotheses about which are most sustainable and stable.

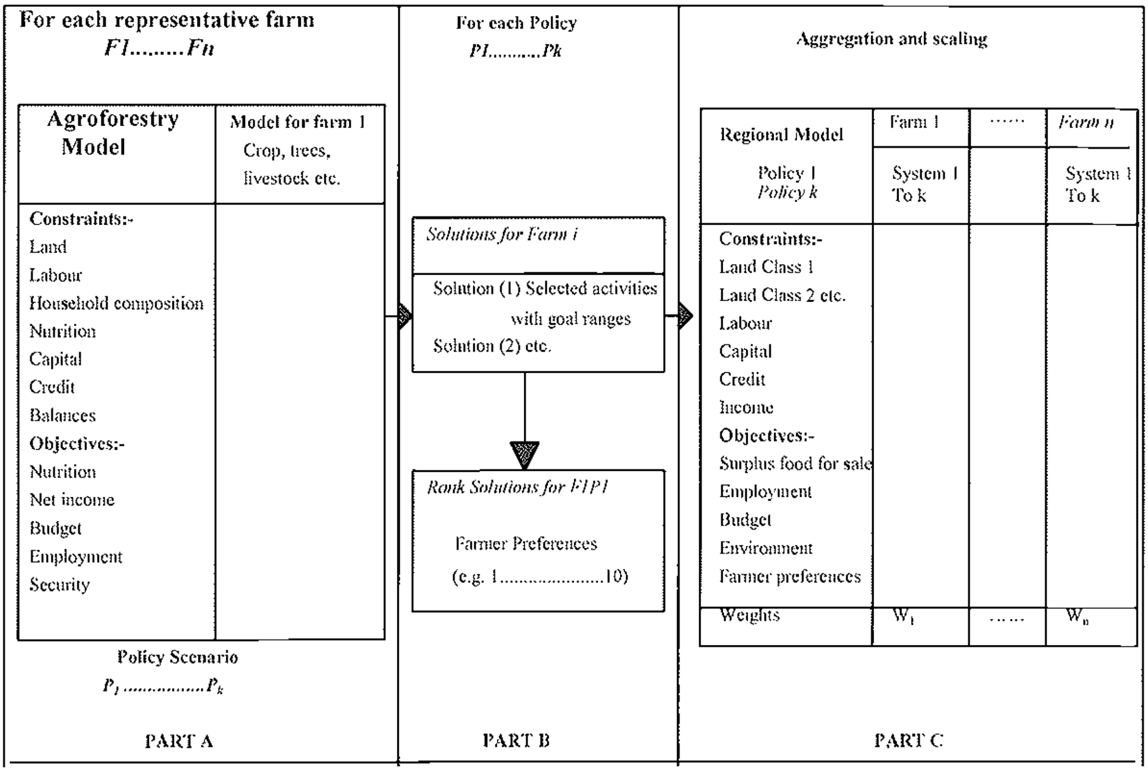

Figure 39: The conceptual multi-tiered modelling framework for policy planning.

The three linked parts in Figure 39 can be interpreted as follows: Part A is a generalised goal format for a single farm. The model would run for each defined representative farm for each spatial unit within the region (F_1 to F_n) with provision for the objectives, goal levels, priorities and weights to be included.

For each representative farm, the above procedure would be repeated for each potential regional policy (P_1 to P_k). Part B first shows that a set of solutions for F_i and P_j will be generated. The goal programming model solutions for F_i P_j will provide a set of solutions with different characteristics but all meet the goal ranges and are feasible within the constraints specified. These may be ranked by farmers to reflect their preferences using for instance a simple scale (say 1 to 10). If access to farmer preferences is not available, compromise programming using either the L1 or L∞ metrics can be applied to work out the best compromise between solution sets.

Solution sets for all (F_n) farm household types each operating under all potential policies (P_k) may now be transferred to Part C as well as the relevant farmer preferences or compromised solution sets. Some culling of solutions may take place at this stage but it would be desirable to retain all options until it is obvious which solutions are dominant. Part C provides the format of the regional-level model. Constraints may refer, for example, to total regional area available of different land classes and budget. The regional objectives may relate to surplus food for sale and overall employment levels. The activities represent each of the solutions for F_i P_j (generated in Part B). Hence, for farm household type and policy there will be a range of possible systems (S_1 to S_k) as shown in Part C.

Policy at the regional level may be directed towards simple goals, for example creating a surplus over local consumption needs, i.e. to maximise production of food crops and /or export crops. Social policy may be directed towards maximising local farm employment. Budget policies may be to either raise target levels of tax or cap subsidy payments. Environmental policy may reflect a will to maximise the area under tree cover, or reach target levels of tree planting for particular species. At the national level, interest rates, exchange rates, subsidy rates, tax rates are the key instrumental variables affecting input prices (seed, fertiliser, pesticide etc.) and output prices (export crops and food crops).

There is a scale relationship linking potential output of a region to the areas of each zone and land classification, the farming population and their intensity of cultivation. Designated forest reserves restrict the potential area under cultivation but modern satellite imagery makes it possible to monitor areas burned and subsequently used for crop cultivation.

7.8 Modelling output.-

7.8.1 Basic Modelling

7.8.1.1 Subsistence

Diverse cropping patterns emerge under subsistence which is modeled by limiting the purchase of staple foods from the market and permitting sale of a modest surplus over subsistence.

Typically maize and tomatoes are grown on the virgin plots and a combination of all three perennials plantain, cassava and coco-yam is interplanted into the maize for harvesting through years two and three before the plot is abandoned to bush fallow for a variable number of years.

Tomatoes tend to be grown as the most effective cash earner after subsistence is being met.

7.8.1.2 Use of the Market

Relaxing the constraint layer restricting market access produces the predictable specialisation in profitable alternatives tomatoes and coco-yam for sale. It is clear that this is a high risk strategy given what we know about access to and pricing in the tomato market.[26]

7.8.1.3 Use of Hired Labour.

In a hand labour system periodic peaks and troughs are dictated by the seasonal calendar. Planting commences after the rains on all farms in the locality almost simultaneously. Labour is constrained by local availability and may have very high marginal value productivity at peak demand periods. Consequently additional labour can not be purchased at the quoted day rate at critical periods during the year. The financial appraisal method is appropriate to chronic under employment situations only. In the study area a comparison of farming systems requires the detailed distribution of labour time to be modeled and constraints placed on labour availability.

It is clear from the survey data that small farmers in all three ecological zones hire additional day labour when they require it and a supply is available. At a higher level of aggregation say village or district, the supply of labour may be critical at certain peak periods which are identifiable through the labour profile. Aggregate models can sensibly limit the labour supply to the available population.[27] Depending on the precise form of the structural equations, day labour can be hired for the collective tasks which not only include field work but also the burden of carrying produce to the market and back. Opening up the Market as a trading opportunity in a maximising model is unbounded if not otherwise constrained. Buying prices were set higher than selling prices by a substantial margin to avoid this problem. When the seasonal fluctuation in prices creates a differential large enough to drive profitable storage and transportation activities they will be selected. Commodity trading was significant even though performance was restricted by headloads to 25kgs per adult day and labour hire was subject to cash constraints. One method of suppressing this logical but diversionary commercial opportunity is to prohibit sale of crops which are not grown on the farm.[28]

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[26] The risk return model sequence MDAlley1-3.mod produces diversification reducing the area devoted to tomatoes as a result of compromise between maximising residual expectations of net cash income and minimising variability in net cash income.

[27] Given the land areas cropped, the composition of households and the migratory habits of household members it is possible to identify the size of the potential labour supply.

[28] The African equivalent of the farm shop and farmer wholesaler diversification world wide.

Table 24: Modelled cropping activities in year 1 across the four runs. (Forest Zone).

Year 1	Maximising Expectation	ha	Zero Expectation	ha	L1	ha	L inf	ha
Plot 1	Major Maize	0.11	Minor Cow Pea	0.35	Major Maize	0.46	Major Maize	0.43
	Tomato	0.34			Tomato	0.01	Tomato	0.04
	Cassava	0.07			Plantain	0.04	Plantain	0.08
	Cocoyam	0.41			Cassava	0.02	Cassava	0.00
							Cocoyam	0.16
	Totals	0.94	Totals	0.35	Totals	0.53	Totals	0.71
Plot 2	Cassava	0.01	Major Cow Pea	0.14	Cassava	0.08	Cassava	0.09
	Cocoyam	0.47	Minor Cow Pea	0.19	Cocoyam	0.40	Cocoyam	0.39
			Cassava	0.09				
			Cocoyam	0.06				
	Totals	0.48	Totals	0.48	Totals	0.48	Totals	0.48
Plot 3	Plantain	0.06	Major Maize	0.06	Plantain	0.09	Plantain	0.08
	Cassava	0.11	Minor Maize	0.36	Cassava	0.02	Cassava	0.005
	Cocoyam	0.31	Plantain	0.07	Cocoyam	0.37	Cocoyam	0.40
	Totals	0.48	Totals	0.48	Totals	0.48	Totals	0.48

7.8.2 MCDM Models

A series of models were run simulating the maximum expectation system as a starting point for a compromise solution between expectation and mean absolute deviation. Tradeoff was planned with a second model looking to minimise disappointment from an aspiration level for expectation and risk (ideal point).

If the target level for income (expectation) is set to zero, the modeled system is dictated by the subsistence requirements imposed by the farm family structure and the dietary diversity constraints. It can be seen that (Table 24) the cropping pattern of the zero expectation run is a mixture of staples with some cowpea[29]. The shift from subsistence farming to a maximised target expected net revenue (whilst minimising the associated risk) is to incorporate more financially productive yet more risky crops such as tomatoes. As additional cash is being made from the sale of excess staple crops, subsistence requirements can be supplemented by the purchase of alternative market commodities.

Table 25: Modelled cropping activities showing the progression through time (L1 run) (Incomplete to show annual to perennial switch).

	Year 1	ha	Year 2	ha	Year 3	ha	Year 4	ha	Year 5	ha	Year 6	ha
Plot 1	Major Maize	0.46					Major Maize	0.04				
	Tomato	0.01					Major Cow Pea	0.36				
	Cassava	0.02					Tomato	0.05				
							Plantain	0.01				
							Cassava	0.06				
							Cocoyam	0.35				
Plot 2			Minor Maize	0.46					Major Maize	0.06		
			Cassava	0.02					Plantain	0.01		
									Cassava	0.06		
									Cocoyam	0.35		
Plot 3					Minor Maize	0.46					Minor Maize	0.06
					Cassava	0.02					Plantain	0.01
											Cassava	0.06
											Cocoyam	0.35

Table 25 and Table 26 show the progression through time of the annual and perennial crops on any given area of land. Plot 1 in each year is a freshly cleared plot, plot 2 has been cropped for one year and plot 3 for two years. After three years, the plots are abandoned to fallow.

[29] most likely to satisfy the protein requirements of the family.

Table 26: Modelled cropping activities showing the progression through time (Linf run) (Incomplete to show annual to perennial switch).

	Year 1	ha	Year 2	ha	Year 3	ha	Year 4	ha	Year 5	ha	Year 6	ha
Plot 1	Major Maize	0.43					Major Maize	0.04				
	Tomato	0.04					Minor Maize	0.00				
	Cassava	0.005					Major Cow Pea	0.36				
	Cocoyam	0.16					Tomato	0.05				
							Plantain	0.01				
							Cassava	0.01				
							Cocoyam	0.40				
Plot 2			Minor Maize	0.31					Major Maize	0.06		
			Cassava	0.005					Plantain	0.01		
			Cocoyam	0.16					Cassava	0.01		
									Cocoyam	0.40		
Plot 3					Minor Maize	0.31					Minor Maize	0.06
					Cassava	0.005					Plantain	0.01
					Cocoyam	0.16					Cassava	0.01
											Cocoyam	0.40

The results show that the optimal compromise solutions involve much diversification in the cropping pattern. This will be a reflection of the input parameters, i.e. when crops need labour inputs, when the crop is harvested and the marketable and dietary value for a particular crop. The two tables show similar results except that cocoyam is increased in area for the strongly risk averse solution (L∞ - Table 26). Cocoyam demonstrates less variability in yield and price so will have a stabilising effect on the solution's outcome.

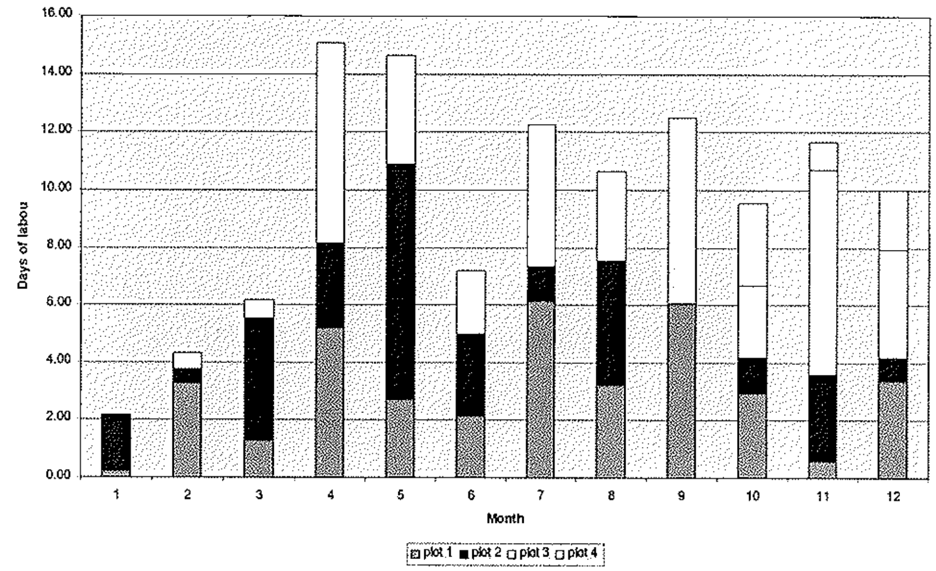

Figure 40: Average labour use on each plot (maximising expectation run).

Figure 40 shows how labour is used on each plot throughout the year. This is the average across the ten year run. It can be seen that peaks in labour occur from April to December.

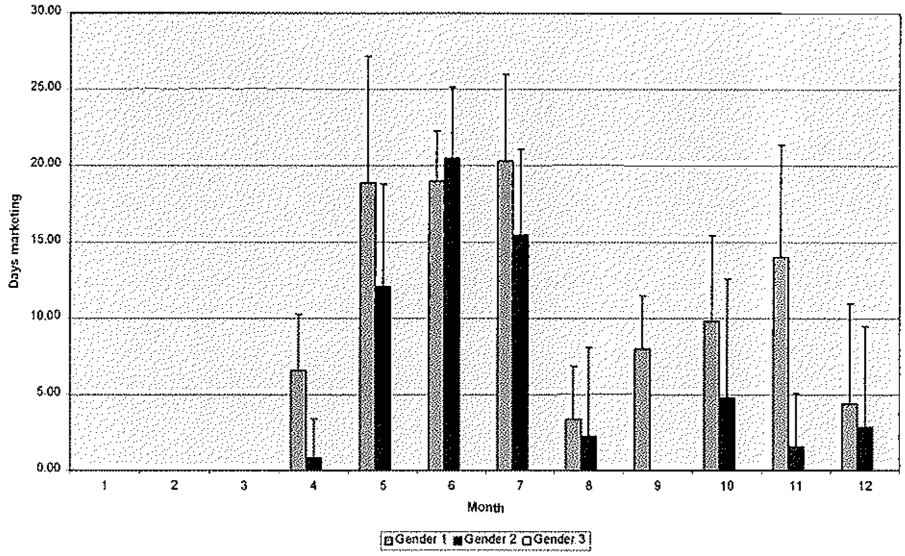

Figure 41: Average number of days spent marketing commodities (maximising expectation run). [Gender 1 = male, 2 = female, 3 = teenagers]

Marketing uses a significant amount of time in terms of labour. This marketing is in direct conflict with the labour needed to carryout the fieldwork operations. Optimal allocation of labour is seen as one of the most restrictive constraints within the hand based agricultural system.

7.8.3 Developing an aggregate regional model

7.8.3.1 The average household

The objective of the models is to find the optimal deployment of land, labour and capital resources subject to constraints. The objective is set to maximise a cash surplus after providing for an adequate subsistence. If the resources are pooled as a collective with no external labour there is an average cash surplus of 2.35 Mcedis per household over WHO energy and protein requirements for all household members.

Households can be classified into three types, those which have large holdings of land relative to their family labour supply, those with large family labour relative to land and a third group represented by the average[30].

It is constructive therefore to compare the extreme resource imbalances labour scarce / land rich (NorthC) with 5.15MCedis household income and labour rich / land scarce (NorthD) with 0.57MCedis household income.

[30] The average farm does not exist as a real entity and may be unbalanced in the resource ratios given.

Table 27: Northern regional aggregate model results

Aggregate regional model
Northern Ghana
Eco-zone Guinea Savannah
Scale up by Household Numbers

Objective:		Result	Sample	Resources	labour	Land
Cash surplus		Mcedis	HHolds	persons	adult equiv	ha crops
over subsistence		117.52	50	426	291	240.35

rewards	per unit	MCedis	2.35	0.28	0.40	0.49

Livestock	totals	fowls	cattle	goats	sheep
adult	heads	687	360	198	179

Labour	Market	season	Jan	April-may	june-aug	Sept	Dec	other
shadow	ooo cedis	adult/hr	4.25	0.0915	0.1164	0.0915	1.15	0
quoted	0.408	adult day	34	0.732	0.9312	0.732	9.2	0
multiples of quote			83.33	1.79	2.28	1.79	22.55	0.00

Commodity Markets				
shadow	prices	000 cedis	July max	Dec min
food	energy(MJ)		0.039	0.036
food	protein(g)		0	0

Optimal deployment of resources to maxincome after subsistence.					
Crop Rotation	plot no	1	2	3	4
		Yam	millet rice	cassava	cassava cashew*

NB* Cashew is a perennial tree crop now extensively planted in Ghana under recent extension advice.

Model	activities						
PlantFoods	Eaten	Maize	Cassava	Groundnut	Sorghum		
	Bought	Maize		Groundnut	Sorghum		
	Sold	rice	Cassava	cashew	millet	Yams	
Anim Food	Eaten	Milk					
	bought						
	sold	Milk	eggs	beef	chicken	goat	lamb
Food from the wild (FFW) all sold							
Bushmeat							
season	available	April	may	June	July	Aug	Sept
season	yes	yes	yes	*** no	*** no	*** no	yes
Fungi							
season	available			June	July	Aug	
season	gathered			yes	yes	yes	

7.8.3.2 Specific households – representative households

The normal length of the working day varies between five and eight hours. On the basis of twenty-four working days of eight hours in each month upper limits are set for labour activity in the aggregate there are 55,872 adult equivalent labour hours.

Ownership of domestic livestock necessarily reduces the length of the day available for fieldwork[31]. On the basis of reported labour requirements fifty two percent of labour time is taken up with livestock keeping, so the comment that field work rarely exceeds five hours per day[32] is consistent with these labour requirements for livestock. Livestock numbers are taken as given in these particular models.

The other activities competing for available labour time are bushmeat hunting for males and fungi gathering for females. Gender differentiation of labour tasks has serious repercussions on labour

[31] Oxen are not in general use in the sample surveyed.
[32] Dr S.J. Quashie-Sam pers. comm.

productivity. Significant improvements in labour efficiency can be achieved if gender differences are imaginary rather than real and can be dissolved[33].

The main difference between an aggregate model and the individual farm model is the closed nature of the labour market in the aggregate unless there is an influx of day labourers from outside[34]. If households are free to hire day labour by the hour and sell hours of family labour to neighbours there is a market based solution to the uneven allocation of land. The only difficulty is to write the appropriate constraint to the use of the labour market by individual farming households.

The compromise is to set an upper limit of available labour per hectare of cultivated land. In the first runs of the model this has been applied in a weak form limiting the amount of hired labour.

Shadow wage rates (dual values) are defined by the marginal value productivity per hour of labour and only apply when the monthly labour constraints are binding. It is inevitable that labour is a scarce resource in farming systems which are not based on machines. The planning process assumed that the quoted daily wage of 408 Cedis would apply in cost benefit comparisons between Agroforestry interventions and the traditional farming practice. The models reflect the values of the traditional farming practice and demonstrate that under regional scarcity conditions shadow wage rates vary from a peak of 83 times the quoted market rate in January to a low of 1.79 times the quoted market rate in April may and September. The seasonality in the labour market requires system models to properly price scarce resources.

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[33] Tibaijuka (1994) shows this for small holder Banana and coffee farms in Kagera region Tanzania.

[34] Not relevant in this region because of remoteness, low population density and lack of transport.

Table 28: North C – Labour Scarce and Land Rich Scenario.

Individual Farm Model
Northern Ghana
Eco-zone Guinea Savannah

Northc labour scarce Land Rich

Objective:	Result	Sample	Resources	labour	Land
Cash surplus	Mcedis	HHolds	persons	adult equiv	ha crops
over subsistence	5.15	1	3	2	10.8

rewards	Per unit	MCedis	5.15	1.72	2.58	0.48

Livestock	Totals	fowls	cattle	goats	sheep
adult	Heads	15	0	5	2

Labour	Market	season	Jan-mar	April-may	june-aug	Sept	other
shadow	Ooo cedis	adult/hr	0.051	0.0915	0.1164	0.0915	0.051
quoted	0.408	adult day	0.408	0.732	0.9312	0.732	0.408
multiples of quote			1	1.79	2.28	1.79	1.00
hire	Males	Jan	Apr	until	august		oct-nov
hire	Females	Feb-mar				Sept	Dec

Commodity Markets				
shadow	prices	000 cedis	July max	Dec min
food	energy(MJ)		0.039	0.036
food	protein(g)		0	0

Optimal deployment of resources to maxincome after subsistence.					
Crop Rotation	plot no	1	2	3	4
		Yam	millet	cassava	cassava

Model	activities						
Plant	Eaten	Maize	Cassava	Groundnut	Sorghum		
foods	Bought	Maize		Groundnut	Sorghum		
	Sold		Cassava		millet	Yams	
Animal	Eaten		Milk				
foods	bought		Milk				
	sold	eggs			chicken	goat	lamb
Food from the wild (FFW) all sold							
Bushmeat							
season	available	April	may	June	July	Aug	Sept
season	hunted	yes	yes	***	***	***	yes
				no	no	no	
Fungi							
season	available			June	July	Aug	
season	gathered			yes	yes	yes	

Constraints are placed on cash flow in the models by insisting that income must exceed expenditure with a carry forward of unspent balances. Similar accounting practice is applied to field crop storage so that commodities can be traded into and out of store with one percent per month loss of weight. An additional constraint is that households do not trade in commodities that they have not produced.

A similar logic is applied to non crop commodities (animal products and food from the wild) but without storage and carry forward of stocks.

Diversity in the diet is prescribed with monthly intakes of prepared foods supplying between 30 and 40 times the WHO daily requirements for energy (MJ) and protein (g) described in their published tables. The results of the models show remarkable stability in the shadow price of the (MJ) between a min 36 and max 39 cedis due to the live storage of roots and tubers and the dry storage of cereal grains. Protein has zero shadow value demonstrating that if adequate energy is supplied there is an automatic oversupply of protein.

Diversity is achieved by marketing effort buying in maize, ground nut and sorghum selling yams, millet, cassava , rice and cashew. All animal products and FFW is sold except milk which is bought in by households without cows.

Table 29: North D – Land scarce and labour rich scenario.

Individual Farm Model
Northern Ghana
Eco-zone Guinea Savanna

NorthD land scarce labour rich

Objective:		Result	Sample	Resources	labour	Land	
Cash surplus		Mcedis	HHolds	persons	adult equiv	ha crops	
over subsistence		0.57	1	10	9	1.6	
rewards	per unit	MCedis	0.57	0.06	0.06	0.36	
Livestock	totals	fowls	cattle	goats	sheep		
adult	heads	5	0	3	0		
Labour	Market	season	April-may	june-aug	Sept	other	
shadow	ooo cedis	adult/hr	0.0915	0.1164	0.0915	0.05	
quoted	0.408	adult day	0.732	0.9312	0.732	0.408	
multiples of quote			1.794	2.282	1.794	1.000	
hire	males		apl	jun-july			
hire	females			may	Aug-Sept		
work	males		Jan-mar				
work	females		feb			oct-dec	
Commodity Markets							
shadow	prices	000 cedis	July max	Dec min			
food	energy(MJ)		0.039	0.036			
food	protein(g)		0	0			
Optimal deployment of resources to maxincome after subsistence.							
Crop Rotation	plot no	1	2	3	4		
		Yam	millet	cassava	cassava		
Model	activities						
Plant	Eaten	Maize	Cassava	Groundnut	Sorghum		
foods	Bought	Maize	Cassava	Groundnut	Sorghum		
	Sold	rice	Cassava		millet	Yams	
Anim	Eaten		Milk				
foods	Bought		Milk				
	sold	eggs			chicken	goat	
Food from the wild (FFW) all sold							
Bushmeat							
season	available	April	may	June	July	Aug	Sept
season	hunted	yes	yes	***	***	***	yes
				no	no	no	
Fungi							
season	available			June	July	Aug	
season	gathered			yes	yes	yes	

The crops grown are essentially the same across all farms but the aggregate model with a severe labour constraint introduces some second best crop alternatives rice and Cashew. Interestingly Cashew is the most widely adopted Agroforestry intervention in recent years indicating that it is competitive at the margin under scarce labour conditions. . The second best crops reduce the marginal value product of land from 402 000 Cedis per ha on virgin yam plots to 165 000 Cedis per ha on third and fourth year Cassava.

Providing lightly restricted access to the labour market both for hired labour at 408 Cedis and the sale of family labour at 400 Cedis raises the MVP of virgin Yam plots to 695 000 Cedis 361 000 cedis on three and four year old cassava regardless of the relative endowments of labour and land (such is the benefit of a flexible labour market).

The aggregate model which reveals massive fluctuations in the shadow wage rate has labour surpluses with zero MVP in Feb.- march and oct-nov. The individual farm models with their access to the labour market have the same high shadow wages in the summer April through September but without the massive peaks in December and January.

7.9 Modelling conclusions

Highly complex and subtle models have been developed of the traditional cropping systems in three selected regions of Ghana. The first stage of development highlighted the large amounts of information which is required to formulate such models. The minimum dataset for planning models is one of the most important outputs from the project.

The simplest models have been implemented sequentially from basic subsistence through more developed access to the market place. These have shown that as the market becomes more connected with the farm household system. Alternatives such as collection of food from the wild become an increasingly important source of income and labour is hired to free up the family labour used in such off-farm activities. In addition, the time required to transport and market surplus commodities is a large drain on resources used in the fields. Access to suitable labour markets which have been represented within the modelling sequence are not necessarily available 'on the ground'. It may be that because of low population densities and large travelling distances that at peak demand times in the year, there is no suitable labour market open to the farmers.

The multiple criteria models have shown that as financial returns increase, risk is increased. Risk reducing measures include the use of a variety of mixed crops. This is well matched by the farming strategies found in the fieldwork survey.

Although the traditional systems can be considered a form of temporal agroforestry, the interventions detailed in chapter 6 are not selected in the models. This is because when there is enough land for partial restoration of the soil nutrient levels and thus yields to near their starting point, the traditional systems have the most efficient use of the labour available. As land becomes relatively more scarce (under population pressure), it is at this point that the interventions become competitive and should be selected as better. The exact conditions under which a switch over should be made may require subsidy or intervention. This is because the slow degeneration of the traditional system causes increasing areas of cultivation and a reduction in fallowing period. This decreases labour productivity to such a degree that the stakeholders can not withdraw land from the system and invest in Agroforestry practices with no immediate food return. The appropriate form of subsidy might be expressed in staple food crops on a revolving loans system in a particular district.

The complexity of strategies discovered needed a much more complex approach to the modelling than has been developed by any research team (to our knowledge). It has only recently been possible to capture this complexity both in terms of computing power and suitable software development tools. The beauty of linear programming, however, is that once the simple key logic is understood, then complex multi-dimensional models can be understood. With this premise, LP, MCDM and Goal Programming offer much in decision support and policy analysis to both researchers and AF professionals in the developing (and developed) world.

8 Concluding remarks

8.1 *"The Agroforestry Ethic"*

Agroforestry is not one identifiable prescription more an approach or ethic – i.e. that of actively incorporating trees and tree products into the farming system with the aim of providing some level of net benefit to the land-user. Set within this broad-brush framework are a multitude of different technologies, techniques and intervention packages which have been tested in a variety of countries, both on-farm and on-station. Within each package or intervention, there is a further layer of complexity in spacing, species selection, vertical architecture and so on. Add in to this 'boiling pot' constraints, goals, needs and wants dictated by the current local natural, social, economic and political environments, finding relevant, practical and pragmatic solutions to land-use development problems becomes increasingly difficult.

8.2 *"Greater understanding of current practice paves the way for further development"*

In addition, this project has elicited some of the complexities of the local farming systems. Inter-cropping of two and commonly three crops is regularly practiced. The specifics and diversity of crops varies with location and historical precedent. It is also paramount to recognise the traditional bush-fallow system as a sequential or temporal Agroforestry system and that only a recent product of population and tenure pressures has led to the increasing breakdown in this system. In other words, Ghanaian farmers are exceptionally good agroforestry practitioners who have a multitude of insights about their natural environment, which we (as responsible researchers) must respect, value highly and most importantly come to understand and 'take on-board'. Greater understanding of existing practice is a precondition for development of an advisory tool by **user groups**

8.3 *"Coping with complexity"*

In answer to a recent criticism at a conference:

"Mathematical programming has been in the research arena since the 1950s, why is it that LP/MCDM is not more widely used, particularly in the developing world?"

The response was:

"As a product of the 'Age of Information', the necessary computing power has only recently become available where models can be built which come close to an acceptable level of complexity in the realism/processing time/transparency trade-off. Only now are we beginning to realise fully the capabilities and potential of a well-developed but under-utilised modelling paradigm. Historically, mathematical programming has suffered from a lack of understanding, difficulties in matrix construction and data management, a wealth of jargon, and because of the restricted supply of trained personnel and access to necessary hardware, [mathematical] modelling has tended to remain within the realms of a small set of experts. However, with the advent of the personal computer, and more easily understood and well-designed general user interfaces, there is a real opportunity to develop software [indeed this is already happening] which will allow the use and application of mathematical modelling to be carried out by a much wider range of users."

This project has taken the first tentative steps to capture the complexity of the Ghanaian smallholder farmer. The data base derived from the survey serves as a platform for running simulation models of fieldwork practice. Templates of biophysical input output coefficients are complemented with household data to complete an integrated model of a farm household. With the development of these models it has been possible to demonstrate that mathematical programming can be used to assist in the solution of complex every-day decision making problems. In addition, these computer-based tools can help in the design, planning and selection stages of AF technology interventions.

The output of the models is a logical consequence of the model architecture and input parameterisation. A critical analysis of the model was made at the workshop (July/August 1997). The collective feeling of the participants was that this would be a very useful way of handling the design and planning problems faced by the AF professionals and extensionists.

8.4 *"A Need for Aptitude and Training"*

At present there is a significant lack of trained Ghanaians who would be in a position to immediately utilise the multiple objective models. However, out of 25 local AF researchers and professionals gathered for the workshop more than half attended sessions demonstrating the use of ITEs biophysical models and 12-15 people attended sessions in simple Excel-based LP modelling. The participants showed a keen aptitude for these modelling techniques and were able to assimilate new technologies at a very rapid rate. An intensive programme of training workshops would empower a group of local researchers to become proficient enough to move on to the more complex Xpress MP models. The shift from Excel to Xpress is not only one of complexity, but also the need to understand a generic language for writing the program structures. However, the separation of model from data within xpress makes the input transparent, facilitates data checking and matrix manipulation easier.

One of the products of the workshop was a first draft of a self-teaching manual on using Excel for linear programming. This manual collates the material generated by the workshop, and works through a series of four simple models illustrating the LP paradigm; showing how activities (variables) are linked to the constraints. The manual also develops the LP through a series of steps to the beginnings of multiple objective models. In each section, an explanation of the type of information is provided, the model developed, and the output given and described. Within Ghana, there are a variety of teaching, governmental and non-governmental organisations, which could directly benefit from the application of such a teaching tool.

ITE in collaboration with ICRAF and IERM have run workshops in the UK and Kenya which have proved successful in training researchers and extensionists in the use of the AMP biophysical models. This workshop package could easily be developed for use in Ghana particularly with the support of IRNR at Kumasi.

8.5 *"Participation facilitates understanding and uptake"*

Further developments in the models and subsequent creation of a full decision support system must now be carried out hand-in-hand with the local institutions and relevant personnel. Without their vital input, the models will once again be assigned to the shelf as 'a sounds very impressive – but what is linear programming anyway' tag. Indeed, the only hope for any computer-based tool to be taken up and used by the local researchers and extensionist must lie in their ability to sell the product to their own financiers, colleagues, peers and ultimately customers (farmers). Thus, any necessary marketing effort for products of research will be greatly reduced if the whole process of design and development is made transparent to the end-users.

8.6 *"What to Extend?"*

Not withstanding, it is important at the close of this phase of the project to emphasise the possibilities for this modelling paradigm particularly when linked up with biophysical models of crop/tree growth and yield. As was pointed out by one of the extension workers at the workshop:

"There is no point to having an extension service, if you have nothing to extend"

It is this constraint which must be addressed if there is to be any hope of uptake of AF interventions. Indeed, this comment raises a collection of important key questions:

1. how do we empower the local AF services to provide for the needs of the end-point beneficiaries;
2. what advice and information should they be extending;
3. How can we (as outsiders) help in this process?

One real way of benefiting farmers in the field is to (assuming there is an enabling environment for the extension sector) empower the extensionists to deliver reliable and sound management advice, which is rooted in the local farming system - not to provide generally accepted AF norms. The emphasis must be to use local systems and crop/tree species/varieties with which the farmer will have most affinity and understanding. Our models coupled with AMP biophysical models will be able to deliver just this kind of planning information to the extensionists and thus the farmer.

8.7 *"The Extension Service in Change"*

At present in Ghana, the Ministry of Food and Agriculture is undergoing a decentralisation process. Power, funding and control is being shifted from central government to the district assemblies. Each district has an appointed District Agroforestry Officer who is responsible for the extension, research and development in his/her district. The central Ministry will still retain control over national policy and much of the information which is being disseminated but the District Agroforestry Officer will be answerable ultimately to the local District Assembly and not the Ministry through the Regional Agroforestry Officer as before.

This process is partly complete. The ministry retains funding and policy control at present but this will be reduced to policy control alone in the near future. This shift in emphasis from the national to the district level will provide local government with more control over resources and resource deployment. Decision support systems which this project have shown as a realistic goal will become more and more needed by these local governmental organisations to assist in the complex deployment of public funds, policy measures and pertinent information and developments.

8.8 "Enabling attitudes towards Agroforestry"

There is a lack of surveys, which account for attitudes towards trees and agroforestry particularly from the important perspective of the farmer. Amanor has carried out significant work in Ghana and the IRNR holds over 30 MSc theses in agroforestry, which would prove useful. One of the keys to successful uptake is the acceptability of novel technologies. The modelling systems developed will be able to play a key role in flexing technologies to local needs and wants.

8.9 "Flexibility is the key"

Uptake will be greatly improved if the models, dissemination strategies, and ultimately AF technology packages remain flexible. This flexibility is vital because it allows local peoples to express their preferences within the framework. For example, the incorporation of a locally used tree species within a developed technology would reduce the effort required to instruct the stakeholders in its use, care and product capabilities. Exotics although may seem superior to the outsider researcher are often too alien to be of use to local farmers, many of whom have invested large amounts of time and developed a system of tree management historically for their native species.

In addition to the technologies developed on the ground, the modelling systems (and ultimately DSS) must be flexible to be able to cope with changing circumstances both through time and space and to allow for the inclusion of local ways of life. This will be the key to adoptability by local institutions of such a DSS – if they can mould the product to their particular specification. With the modelling paradigm presented herein, there is a real possibility of achieving this aim. In the future, when the models are linked in a DSS, the GUI will allow the user: to manipulate all of the parameters within the modelling system and indeed; and access to the underlying code so that all parts of the model can be scrutinised and altered according to their local knowledge.

8.10 "Validating and Proving the Technology"

It has been demonstrated that the model functions in a superior way to other more financially based economic tools. System models have been used for comparison against existing cost benefit analysis (CBA) in which day-to-day activities are costed but not planned. The level of planning detail in the system models reveals the reasons why existing cost benefit software packages are unable to make legitimate comparisons of real systems for decisions on the adoptability of alternative agroforestry practices for smallholders and provides a new standard for comparison of alternatives.

Biophysical models in themselves only generate information. The LP/MCDM paradigm is required to harness the information system and drive it to find solutions that are in some sense optimal of the goals, values, and aspirations of the stakeholders.

Models at the farm level can be aggregated to a local district level to reveal the carrying capacity of the system, the extent of marketable surpluses of produce and the marginal value productivity of scarce resources. At regional level for a limited range of crude supply, demand balance predictions in the context of adequate census data.

8.11 "Information Flows and Monitoring Systems"

The workshop revealed the full extent of the lack of information flow monitoring current agricultural productivity and pricing, particularly in the livestock sector. The workshop also identified the need for improved standards of information reporting in respect of date and location, so that the spatial and temporal dimensions can be fully utilised in future work. Particularly if this can be linked to the interpretation of satellite imagery and prediction of environmental and micro climatic impacts arising from the scale effects in the practice of farming systems.

In the wider context, there are a variety of existing dissemination networks which could be tapped – ADDS and FEWS at the USGS, FAO databases and information networks, AFRENA, HULWA, ANAFE and CORAF to name but a few. However, at the local scale, there is a significant lack of monitoring infrastructure to allow local feedback of information and resource decisions. The modelling proposes the format for a minimum dataset. This could form the basis for a new method of reporting, collecting and disseminating project success and information.

8.12 "The Computer Revolution"

It is pertinent to draw the comparison that as recently as 15 years ago users of computers required a high level of programming skills to be able to access their hardware. However, nowadays virtually all sectors rely on computers (both PCs and Macs), yet the majority of computer owners/users do not have any idea of how to program. There is an implicit statement in the definition of a decision support system – that of providing a sound general user interface (GUI) to facilitate the use and understanding of the underlying model(s). A good user interface will also allow the 'adventurous' to explore the inner working of the system

8.13 "The Internet and World Wide Web"

Currently there are nine Internet Service Providers (ISP) in Ghana. Of these the three most prominent ones are: Network Computer Services – www.ghana.com; Africa Online Ghana – www.africaonline.com.gh; Ghana Internet Service – www.internetghana.com. In total there are only 4500 Internet users but a much wider subscription to email only accounts. Generally in Africa, the cost of access is high with an average monthly cost of $58. However, with the current expansion rates these costs should begin to drop. In addition to the restrictively high costs most of the ISPs access points are provided for in the capital cities. In Ghana, there are now local access points in Kumasi and Tacoradi as well as the capital Accra. International access is currently one of the fastest in Africa, running at speeds of over 640Kbps.

The Internet is expanding exponentially in Ghana with new initiatives beginning regularly sponsored by the Government, International Agencies and the private ISPs (information from www.webstar.com.gh). At present, the research and university sectors are poorly represented on the web with only a few of the institutions having web sites. A similar situation is reflected in the governmental agencies and ministries with only two ministries have a web presence – however, there is a good overall governmental site (www.ghana.gov.gh).

There is a lack of telecommunications infrastructure, which is hindering the development of regional Internet access points. The Ministry of Communications has recently announced the licensing of a second telecommunications company, which will serve to enhance the existing system. As well as the land line network, there is a fairly well developed cellular network covering the major cities including Kumasi and Tamale, but call costs are high.

8.14 "And Finally"

To sum up, the project has achieved its goals and presented a framework for local and regional planning which can be of use both in Ghana and beyond – the methodology developed could be used for a variety of planning scenarios.

Chapter 4 outlines the major activities of the project in the field and highlights the need for baseline data from which enlightened comparisons can be made. The collection and analysis of this baseline data consumed a significant part of the project's labour time. Chapter 5 of the report has presented a summary of the basic data on the current practice of the local farmers which is needed to formulate a cohesive understanding of the local systems – a prerequisite for any future operational planning and implementation of suitable alternative technologies. Chapter 6 outlines the inadequacies of traditional financial appraisal techniques, particularly when applied to complex smallholder systems. Chapter 7 develops the linear programming framework for decision support through from the simplest models to the more complex multiple-criteria models which allow for an analysis of, and optimal solution to, complimentary and conflicting multiple objectives. It also proposes the level of informatics (minimum dataset) which is required for planning support and how this can be utilised as input to the modelling framework.

Further research must be on the integration of computer based technologies coupled with local development of suitable AF solutions, which can then be further refined through testing both on-farm and on-station. These solutions must be site specific – thus the integration with a GIS based approach would seem appropriate. Techniques must be developed to cope with the lack of historical data such that sensible and sensitive decisions can be made. Biophysical models can now provide the much needed information about crop growth, yield and, vitally, variability. This output data can be used in the LP framework as input parameters to assess the optimal resource deployment at the local or regional scales.

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