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Project title

Development and promotion of improved techniques of water and soil fertility management for the sustainable production of crops on land in the humid forest belt, Ghana. Integrated Food Crops Project, Brong Ahafo, Ghana.

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NRSP Production System

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Date

Contents:

1. Executive Summary

The project purpose was to develop and promote new improved techniques to reduce the fragility and enhance the fertility of soils in cultivated areas of humid forest belts. This has been addressed through research conducted within the Brong Ahafo region of Ghana, where forest encroachment is associated with reduced soil productivity experienced under shortenning bush fallows.

Dry season vegetable production (DSVP) provides an important contribution to livelihoods for a wide range of households in the Brong Ahafo region. PRA surveys indicate that farmers attribute poor vegetable yields and quality to declining soil productivity, which is necessitating increased chemical fertiliser and water applications.

The purpose has been achieved by working collaboratively with local farmers, Ministry of Food and Agriculture (MoFA) extension staff and MoFA research centres and staff. Through a series of on-station and on-farm trials, farmers representative of the subsistence and commercial sectors in the humid forest and forest/savanna transition zones have been introduced to new technologies (for this region) of leguminous green manures, animal manures and composting. Agricultural extension agents (AEAs) have been trained in farmer-participatory techniques and have had on-the-job training in on-farm trial and farmer field day planning and implementation. The new techniques have been introduced to supplement, and as a potential alternative, to current fallow-based and inorganic fertiliser / chemical based methods of managing soil productivity.
AEAs have been active in making presentations at project workshops, which has increased their confidence in speaking at large meetings and reporting farmer-identified problems and priorities to more senior MoFA officials and researchers.

The research outputs are:
1. Improved animal manure technologies suited to dry season vegetable production systems, including recommendations for combined use with inorganic fertilisers.
2. Recommendations on the use of suitable species of green manures for dry-season production.
3. Description of the effect of improved technologies on soil fertility levels and water-holding capacity.
4. Analysis of the costs/benefits of new technologies in terms of labour use, requirements for pest and disease control, inorganic fertiliser and water inputs, and crop productivity.
5. Manual outlining most promising improved techniques for use by extension services and non-government organisations involved in agricultural extension activities.
6. Design for an appropriate research programme to address key constraints to vegetable production in the wet season

Project staff have worked closely with the Reading-based NRSP SEM-funded Participatory Farm Management project (R6730) and together have developed methods for monitoring and evaluating on-farm trials by mainly illiterate farmers. These methods were successfully used during second and third year's evaluations and the cost-benefit analyses of the on-farm trials.

The outputs from the project contribute both materially and non-materially toward the UK Department of International Development (DFID) goals in terms of addressing poverty, contributing towards social and human development and to environmental sustainability and regeneration. Poverty is directly addressed through increased returns to vegetable cultivation in terms of reduced bought inputs required, improved quality of produce and greater returns to labour. Family health may be improved by the greater use of vegetables and improved incomes of both male and female members. The development of facilitation skills among extension workers and self-confidence in farmers helps the move away from prescriptive extension messages towards more farmer participatory technology testing and adaptation. The reduction in chemical fertiliser use will help reduce pollution of ground water sources. Introducing sustainable methods for permanent cultivation offer an alternative to further forest encroachment in response to a decline in soil productivity levels.

2. Background

The amelioration of soil chemical and physical properties by incorporating organic matter influences crop growth through increasing the supply and availability of plant nutrients and water, improving conditions for root growth, and reducing loss of nutrients and water through leaching, surface erosion and evaporation. A broad view, considering the effects on both soil physical and chemical properties, is needed to assess the overall impact of such soil ameliorants. Different cover crops/ green manures/ crop residues/ composts/ animal manures are appropriate depending on the relative importance of biological tillage, nitrogen addition, total organic matter addition, speed of decomposition and the nature of the following crop (Wilson, 1991).

A substantial body of work already exists on the cultivation and incorporation of green manures and cover crops within farming systems (La Rue Pollard, 1988; Kiff et al., 1996). Sufficient information is available to select species likely to flourish under the various conditions at the project site. Actual testing of green manure species in the project area was, however, a new research undertaking.

A range of composting and manuring techniques suited to vegetable production are known, some involving the direct application of organic matter (OM) to the soil, others the intermediate processing of materials before application. The incorporation of green manures is an example of direct application, as is basket composting (composting directly adjacent to plant growth) (Watson, 1988). Animal, particularly ruminant, manures and already decomposed composts have already undergone intermediate processing by microbes and contain nutrients in a form usually more readily available to plants than those when OM is applied directly (Handrek, 1986; Inckel, 1994).

Research into the mechanisms by which organic matter influences soil fertility show the importance of the carbon to nitrogen (C:N) ratio as it effects:

- the speed of micro-organism action on the material and consequently
    - i) time taken for nutrients to be available to plants
    - ii) proportion of undecomposed OM in the soil
- the related period and severity of nitrate deficit for plants
- the proportion of material converted into humus, rather than oxidised.

The C:N ratio in the organic matter of the furrow slice of arable soils commonly ranges from 8:1 to 15:1, the median being between 10:1 and 12:1. The C:N ratio in plant material is considerably higher than this, ranging between 20:1 for certain high-protein legumes and up to 100:1 for straw-like residues. When such residues are added to the soil, nutrients, particularly nitrates, initially become less available to higher plants because of competition from rapidly multiplying microflora (Brady, 1974; Wambeke, 1992).

There is potential for the addition of inorganic N sources to organic residues in order to reduce initial reduction in nitrate availability. Little formal research has yet been reported on the combined use of organic composts with inorganic fertilisers, yet its widespread practice among farmers is beginning to be documented (Tamang, 1992).

The project assessed the potential of green manures, animal manures and compost made from locally available sources of OM as soil ameliorants. These were assessed on their ability to reduce the requirement for, and increase the efficient use of, inorganic fertilisers and water, to increase soil OM, improve crop production, crop quality, and quality during post-harvest handling. The impact of the new technologies on the financial risk involved in dry season vegetable production was also anlaysed.

In-country appraisals have shown that there is an opportunity for more efficient use of farmyard manure and recycling of crop residues to enhance soil structure, fertility and water-holding capacity, and reduce dependency on external, high cost inputs (Ashitey et al., 1994; Holland, 1995). The potential contribution of green manures to soil productivity maintenance and weed control is as yet unexplored. Specifically in other countries green manures are successful on land similar to that on which dry-season vegetables are grown, rendered unproductive due to waterlogging for part of the year (La Rue Pollard, 1988).

The very variable profiles of current vegetable cultivators, in terms of age, land ownership, gender, use of bought inputs and involvement in other agricultural activities, reflect the different backgrounds from which they have emerged. Before 1970, vegetable production in Ghana was mainly smallscale and predominantly for home consumption. The establishment of local markets in the '70's and '80's enabled farmers and principally women farmers to sell surplus vegetables for cash and this became an increasingly important form of income generation. Successive droughts during this same period were a precursor to devastating bush and forest fires throughout Ghana in 1983, which destroyed many of the smallholder cocoa farms in Brong Ahafo region. Cocoa was the main cash crop at that time. Since cocoa prices were already low and erratic, farmers were reluctant to invest again in cocoa re-planting with its long gestation period, and turned instead to horticulture. Thus the commonly marketed vegetables, tomatoes (*Lycopersicon lycopersicum)*, garden eggs (*Solanum aethiopicum),* okra *(Hibiscus esculentus)*, onion *(Allium cepa)* and chilli peppers *(Capsicum fructescens)* began to be cultivated for sale in both wet and dry seasons by these commercially-orientated farmers (Warburton et al., 1995). The lack of employment opportunities for school leavers and young men has resulted in the development of a second goup of commercial producers, investing both in the hiring of land and high levels of inputs into the crops grown exclusively for sale (Kiff et al., 1997).

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3. Project Purpose

To improve the sustainable production of vegetables on previously forested land through increasing the availability of nutrients and water, and reducing the financial risks involved in cultivation.
New improved techniques to reduce fragility and enhance fertility of soils in cultivated areas of humid forest belts developed and promoted.

4. Outputs

4.1. Improved composting/mulching technologies suited to dry season vegetable production systems, including recommendations for combined use with inorganic fertilisers.

From the first village meetings and farmer surveys it became apparent that mulching in the dry season was not a suitable technology to introduce at present because of the continuing practice of burning by bush meat hunters and high risk from accidental fires during the dry season. The first surveys also identified high input costs, water availability and labour costs/ availability as the key constraints to dry season vegetable production (Kiff et al., 1997). As compost making involves considerable labour inputs it was decided to first introduce the use of animal manures as organic fertilisers. Some labour would be required for manure collection, but with a greater concentration of nutrients than compost, volume for volume, they would give a better return to labour invested. Sufficient sources of animal manure were found to be available locally for on-station and on-farm trials to be initiated.

4.1.1 Use of animal manures

Sheep manure and the combination of sheep manure with poultry manure has produced the best yields and quality of fruits in on-station trials (Kiff et al., 1997; O'Connell, 2000b). However, the cost-benefit analysis conducted by farmers found cow, poultry and a combination of cow and poultry manure more profitable than sheep/ goat manure and mixtures of these with poultry manure (Chan et al., 2000). Such findings highlight the importance of availability and labour implication in farmer's selection and preference for techniques. Cost/benefit analyses has demonstrated that gains can be made in returns to production through improved quality of the product and by reducing costs involved in production through use of organic manures and reducing the purchase of fertilisers.

Use of animal manures was a successful introduction to the use of organic wastes to enhance soil productivity and interest has now been sparked in cultivators to make compost. Such a practice will allow sufficient production by all cultivators, making the best use of scarce animal manure as an active component in the composting process.

Results from on-station trials

4.1.1.1 Investigation of the effect of different manure types applied singly and in combination with various levels of NPK on tomato production in the dry season. (Kiff et al, 1998)

The nutrient content of the animal manures was found to vary considerably, probably due to a combination of differences in diet and methods of storage. The nutrient content of animal manures used in on-farm and on-station trials in 1997 are shown in table1.

Four different animal manures used singly and in two different combinations with NPK, 23:15:5 (25% and 50%) were applied in a diamond trial design to dry season tomatoes (Rasta variety, NR 46 Wenchi Agricultural Research Station). Nutrient additions under each of the 13 treatments are shown in table 2. Estimates of nutrients available in the first season after application in each treatment are given in table 3.

Table 1 Nutrient content ranges found in different animal manures used in on-station and on-farm trials in 1998

Animal manure type	Source	Dry matter %	OM % w/w	pH	N% w/w	P% w/w	K% w/w	Mg% w/w	Cu mg/kg	Zn mg/kg	Ca% w/w	Mn mg/kg
Poultry	Dwomo	85.9	69.5	7.71	14.67	2.45	1.99	0.74	39.6	265	4.75	365
	Wenchi, Karmu	95.4	19.4	7.78	2.96	0.31	0.47	0.12	8.2	47	0.72	92
	Koforidua	83.0	62.1	7.38	15.8	2.79	1.69	0.62	37.4	320	10.5	554
	Badu	85.4	82.4	7.19	17.92	2.01	1.65	0.60	26.3	215	2.75	240
Cow	Boahoniaba	79.0	19.3	9.79	5.69	0.35	2.02	0.66	37.4	92	1.68	320
	Wenchi	93.3	19.7	8.79	5.67	0.20	0.73	0.34	13.2	28	0.61	625
	Sunyani	69.1	52.9	9.51	11.15	0.38	2.88	0.53	22.8	69	1.37	376
Sheep	Badu	70.4	12.7	10.43	6.72	0.22	2.06	0.45	15.2	86	0.90	540
	Wenchi farm	39.9	33.3	9.76	9.16	0.41	1.32	0.47	13.8	104	2.90	325

Analyses by Natural Resources Management Ltd., 1998

The manures were applied in a ring around each plant in the following quantities:
100% manure = 490 g air dried manure (1 full peak powdered milk tin for cow manure)
75% manure = 368 g and 25% NPK (= 25% of match box = 5 g)
50% manure = 245 g and 50% NPK (= 10 g)
100% NPK (23-15-5) = 20 g

Results were analysed by the statistical department at Reading University (Abeyasekera, 1999a, 1999b). Optimum levels of manure to apply were found to be in approximate 50:50 combinations of manure and chemical fertiliser for both maximising total fruit weight and fruit number. All four manure types, sheep, poultry, goat and cow showed similar response curves (figures 1 and 2). Commercial farmers, however, sell their produce by volume, rather than weight. These farmers therefore are looking to produce large-sized fruit, as these 'fill crates more quickly'. The data was further investigated to determine the relationship between manure application and fruit size. This proved inconclusive due to the nature of relationship between average fruit size and manure application. Both low and high applications produced larger fruit than the 50:50 mixture. Fruit quality, as assessed by farmers and as measured during shelf-life tests, was found to increase significantly with the application of animal manures.

The reason for the better yield performance of combinations of manure and chemical fertilisers over sole applications is likely to be due to the balance of readily available nutrients (from the chemical fertiliser) in relation to the longer-releasing nutrients (from the manures). The 50:50 mixture would then be where the proportion of each is particularly beneficial for this season's productivity. This theory is supported by the fact that yields did not increase according to total levels of macro nutrients present (table 2), nor estimated nutrients available in the first year (table 3). Chemical fertilisers provided nutrients in an immediately accessible form at key growth periods, while organic manures help retain nutrients and are instrumental in their more long-term release, over the whole cropping period.

Table 2 Major nutrient additions from 490g of animal manures (air dried), and in varying combinations with 5g and 10g of NPK (23:15:5)

Fertiliser	100% (g)			75% (g)			50% (g)		
	N	P	K	N	P	K	N	P	K
NPK (20g)	2.3	1.5	0.5						
Sheep	4.32	7.24	6.80	3.82	5.81	5.23	3.31	4.37	3.65
Cow	3.55	2.35	5.97	3.24	2.14	4.61	2.93	1.93	3.24
Poultry	3.27	16.02	1.32	3.03	12.40	1.12	2.79	8.76	0.91
Goat	2.11	1.34	4.15	1.58	1.39	3.24	2.21	1.42	2.33

Table 3 Availability of major nutrients in the first season (assuming 60% availability of P and K in cow, sheep and goat manure, 75% availability in poultry)

Fertiliser	100% (g)			75% (g)			50% (g)		
	N	P	K	N	P	K	N	P	K
NPK (20g)	2.3	1.5	0.5						
Sheep	2.59	4.34	4.08	2.52	3.64	3.19	2.45	2.92	2.29
Cow	2.13	1.41	3.58	2.18	1.44	2.82	2.22	1.46	2.04
Poultry	2.45	12.02	0.99	2.42	9.39	0.87	2.38	6.76	0.75
Goat	1.27	0.8	2.49	1.53	0.98	2.00	1.79	1.15	1.50

Figure 1 **Fruit weight obtained with different manure applications**

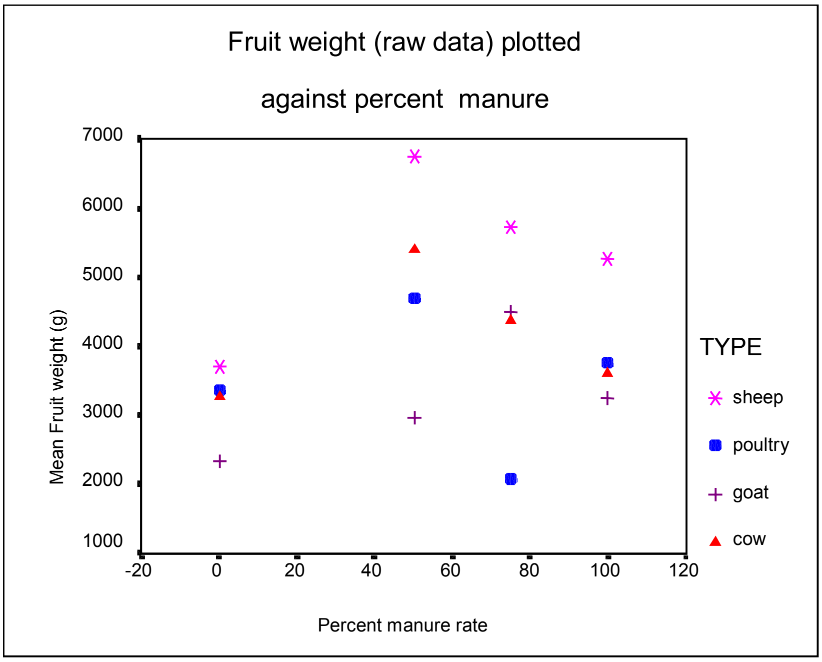


Figure 2 **Predicted variation in fruit weights**

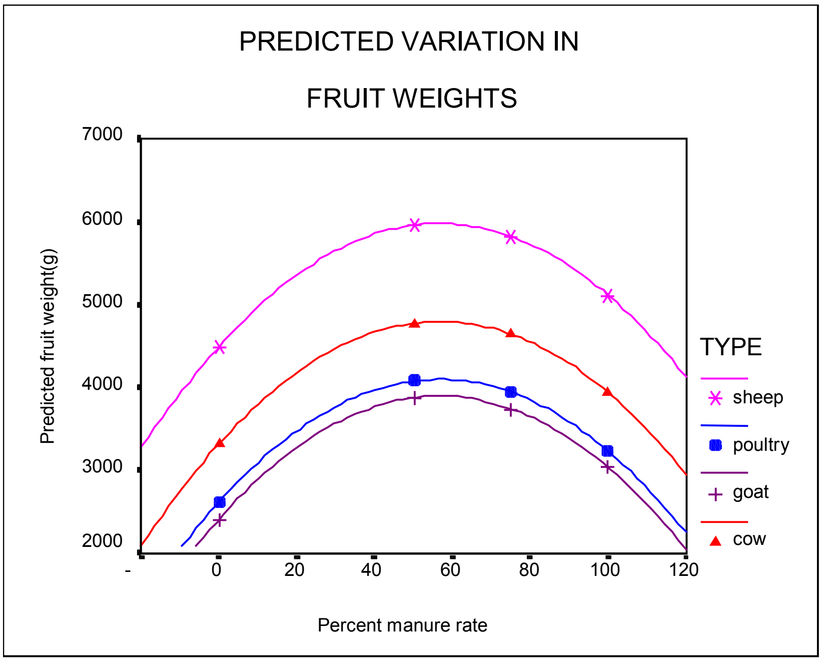


Table .2 shows that application of 100% NPK provided lower levels of potassium than did the 100% manure treatments and that all the manures had an approximately equal, or slightly higher level of nitrogen, except for the goat manure. Phosphorus levels were the most variable, the goat manure with a very low level (0.8g) and poultry a high level (12.4g). The goat manure had low nitrogen and phosphorus contents (lower than the 100% NPK treatment), but a relatively high potassium content and did relatively well. This high potassium content is potentially important because analysis of soil samples taken by staff of the Soil Research Institute (Kumasi) from the trial site showed that the soil had a naturally high potassium content and an average to low phosphorus content (Dennis and Boadi, 1997).

4.1.1.2 Investigation of the effect of different levels of manure application on tomato production in the dry season. (Sunyani and Wenchi sites over several years).

Fertiliser application rate trials are particularly sensitive to lack of homogeniety in the trial site, either inherent, or introduced by previous trials, or different land uses. Every effort was made to select suitable areas, both at the Sunyani site in years 1 and 2 and at Wenchi Agricultural Research Station in years 2 and 3. However , results from the the five fully replicated trials did not produce statistically significant differences between treatments, even with the use of four replicates (in year three).

Results from on-farm trials:

Different manures were selected for testing by farmers according to the types of manure available locally. Their performance was compared against the farmers' usual practice which varied between locations as to whether chemical fertiliser was used and in what quantities.

Initially 4-6 farmers were selected/ volunteered to take part in the trials from each of the four villages. Efforts were made to obtain a representative cross-section in terms of age, gender and land-holding type.

Each farmer was asked to give an overall ranking to the different treatments based on their own assessment criteria. The criteria that farmers used varied, as shown in table 4.

Table 4. Criteria used by 11 farmers in assessing their trials in 1997/1998:

Criteria	**Number of farmers using given criteria**
Size of tomato fruits	5
Amount of fruits	3
Vigour and health of the tomato plants	2
Rate of growth of the green manure and its weed suppressing ability	2
Resistance to disease	1
Earliness of fruiting	1
Survival of transplanted tomato seedlings	1
Firmness of fruit	1
Amount of watering required	1
Criteria used by farmers where harvest did not, or has not yet occurred	
Health and vigour of the tomato plants	2
Number of fruits that appear to be forming	1

The general appearance of plants in terms of health and vigour, amount of fruit and size of fruit were the most frequently mentioned criteria. Size of fruit was mentioned more frequently by farmers than number of fruits. The farmers said that this is a particularly important factor in term of quality (amount of flesh contained by the fruit) and in the price obtained for the crop (the ability of the crop to fill crates) for sale.

After three years of trials, 13 of the 14 farmers who had experimented with the use of animal manures said that they planned to continue using manure on their farms. Poultry and sheep/goat manures were the most popular (all farmers but one planning to continue use). Cow manure was less popular (4 out of 8) continuing use (Chan et al., 2000). This is probably because of the poorer quality of this manure,

due to leaching and soil being mixed with the manure in the kraals. Extension advice includes better management of animal housing to improve the quality of manure collected (Kiff et al., 2000).
Farmers tried different rates of application of manure and ways of applying the manure to the crop (Nelson et al., 1998; O'Connell et al., 2000). Recomended rates of manure usage were worked out on a per plant basis and as a volumetric measure of air dried manure. This was to accommodate farmer's use of different planting distances and practice of fertiliser application by volumetric measure to individual plants. For plants grown at the recommended spacing of 90cm x 30cm, (37,030 plants per hectare, MoFA recommendations), this equates to 33t/ha of cow dung, 19 t/ha of sheep manure and 11 t/ha of air-dried poultry manure. Some farmers preferred to apply the manure into a trench and incorporate before transplanting seedlings. Others applied the manure in a ring around the plant after transplanting.
Farmers tended to prefer using poultry manure because less volume is required for the same fertilising effect and therefore less labour is involved in porterage. However, farmers found negative growth effects from use of too much, or too fresh poultry manure.

Concerns about the benefits from animal manures being restricted to those farmers who own livestock were shown to be unfounded (Chan et al., 2000). Only three of the 13 farmers planning to continue using animal manure had sufficient livestock to provide the manure. Farmers had already identified local sources of manure that at present make no charge for the commodity. Should the practice be adopted more widely, however, shortages may occur and so in the second year of the project investigation of composting was initiated by the project.

4.1.2 Composting

The idea of compost production was introduced to enable greater volumes of organic fertiliser to be produced from the available animal manure. Large amounts of vegetative material, particularly elephant grass (*Pennisetum purpureum*), are available for composting because of the fallow-based farming systems practised in the area. Composting also offers the potential advantage of destroying weed seeds and plant pathogens (if sufficient heat is generated). Compost was first made on the Sunyani on-station site by using alternate layers of elephant grass, poultry manure, wood ash and a small amount of soil. Some was made in metre cubed pits, some in heaps protected by wooden sides and a thatched roof. Sufficient compost was made for trialling by two farmers. Unfortunately problems with localised flooding and seedling supply curtailed the trials (O'Connell, 2000). In the third year farmers were encouraged to make compost themselves through a series of demonstrations held at the on-station site and cross-visits to farmers already trying the technique under the Dannida-funded Land Resource Management Project. At least six of the project trial farmers were motivated to produce compost in the third year (Chan et al., 2000).

4.2. Recommendations on the use of suitable species of green manures for dry-season production.

Of the several green manures tested over a three year period, trial results and farmer evaluations indicate that *Mucuna pruriens* and *Canavalia ensiformis* are the most suitable in terms of biomass production, effect as a green manure and suitability to the cropping systems.
A total of 16 different species of green manures were trialled by the project. Six of these were of the genus *Sesbania*, suited to growth in waterlogged conditions (used extensively in Asia in association with irrigated rice). Eight were suited for growth on non-flooded areas; four varieties of *Mucuna pruriens* (a local variety is traditionally used in small amounts to thicken soups), *Canavalia ensiformis*, *Crotalaria juncea*, *Crotalaria* sp. (available from CRI), *Cajanus cajuns* and *Calapagonium mucuniodes*.. A further two, *Tephrosia vogellii* and *Indigofera hirsuta* were trialled for their suitability to the area because of their pest-suppressing qualities.

4.2.1 Green manures suited to seasonally flooded areas:

Trials were initially conducted on station for the *Sesbanias,* as these were a new introduction to the region. Growth of all varieties was very poor in the first season, producing between 2.8 and 4.2 t/ha (Kiff et al., 1998). In the second year growth was better, but subsequent tomato yields low and of poor quality. It was suspected that the poor soils profile of the Sunyani research site (Dennis et al., 1997) was adversely effecting production and so a further trial was conducted at the Wenchi Agricultural Research site. Reasonable biomass yields were obtained for the green manures (table 4.2.1) and significantly greater yields obtained from *Sesbania aculeata, S. bispinosa* and *S sesbans* than *S rostrata* and *S speciosa*. There was no significant difference between biomass in the control (left to weeds) than the treatments (O'Connell et al., 2000), but nitrogen content of the leguminous *Sesbanias* would have been higher than the weed mixture, dominated by elephant grass (*Pennisetum purpureum*) (table 5).

Table 5 Mean biomass yields for *Sesbania* spp. Wenchi on-station trial 2000

Variety	Biomass (kg) fresh weight	Biomass t/ha fresh weight	
Control	26.8	14.18	a,b
Sesbania aculeata	33.8	17.88	a
Sesbania bispinosa	23.5	12.43	b,c
Sesbania rostrata	13.5	7.14	c
Sesbania sesban	25.8	13.65	a,b
Sesbania speciosa	8.8	4.66	c
Least significant difference (5%)	9.15	4.84	
Coefficient of variation	23%		

Comparison	**p-value**
Comparison for all varieties	0.001
Control vs. others	0.103

A,b,c,refer to treatment groupings according to significant difference.

Tomato yields showed great variation between plots and no significant difference were detected in number and weight of either healthy, or unhealthy fruit, nor in truss number. Overall, poor yields and quality of fruit from this and previous trials, suggests that *Sesbania* spp. are not suitable green manures for tomato production.

4.2.2 Green manures suited to non-flooded conditions

Those green manures suited to non-flooded conditions were trialled both on- station and on-farm (Kiff et al., 1998, Nelson et al., 1998, O'Connell et al., 2000a, O'Connell et al., 2000b.).

On-station trials

In the first year of trials very variable biomass yields were obtained between replicates for the different green manures (table 6). While this lead to inability to detect significant difference between the different species (p=0.099), it highlighted the likely experience of farmers with the new technology. The trial was sited on the driest/ highest ground of a trial site selected for its similarity to local farmer's river side dry season sites, but was subject to sporadic waterlogging despite it's distance from the stream bank. Subsequent tomato crops were also very variable and no significant difference detected between treatments.

Table 6 Weight of fresh biomass per plot for each replicate:

Species	Rep 1 (kg)	Rep 2 (kg)	Rep 3 (kg)	Average (kg)	Equivalent t/ha
Mucuna pruriens (mottled seed)	27.0	29.0	12.4	22.8	20.27
Mucuna pruriens (white seed)	38.4	21.6	7.0	22.3	19.82
Canavalia ensiformis	18.4	7.4	13.0	12.9	11.47
*Cajanus cajan*s	4.0	14.0	3.3	7.1	6.31
Crotalaria sp.	40.2	22.2	15.0	25.8	22.93

Using an apparently more uniform site at Wenchi Agricultural Research Station (carefully chosen for previous uniform cropping) eight varieties were grown in a randomised block design. Better biomass yields were obtained than at the Sunyani site (table 7).

Table 7 Mean biomass yields for the different varieties and the least significant difference (5%) obtained from the analysis of variance.

Variety	Biomass (kg) fresh weight	Biomass t/ha fresh weight		Estimated dry weight of biomass t/ha (from subsequent samples
Calapagonium mucunoides	24.1	12.75	c	3.16
Canavalia ensiformis	37.7	19.95	b,c	3.39
Control	46.6	24.66	b,c	
Crotalaria juncea	26.5	14.06	c	2.53
Crotalaria sp	61.1	32.33	a	5.82
Mucuna pruriens (black)	60.8	32.17	a	9.01
Mucuna pruriens (cream)	49.7	26.30	a,b	4.21
Mucuna pruriens(dark mottled)	36.2	19.15	c	4.02
Mucuna pruriens (lightly mottled)	27.1	14.34	c	4.02
Least significant difference (5%)	12.5	6.61		
Coefficient of variation	17%			

a,b,c,refer to treatment groupings according to significant difference.

Crotalaria sp and *Mucuna pruriens* (black) are the only varieties with more biomass than the control (of natural fallow vegetation), and both are significantly larger. However, it is not just biomass that mediates green manures effect on soil fertility, but the nutrient content of the biomass is also important (table 8). Legume green manures will contain greater amounts of nitrogen than weed species dominated by elephant grass. Estimated figures for dry weight of biomass are also given, calculated from samples from plots outside of the experimental area (all the biomass produced within the experiment was incorporated).

Analyses of tomato yields showed no statistical difference between treatments in number or weight of either healthy, or unhealthy fruits, nor in number of trusses formed (O'Connell, 2000b).

Table 8 Nutrient content of variety of green manures grown at Wenchi Agricultural Station 2000, analysis by SRI, Accra.

ID No	Plant material	Wet wt g	Wt dry g	% H_2O	% N	% P	% K	Ca	Mg	Cu	Fe	Mn
10	*Mucuna* cream (no flower)	550.0	86.16	84.33	7.03	3.38	3.1	13370	10550	90	?	560.0
11	*Mucuna* light mottled (no flower)	202.4	56.14	72.27	5.04	2.15	1.7	7750	10550	0	?	620.0
14	*Mucuna* dark mottled	650.8	138.27	78.75	3.58	1.31	2.5	8880	5240	0	?	560
12	*Mucuna* black (no flower)	152.0	42.69	71.91	4.26	1.98	2.3	7386	8850	65	?	740.0
13	Canavalia ex Sunyani (flower buds developed)	409.1	69.45	83.02	3.78	1.61	3.1	8880	7150	45	?	500.0
6	*Crotalaria* sp	600.0	105.81	82.37	?	2.13	3.6	8500	9270	45	530	620.0
1	*Crotalaria* ochroleuca	400.0	67.42	83.15	5.18	1.52	2.0	5880	10330	45	900	620.0
2	*Crotalaria* naragutensis	500.0	103.24	79.35	4.00	1.72	1.7	4380	8850	13	820	860.0
3	*Sesbania* sesban	300.0	70.95	76.35	4.20	1.41	?	8500	2910	54	410	210.0
7	*Sesbania* sesban ex on-station	300.0	97.79	67.40	5.29	1.89	2.6	8136	2900	45	?	630.0
5	*Sesbania* aculeata	400.0	102.50	74.38	?	1.79	2.2	7000	2910	45	490	620.0
9	*Sesbania* rostrata	600.0	253.96	57.68	?	2.14	2.0	8636	5030?	45	?	590.0
8	Calapagonium mucunoides ex Setropa	300.0	74.52	75.16	?	.82	?	3620	9270	110	?	686.0

On-farm trials

In the first year of trials all the farmers who tested green manure species ranked production of tomatoes to be better on these plots than on their control plots, whether this included the use of chemical fertilisers or not. The criteria used for ranking included size and quality of fruits as well as total yield, as explained in detail under animal manure trials on-farm, above (Kiff et al., 1998).

In the second year of trials, problems were experienced in the germination of green manure species (seed had been multiplied on the Sunyani on-station site, but probably not dried sufficiently before storage). Also late arrival of rains and dry conditions caused poor growth in the green manures, or delayed planting by some farmers. At the Tano district sites (Dwomo and Koforidua) greater yields of tomatoes were obtained by using the animal manures, than the green manures. At the Wenchi district sites (Bepoayase and Akrobi) no clear pattern emerged as only two farmers completed trials with both animal manures and green manures (O'Connell, 2000a)

After the third year of trials it became apparent that a greater preference for green manures were shown by farmers in the Wenchi district than those in the Tano. The two districts are in differentiated by a number of factors:

- Agro-ecological zone (Wenchi in the transition zone (forest to savanna) and Tano in humid forest belt).
- Tano farmers use seasonally flooded/ irrigated valley bottoms, whereas Wenchi farmers cultivate mainly rain-fed upland areas.
- The majority of Wenchi farmers grow dry season vegetables on family land, wheras those in Tano district rely predominantly on rented land. However, a separate analysis indicates that land tenure does not at present have a significant influence on farmers' preferences for green manures (Chan et al., 2000).

It is likely that one or more of the following factors may explain this difference of interest in green manures:

- The green manure species/varieties that were tested on farm did not grow well in water-logged conditions. Waterlogging is much less likely to occur in the upland areas, whereas the risk of waterlogging is much higher on the valley bottom farms.
- Green manures lead to better soil moisture retention (figure 5), which is obviously more important in the drier upland areas. The particular popularity of *Mucuna* probably reflects the fact that the farmers perceived *Mucuna* to be the best at conserving moisture in the soil. Farmers particularly mentioned the moist, friable nature of soils under the *Mucuna* crop, compared to that under other species, or normal fallow vegetation.

Crotalaria spp. were liked by the farmers because of the very tender nature of the stems that allowed it to be incorporated into the soil with much less effort than the other species. Its potential suppressing effect on root-feeding nematodes was also of great interest to the farmers, who suffer greatly from this pest. The usual control method of using rotations is difficult to practice because of trader pressure to specialise in a single vegetable species in a given location.

Edibility of *Mucuna* spp. seed

Some farmers expressed interest in using the seeds of the newly introduced *Mucuna* varieties in soups (as they traditionally do with the local variety of *Mucuna*, adua apia). *Mucuna* is known to contain L-dopamine, which is used medicinally to treat the symptoms of Parkinson's disease. However it may also produce side effects such as uncontrolled muscle twitches and psychotic disorders, including schizophrenia. Samples from the various varieties undergoing trial were sent for analysis to the USA (table 9). There the local variety of *Mucuna* was found to have the lowest L-dopamine content and in fact the equal lowest content to any of the samples analysed to date by the lab. This suggests that a certain amount of domestication has occurred in farmer's collection and propagation of seed for consumption. The local variety possesses very itchy hairs on its leaves and stems, which make it unsuitable to grow as a green manure.

Table 9 L-dopa content of newly introduced and local *Mucuna* varieties

Variety	L-DOPA (%w/w)		95% confidence (+/-)
1. *Mucuna pruriens* local variety (locally known as Adua apia)	2.17	a	0.03
2. *Mucuna pruriens* white seed	3.12	b	0.05
3. *Mucuna pruriens* light mottled seed	4.34	c	0.04
4. *Mucuna pruriens* dark mottled seed	4.50	d	0.02
5. *Mucuna pruriens* black seed	5.64	e	0.05

a,b,c,d,e All values significantly different from one another.
Analysis by Rolph Myhrman, World Hunger Research Centre, Judson College, Illinois, USA

4.2. The effect of improved technologies on soil fertility levels and water-holding capacity.

Soil analyses have shown that the cultivated soils in Brong Ahafo are generally slightly acid with variable levels of phosphorus, potassium and organic matter, these levels tending to be low on soils experiencing longer cultivation (Dennis and Boadi, 1997). The use of green and animal manures provides organic matter and some essential macro and micro-nutrients to the system. Applications of animal manure, or fertiliser phosphate, are required where there are low levels of this element in addition to green manure. On-station trials have shown that green manures can increase the soil water-holding capacity, but further replication is required to identify whether there are clear differences between species and at what depths these occur (Milliner, 1998, 2000a, 2000b).

4.3.1 Soil fertility

The project liased closely with the Ghanaian Soils Research Institute, both in Kumasi and in Accra, for soil survey of the trial sites and for soil analyses (Dennis et al., 1997, 1998; Nyameke, 1999). Unfortunately soil analysis and report production was subject to many delays which led to a second year of trials being conducted at a site that was not of sufficient uniformity.

A build-up of phosphorus was identified in soils to which farmers were applying NPK fertiliser under intensive dry-season tomato production. Low phosphorus levels were detected in areas under cultivation, but not receiving NPK (Dennis et al., 1997). Green manures are not suited to areas with low phosphorus levels, animal manures should be used in these areas, particularly poultry manure, which contains particularly high levels of phosphorus (table 1).

4.3.2 Soil water-holding capacity

The impact of the three most promising species of green manure on the moisture content of soils during the subsequent tomato crop's growth was monitored (Milliner 1998, 2000a, 2000b). This was conducted over three years, using tensiometers placed at 30cm and 60cm depths. Equipment constraints limited this investigation to a single replication. Differences in soil moisture retention at a depth of 30cm under different species of green manure during the growth of the subsequent tomato crop are shown in fig 3. The control had fallow vegetation incorporated before transplanting.

Fig 3. Tensiometer readings during growth of the tomato crop following incorporation of different species of green manure.

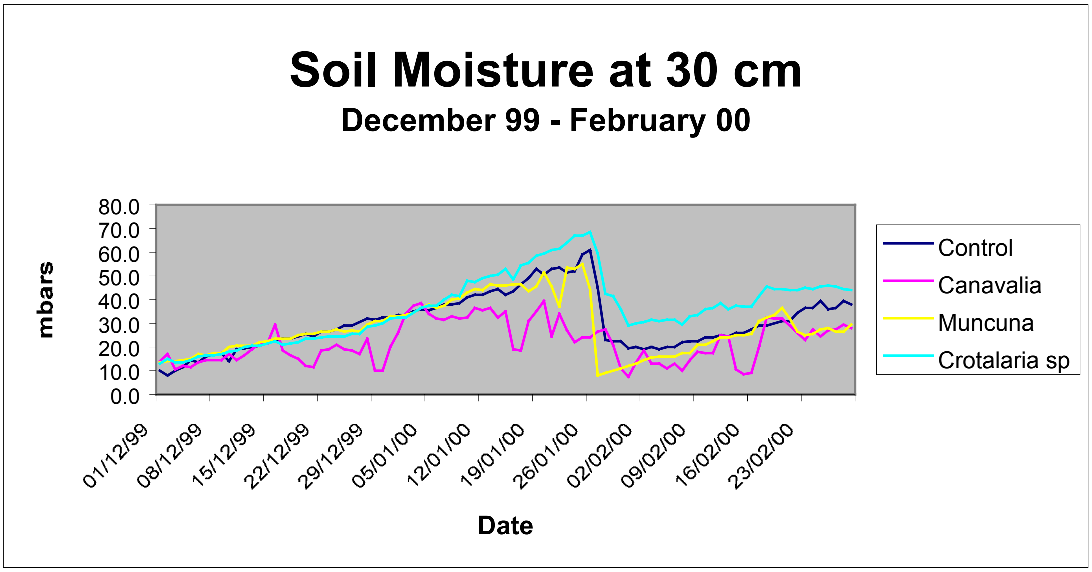
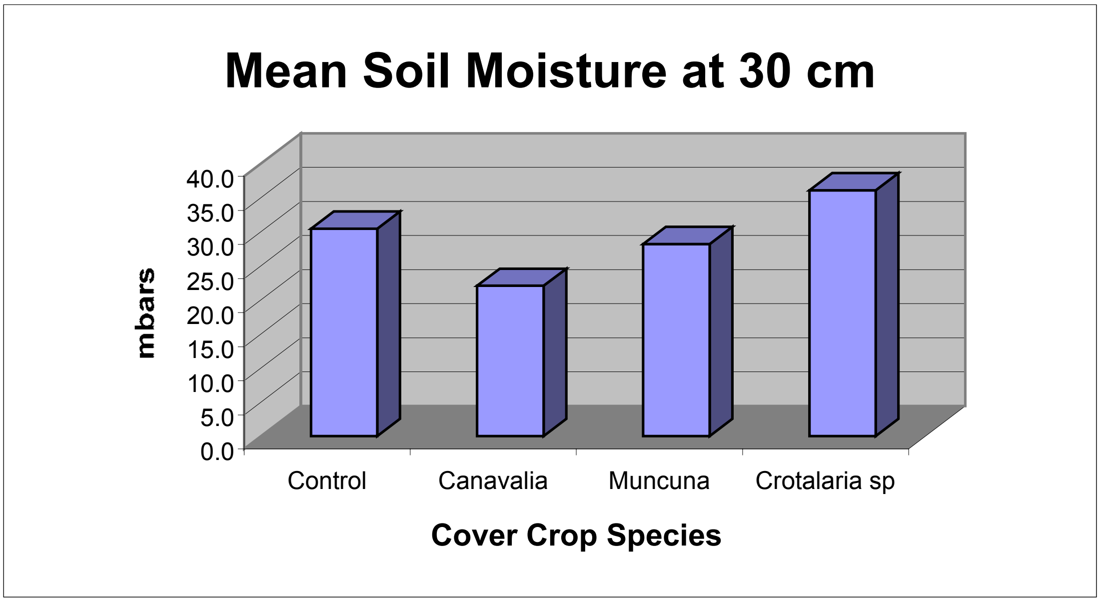


Table 10 ANOVA significance test (at 30 cm) at 95% confidence level.

Species	DF (total)	F	P
Control/*Canavalia*	90	3.45	0.000
Control/*Mucuna*	90	12.70	0.000
Control/*Crotalaria*	90	9.65	0.000
Canavalia/Mucuna	90	3.66	0.000
Canavalia/Crotalaria	90	3.03	0.001
Mucuna/Crotalaria	90	2.23	0.005

Figure 4 Mean values for soil moisture at 30cm 1999/2000



Analysis shows highly significant differences between water retention by the different species of green manure (table 10 and fig 4). The following conclusions were drawn from the three years of study:

- Soils under cover crops, which have been incorporated as green manure, preserve more moisture than soils left bare or with natural weeds in the top 30 cm. This was true for all three years.
- Soil texture has a significant effect on short-term moisture levels whereby sandy loam responds more rapidly to moisture fluctuations than sandy clay loam.
- Cover crops preserve more soil moisture on sandy loam than on sandy clay loam, subject to rainfall.
- Evapotranspiration has a significant impact on soil moisture in the top 30 cm, subject to amount and frequency of watering.

4.4 Analysis of the costs/benefits of new technologies in terms of labour use, requirements for pest and disease control, inorganic fertiliser and water inputs, and crop productivity.

A participative assessment was carried out with collaborating farmers at the end of the project to quantify and compare the cost (labour and financial) and the benefits (financial income) associated with using green manures and animal manures in relation to farmers normal practice for dry season tomato production. It was decided to consider labour and financial costs separately, rather than assigning an opportunity cost to labour and conducting a single analysis. This option was chosen because an aggregate measure of "net benefit" does not fit with farmers' decision-making. The farmers tend to consider financial profitability and labour inputs as separate factors, and the extent to which labour requirements affect a farmer's interest in a technique varies between farmers and over time (Chan et al., 2000).

4.4.1 Comparison of labour inputs and financial costs for the different techniques

The following is a summary of the findings on labour inputs and financial costs that came out of the participatory budgets which were made with the trial farmers in each of the four villages.

Table 11 Average labour requirements for green manures and animal manures as compared to farmers' normal practice (labour requirements for 0.5 acre)

	Akrobi	Bepoyease [1]	Bepoyease [2]	Dwomo	Koforidua
Normal Practice (no. of man-days)	105	59	56	160	126
Green Manures (no. of man-days)	113	92 *	89 *	183	137
Green Manures (% increase compared to normal practice)	+8%	+56% *	+59% *	+14%	+9%
Animal Manures (no. of man-days)	120	75	72	176	126
Animal Manures (% increase compared to normal practice	+14%	+27%	+29%	+10%	+0%

Notes:
[1] *Figures from Kwadwo Fordjour and Ben Nketiah*
[2] Figures from Kwame Kentor, Grace and Lydia
** In Bepoyease, farmers normally don't ridge for dry season tomatoes, so ridging was considered an extra task associated with using green manures.*

With the exception of Bepoyease, the increase in labour inputs associated with use of green manures, when considered as a proportion of total labour requirements over the cropping season, is not as great as initially thought from talking with collaborating farmers (table 4.4.1). In proportionate terms, the labour requirements for using green manures and animal manures appears to be similar. This suggests that the problem for farmers appears to be associated with the *type* rather than absolute amount of work involved, in the sense that the cutting and incorporation of green manures is seen to be "very tedious" work.

For Bepoyease, the use of both green and animal manures entails a substantial proportionate increase in labour requirements over and above requirements associated with their normal practice. This is because of the different production methods used by farmers in Bepoyease, and the lower level of commercialisation of production. Farmers in Bepoyease do not normally ridge, but they have been ridging as part of the process of incorporating green manures, so ridging is considered an extra task. Moreover, Group 2 in Bepoyease calculated their costs based on planting the tomato crop straight after the harvest of the minor season maize crop, when there is still residual moisture in the soil and little land clearing is required. This system/timing meant that labour inputs were considerably reduced (no watering or land clearing). Finally, Bepoyease use less inputs (fertiliser and pesticides) than farmers in the other three villages, so again time spent on these activities is much reduced compared to the other farmers.

Table 12 Average financial costs of using green and animal manures as compared to normal practice (with hiring of labour) (costs for 0.5 acre)

	Akrobi	Bepoyease [1]	Bepoyease [2]	Dwomo	Koforidua
Normal Practice ('000 cedis)	446	168	175	916	638
Green Manures ('000 cedis)	446	333*	340*	996	584
Green Manures (% increase compared to normal practice)	+0%	+98%*	+94%*	+9%	-8%
Animal Manures ('000 cedis)	482	220	227	961	587
Animal Manures (% increase compared to normal practice	+8%	+31%	+30%	+5%	-8%

Notes:
[1] *Figures from Kwadwo Fordjour and Ben Nketiah*
[2] Figures from Kwame Kentor, Grace and Lydia
** In Bepoyease, farmers normally don't ridge for dry season tomatoes, so ridging was considered an extra task associated with using green manures*

The use of green and animal manures can actually increase overall financial costs of production when farmers hire labour (table 12) The increased labour requirements are translated into increased financial costs which may outway the savings in reduced inputs of inorganic fertilisers. Nevertheless, with the exception once again of Bepoyease, as a proportion of overall production costs throughout the season, the increases are not substantial.
The reasons for the differences in the Bepoyease situation are similar to those mentioned under the discussion on labour inputs. The *proportionately* high increases in financial costs associated with use of animal and green manures as compared to normal practice are partly to do with the fact that overall, absolute production costs are much lower. Also, in the case of green manures, the higher costs are associated with extra labour requirements being greater than for the other villages because ridging does not usually take place under normal practice.

Table 13 Average financial costs of using green and animal manures as compared to normal practice (without hiring of labour) (costs for 0.5 acre)

	Akrobi	Bepoyease [1]	Bepoyease [2]	Dwomo	Koforidua
Normal Practice ('000 cedis)	194	33	0	196	163
Green Manures ('000 cedis)	154	33	0	121	96
Green Manures (% increase compared to normal practice)	-21%	0%	0%	-38%	-41%
Animal Manures ('000 cedis)	209	67	34	121	136
Animal Manures (% increase compared to normal practice	+8%	+10.5%		-38%	-17%

Notes:
[1] *Figures from Kwadwo Fordjour and Ben Nketiah*
[2] *Figures from Kwame Kentor, Grace and Lydia*

In a scenario where farmers do *not* hire any labour, i.e. where labour is not a financial cost, the use of green manures compared to normal practice leads to a substantial reduction in financial costs of production, apart from in Bepoyease where costs remain the same (table 13). This is because farmers

consider that there are no extra financial costs associated with using green manures, but money normally spent on buying fertilisers can be saved.
In Akrobi and Bepoyease, financial costs actually increase as a result of using animal manures. This is primarily due to costs they estimated for transporting the manure from the manure source to their farm. There was considerable variation in costs associated with transport between the different villages. This may partly reflect that in some cases the source of animal manure was very close, whereas in other cases farmers had to get to the next village or town to collect it.

4.4.2 Quantifying benefits from improvements in fruit quality

Traders will typically pay full price (that agreed before harvest) for around 40% of the total produce bought. They buy the remaining 60% at a discounted price ranging from around 40% to 100% of full quoted price, with the amount of the discount depending on the quality of fruit.

Comparison of the average quality scores indicates that all of the green and animal manures, with the exception of *Sesbania*, produced better quality fruit than the control treatments, as measured by the total quality scores. What is even more striking is the comparison of the proportion of farmers who are producing tomatoes that are likely to be of a good enough quality to fetch the full quoted price per crate (see table 4.4.4 notes, below). With the exception of *Mucuna* (light mottled) and *Sesbania*, for all the green manures and animal manures a minimum of 79% of the farmers were producing tomatoes of a quality that could fetch full price. In the case of *Crotalaria*, cow manure, poultry manure, sheep/goat manure, and the mixture of cow and poultry manure, *all* of the farmers were producing tomatoes of a quality that could fetch full price

Effects of using different treatments on overall fruit quality (total quality scores)
The table below shows the total quality scores averaged over the 98/99 and 99/00 trials for each treatment and each farmer.

Table 14. Total quality scores by treatment and farmer

TOTAL QUALITY SCORES (Average of 98/99 and 99/00 scores)	**Canavalia**	***Mucuna* (Dark Mottled)**	***Mucuna* (light mottled)**	***Crotalaria***	***Sesbania***	**Cow**	**Poultry**	**Sheep/ Goat**	**Cow-poultry**	**Sheep/goat – poultry**	**Control**
Mr. Assuah	1.60	1.60						1.60			2.00
Abena Ahenkaa						2.20	2.00		2.20		2.75
Agnes Asantewaa						2.20	2.00		2.20		3.20
Ampah	2.60	2.60		1.50		1.50	1.50		1.50		2.20
Mary Ameyaa	1.60	1.60		1.75							3.00
Takyi Kwaku	2.20	2.20									2.80
Kwame Kentor	1.54			1.78			2.00	1.88		2.00	2.30
Ben Nketiah	1.50	2.00		2.00			2.00	1.60		2.00	2.00
Kwadwo Fordjour	2.20	2.00		1.00			1.80	1.80		1.60	1.40
Lydia Adomah	2.40	2.75		1.50			2.20	2.20		1.50	2.20
Grace Darkoah											
Takyi Kingsley	1.60	1.50				2.00	1.60		1.70		2.48
Elizabeth Foriwaa	1.80	1.80				1.47	1.46		1.25		2.85
Sophia Boateng	1.80	1.60				1.80	1.80		1.80		2.50
Ebenezer					3.67	1.30	1.63		1.18		2.45
Boy Alone						2.10	2.00		1.60		3.10
Felicia Addai	2.17	1.83	2.00			2.25	1.83	2.25	1.67	2.75	2.50
Thomas Awuah	2.33	2.50	2.50	2.33		2.33	1.92	2.33	1.83	1.67	2.75
Peter Mensah	1.80	1.80									2.60
Bernard Amoah	1.83	1.63					1.67				3.67
AVERAGE QUALITY SCORE:	**1.93**	**1.96**	**2.25**	**1.69**	**3.67**	**1.92**	**1.83**	**1.95**	**1.69**	**1.92**	**2.57**

% farmers who could get full price for their tomatoes *	93%	79%	50%	100%	0%	100%	100%	100%	100%	83%	42%

Notes:
N.B. The scoring system is from 1 to 5, with 1 = very good quality and 5 = very poor quality.
** This percentage is based on the number of farmers whose total quality score for the particular treatment is smaller than 2.50 (i.e. the nearest "whole number" is 1 or 2). This follows the weighting system used in the Cost Benefit Analysis.*

Key to green manure treatments:

Green manure treatment	Species of green manure
Canavalia	*Canavalia ensiformis*
Mucuna (dark mottled)	*Mucuna pruriens* (with dark mottled seed coat colour)
Mucuna (light mottled)	*Mucuna pruriens* (with light mottled seed coat colour)
Crotalaria	*Crotalaria juncea*
Sebania	*Sesbania sesbans*

4.4.3 Cost-Benefit Analysis

The different scenarios used for the analysis were as follows:

Farmer *hires* labour for certain tasks:
Scenario 1: Price per crate of tomatoes is C20,000
Scenario 2: Price per crate of tomatoes is C50,000
Scenario 3: Price per crate of tomatoes is C100,000

Farmer *does not hire* any labour:cenario 4: **Price per crate of tomatoes is C20,000**
Scenario 5: Price per crate of tomatoes is C50,000
Scenario 6: Price per crate of tomatoes is C100,000

Table 15 Summary of profits (findings from the Cost-Benefit Analysis)

AVERAGE (MEAN) PROFITS *(Cedis)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Canavalia	(238,844)	227,328	1,004,281	221,469	687,641	1,464,594
***Mucuna* (dark mottled)**	(183,619)	365,391	1,280,406	276,694	825,703	1,740,719
***Mucuna* (light mottled)**	(178,000)	431,000	1,446,000	310,000	919,000	1,934,000
Crotalaria	(152,300)	263,950	967,700	190,100	606,350	1,300,100
Cow	301,250	1,866,875	4,476,250	893,350	2,458,975	5,068,350
Poultry	192,313	1,337,000	3,244,813	645,350	1,790,563	3,620,250
Sheep/goat	135,688	859,906	2,066,938	393,188	1,117,406	2,324,438
Cow-poultry mix	135,000	1,451,250	3,645,000	727,100	2,043,350	4,237,100
Sheep/goat – poultry mix	51,786	621,250	1,570,367	307,071	876,536	1,825,643
Control	(201,700)	295,925	1,125,300	188,650	686,275	1,515,650

Notes:
** These profits are averaged between years (98/99 and 99/00), and between all farmers who tried the technique in question.*
Figures in (brackets) represent losses.

Table 16 Percentage of farmers making a profit (findings from the Cost-Benefit Analysis)

% OF FARMERS MAKING A PROFIT *	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Canavalia	19	69	88	100	100	100
***Mucuna* (dark mottled)**	19	50	75	81	88	88
***Mucuna* (light mottled)**	50	50	100	100	100	100
Crotalaria	20	60	80	100	100	100
Cow	60	90	100	90	100	100
Poultry	56	94	94	100	100	100
Sheep/goat	38	88	100	100	100	100
Cow-poultry mix	40	90	90	80	100	100
Sheep/goat – poultry mix	43	71	100	100	100	100
Control	10	60	90	75	100	100

<u>Notes</u>:
** These figures represent the numbers of farmers making a profit expressed as a percentage of the number of farmers who tried the technique in question.*

Discussion and interpretation of findings
There are a number of reasons why caution is needed in drawing conclusions from the available data (see Chan et al., 2000), Nevertheless, the data does appear to reveal a number of clear patterns:

- All of the animal manure treatments are more profitable than either the green manures or farmers' normal practice.
- Of the animal manure treatments, the cow manure, poultry manure and the combined cow/poultry manure treatments were more profitable than sheep and goat manure and the sheep-goat and poultry manure mixture.
- Of the green manure species, Canavalia and the *Mucuna* (dark mottled) proved to be significantly but not dramatically more profitable than farmers' normal practice [1], whereas was less profitable than normal practice.
- Use of the animal manure treatments appears to reduce the risk of making a significant loss if market prices for tomatoes are low.
- The extent to which farmers rely on hired labour on their dry season vegetable farms has a significant effect on financial profitability. For example, under **Scenario 1** (price per crate is C20,000, farmers hire labour for tasks as specified in the participatory budgets) only 3 of the 16 farmers involved made a profit on Canavalia, whereas under **Scenario 2** (price is C20,000, no use of hired labour) all of the 16 farmers made a profit.
- However, with the exception of farmers in Bepoyease, the extent to which farmers hire labour does not have a significant impact on the *relative* performance of the different treatments.
- The market price of tomatoes obviously has a very significant effect on overall profitability.
- The findings from the Cost-Benefit Analysis generally complement findings from the qualitative assessment, although it would be difficult to explain the popularity of the green manures on the CBA results alone. However, results of the qualitative assessment suggest that the existing CBA does not capture a number of demonstrated and potential cost-savings, as well as longer-term benefits, of using green manures, and this may to some extent explain the divergent implications.

[1] Average profits for the different treatments were compared against average profits for the control plots *of those farmers who had tried the technique in question*. Therefore, average control plot profits used as the benchmarks for comparison are not the same as the averages given in **Table 15,** which shows average control plot profits for *all* the trial farmers.

4.5. *Manual outlining most promising improved techniques for use by extension services and non-government organisations involved in agricultural extension activities.*

A manual was produced in collaboration with the crop post-harvest section of the integrated food Crops Systems Project and MoFA colleagues (Kiff et al., 2000). The manual contains sections on extension methods and tools to encourage farmer participation, plant nutrition, the contribution of chemical and organic fertilisers to soil productivity and organic agricultural production. Two chapters deal with good seed selection and nursery practices, five with the use, propagation and storage of green manures, animal manures and compost and two with post-harvest handling and processing issues. Fourteen one-page extension leaflets contain the practical details of each technique recommended and how to select the most appropriate technique for different situations. These are included in the back of the manual and have been produced independently (2000 copies of each) by the MoFA extension services for distribution through the usual extension channels.

4.6. *Design for an appropriate research programme to address key constraints to vegetable production in the wet season.*

In the second year of the project a survey was undertaken in collaboration with the University of Reading to investigate the potential for the use of green manures in the wet season (Galpin et al., 1999). A project proposal addressing the key problems encountered with the shortening of bush fallow rotations was submitted to NRSP in early 2000. The proposal was fully supported by the Regional Director, Mr Osei Frimpong and drawn-up in collaboration with MoFA colleagues. It was not selected for funding.

5. Research Activities

5.1 *Developing improved technologies*

5.1.1 Farmer participatory surveys

In collaboration with MoFA colleagues who had been working with the on-going crop post-harvest and the earlier crop protection sections of the IFCSP, four representative, but contrasting villages producing dry season vegetables commercially were identified. A PRA was conducted in each village to investigate and document present soil fertility and water management practices during the dry season. Potential sources of animal manure and compost materials, the potential for cultivation of green manures, farmers' attitudes to recycling of organic matter, current cropping patterns and labour spent on dry season vegetable cultivation were also documented (Kiff et al., 1997).

5.1.2 Devise and field test improved techniques of using animal manure.

Four types of animal manure were found locally; poultry manure from relatively large-scale broiler and layer enterprises, cattle manure from communal kraals where livestock are housed at night (normally uncovered) and sheep and goat droppings in household night kraals and scattered around the back yards. All of these sources were largely untapped, poultry manure being burned and back yard sweepings thrown away into the bush. Just two farmers were reported as using animal manure within the five villages visited. They were from the north of Ghana were this practice is common. Following the initial PRA and identification of labour as a key constraint to production, the use of animal manure, rather than compost making, was chosen as an initial entry point for encouraging the addition of organic matter to the soil.

5.1.3 Collaboration with colleagues from the crop protection project.

Collaboration with colleagues was planned, but due to timing of funding, insufficient time remained for them to be able to conduct linked investigations. However their findings with regard to improved post-harvest handling practices and pure-line seed selection are included in the extension manual (Kiff et al., 2000).

5.1.4 Farmer assessment of the effectiveness and suitability of the new technologies sought.

The on-farm trials were located in two different agro-ecological zones. Akrobi and Bepoyease are located in the transitional zone in the Wenchi District and Koforidua and Dwomo in the forest zone in the Tano District of the Brong Ahafo Region. All four villages are predominantly farming communities and rely to a large extent on vegetable production for their livelihoods.

Dry season vegetable cultivation, mainly of tomatoes, is particularly extensive in Dwomo and Koforidua. In these areas most farmers use chemical fertilisers and pest control measures during the dry season, and it is more common for the cultivator to hire land, than to own it. Farmers, consequently, are putting a high level of inputs, both capital and labour, into dry-season vegetable cultivation. While both men and women are involved in vegetable production, more men are involved in commercial dry-season tomato production than women.

A range of vegetables, okra, egg plant, chilli and tomatoes are grown in Akrobi and Bepoyease, with okra as the main commercial crop. In these areas farmers most commonly cultivate their own, or family land and the majority do not use any chemical fertilisers or crop protection products. Cultivation in these areas is less input-intensive. Approximately equal numbers of men and women are involved in dry-season vegetable production.

Farmer assessment of the technologies was encouraged and sought throughout the project. This was conducted at the individual farmer level, in their ranked assessment of trials on their own land according to self-determined criteria and also at the village level, with discussion between farmers on performance of the different techniques on different farmer's land. Farmers were also invited to the on-station sites to see trials (particularly of the different varieties of green manure and at the time of incorporation into the soil). Some of the farmers had previously been involved in taste trials of new pure line varieties being developed. These farmers conducted their own "taste tests" with their families on tomatoes grown using different organic supplements. There was a general agreement that those grown using green manures had firmer fruit with more flesh and were tastier than others. These fruit also looked better and several women reported being able to sell them more easily (saving time at market).

5.2 Introducing the use of green manures

5.2.1 Identify opportunities within cropping cycle for the cultivation of green manures.

Strategies to introduce the concept of green manure cultivation were developed for each of the villages following the initial PRA. Strategies were related to soil types present, water availability, timing of cultivation and husbandry practices employed. Green manures were selected suited to waterlogged conditions and others suited to non-flooded conditions. Green manures with different lengths of vegetative phase (time to optimum incorporation) were also considered. Where possible these were sourced from within Ghana, but flood-tolerant *Sesbania* spp., nematode resistant *Crotalaria juncea*, and high yielding green manures suited to the region were imported.

5.2.2 Conduct species trials to select most suitable green manures for different locations and cropping systems.

Green manure species trials were conducted on-station and on-farm as detailed above.

5.2.3 Determine most effective method and time for adding the biomass to the soil to increase crop production.

A two week gap between incorporation and transplanting is recommended, however this requires that adequate moisture is available for breakdown of organic matter. Under high rainfall conditions, 10 days is sufficient, but where conditions are dry 3-4 weeks is required. Use of supplementary water is only an option where this is readily available.

5.2.4 Measure effect of incorporation of different species of green manures on crop production and nutrient status of the soil.

Summarised under outputs above.

5.3. Quantification of changes in soil fertility levels and water-holding capacity associated with improved technologies.

Initial soil profiles of the research and on-farm sites were made (Dennis and Boadi, 1997, 1998) and nutrient analysis of animal manures and green manures used in both the on-station and on-farm the trials monitored throughout the project (Nyamekye, 1999).

5.4. Effectiveness of improved technologies monitored

Improved technologies were tested and monitored on-station (4 animal manure and manure in combination with chemical fertiliser rate trials, 8 green manure trials over 3 years on two sites). Also on-farm (18 collaborating farmers from four sites and 5 collaborating farmers in a further site that due to AEA support problems was not included in formal trials). Farmers over-all evaluation of the different techniques in terms of their own criteria was sought after three years (Chan et al., 2000)

5.5. Document practical findings of research in terms of successful improved technologies in manual form, suitable for use by extension agents.

Dissemination of information generated by the project has been through posters, flyers, reports, workshops, papers to scientific conferences, farmer field days and links to similar projects and institutions. A manual on soil fertility for use by extension agents and students of agriculture has been produced, together with 14 illustrated extension leaflets suitable for farmers' use.

Findings from the research were presented at two workshops, one after eighteen months (Meijer and Kiff eds., 1998) and one after three years (O'Connell and Kiff eds., 2000). These workshops were to disseminate results and also to invite comments and suggestions for direction of the project and the content of outputs. The extension manual chapters and extension leaflets were presented to participants at the last workshop and discussions groups commented on content and layout. These suggestions were incorporated into the final document. The extension leaflets were also field tested by collaborating extension agents (trained in the techniques) with farmers who had not previously been involved. Again suggestions were incorporated into the final document.

5.6.1 Conduct a farmer participatory survey within the IFCSP area

A second PRA was conducted in villages in the Wenchi district to explore the potential for green manure use by farmers for wet-season production. This was conducted by members of the project team in collaboration with University of Reading researchers (Galpin et al., 1999). During this survey key constraints in wet season cultivation were identified.

5.6.2 Develop an appropriate research programme to address the key constraints.

In collaboration with MoFA colleagues a project was developed and submitted to NRSP for funding.

6. Contribution of Outputs

Dry-season vegetable farmers face increased dependency on chemical fertiliser and supplementary water inputs due to decreased soil productivity caused by prolonged cultivation that has mined the soil's previously high organic matter content. Farmers also complain of increased incidence of pests and diseases on the crops. These factors have increased the cost (capital and labour) and the risks associated with vegetable production. Project recommendations for the use of green manures, animal manures and composts provide a low-cost alternative to chemical fertiliser additives that can replace, or be used in conjunction with the bought inputs. They also provide a means of improving longer-term soil productivity, soil health and water-holding capacity through building-up the soils organic matter content. The techniques offer sustainable ways of intensifying cropping to a region where increasing population pressure is challenging the sustainability of traditional fallow-based systems in wet as well as dry-season systems.

6.1 Addressing poverty

Dry season vegetable production is an important source of income for a wide range of cultivators in the Brong Ahafo and other regions in Ghana. Large-scale (1-2 acre) commercial enterprises require adequate returns to high levels of labour and bought inputs, while smaller-scale, lower-input enterprises are looking for regular and reliable contributions to farm income as well as supplying household needs. Women are responsible for food preparation and vegetable production can be a source of income, even when not sold outside the family, because of the social arrangement of "chop", or food money paid by husbands/ fathers.

The introduction of low external input alternative methods to soil productivity improvement and maintenance will allow cultivators with less capital to enter commercial production. It also reduces the risk for present cultivators who had been experiencing a reduction in profits as more and more external inputs were required to try and maintain production levels. Quality of vegetables can be improved which increases the price obtained and widens the markets to which the products can be sold. Women are particularly involved in local market and elite road-side sales, where a premium for quality vegetables is obtained.

6.2 Contributing towards social and human development

The dominant extension paridigm in Ghana is the training and visit system. Extension officers are used to the system of being given a message that they are then to pass on to farmers. The project encouraged farmer-orientated and farmer-directed extension and research through training in participatory techniques, the instigation of farmers' groups and farmer cross-visits. Farmers conducted their own monitoring and evaluation of on-farm trials, using self-determined criteria for assessment. These criteria varied between different groups of cultivators, with women tending to put more emphasis on vegetable quality and taste than male farmers. Assessment under commonly mentioned criterium, such as labour, also produced different results from different cultivators. For example, cultivators that practice ridging in tomato cultivation found incorporation of green manures to require 10%, or less additional labour, whereas those not practising ridging experienced over 50% increase in labour requirement with the new technology.

Participatory farm budgeting and evaluation techniques introduced (in collaboration with Reading University) were empowering for illiterate farmers who previously had not spoken during farmer gatherings and field visits. One such farmer (Mr Takyi Kingsley) having constructed a visual evaluation of his trials with symbols representative of yield, fruit quality, plant health and disease presence, expounded at some length at the next farmers meeting on his opinion of the various treatments. Previously he had not spoken at meetings where researchers were present. Other farmers also started to use farmer notebooks (a practice encouraged by the extension services and rewarded when best district farmers are chosen). The ability to write (in symbol form) gave farmers confidence in asking extension staff about problems they were experiencing. Economic analysis of production of vegetables within the trials was a new experience, even for the most experienced farmers. Some have started to apply the principal to other crops and income-generating activities, e.g. a snack preparation enterprise.

Evaluation by Pat Norrish and team (consultants to NRSP) of the effectiveness of the project's activities comment on the "enthusiasm and positive impact generated by the project amongst project staff, intermediaries and farmers". With regard to communication activities they found "many positive changes in the cognitive, attitudinal and behavioral dimensions of the operations of all stakeholds". For the local project team this is manifest as "a change in perception of the role of farmers in research and development" and has led to "development of more participative approaches to their work". Further the team report "changes have occurred in two levels of farmers. These are farmers who have participated formally in the project, and those who have learnt from contact farmers. A the cognitive level, both types of farmers now know the benefits of organic fertilisers, with regard to higher crop yields and this has led to a more positive attitude towards the use of animal manure in particular". The report concludes that " The success of the project in both technology development and autonomous diffusion of successful technologies indicates that the participatory research/development approach, especially through on-station and on-farm trials is a good opportunity for dissemination". (Norrish, 2001 draft report to NRSP, R6789 section)

6.3 Contribution to environmental sustainability and regeneration

The addition of organic matter to the soil will help maintain soil structure and reduce the erodibility of the soil. Reduced chemical fertiliser additions will reduce the danger of pollution of water courses.

Productive use of animal manures will reduce carbon emissions from burning poultry manure and composting of manures may reduce disease transmission by destruction during the hot composting process. Collection of manure from kraals and the homestead may lead to better hygiene, though precautions need to be exercised in handling the manure.
Green manures offer an improved fallow system that may facilitate the sustainable intensification of cultivation in the wet as well as dry seasons. The ever-shortening bush fallow system practised tends to lead to further forest encroachment as productivity levels decline, as seen at the Manso site. (The Manso site was not one of the long-term on-farm research sites due to problems in the availability of the local AEA.)

6.4 Promotional pathways

The series of farmer and AEA training sessions, farmer field days, on-station visits and workshops were all important dissemination and promotional pathways during the life of the project. A poster was produced during the first year of the project to explain the aims of the project (produced for researcher, secondary-educated extensionists and an international NGO audience). Regional-level workshops, one held mid-project and one at the end, were important for discussion of findings, re-orientation of the project and informing and involving University researchers, National NGOs, other development projects and more MoFA staff in the project. Proceedings from the first workshop can be found in Meijer and Kiff, 1998, and those of the second in O'Conell et al., 2000. During the second workshop the proposed chapters and extension leaflets for the extension manual were discussed and working groups commentated in detail on each section. These comments, together with those from farmers who field-tested the extension leaflets were incorporated into the final publication. Activities and findings were documented throughout the project in a series of project reports (see section 7) which were shared with in-country, regional and DFID UK advisors, interested NGOs in-country (international and local), University researchers, MoFA, Soils Research Institute Soils, and Crop Research Institute staff.
Close collaboration with MoFA has ensured the acceptance and ownership of findings by the national extension service. They have developed, on their own initiative, a proposed follow-on 6-month dissemination project to train extension workers, subject matter specialists and Agricultural college staff in the technologies. This proposal is with the NRSP Programme Manager for consideration.

6.5 Follow-up action / research required

The Regional director of agriculture, Dr Agbeli, identifies a need for active dissemination of the 600 extension manuals and 14,000 extension leaflets produced by the project. These detail approaches to participative extension methods, background to soil productivity, use of organic soil ameliorants, pure-line selection for vegetable crops and post-harvest handling of produce. As mentioned above, collaborators have independently produced a proposal for a six-month pilot project, involving just local staff, which would train MoFA extension agents and subject matter specialists, and agricultural college staff in the techniques (copy submitted to NRSP in June 2000). Training would involve practical field work and development of demonstration sites in each district. The activities would be carried out within other districts in the Brong Ahafo region.

7. Publications and other communication materials

Publications

Boa-Amponsem, K., and Suglo, V. 1998. Workshop for Further Identification of Vegetable Research Priorities in the Brong Ahafo Region of Ghana. *Workshop Proceedings, 10 – 11 September 1998.*

Jackson, D., Kiff, E., Chan, M-K., Meijer, A. and Nelson ,D. 1998. Adapting to change in soil fertility management in high value horticultural production in Ghana through the farming systems approach. *Paper presented at the 15 International Symposium of the Association of Farming Systems Research-Extension, Pretoria, South Africa 29 November – 4 December 1998.*

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Jackson, D. 1998. Integrated Food Crops Systems Project (R6789). Trial monitoring visit *(November 1998)*

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Kiff, E., and Floyd, S. 1997. Planning on-station trial site and trial protocols for on-station and on-farm trials in 1997/98. Integrated Food Crops Systems Project, Ghana. (R6789).

Kiff, E., Meijer, A., Ponder, V. and Nelson, D. 1998. On-station trial results for 1997/1998.

Kiff, E., Chan, M-K., Meijer, A., Nelson, D. and Ponder, V. 1998. Evaluation of 1997/8 trials and planning protocols for 1998/1999 on-station and on-farm trials. Holding mid-project workshop involving MoFA and University staff to discuss research findings and future direction for project activities. *(May/June 1998).*

Kiff, E., O'Connell, N., Musa, H., and Nelson, D. 1999. Monitoring and evaluation of on-station and on-farm trials. Integrated Food Crops Systems Project, Ghana (R6789) *December 1999.*

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Linked publicatons

Galpin, M., Shepherd, D.,Awiti, S., Biney, K., Meijer, A., Musa, H.,O'Connell, N et al., 1999 An assessment of the potential of green manuring for use in wet season vegetable production in Wenchi District, Brong Ahafo Fegion, Ghana, using Participatory Farm Management methods.

Galpin, M., Dorward, P. and Shepherd, D 2000 Participatory Farm Management methods for agricultural research and extension : a training manual. University of Reading, Reading, UK.

8. Project Logframe

(see over page)

9. Keywords

Green manure, animal manure, compost, vegetables, dry-season, soil fertility, soil moisture, forest-agriculture interface.

8. Project logframe

Narrative summary	Measurable indicators	Means of Verification	Important assumptions
Goal: To develop and promote strategies to secure livelihoods of poor people dependent on agricultural systems near receding forest margins.	By 2002 new approaches to improve fragile soils of low fertility in humid forest zones validated	Data collected and collated by the programme manager	Sustainable sedentary systems for poor and fragile soils can be devised Land ownership issues can be overcome
Purpose: New improved techniques to reduce fragility and enhance fertility of soils in cultivated areas of humid forest belts developed and promoted.	Two new techniques to enhance soil fertility and reduce fragility suited to the receding forest margin areas developed and promoted by 2001.	Project reports Programme manager monitoring and evaluation Demand from farmers and extension workers for training in the new techniques.	Target groups and institutions are able to invest in the uptake and application of research findings.
Outputs: 1. Improved (composting/mulching) animal manure technologies suited to dry season vegetable production systems, including recommendations for combined use with inorganic fertilisers. 2. Recommendations on the use of suitable species of green manures for dry-season production. 3. Description of the effect of improved technologies on soil fertility levels and water-holding capacity.	1.1 Trials comparing performance of (composts prepared using 2-3 different composting techniques) different animal manures in combination with 2-3 levels/ types of inorganic fertiliser initiated by July 1997. 1.2 Two improved (composting) techniques involving use of animal manures plus inorganic supplements produced by October 1999. (1.3 Trials investigating three different mulching techniques in three locations initiated by November 1997.) 1.4 Effectiveness of (mulching) techniques involving use of animal manures determined by October 1999. 2.1 Trials testing 6 potentially suitable species of green manures initiated by April 1997. 2.2 2 species of green manure together with appropriate management practices identified by October 1999. 3. Sustainability analysis of new technologies in terms of soil productivity produced by 1999. 4. Socio-economic analysis of trial and survey	1 & 2 Field reports, Experimental protocols, Experimental data. 3 & 4 Project reports. 1-4 Scientific papers	The risk to mulched vegetables posed by fire management practices, may make the technology unsuited to the present farming system. Changes in soil nutrient and water-holding capacity associated with new technology may not be statistically significant after just two growing seasons.

4. Analysis of th e costs/benefits of new technologies in terms of labour use, requirements for pest and disease control, inorganic fertiliser and water inputs, and crop productivity. 5. Manual outlining most promising improved techniques for use by extension services and non-government organisations involved in agricultural extension activities. 6. Design for an appropriate research programme to address key constraints to vegetable production in the wet season.	data produced by 1999. 5. Successfully trialed improved composting/mulching techniques, suitable green manures and subsequent organic matter management described. 6. Constraints to wet season vegetable production clearly itemised and necessary research to address these issues detailed with reasoned priorities set.	5.Manual produced and distributed through collaborative and target institutions to extension workers, subject matter specialists and researchers. 6. Wet-season vegetable research programme report	
Activities: 1.1 Farmer participatory survey within the IFCSP area. to investigate and document within selected households; present soil fertility and water management practices during the dry season, potential sources of additional compost/ mulch materials, potential for cultivation of green manures, farmers' attitudes to recycling of organic matter and current labour spent on dry season vegetable cultivation 1.2 Devise and field test improved (composting/mulching) techniques using animal manures suited to the specific context of local dry season vegetable production systems. 1.3 Commission colleagues from the CPP project to assess initial incidence of pests and disease within field site areas and monitor changes. 1.4 Farmer assessment of the effectiveness and suitability of the new technologies sought. 2.1 Identify opportunities within cropping			Willingness of farmers to trial the new technologies. Suitability of existing and potential research sites for on-station trials. Ability to import required green manure species without undue delay.

cycle for the cultivation of green manures. 2.2 Conduct species trials to select most suitable green manures for different locations and cropping systems. 2.3 Determine most effective method and time for adding the biomass to the soil to increase crop production. 2.4 Measure effect of incorporation of different species of green manures on crop production and nutrient status of the soil. 3. Quantification of changes in soil fertility levels and water-holding capacity associated with improved technologies. Soil samples will be taken before initiation of trials, then at 6 month intervals at selected field sites throughout the life of the project. 4. Effectiveness of improved technologies monitored in terms of production, and use of fertiliser, water, need for weeding, pest and disease control, and labour. 5. Document practical findings of research in terms of successful improved technologies in manual form, suitable for use by extension agents. 6.1 Conduct a farmer participatory survey within the IFCSP area to identify and set priorities to agronomic constraints in the cultivation of wet season vegetables 6.2 Develop an appropriate research programme to address the key constraints.			