DEPARTMENT FOR INTERNATIONAL DEVELOPMENT
STRATEGY FOR RESEARCH ON RENEWABLE NATURAL RESOURCES

NATURAL RESOURCES SYSTEMS PROGRAMME
FINAL TECHNICAL REPORT

DFID Project Number

R7560

Project title

Review of technologies being evaluated for the Forest/Agriculture Interface

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Organisation

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NRSP Production System	*Date*
Forest/Agriculture Interface	Sept 18, 2001

1. Executive Summary

Provide a brief summary of the purpose of the project, the outputs of the project, the research activities and the extent to which the OVIs at purpose level were achieved. The contribution of the project towards attainment of the NRSP purpose (refer NRSP programme logframe) should also be assessed. (Up to 500 words).

The purpose of the project was to step back and make a thorough evaluation of the various techniques which have been proposed to ameliorate the decline in productivity of the shifting cultivation systems predominant in the Forest/Agriculture Interface (FAI). In this way, the project was intended to contribute to the process of making research by institutions in target countries more relevant to the needs of farmers in FAI production systems. In turn this should help to improve the livelihood security of farmers through improved land use.

The outputs of the project were (1) an enhanced understanding of the biophysical and socio-economic conditions required for success of techniques for stabilisation of the soil and vegetation resources of the FAI, and (2) dissemination of the findings of the review.

Enhanced understanding was from a detailed analysis of the ability of the techniques to address the constraints to increased production of soil fertility and weed encroachment, as well as socio-economic constraints to their adoption by farmers. Cases where farmers had adopted some of the techniques were also examined, and suggestions for future FAI research were made. Dissemination of these results was in the form of a 220-page review, two trip reports, and a web-based searchable database containing information on biophysical and input requirements of each technique (http://www.cranfield.ac.uk/iwe/fai.htm).

The research activities consisted of in-country visits to Nepal and Ghana by members of the team (Dr Robin Matthews, Dr Kevin Waldie, and Mr Anil Graves) to meet with researchers involved in research on FAI-related issues. Subsequent research activities consisted of collating the information from these interviews, reviewing published international literature and other sources collected during the country visits. A database summarising this information in Microsoft Access was constructed, and a web-site containing all project documentation and the database was developed using Microsoft FrontPage.

Purpose level OVIs were (1) the availability of ways for research institutions in FAI target countries to improve technical research design for the FAI, and (2) the use by NRSP of the research findings in subsequent research calls for the FAI in NRSP target countries. The project has contributed to achieving these through a thorough review of the biophysical and socio-economic characteristics of the various techniques being evaluated in previous DFID FAI projects, including an analysis of cases where some of the techniques have been adopted (e.g. cover crops). Tools for evaluating which techniques are likely to be successful have been developed. Suggestions for future FAI-oriented research were made at the end of the review. The results of the review should, therefore, help to focus future research away from those techniques that are likely to have only limited impact. The highlighting of the diversity of farming systems at the FAI should also help to target research more efficiently.
The project contributes to the NRSP purpose of delivering new knowledge to enable poor people, dependent on the NR base, to improve their livelihoods by identifying the conditions under which low-input techniques of intensification are likely to have a positive benefit, and therefore be taken up by farmers.

2. Background

Information should cover a description of the goal to which the project sought to contribute through addressing a researchable constraint or opportunity. How the research builds on previous work to derive 'new knowledge' and how the demand for the project was identified should also be explained.

The goal that the project sought to contribute to is the development and promotion of strategies to secure the livelihoods of poor people dependent on agricultural systems near the receding forest margin. Previous DFID research in the FAI has focused on three regions - the margins of the high rainforest in South America (Brazil and Bolivia), and the more densely populated forest margins in West Africa (Ghana) and Asia (Nepal).

In Ghana, Bolivia and Brazil, the forest-agriculture interface (FAI) is characterised by rapid changes in land use following conversion of forest to agriculture, with problems related to the sustainability of the new land use arising due to remoteness, lack of social & agricultural services, absence of capital to finance inputs or improvements, and difficulties in marketing produce. Consequently, these systems are characterised mainly by shifting cultivation, in which itinerant farmers clear natural woody vegetation from plots of land to plant crops. Farming continues for a few years until the soil fertility declines, when the plot is abandoned and the farmers move to a new location where the cycle is repeated. After some time, when natural fallow has restored some of the fertility of the original plots, they may again come under cultivation. However, in many parts of the world, a steadily increasing population is increasing the pressure on these traditional cultivation systems, resulting in a move towards longer cropping periods and shorter fallow periods. This, in turn, is causing a build-up of weeds and other pests, and incomplete restoration of soil fertility before the cycle restarts. Moreover, losses of soil organic matter and nutrients are often high just after the initial clearing, and inappropriate soil conservation practices during the cropping period can lead to further losses of soil fertility through leaching, erosion, and structural deterioration. The situation is often further complicated by the fact that most shifting cultivation is practised by disadvantaged social groups who do not have permanent rights to land, and as such have little incentive to expend the extra effort required to develop more sustainable systems. In Nepal, the forest/agriculture interface is characterised by more settled agriculture, but there is increasing pressure placed on the sustainability of the system by the growing population, and the increased flow of nutrients from forested to cultivated areas.

Projects commissioned in the first phase of NRSP have addressed specific techniques relating to soil fertility and interactions between crops, livestock and agroforestry. These techniques have included cut and carry grasses (R6382, R7412), leguminous cover crops (R6382, R7412), agroforestry (R6382,R7412), green manures (R6789), animal manures (R6789), crop rotations (R7412), relay cropping (R7412), forage alleys (R7412), mulches (R7412), fast growing timber (R7412), perennial crops (R6382), and legume tree species in short-term fallows (R7056). These techniques have been tested by selected farmers participating in the projects, and possibly by neighbouring farmers. However, to date, wider uptake has been generally poor. It has been assumed that this is due to inadequate attention to promotion pathways and dissemination, although there is also some concern that a number of these techniques may not actually 'work' as claimed in every environment.

There was a need to temporarily step back from this research and to make a more strategic appraisal of the value of each of these techniques and where and under what biophysical and socio-economic conditions they are likely or not likely to be successful. Demand for the project, therefore, arises from the concern expressed in NRSP documentation that there may be fundamental reasons for the lack of uptake of the techniques.

The project does not aim to generate new knowledge, but rather to analyse and synthesise existing knowledge on techniques being evaluated for forest/agriculture interface production systems, with a view to enhancing understanding of the biophysical and socio-economic constraints to the adoption of the techniques, and from this analysis to make suggestions for future FAI research.

3. Project Purpose

Describe the purpose of the project and what changes it was intended to achieve.

The purpose of the project was to step back and make a thorough evaluation of the various technologies proposed as ways of ameliorating the decline in productivity in the shifting cultivation systems predominant in the Forest/Agriculture Interface (FAI), with a view to making future FAI research more relevant to farmers' needs. Much previous research had focused on biophysical constraints to intensification at the FAI, such as soil fertility and weed control, but few of the techniques evaluated in previous projects had been taken up by farmers. It was intended that, if necessary, the project would result in a change in focus of research planners to concentrate further research only on those techniques that have a greater likelihood of improving the livelihoods of FAI farmers. This was to be done, firstly by determining which techniques had potential to address biophysical constraints identified in FAI systems, secondly, by identifying socio-economic constraints to their adoption by farmers, and thirdly, in the case of techniques that had already been adopted by farmers, by identifying the reasons for their adoption.

4. Outputs

Describe the research results achieved by the project. Comment on whether all the anticipated outputs were achieved and if not, what were the reasons? Suggest what else needs to be done to take the research results forward.

Research results should be presented comprehensively and concisely using tables, graphs or sketches as much as possible rather than lengthy writing.

We attempt to summarise below the contents of the main review contained in Annex A. Obviously, we cannot include all the material in the review, and the reader is advised to read material in the Annexes together with this FTR.

Several techniques have been researched as possible technical solutions to declining productivity at the FAI, including alley-cropping, biomass transfer, cover crops, multi-purpose tree species, animal manure, *Tithonia diversifolia*, improved and enriched fallows, and legume intercrops. To analyse them generically, we grouped the techniques into those dealing with soil organic matter management, nitrogen management, phosphorus management, and weed control. We also considered socio-economic aspects of each technique.

The review suggested that many of the techniques may in themselves be insufficient to prevent the decline in productivity experienced upon clearing the land of secondary vegetation. The following are some of the major issues.

Biomass quantity

Large quantities of biomass are required to develop soil physical structure, and supply N and P for crops. Young (1989) estimated that about 8.4 t DM ha^{-1} y^{-1} was required for humid regions, 4.2 t DM ha^{-1} y^{-1} for sub-humid regions, and about 2.1 t DM ha^{-1} y^{-1} for semi-arid areas (Table 1). Within the constraints faced by resource-poor farmers, such quantities of plant biomass may be difficult to supply.

Table 1: Estimated inputs of plant biomass required for the maintenance of soil organic matter in various climatic zones.

Climatic zone	Initial topsoil carbon (%)	Oxidation loss (kg C ha$^{-1\ yr-1}$)	Erosion loss (kg C ha^{-1} yr^{-1})	Required addition to soil humus (kg C ha^{-1} yr^{-1})	Required plant residues added to soil (kg DM ha^{-1} yr^{-1})	
					Above ground	Roots
Humid	2.0%	1200	400	1600	8400	5800
Sub-humid	1.0%	600	200	800	4200	2900
Semi-arid	0.5%	300	100	400	2100	1400

(Araki, 1993).

Similarly, the quantity of biomass required to supply adequate N and P for crop needs is also high. Table 2 shows the amount of dry and fresh biomass required to supply specifies quantities of N using *Tithonia diversifolia* and cattle manure.

Table 2: The required dry weight and fresh weight amounts of Tithonia diversifolia *(3.5% N dry matter content) and cattle manure (1.5% N dry matter content), assuming a 25% recovery rate of N by the first crops (Giller & Cadisch, 1995), 80% water content of fresh* Tithonia *biomass, and 60% water content of fresh manure. Adapted from Jama* et al. *(2000) and Lekasi (1998).*

Crop N removal (kg ha^{-1})	**N application requirement**	**Dry biomass requirement (t ha^{-1})**	**Estimate fresh biomass requirement (t ha^{-1})**
Tithonia diversifolia			
25	100	3	15
50	200	6	30
75	300	9	45
100	400	12	60
Cattle manure			
25	100	7	17
50	200	13	33
75	300	20	50
100	400	27	67

Tithonia diversifolia in biomass transfer techniques has been suggested as a means of supplying P. However, biomass requirements are once again large (Table 3). It may be very difficult for farmers to access such large quantities of biomass, particularly as this necessitates the devotion of large quantities of scarce resources such as labour, land and possibly time and capital. Shifting cultivation and other long fallow techniques may continue to be relatively attractive, particularly where land is available and labour is limiting.

Table 3: Tithonia *biomass requirements based on various levels of P fertilisation assuming a mean P concentration of 0.37% in the dry matter, and a dry matter content of 15%.*

Phosphorus requirement (kg ha^{-1})	Dry biomass requirement (t ha^{-1})	Fresh biomass requirement (t ha^{-1})
5	1.4	9.0
10	2.7	18.0
15	4.0	27.0
20	5.4	36.0
25	6.8	45.0
30	8.1	54.0
35	9.5	63.1
40	10.8	72.1
45	12.2	81.1
50	13.5	90.1
55	14.9	99.0

Developed from data in Jama *et al*. (2000).

Biomass quality

The use of many of the organic matter techniques is greatly complicated by the issue of biomass quality and the subsequent effect that this has on nutrient release dynamics and the appropriate use of organic matter (Table 4). The slashing and burning of vegetation may bypass many of these problems, as it may provide a rapid release of nutrients from relatively low quality organic matter (it is worth noting that much N is lost when vegetation is burnt). Immobilisation of N and P may result where low quality organic matter is used and this may actually reduce crop yields.

Table 4: Possible technical options for organic matter of varying quality. The table indicates critical levels of N, P, lignin and polyphenols required for good quality biomass. (Developed from the Organic Resources Database (Mafongoya et al., 1997; Gachengo et al., 1998)).

N > 2.5%	**P > 0.25%**	**Lignin < 15%**	**Polyphenol < 4%**	**Comment**
✓	✓	✓	✓	**Green manure** High quality organic matter could be used as a green manure.
✗	✓	✓	✓	**Integrated nutrient management** Low levels of N, P or N and P may cause net immobilisation of N, P or both N and P. If incorporated immediately, use with N, P or both N and P fertiliser. Alternatively mix with very high grade organic matter to compensate for low N, P or N and P levels.
✓	✗	✓	✓	
✗	✗	✓	✓	
✓	✓	✓	✗	**Compost/soil physical improvement** High levels of lignin and polyphenol may encourage immobilisation of N and P or reduce the rate of mineralisation despite high levels of N and P in the organic matter. This organic matter may be composted to start the breakdown process
✓	✓	✗	✓	
✗	✗	✗	✗	**Surface mulch or erosion control** Low levels of N and P and high levels of Lignin and Polyphenol make this organic matter unsuitable for use as a fertiliser technology. It may be used however as a surface mulch to protect against evaporative losses or to control surface water flow.

Biological nitrogen fixation

Estimates of N fixation by legumes vary considerably from place to place and from species to species. However, most of the literature indicates that legumes are not able to fix sufficient quantities of N to maintain a main crop within farmer resource constraints (Table 5).

Table 5: BNF estimates for a various countries in Africa. (Source: Dakora & Keya, 1997).

Legume species	**Country**	**BNF (kg N ha^{-1})**	**Reference**
Food legumes			
Soybean	Nigeria	15-125	Eaglesham (1982)
Cowpea	Kenya	24-39	Ssali & Keya (1984)
	Ghana	201	Dakora *et al*., (1987)
	Nigeria	122	Ealesham *et al*., (1981)
Groundnut	Ghana	32-134	Dakora (1985a)
Common bean	Kenya	17-57	Ssali & Keya (1986)
Bambara groundnut	Ghana	40-62	Dakora (1985a)
Tree and Shrub Legumes			
Leucaena	Tanzania	110	Hogberg & Kvarnstrom (1982)
	Nigeria	448-548	Sanginga *et al*., (1985)
	Nigeria	304	Danso *et al*.,
Sesbania rostrata	Senegal	505-581	Ndoye & Dreyfus (1988)
Sesbania sesban	Senegal	43-102	Ndoye & Dreyfus (1988)
Gliricidia sepium	Nigeria	108	Danso *et al*., (1992)
Albizia lebbeck	Nigeria	94	Danso *et al*., (1992)
Acacia holosericia	Senegal	36-108	Peoples & Herridge (1990)

Factors affecting P management

Nutrient mining may be a problem in areas that are intensively used for mobilisation and transfer of nutrients, leading to the possibility that the farmer has to apply nutrients to the growth of the biomass source to obtain sufficient quantities. This has been noted in cut and carry techniques, for example. Where the quantity of P, in plant biomass or in animal biomass is low in the applied biomass, there is the danger that there may be a net immobilisation of P, as micro-organisms multiply to breakdown the organic matter. It is therefore important that the quality of organic matter applied as green manure be sufficient to enable net mineralisation of P. Soluble P is rapidly adsorbed by soil and organic matter particles, making it unavailable to plants. The *p*H of the soils can have a significant impact on the availability of soluble P. The optimum *p*H for P solubility is between 6 and 7. Where *p*H is below 6 or above 7, there is a tendency for P to become unavailable to plants, either through reaction with silicate material, fixation by hydrous oxides, or fixation by calcium phosphates. In many tropical areas, acidity may limit the release of soluble P made available through plant or animal biomass. The success of providing P through plant or animal biomass may to some extent depend on the texture of the soil to which it is applies. Where soils are very clayey, the recovery of added P tends to be low. Where the clay content of the soil is low, the recovery of added P tends to be higher. Labile P appears to be more mobile in lighter textured soils, and it may be difficult for farmers on very heavy textured soils to derive the same level of P benefit as farmers on lighter textured soils using the same quantity of organic P input.

Weed management

Farmers at the FAI traditionally use a combination of manual weeding, long fallow rotations of secondary vegetation, and fire to control weed development. Weeds may contribute more to causing crop yield reductions than declining soil fertility levels, and are a major reason why FAI farmers bring new areas of land into cultivation. In the projects reviewed, the use of cover crops in various combinations helped to control the density of weed populations and weed biomass, but had no practical significance on subsequent crop yields (Table 6). Even the use of integrated weed management at farmer input levels did not always result in weed suppression effects that would allow continuous and sustained cultivation (Table 7).

Table 6: Effect of Canavalia ensiformis*,* Mucuna pruriens*,* Mucuna nivea*, and* Dolichos lablab *and a weedy fallow on seedling emergence, total dry biomass and grain yield in Bolivia (Source: Southgate et al., 1999).*

Winter cover crop	**Seedling emergence (plants m^{-2})**	**Total dry biomass ($g\ m^{-1}$)**	**Total dry grain yield ($g\ m^{-1}$)**
Weedy fallow	19	68	27
Canavalia ensiformis	77	404	162
Mucuna pruriens	59	260	112
Mucuna nivea	72	403	174
Dolichos lablab	40	130	52
S.E.D	14	55	21
F test probability	$P<0.01$	$P<0.001$	$P<0.001$

Various problems are associated with the use of cover crops in weed control. They may fail to compete effectively with the weeds or they may fail to provide sufficient spatial and temporal coverage to make a significant contribution to weed population decline. Conversely, and especially when used as intercrops, they may end up themselves competing excessively with the main crop for environmental resources and thereby reducing main crop yields.

However, there is evidence that integrated strategies involving cover crops, herbicides and burning, were able to control *Imperata contracta* in banana plantations after 2-3 years. Also, reports from other countries (e.g. Uganda, Honduras, Benin) indicate that cover crops alone can be successful in reducing weed populations and increasing crop yields, especially where farmers can rotate the land and give sufficient time for the cover crop to control weed populations.

Table 7. The effect of weed development on the yield of rice (kg ha^{-1}) under integrated weed management strategies at typical farmer input levels (Source: Pound et al., 1999).

	Site 1		**Site 2**	
Treatment	**Year 1**	**Year 2**	**Year 1**	**Year 2**
1	4045	2234	2585	1131
2	4073	2219	2600	1025
3	4423	2571	2751	1149
4	4107	2468	2650	1041
5	4547	2681	2789	1259
SED	88	117	58	84

Socio-economic issues

Organic matter techniques often do not provide sufficient benefit when used within the land and labour constraints that face most resource-poor farmers. Many of the techniques, despite being low input, require some capital for mobilisation of fertilisers and labour. Due to the large quantities of biomass required to supply N and P and improve soil physical conditions, many of the techniques are very labour demanding. As an example, Table 8 provides an estimate of the labour requirements for the use of *Tithonia* biomass.

Table 8: Estimated labour requirements for the harvesting of Tithonia *biomass required to supply various levels of P, assuming a harvesting capacity of 120 kg FW day^{-1}.*

Phosphorus requirement (kg ha^{-1})	**Green biomass requirement (t ha^{-1})**	**Labour requirement (days ha^{-1})**
5	9.01	75
10	18.02	150
15	27.03	225
20	36.04	300
25	45.05	375
30	54.05	450
35	63.06	526
40	72.07	601
45	81.08	676
50	90.09	751
55	99.10	826

Developed from ICRAF (1997) and Jama et al. (2000).

Large quantities of biomass require large areas of land (Table 9). By definition, resource-poor farmers are often unlikely to have this, except as a common resource. Where resource poor farmers do have relatively large quantities of private land, it is more profitable to grow a main crop over the whole area at low input-output level, than to turn most of it over for the purpose of biomass production in order to produce intensively on a smaller area of land. Resource poor farmers often lack security of tenure over land, as they may share-crop, rent or have usufruct rights only, which precludes investment in long term issues such as soil organic matter improvement.

Farmers may also discount the value of future benefits derived from using organic matter techniques at a high level, making the introduction of new techniques difficult to implement. This may be partly related to the difficulty or ease with which they may access credit, but may also be influenced by various other factors, for example, insecure tenure (Nelson *et al.*, 1998), or lack of access to assets, reflecting their own inability to consider long-term benefits in such circumstances. Nelson *et al.* (1998) used the APSIM model to simulate the NPV of alley cropping with two different alternatives, open field and fallow rotation at two different discount rates, 10% (Figure 1a) and 25% (Figure 1b). The 10% discount rate, reflected the supposed cost of borrowing credit under state supported schemes (Nelson *et al.*, 1998). At this discount rate, cost benefits analysis showed that the estimated benefits derived from reduced erosion and improved sustainability from the alley-cropping system would eventually cause its NPV to exceed the NPV of the two alternatives, making it more attractive in the long run (Nelson *et al.*, 1998). But farmers would have to wait at least four years for alley-cropping to become a viable alternative to the open-field system. Additionally, farmers would require at least a twenty-year planning horizon before the prospect of negative NPV from the open field system discouraged its use.

Table 9: Estimates of the amount of land required to supply a crop extracting 100 kg N ha^{-1} and assuming a 25% recovery rate of applied N. (Total N application requirement = 400 kg N ha^{-1}).

Plant	N fixation ha^{-1}	Land area (ha) required to supply 100 kg N ha^{-1} to a main crop	Source
Biological Nitrogen Fixation			
Alfalfa	200	2.0	(Brady, 1990)
Clover	125	3.2	″
Soybean	75	5.3	″
Cowpea	75	5.3	″
Lupine	75	5.3	″
Vetch	87.5	4.6	″
Bean	40	10.0	″
Calapogonium mucunoides	64	6.3	(Giller *et al*., 1997)
	126- 182	3.2 - 2.2	″
Centrosema pubescens	67 - 136	6.0 - 2.9	″
	80 - 280	5.0 - 1.4	″
Gliricidia sepium	170 - 204	2.4 - 2.0	″
Leuaceana leucocephala	76 - 274	5.3 - 1.5	″

The incentive to produce more than subsistence yields is reduced where access to markets is limited by inadequate transport infrastructure. Evidence suggests that organic matter technologies are more likely to be adopted in areas like the peri-urban interface where high value perishable products (like vegetables and milk) make the extra investment of labour and capital worth while. Expending extra inputs of capital, labour and land is irrational, if current methods secure food at subsistence levels and surplus cannot be marketed or exchanged. Where transport infrastructure provides efficient and reliable connections to markets, farmers will often respond by increasing production and use the techniques and resources required to do this. However, markets also do not always respond in a way that supports investment by small farmers. An increase in food availability, for example because of good weather, serves merely to drive down prices. As there are many farmers supplying produce with relatively few outlets, they are vulnerable to exploitation by marketing agents and middle-men.

There are also competing demands for the use of certain resources. For example, fertility enhancement through animal manure precludes the use of that manure as a fuel. The growth of hedges to provides biomass for fertility, precludes the use of the hedge area for crops or for fodder, factors that may well be more urgent than the build up of soil fertility. Certain techniques may not be used by farmers because they are thought to increase pests. Cover crops may provide an environment that allows multiplication of pests that are harmful to crops or the farmers themselves, in the case of rats, snakes and scorpions that are harmful to the farmer.

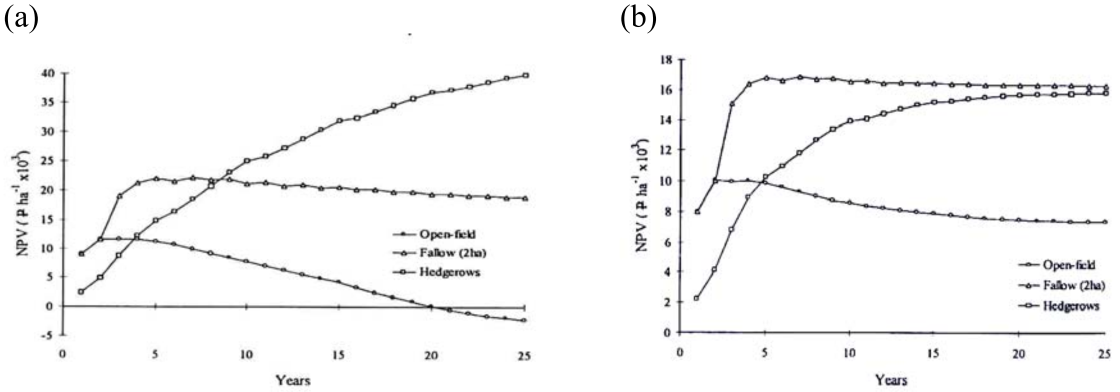

Figure 1. The effect of (a) a 10% discount rate, and (b) a 25% discount rate on the NPV of open field, fallow and hedgerow intercropping systems. Where farmers have to borrow credit to make use of new technologies, such considerations may influence their future perceptions and planning horizons. Insecurity may also make them discount the value of new technologies at relatively high levels, diminishing the future benefits of those technologies (Source: Nelson et al., 1998).

Summary

The general weight of evidence suggests that these techniques are not sufficient in themselves to maintain productivity at a level that might make a practical difference to farmers' livelihoods. Continuous and sustainable agriculture may be extremely difficult with the use of these techniques alone, and farmers may continue to use long fallow techniques, especially where land is available for this. However, evidence suggests that farmers do adopt techniques, but not always for issues related to fertility enhancement. Thus, potential improved interventions should be evaluated on their ability to meet farmer perspectives such as increased food security, improved cash generation, reduced risk, and enhanced quality of life, rather than researchers' perspectives of improved soil fertility or weed control. In Table 10, we have attempted to classify the techniques we reviewed into categories more closely related to farmer perspectives.

Table 10: Possible classification of FAI techniques and practices according to likely farmer perspectives.

Problem being addressed	**Technique**	**Possible reasons for adoption**
More food for the household	Improved varieties	Better yields
	Intercropping	Better yields?
	Cover crops	Extra crop, better following main crop yields
	Animal manure	Better yields
	Multipurpose trees	Extra food source
	Composting	Better yields
More cash generated for the household	Enriched fallow	Cash income from trees
	Cover crops	Cash from grain legume
	Animal manure	Cash from sale
	Multipurpose trees	Cash from sales of fruit
	Composting	Cash from sale?
	Crop residues	Cash from sale?
Enhanced quality of life for members of the household	Biomass banks	Less need to carry fodder from off-farm
	Cut-and-carry grasses	Less need to carry fodder from off-farm
	Cover crops	Ease of cultivation, more varied diet?
	Crop diversification	More varied diet
	Animal manure	Ease of cultivation, dairy products, fuel source
	Multipurpose trees	More varied diet, fuel source
	Composting	Repository for household waste

	Crop residues	Fuel source
	Tithonia hedgerows	Hedgerow for privacy/aesthetic value?

These issues are explored in more depth in the synthesis section of Annex A, which attempts to summarise the main strengths of each technique, examine where the various techniques have been adopted and why. Such summaries we hope will provide material for future research at the FAI, helping people to understand the characteristics of the various techniques and the consequences of these characteristics. Table 11 is an excerpt from Annex A synthesising the findings in tabular format.

Table 11. Tabular summary of the findings in the synthesis chapter of Annex A.

Temporal techniques

(Improved fallow)

Regenerative dynamic:	Temporal, relying on fallow period of woody and herbaceous legumes to 'improve' fallow and rejuvenate fertility, soil organic matter and suppress weeds.
Positives:	May fit well with the evolution of many FAI areas as populations rise (long fallow to short fallow). Therefore builds on a known technology - long fallow rotations. Multifunctional (SOM, nutrients and weed control). Relatively flexible as fallow can be extended or shortened. Could also be developed to provide other services, (fuelwood). No spatial competition between crops and regenerative trees.
Negatives:	Temporal competition for land. Incapable of sustaining yields where fallow periods are therefore reduced below certain limits. Moderate capital and labour requirements.
Possible niches:	Areas where short, natural fallow periods already exist, or are becoming more prevalent (Ghana). Areas located far from the homestead, therefore less intensively used (Ghana). Areas where land has been more or less abandoned, because of weeds or low fertility (Ghana, Nepal, Brazil, Bolivia).
Socio-economic considerations	Ideally the farmer will be able to fallow the land for several years. Moderate capital availability for investment in seeds/seedlings; therefore credit at reasonable rates, some off-farm income or an 'intermediate' level of wealth may be required. 'Intermediate' level of land scarcity, security of tenure, good access to land markets at reasonable rates. 'Moderate' labour availability as more labour intensive than natural fallow. Possibly an opportunity cost to agricultural labour might encourage fallow. Low opportunity cost of natural fallow, and 'intermediate' levels of population density.
Biophysical considerations	Ideal climatic conditions for plant growth may result in the potential to reduce the fallow. However, sub-optimal conditions can be compensated for, by adjusting the length of the fallow. The same can be said for temperature. Soil *p*H should ideally be neutral for optimal BNF in legume/*rhizobial* association. Loamy to clayey soils may allow the fastest recovery of SOM and fertility. Sandy soils may require longer fallow periods.
Suggestions	In Ghana, there may be opportunities, as natural fallow rotations are already important. In Nepal, land pressure may be too high, but some possibilities might exist on abandoned land. In Bolivia and Brazil, conversion of land to pasture may offer better economic opportunities than arable agriculture, but land might eventually be put under improved fallow if pastures also degenerate. Might be useful to integrate other services into the fallow, for example fuelwood. Some integrated use of herbicides may be necessary to kill weeds. Some fertiliser use may also be required if fallow period becomes very short. Could be used in less than optimal biophysical conditions.

Enriched fallow

Regenerative dynamic:	Temporal, relying on multipurpose trees species to enrich the fallow period more and make them more productive, supplying cash and/or subsistence benefits.
Positives:	May build on known techniques as enriched fallow may be traditionally practised at the FAI (e.g. oil palm in fallow). Multifunctional (SOM, nutrients and weed control), with additional cash income possibilities. Relatively low opportunity cost (natural fallow). Relatively easy exit route. Could potentially lead to permanent establishment of spatial agroforestry systems with high mixed cash and subsistence value. Spatial competition for land.
Negatives:	Temporal competition for land. Requires relatively large areas of land. Difficult where population pressure, (or other considerations) cause land to be brought back into cultivation for staple crops, or before benefits of enriching plants can be felt. Suitable outlets may be needed for tree products. Investment in seedlings or seeds will be needed and some labour required for planting. May not be adopted where use of fire is widespread.

Possible niches:	Could be used in areas where short, natural fallow or enriched fallow periods already exist. Alternatively where there is a high potential cash or subsistence value for tree products. Also on land nearest to the homestead, as such fallows may require relatively high labour requirements and protection from thieves.
Socio-economic requirements	The length of fallow needs to be long enough to allow enriched plants to produce, unless they become a permanent feature of the system. Quite high capital availability for investment in seedlings; therefore credit at reasonable rates, some off-farm income or an intermediate level of wealth may be required. 'Intermediate' levels of land scarcity, and security of tenure. 'Moderate' labour availability will be required for planting and maintenance of seedlings. Low opportunity cost of natural fallow. 'Intermediate' levels of population density. Market or other outlets for tree products may be necessary.
Biophysical considerations	Good plant growing conditions will be needed for trees planted to enrich fallow and to ensure no competition with staple crops, if the system becomes permanent. Soil *p*H should ideally be neutral for good plant growth and loamy soils may be best for optimal tree growth.
Suggestions	Enriched fallow should be seen primarily as a diversification technique rather than as a fertility technique. Good support (nurseries) may be needed, as good fruit tree development requires access to good provenance. An alternative strategy may be to select valuable naturally occurring trees from the fallow for preservation in the cropping phase. Locating enriched fallows near the household might encourage development into permanent agroforestry systems as valuable trees could be kept. However, competition will have to be avoided with main crop. Location close to homestead is important, as high value trees are unlikely to be planted where they cannot be protected and maintained. In Ghana, there may be potential for developing permanent agroforestry systems, through enriched fallow, if competition with main crops can be avoided. In Nepal, land pressure may be too high for enriched fallow, although wealthier farmers may be able to develop permanent orchards in this way. In Bolivia and Brazil, conversion of land to pasture generally provides the best economic opportunity. However, land near the homestead could be turned into orchard through enriched fallow.

Sequential cropping with herbaceous or grain legume cover crops

Regenerative dynamic:	Temporal – N regeneration with single seasons herbaceous or grain legumes.
Positives:	No direct competition with main crop, fixes N, mobilises other nutrients, provides SOM, often improves soil physical structure, soil moisture content.
Negatives:	Quantity of N fixed is unlikely to provide sustainable basis for continuous cropping. Temporal niches may be difficult to find and the farmer may want a harvestable product, as in the case of grain legumes. In this case much of the N is removed with the harvest. Where cover crops do not provide full temporal coverage, weeds may benefit from added N rather than the crop and weed infestations may become even worse.
Possible niches:	Where natural off-season fallow is already practised. Useful for high value or staple crops. Most likely where land intensification is already relatively high and climatic conditions allow year round growth. Where weed infestations are problematic.
Socio-economic considerations	Some capital may be required for seeds as well as supplementary fertiliser and possibly herbicide. Land intensification may need to be high.
Biophysical considerations	Bimodal or year round rainfall. Suitable climatic conditions to allow for satisfactory off-season plant growth.
Suggestions	Sequential cover crops provide partial solutions to a variety of problems. In particular, farmers appreciate their impact on soil physical characteristics, such as softness and moistness. Where weeds are a problem, cover crops may also be useful. Good off-season plant growth conditions are required especially if weed control and rapid BNF is desired. Possible use in Nepal as a seasonal fallow if suitable temporal niches are available. Unlikely to be grown in summer, unless as a grain legume, as other crops take precedence. In Ghana, Bolivia and Brazil, most FAI areas may be too sparsely populated to make sequential intercropping suitable, except on more intensively cultivated high value plots of land.

Biomass transfer techniques

(Off-farm)

Regenerative dynamic:	Transfer. Herbaceous and perennial plants (often leguminous) may be used to transfer nutrients from one area to another.
Positives:	No direct competition with main crop for environmental resources. May provide a net increase of on-farm nutrients. May increase SOM.
Negatives:	Much labour is required for pruning, transport and incorporation of biomass. Establishment of biomass banks may be costly. Large quantities of biomass required for significant effects. Biomass transfer is most likely to occur from common land anyway. Unlikely to supply full crop requirements in quantities that farmers can supply.

Possible niches:	Where land intensification is leading to reduced possibility of fallow rotation. Supply of biomass to high value crops, especially in areas where biomass-supplying plants are very plentiful. Where areas of land have been given over to used groups or individuals, on areas of land that may be too distant for cultivation (Nepal). Where common resources have been degraded.
Socio-economic considerations	Large labour availability for prunning and transfer of biomass. Alternatively capital to be able to purchase labour for biomass transfer. Availability of high quality plants from common land.
Biophysical considerations	
Suggestions	Biomass transfer is generally widespread where there is access to large quantities of organic matter from common resources that already exist. It is unlikely that most resource-poor farmers at the FAI will be willing to develop biomass banks off farm on common land, although they may be willing to invest in their management. Development of biomass transfer from common resources may be possible in Nepal, where it is already a major technique. Also in areas where fodder is needed for stall-fed animals. Some development may also be possible where leasehold schemes or community management schemes give control of land to resource poor farmers. In Ghana, the relative availability of land may make fallow techniques more suitable. In Bolivia and Brazil, the high availability of land and the low availability of labour makes transfer of off-farm perennial biomass relatively unattractive, especially as the arable cycle is relatively short and the end aim is often conversion to pasture.

(On-farm)

Regenerative dynamic:	Transfer. Herbaceous and perennial plants (often leguminous) may be used to transfer nutrients from one area to another.
Positives:	Recycles leached nutrients from below crop root zone. Transfers nutrients from one area of the farm to another.
Negatives:	Very labour intensive, as much labour is required for pruning and incorporation of biomass. Establishment of biomass banks may be costly. Large quantities of biomass required for significant effects. Unlikely to supply full crop requirements in quantities that farmers can supply.
Possible niches:	Where the farmer has land that cannot be cultivated. Where other requirements such as fodder are important.
Socio-economic considerations	Access to large farm areas, or insufficient labour to fully cop land. Fodder requirements, especially in mixed farming systems.
Biophysical considerations	Good plant growing conditions, to make investment in fodder banks worthwhile
Suggestions	On-farm biomass transfer are most likely to be used where they have some other purpose, for example fodder provision for stall-fed livestock and where alternative fodder supplies are limited. Such conditions are likely to be very specific, but are probably likely to occur at spatial FAIs. On the whole it is not likely that on-farm biomass transfer will be used by farmers for the primary aim of SOM and soil fertility enhancement.

Compost

Regenerative dynamic:	Transfer - collection and transfer of nutrients from one area to another
Positives:	Increases the speed of decomposition of plant material and allows moderate grade material to be used with less risk of immobilisation. Short time horizon for benefit.
Negatives:	Requires manipulation of very large quantities of biomass for full soil and crop needs. Requires large labour resources for preparation and transport of compost. Requires good supply of water to help decomposition. There may be many competing demands for biomass used in compost.
Possible niches:	Most relevant to spatial FAIs where land intensification makes other fertility techniques less suitable. In both temporal and spatial FAIs, close to homestead on high value subsistence and cash crops.
Socio-economic considerations	Large labour resources for preparation and transport of compost. Some capital availability to improve the compost, or to pay for transportation and incorporation of compost.
Biophysical considerations	Access to water and large quantities of biomass. Alternatively, adequate rainfall to keep the compost moist.
Suggestions	Preparation, transportation and incorporation of compost can be extremely labour demanding and compost should seen as a partial solution to soil fertility. Low cost techniques of improving compost quality (by mixing with manure and/or fertiliser for example) and reducing labour input may therefore be useful. Compost may be most important on land near the homestead, especially in temporal FAIs such as Ghana, where fertility may be regenerated by fallow and in coloniser FAIs such as in Brazil and Bolivia, where land tends to be converted to pasture. In spatial FAIs such as in Nepal, more widespread use may be possible, especially by wealthier farmers. However, topography may

	make use difficult on isolated fields.

Animal manure

Regenerative dynamic:	Transfer – collection and transfer of nutrients from one place to another.
Positives:	Particularly useful in climatic conditions which do not favour decomposition, for example very cold or dry conditions, as the rumen provides good conditions for decomposition. The farmer has the added advantage of benefits from owning cattle, such as milk, meat and draught power.
Negatives:	Much of the N can be lost in urine if this is not collected, used or stored. N can be lost through volatilisation, leaching and denitrification. Very large quantities of animal manure may be required for 'ideal' effects on crops. Labour requirements for transportation and incorporation are therefore high. Low quality manure may cause immobilisation of N and P. There may be many competing demands for manure, for example as fuel. Water may be required to keep the manure-compost moist.
Possible niches:	In both spatial and temporal FAIs, locations close to the homestead, on high value subsistence or cash crops, may be most suitable for manure-compost. In general, will be most used in spatial FAIs where land intensity precludes fallow regeneration of soil. In areas where soil physical improvements are necessary.
Socio-economic considerations	Large household labour availability, or access to labour through cultural or capital means. Availability of stall-fed livestock and manure. Availability of suitable alternatives for other services provided by manure.
Biophysical considerations	Disease-free areas, especially from tse-tse fly.
Suggestions	Manure may be a partial solution to fertility problems at the FAI, due to the high labour requirements and the competing demands for its services. In both temporal and spatial FAIs it may be most suitably used close to the homestead on high value cash and subsistence crops. It may be best to concentrate on improving techniques of manure-compost production. For example, it could be enriched with fertiliser, which might aid decomposition and reduce the quantity of manure required for nutrient supply.

Spatial techniques

Alley cropping

Regenerative dynamic:	Spatial – BNF, mobilised nutrients and SOM through *in situ* banks of leguminous perennials
Positives:	Requires no fallow period. Useful on slopes, where erosion is problematic.
Negatives:	May result in suppression of main crop through excessive competition. Highly inflexible. High cost to not following prescribed practice. High initiation costs. Requires long planning horizon, as benefits from investment are slow to accrue. Difficult to use in a niche. Extra nutrients may be required to ensure that competition does not occur, making it difficult for resource-poor farmers to use. High exit cost in labour and capital terms (removing hedgerows). Hedgerow interference with tillage operations.
Possible niches:	On sloping land, where erosion is problematic.
Socio-economic considerations	Access to large amounts of capital for planting of hedgerows. Seedling availability. Labour availability, either through the household or purchased. Land scarcity may encourage use of alley cropping as rotational techniques will be unsuitable. Capital for inorganic fertiliser. Security of tenure.
Biophysical considerations	Neutral soil conditions, high fertility and inorganic fertilisers, adequate precipitation to ensure that competition with the main crop cannot occur.
Suggestions	Alley cropping may be most useful at FAIs where the hedgerows provide additional services, for example, fuelwood, fruit, fodder and medicine. Also in areas where soil erosion is a problem. The fertility function of alley cropping may probably be best seen as an added bonus if it occurs, particularly as nutrients may be required to keep the system sustainable and ensure that competition does not take place. And selecting for example leguminous trees species on the basis of large biomass requirements tends to make life difficult for the farmer, as the cost of not following prescribed practice can be disastrous for crop yield.

Multipurpose trees

Regenerative dynamic:	*In situ* provision of multiple benefits
Positives:	Provision of multiple benefits from trees including fodder, food, medicine, fuelwood. Once established, relatively low input requirements.
Negatives:	Long planning horizon required. Seedling availability. High capital requirement for seedling purchase, protection and maintenance. Competitive effects with crops in planted on arable

	land.
Possible niches:	In both temporal and spatial FAIs, most applicable on land close to the homestead. Wealthier farmers may be able to multipurpose orchards, particularly if demand exists for products.
Socio-economic considerations	Pressure on common resources. Land scarcity and increasing population pressure. High capital availability and long planning horizons. Poor farmers may be limited in the number of multipurpose trees they can plant by requirements to produce food. High capital requirements are needed and a means of protecting and maintaining seedlings during establishment. Security of tenure.
Biophysical considerations	Good plant growing conditions.
Suggestions	Multipurpose trees may be best seen as a means of providing for immediate subsistence and cash needs, rather than provision of soil fertility and organic matter. These may be seen as secondary benefits. Large collections of multipurpose trees may be best used on land close to the homestead where trees can be protected and tenure is secure. Good access to capital may be required on land that is planted with multipurpose trees away from the homestead in particular for protection and watering during establishment.

Full and relay intercropping with herbaceous or grain legume cover crops

Regenerative dynamic:	Spatial. Some BNF is provided during crop growth.
Positives:	May provide some nutrients without sacrificing land for legume. Reduced competition and/or facilitation of main crop.
Negatives:	The legume is unlikely to produce sufficient N to allow continuous cropping of the main crop. Competition for resources, such as water and nutrients may reduce main crop yields.
Possible niches:	Spatial FAIs where land intensification is high. Temporal FAIs where high value crops are grown together or with a grain legume of cash or subsistence value in optimal plant growing conditions.
Socio-economic considerations	Capital will be required for seeds, fertiliser and herbicides. Such techniques will not be capable of providing adequate N especially where grain legumes are valued for subsistence or cash value. Land intensification will increase likelihood of intercropping. Intercropping may also be most likely in areas of with animal or mechanised draught.
Biophysical considerations	Optimal climatic and soil conditions will be required to ensure that competition does not occur. This may even mean providing nutrients in certain conditions.
Suggestions	Intercropping should not be promoted as a fertility enhancing technique, but as a strategy for crop diversification and risk reduction. Full intercropping may be unlikely unless long season legumes prevent competition with main crop. Otherwise relay cropping will be most useful. Grain legumes might be useful if competition with the main crop can be reduced. In Nepal there may be some scope for intercropping, but more probably as a risk reduction and crop diversification strategy rather than as a soil improvement technique. In Ghana, Bolivia and Brazil, intercropping may only be useful in intensively cultivated areas, for example near large population, possibly with high value crops.

We suggest that it may be unrealistic to expect widespread adoption of organic matter techniques at the FAI as biophysical and socio-economic conditions are diverse. Because of this each technique may be suitable only for a certain subset of farmers. Rather than perceiving this to be a failure of the technique, it may be seen as the natural state of affairs. However, the relevance of the techniques can be increased by making them address the problems of sub-sets of farmers and by providing tools that may, for example, help researchers approach resource problems at the FAI with a greater understanding of the priorities and needs of farmers.

Stabilisation of cultivation systems at the forest/agriculture interface may be achieved by developing means of improving the livelihoods of the people involved, so that there is less need for farmers to move on and clear new forested areas. People should be seen as part of the solution rather than part of the problem. This is not an argument for ‘holistic’ versus ‘reductionist’ approaches. We would argue that both are necessary, i.e. that the starting point should be from a holistic viewpoint, that the analysis of problems in the system is reductionist, and that solutions to the problems are evaluated holistically again. However, care does need to be taken that the reductionist analysis does not restrict thinking to biophysical processes of the system, as has been done in the past, but that socio-economic processes are also taken into account. We have once again provided prototype tools that may allow this. Table 12 is part of a larger table that summarises some of these considerations.

Table 12. Synthesis and development of literary evidence indicating how tabulated information might be used to indicated possible niche uses of organic techniques. For example, alley cropping has been given a '✓1', by the 'Spatial?' category. Literary evidence suggests that where FAI dynamics are 'temporal', alley cropping is likely to have a more limited role, because in temporal FAIs, rotation techniques and clearing land for cropping may be the primary aim of farmers. However, alley cropping may have a role to play in FAIs with spatial dynamics, where scarcity of land is relatively high, giving this category a score of '✓1' indicating that for it to be used, there is likely to be 'some requirement' for spatial dynamics.

Considerations			Alley cropping	Enriched fallow	Cover crops	Etc.
The FAI:						
Is the predominant FAI dynamic:	Temporal?		0			
	Spatial?	✓	1			
Is land availability:	High?		0			
	Intermediate?	✓	1			
	Low?		0			
Is there a fertility/erosion problem?	Yes	✓	1			
	No	✗	0			
Technology considerations						
Can the technology meet other needs? (e.g. immediate subsistence, cash income needs, fodder, poles, medicine, etc.)	Yes		1			
	No	✗	-1			
Can the technology fit in the FAI dynamic?	Yes		1			
	No		-1			
Can the technology mesh well with local practice?	Yes	✓	1			
	No		-1			
Can the technology reasonably contribute to tackling the resource problem?	Yes	✓	1			
	No		-2			
Farmer's perceptions:						
Does the farmer perceive a resource problem?	Yes	✓	1			
	No	✗	-1			
Is the resource base essential for livelihood?	Yes	✓	1			
	No	✗	-1			
Is the farmer willing to invest in technology?	Yes	✓	2			
	No	✗	-2			
Are immediate benefits very important?	Yes	✗	-2			
	No	✓	1			

Full table in Annex A

There is, therefore, a clear need to take a systems approach when considering options for stabilising forest/agriculture interface systems. However, many of the processes, both biophysical and socio-economic and their interactions, are poorly understood, and it is essential that future research addresses this. Bio-economic simulation modelling is proposed as a way of integrating these processes at the system level to provide a means to evaluate different pathways of transition to more settled systems of agriculture.

It must also be recognised that the so-called forest/agriculture interface production system is very heterogeneous, both at the system level with different cultivation systems in the different countries, and also at the individual farm level with between-farm variability in terms of farmer aspirations and attitudes, and within-farm variability in resources. Problems tend to be location-specific, and improved techniques must be matched to individual niches. Further investigation into the 'phenomenon' of low uptake should make use of a more sophisticated scheme of terminology in order to differentiate more clearly the actual basis of concern.

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5. Research Activities

This section should include descriptions of all the research activities (research studies, surveys etc.) conducted to achieve the outputs of the project. Information on any facilities, expertise and special resources used to implement the project should also be included. Indicate any modification to the proposed research activities, and whether planned inputs were achieved. Highlight any special activity achievements (e.g. involvement of policy-makers; or numbers of NGOs etc).

Initial activity involved Tabitha Middleton (née Mason) being employed for one month at the beginning of the project to translate documentation from DFID projects in Brazil from Spanish to English. This was followed by in-country visits to Nepal (14-23 May, 2000) and Ghana (18-26 June, 2000) by members of the team (Dr Robin Matthews, Dr Kevin Waldie, and Mr Anil Graves) to meet with researchers in involved in research on FAI-related issues in those countries. The visits were facilitated by Dr Rama Bhurtel in Nepal, and by Dr James Quashie-Sam in Ghana. In Nepal, discussions with staff at the Department of Forestry and Department of Agriculture in Kathmandu were held, as well as staff at the Agricultural Research Station at Lumle, near Pokhara. In Ghana, those visited included staff from the Land and Water Management Project in Accra, the University of Ghana in Accra, the Council for Scientific and Industrial Research in Accra, and the University of Science and Technology in Kumasi. These visits resulted in the production of detailed trip reports summarising the interviews had in each country (Annex B & C). Subsequent research activities for the remainder of the project consisted of collating the information from these interviews, reviewing project documentation from previous DFID FAI projects, published international literature, and other sources collected during the country visits. Photocopies of DFID project documentation was obtained from the NRSP library at Huntings Technical Services in Hemel Hempstead. Extensive use was made of on-line abstracting services (CAB Abstracts, Web of Science, etc.) and electronic journals (Science Direct, Athens, etc.). This resulted in the production of a 225-page report (Annex A). A database summarising this information in Microsoft Access was constructed, based on the Organic Resources Database System (ORDS), and a web-site containing all project documentation and the database were developed using Microsoft FrontPage. This was mounted initially on the Cranfield website server at Silsoe, but due to centralisation of WWW sites at the university, was subsequently mounted on a server at Cranfield main campus. This change meant that Microsoft FrontPage was no longer compatible, and resulted in some delay while the original web-site material was converted to Oracle.

6. Contribution of Outputs

Explain how the outputs will contribute towards NRSP's goals as stated in the programme logframe and in the relevant production system logframe. Frankly assess the achievements of the project and what benefits it could engender. How might the project's achievements impact on people's lives, stating which people (men, women, which group or groups of the poor)?

Assess the impact of the outputs. This should be reported in 2 ways. Firstly by making a robust assessment of the extent to which the OVIs at the Purpose level were attained, including any evidence of the uptake of research outputs by target institutions and other intended beneficiaries. Secondly by making an assessment of the impact of the project on:

- *the thinking of research partners and stakeholders in the project (including development workers, field extension staff, DFID NR advisers)*
- *policy approaches (national environmental groups etc)*
- *techniques (that people can use covering categories of men and women)*

What else needs to be done to promote the idea and/or understanding and/or product of the research? The text should explain what promotion pathways to target institutions and beneficiaries were identified and suggest what follow up actions might be considered regarding these pathways.

NRSP's overall goal is 'Benefits for poor people generated by application of new knowledge to NR systems', and that of the FAI production system is 'Livelihoods of poor people improved through sustainably enhanced production and productivity of RNR systems'. Before new knowledge can confer any benefits to its recipients, it must be evaluated in the production system it is targeted for. Many techniques that have performed successfully on research stations, or even in farmers' fields in other parts of the world, have not always performed well when introduced onto farmers' fields in a new location. Similarly, much research on potential interventions has focused on sub-components of a system (e.g. soil fertility) without appreciation of how these interventions fit into the socio-economic environment they will be part of. For this reason, techniques that may be successful from a biophysical viewpoint may still not be adopted by farmers. In this review, we have attempted to analyse the techniques that have been evaluated in a number of recent DFID projects in forest/agriculture interface systems (i.e. alley-cropping, biomass transfer, cover crops, multi-purpose tree species, animal manure, *Tithonia diversifolia*, improved and enriched fallows, and legume intercrops) and to consider both their biophysical and socio-economic characteristics that may influence their success or otherwise in helping to stabilise cultivation systems at the FAI. We have also looked at a cases where some of the techniques have been adopted by farmers to try and understand the reasons for this.

A major conclusion of the review was that the techniques being evaluated are unlikely to be able to contribute significantly to intensification of existing cultivation systems at the FAI in that they are inadequate, within the resource constraints faced by FAI farmers, in addressing soil fertility decline and weed control issues. They may, however, be able to be part of integrated crop management strategies. However, it is suggested that the greatest progress may be made by considering potential interventions from farmers' perspectives, and evaluating how they are likely to contribute to their overall livelihoods – this necessitates taking a wider viewpoint than focusing exclusively on techniques aimed at soil fertility or weed control. The question that should be asked with all potential techniques is 'Will adoption of this technique make sense to the farmer?'. High value crops, for example, may provide a cash income that can enhance livelihoods and reduce the need to clear new land from the forest.

It is also suggested that a better understanding of the biophysical and socio-economic processes involved in intensification of agriculture at the FAI is needed in order to design strategies that can achieve this. Modelling, particularly at the community level, is seen as an important tool that can help to integrate biophysical and socio-economic factors and understand the interactions between them. The review also highlighted the enormous heterogeneity of cultivation systems at the FAI, and the difficulty of devising generic solutions to problems there. Potential interventions need to be evaluated in local circumstances. Thus, hopefully, the outputs of the project has contributed to a greater understanding of the nature of problems (in the widest sense) in different FAI systems, and the way in which solutions to these problems can be developed. It is hoped that the review will help reinforce the importance of a change in thinking away from a purely biophysical emphasis on soil fertility and weed control towards a more farmer-centred approach, and consider interventions that make sense for the farmer to adopt in terms of overall livelihoods improvement. If accepted by the research community, and scientists in the target institutions in particular, this should result in more relevant research that can be of benefit to poor farmers at the FAI.

There is unlikely to be any direct impact of the project on people's lives, but more focused research is expected to have some impact at some stage in the future. For example, if appropriate high-value crops can be identified, growing these is promoted, uptake is successful, and markets can be developed, then FAI farmers could obtain an increase in their cash income.

The two revised OVIs at the Purpose level of the project were (a) to make available ways for research institutions in FAI target countries to improve technical research design for the FAI, and (b) that the project's findings are used by NRSP in subsequent research calls for the FAI in NRSP target countries, both by the end of 2001. The first of these has been achieved through a thorough review of the biophysical and socio-economic characteristics of the various techniques being evaluated in previous DFID FAI projects, and an analysis of cases where some of the techniques have been adopted (e.g. cover crops). Tools in the form of tables were developed to help researchers evaluate *a priori* the suitability of each technology for specific conditions. Suggestions for future FAI-oriented research are made at the end of the review. The results of the review should, therefore, help to improve the design of future projects by focusing attention only on those techniques that are likely to have some impact. The highlighting of the diversity of farming systems at the FAI should also help researchers to think more carefully about the target groups their work is aimed at. It is still too early for the findings of the project to have had any effect on subsequent research calls by NRSP, but it is hoped that they will do so by the end of this year.

Similarly, it is still too early to say whether the project's findings have had any impact on the thinking by the research partners. To some extent, as the project was a review of existing projects, published literature, and interviews with in-country researchers, it reflects the thinking of some of them already. It is hope that future contact with them will result in an impact on the thinking of more of them. It should also be mentioned that the Final Report (Annex A) was requested by and sent to the contractors (Reece & Sumberg) of the parallel project **R7515** 'Knowledge dissemination domains in the forest agriculture interface' for use in constructing a database. One of them (DR) has subsequently commented that they have found it 'very useful'.

Although it was beyond the remit of our project to deal with it more fully, we also hope that the definition of the hierarchy of methodologies from knowledge, technology, techniques, through to practices (or products) may help to clarify the thinking of development professionals in terms of what is meant by uptake of research outputs.

Promotion pathways of the project results were identified at the start of the project to be (a) by sending project documentation to the collaborating institutions, (b) through a final workshop with the collaborators to present and discuss the conclusions of the project, and (c) via a project web-site. The first of these will be done once this FTR has been approved by NRSP. The final workshop has been postponed by NRSP management until further notice. The web-site has been completed and can be viewed at http://www.cranfield.ac.uk/iwe/fai. The collaborators have been notified of the web-site address. As a follow-up, a final workshop involving participants in all three current FAI projects (**R7515** 'Knowledge dissemination domains in the forest agriculture interface'; **R7516**, 'Bridging knowledge gaps between soils research and dissemination in Ghana', and this one, **R7560**) may be the best way forward.

7. Publications and other communication materials

Present a comprehensive list of publications (achieved and planned), reports and other media products produced by the project under the headings given below. Any item specified that has not been previously provided to NRSP for the NRSP library must be submitted as an annex to the FTR. All published papers must be annexed to the FTR.

Headings for communication materials:

1. Books and book chapters: N/A
2. Journal articles
    - 2/1. Peer reviewed and published: N/A
    - 2/2. Pending publication (in press): N/A
    - 2/3. Drafted: N/A
3. Institutional Report Series: N/A
4. Symposium, conference, workshop papers and posters: N/A
5. Newsletter articles: N/A
6. Academic theses: N/A
7. Extension-oriented leaflets, brochures and posters: N/A
8. Manuals and guidelines: N/A
9. Media presentations (videos, web sited papers, TV, radio, interviews etc): N/A
10. Reports and data records
    - 10/1. Citation for the project Final Technical Report (FTR):

      Graves, A.R., & R B Matthews, 2001. Review of technologies being evaluated for the Forest/Agriculture Interface, Cranfield University.
    - 10/2. Internal project technical reports:

      Graves, A.R., R B Matthews & K J Waldie, 2000. Trip report to Nepal, 14-23 May, 2000

      Graves, A.R., R B Matthews & K J Waldie, 2000. Trip report to Ghana, 18-26 June, 2000.
    - 10/3. Literature reviews: N/A
    - 10/4. Scoping studies: N/A
    - 10/5. Datasets, software applications:

      Microsoft Access database.

      All project material on a CDROM.
    - 10/6. Project web site, http://www.cranfield.ac.uk/iwe/fai

8. Project logframe

Provide the latest version of project logframe

Attached.

9. Keywords

Key words (maximum of 10, excluding production system) for entry in the NRSP library accession entry for the project's FTR.

Shifting cultivation; intensification; low-input agriculture; agroforestry; tree-crop interactions

10. Annexes

Scientific annex (Annex A) to the FTR together with additional annexes that include publications and possibly some other grey literature published through the project but not previously provided for the NRSP library. Final annex: Final project inventory