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1. SCREENING OF AGROFORESTRY SPECIES AND HERBACEOUS LEGUMES FOR THE FOREST AND FOREST-SAVANNA TRANSITION ZONES OF GHANA

1. 1 Introduction and Justification

Degradation of soils through loss of nutrients is a worldwide problem affecting 135 million hectares mostly in South America and Africa (Oldeman *et al.,* 1992). This is particularly true where depletion is a common feature of food crop oriented small scale farms and has led to low labour and land productivity (Swinkels *et al.,* 1997). Most tropical soils are low in nutrients and susceptible to degradation under continuous cultivation.

The importance of trees and shrubs in the traditional bush fallow for soil fertility restoration and maintenance is well documented (Tonye *et al.,* 1997, Duguma and Tonye, 1994; Kang, 1997; Duguma and Mollet, 1997). Trees and shrubs play a major role in achieving greater and more sustained production of food, fibre and forage even on degraded and infertile soils (Young, 1997). Living trees add organic matter to the soil mainly through the natural process of litter and dead root decay. In addition, during active root growth significant amount of organic matter can enter the soil in the form of sloughed-off root tissue, representing a steady release of carbohydrate-rich organic material (Giller and Wilson 1991, Nair 1993).

Degradation and nutrient depletion of weakly structured tropical soils through overuse and inappropriate tillage are the major problems on arable land in West Africa. These require very long periods of fallow restoration (Wilson *et al.,* 1982; Hulugalle, 1994; Kang *et al.,* 1997).

The soil restoration process of the fallow period is well known. The benefits of using legumes as fallow species can be high, particularly if used as cover and green manure crops. Some measurements in the tropics have shown that fallow legume can accumulate 100 – 200 kg N ha^{-1} in 100 days (Giller and Wilson, 1991).Further benefits that can be derived from using fallow legumes are the improvement of soil fertility through the increase of organic matter content and the reduction in the need of weed control on agricultural land (Bunch, 2001). Agricultural systems such as agroforestry, which imitate in part the structure and processes of natural forest vegetation, have high potentials to increase the productivity of fallow farming systems and to sustain continuous crop production.

Improved fallows, designed to enhance and accelerate the vegetative regeneration of soil fertility and to control weeds through the selective use of such fallow legume species as trees, shrubs and/or herbaceous cover crops, take into account that the restoration of soil fertility during fallow phase through the build-up of organic matter is greatest in the first few years. Aside from leguminous cover crops, trees and shrubs which decisively favour soil improvement can be used. Ideally, they should have the attributes that follow: high biomass production, biological nitrogen fixation, deep rooting system, high biomass nutrient content, fast or moderate rates of litter decay and absence of toxic substances in foliage and root exudates (Young, 1997).

Some fallow species are reported to positively contribute to soil regeneration and nutrient recycling processes (Duguma and Tonye, 1994), but information is scanty on the potential of individual fallow species to soil fertility restoration; and type and quantity of nutrient recycled during the fallow phase.

Screening agroforestry and herbaceous legumes for fertility restoration and maintenance of degraded soils, is a basic stage in developing viable and sustainable cropping system in the tropics. Plant species to be used in short fallow need to have specific characteristics and above all to be adapted to the soil conditions (Duguma and Tonye, 1994). There is a lot of information on suitable agroforestry species and herbaceous species with potential for use in short fallow management (Pieter *et al.,* 1995) but not the best bet species.

Hypothesis

Improved fallows with leguminous trees and cover crops are superior to traditional fallowing practices in terms of soil fertility rehabilitation and in avoiding weed infestation. Agroforestry and herbaceous legume species which adapt well to local conditions will be selected by farmers for short fallows.

Objectives

1. To assess the adaptability of twelve herbaceous and four shrub/tree fallow legume species to local conditions.
2. To evaluate the potential contribution of sixteen fallow species (four shrubs/trees and twelve herbaceous plants) to soil fertility restoration in order to identify the most suitable species for improved fallow system in the Forest and Forest-Savanna Transition Zone of Ghana.

1.2. Materials and methods.

The experiment was conducted on-station at the Wenchi Agricultural Station but participating farmers had access to the plot throughout the trial/screening period for monitoring and assessment.

1.2.1 Experimental Design

The experimental design was a randomised complete block design (RCBD). The trial was conducted between 2000 and 2002. The tree and shrub species were planted from seedlings raised in a nursery while the small seeded herbaceous species were drilled directly in the disc-ploughed plots in September 2000. The large seeded species, namely soya beans, cowpeas, Lablab and Mucuna were sown *in situ*. There were four blocks.

Species screened included:
1) *Gliricidia sepium* (Jacquin) Steudel
2) *Tephrosia candida,* (Roxb.) DC
3) *Flemingia macrophylla*
4) *Cassia bicapaueris*
5) Soya bean TGX 1740 – 2 F
6) Cowpea IT 95 M – 118 – 1
7) Cowpea IT 95K – 1090 – 12
8) Cowpea IT 93K – 915
9) *Aeschynomene histrix,*
10) *Centrosema pascuorum I 9859*
11) *Chamaecrista rotundifolia I 15604*
12) *Clitoria ternatea*
13) *Lablab purpureus* (L.) Sweet
14) *Mucuna cochinchinensis,*
15) *Stylosanthes guianensis* (Aubl.) Sw. I 15557
16) *Stylosanthes hamata*.

There were 64 subplots and each one measured 6 m X 8 m. Data collection on trees, shrubs and herbaceous species was done three, nine and ten months after planting seedlings of *Gliricidia sepium*

(Jacquin) Steudel*, Tephrosia candida,* (Roxb.) DC, *Flemingia macrophylla* and *Cassia bicapaueris* and sowing/drilling of seeds of the legume species in the plots.

Parameters measured included total height and crown diameter of trees/shrubs. For the herbaceous plants the parameters were plot cover (legume, weed, bare), spread, height, leafiness, vigour chewing insect damage on leaves, sucking insect damage on leaves, fungus damage on leaves, leaf drop, virus damage on leaves, presence of flowers, seed (green, ripe), plants alive (number) and deficiency symptoms. The scores were: 0 = none; n = negligible; 1 = 1 – 10% or least, few; 10 = 91 – 100% or most, very many. These variables were recorded under the legume screening demonstration at the experimental site.

Growth performance and biomass production were assessed for trees/shrubs and herbaceous legume species as well. Ground/plot cover by herbaceous species was estimated using a line-point transect method (Daughtry *et al.,* 1995). A cord marked at 5-cm intervals was stretched diagonally across the subplot and the proportion of points in line vegetation was recorded.

Above-ground biomass (including leaves, stems, and reproductive parts) was sampled twice initially from 1 m^2 in 2001 and 2002 nine and 23 months after planting legumes respectively. A sample or sub sample of the fresh biomass was oven dried at 105º C for 24 hours for dry matter determination.

1.2.2 Soil and plant tissue analysis

Core samples were taken from a depth of 0-30 cm in each plot before the establishment of fallow legume species. Analyses of all soil and plant tissue samples were conducted at Kwadaso in Kumasi. Sub samples were taken in the laboratory for determination of pH, organic carbon (%), total N, P (ppm), organic matter (%), CEC (Ca, Mg, K and Na), TEB, exchangeable A (Al + H), CEC (me/100 g) and base saturation (%). Soil organic carbon was determined by wet oxidation using potassium dichromate. Total N was measured by standard Kjeldhal technique. Soil pH was determined in a 1:2.5 of soil: water suspension. The available P was measured using Bray I method. The CEC was determined extraction with ammonium acetate. Plant samples were determined by the Kjeldhal method. P was determined in plant ash solution. K was determined by plant ash by flame photometry. Ca and Mg were determined in ash solution using the ETDA titration method. All soil and plant tissue analytical procedures followed those of the Royal Tropical Institute (1984, 1986). However, the physical soil, analysis which was limited to mechanical analysis (texture), was effected when the soil samples were air dried and passed through a 2 mm sieve to rid sample of large stones, gravel, root fragments and litter whereas particle size distribution was determined using the sand fractions using the hydrometer method to determine the silt and clay fractions (Gee and Bauder, 1986). The textural classification according to the United States Department of Agriculture (USDA) was followed to give the nomenclature or textural class.

1.2.3 Statistical analysis

Data were subjected to analysis of variance (ANOVA) to assess the performance of herbaceous and woody fallow legume species. Differences between means were tested using LSD at P = 0.005 unless otherwise stated. The general linear model (GLM) procedure of Minitab release 13.31 was also used as when needed particularly with unbalanced data. All assumptions of ANOVA were checked by analysis of residuals.

1.3. Results

Table 1.1 Chemical properties of soil of fallow legume species at Wenchi Agricultural Station, Ghana

pH	Organic C (%)	Total N (%)	O. M. (%)	Exc. cations me/100 g				TEB	Exc. Acidity (Al + H)	CEC me/ 100 g	Base Sat. (%)	Available Bray's ppm P	K ppm
				Ca	Mg	K	Na						
6.2	1.69	0.1	2.9	6.2	1.9	0.1	0.0	8.3	0.10	8.4	98.8	13.82	54.7

Table 1.2 Results of soil analysis physical properties for Wenchi Agricultural Station site of fallow legume species screening in the middle belt of Ghana

Mechanical Analysis			**Texture**
Sand (%)	Silt (%)	Clay (%)	
76	15	10	Sandy loam

1.3.1 Growth performance of legumes: plant height

Significant difference ($P < 0.05$) was observed in plant height of the four tree/shrubby species throughout the 21 months of growth. At three months after planting, two species exhibited good initial growth: *Gliricidia sepium* and *Tephrosia candida* with the fastest growth with respectively 116 cm and 138 cm (Table 1.3). This trend continued until 21 months after planting when *Flemingia macrophylla* (393 cm) and *Cassia bicapaueris* (299 cm) exceeded *Tephrosia candida* (281 cm) but never *Gliricidia sepium* (599 cm).

Table 1.3 Height of four fallow legume tree/shrub species at Wenchi, Ghana 2001

Tree/shrub species	Height			
	3 MAP (cm)	9 MAP (cm)	10 MAP (cm)	21 MAP (cm)
Cassia bicapaueris	48	144	175	299
Flemingia macrophylla	69	202	228	393
Tephrosia candida	139	205	233	281
Gliricidia sepium	116	257	356	598
Grand mean	93	202	248	392
$LSD_{5\%}$	27	45	30	216

LSD, least significant difference

1.3.2 Plant height and spread

When all 12 herbaceous legume species were compared for plant spread and height at 3 MAP their growth performance was as follows. *Mucuna cochinchinensis* spread furthest 397 cm followed by

Clitoria ternatea (212 cm), *Lablab purpureus* (211 cm) and *Aeschynomene histrix* (202 cm). The least in spread were Soybean TGX 1740-2F (34 cm), *Stylosanthes guianensis* (37 cm) and *Stylosanthes hamata* (39cm).

The grain legumes (the soybeans and the cowpeas) did not do well. They were highly susceptible to insect pest and disease attack requiring extra attention by way of spraying with pesticides. They were, therefore, replaced with *Mucuna* and *Pueraria*. There was significant difference in both plant height and spread ($p<0.05$).

At 3 MAP plant height was also significantly different ($p<0.05$) among the herbaceous legumes, trees and shrubs. *Lablab purpureus, Mucuna cochinchinensis* and Soybean TGX 1740-2F had plant heights of 87 cm, 82 cm and 75 cm respectively. The least plant heights were achieved by *Centrosema pascuorum*, Cowpea IT 95M-1090-12 and Cowpea IT 93K-915 respectively.

Table 1.4 Mean plant spread and height in cm of 16 fallow species at Wenchi Agricultural Station, Ghana 2000

Legume Species	Three months after planting	
	Spread (cm)	Height (cm)
Soybean TGX 1740	34	75
Cowpea IT 95M-118-1	88	55
Cowpea IT 95M-1090 12	93	41
Cowpea IT 93K 915	117	42
Aeschynomene histrix	202	59
Centrosema pascuorum	98	16
Chamaecrista rotundifolia	118	52
Clitoria ternatea	212	64
Lablab purpureus	211	87
Mucuna cochinchinensis	397	82
Stylosanthes guianensis	37	44
Stylosanthes hamata	39	54
Cassia bicapaueris	28	48
Flemingia macrophylla	38	72
Tephrosia candida	44	131
Gliricidia sepium	77	116
Grand mean	115	64
$LSD_{5\%}$	116 ***	23 ***

LSD, least significant difference; *** highly significant ($p < 0.001$)

1.3.3 Biomass production (Dry matter yield)

The differences among the fallow legume species in biomass production were significant ($P < 0.05$). *Mucuna cochinchinensis* and *Chamaecrista rotundifolia* produced 142 and 112 kg/ha dry matter respectively. Other species with more than 90 kg/ha dry matter yield include *Clitoria ternatea, Stylosanthes guianensis*, *Stylosanthes hamata* and *Lablab purpureus*. Four species produced more than 3 kg/ha of leaf biomass: *Gliricidia sepium* 17 kg/ha, *Tephrosia candida* 12 kg/ha, *Flemingia macrophylla* 9 and *Cassia bicapaueris* 3 kg/ha. Wood biomass yield produced after nine months of growth was highest for *Tephrosia candida, Gliricidia sepium, Flemingia macrophylla and Cassia bicapaueris*

1.3.4 Nutrient Content

Nutrient content differed significantly ($P < 0.05$). Nine months after planting total N accumulation of *Mucuna cochinchinensis* was highest (4.3 kg/ha) followed by *Clitoria ternatea* (3.3 kg/ha), *Lablab purpureus* (2.9 kg/ha) and *Stylosanthes hamata* (2.3 kg/ha). N accumulation of less than 0.5 kg/ha was in *Centrosema pascuorum, Cassia bicapaueris* and *Flemingia macrophylla.*

Table 1.5 Dry matter yield and quantities of mineral nutrients from fallow legume species. screened at Wenchi, Ghana

Fallow species	DM (kg ha^{-1})	Above ground biomass mineral element content on (DM) dry matter basis									
		N (%)	N content (kg ha^{-1})	P (%)	P content (kg ha^{-1})	K (%)	K content (kg ha^{-1})	Ca (%)	Ca content (kg ha^{-1})	Mg (%)	Mg content (kg ha^{-1})
AH	42	2.2	0.88	0.13	0.06	0.86	0.38	1.07	0.37	0.65	0.29
CB	6	2.7	0.08	0.08	0.00	0.72	0.03	0.95	0.04	0.62	0.03
CP	47	2.5	0.58	0.06	0.01	0.65	0.13	0.73	0.14	0.72	0.15
CR	112	1.9	2.06	0.10	0.12	0.83	0.93	1.15	1.22	0.75	0.96
CT	102	2.4	3.00	0.28	0.11	0.59	0.79	0.77	0.74	0.66	0.85
FM	13	2.7	0.2	0.15	0.01	0.67	0.06	0.92	0.08	0.50	0.05
GS	27	3.0	0.80	0.08	0.02	0.74	0.18	0.98	0.23	1.96	0.54
LP	91	3.6	3.00	0.13	0.11	0.76	0.71	0.83	0.71	0.97	0.86
MC	142	2.5	4.29	0.14	0.17	0.79	1.05	0.81	0.47	0.67	0.92
SG	96	1.8	1.60	0.11	0.09	0.85	0.78	1.22	1.23	1.23	1.17
SH	92	2.6	2.25	0.04	0.04	0.64	0.55	1.15	0.95	1.05	1.1
TC	29	3.1	0.92	0.11	0.02	0.74	0.19	0.64	0.13	0.67	0.16
Grand mean	67	2.6	1.64	0.12	0.06	0.74	0.48	0.93	0.53	0.87	0.59
LSD$_{5\%}$	86	NS	NS	NS	0.09	NS	0.62	NS	0.49	0.59	0.83

LSD, least significant difference; NS, not significant; AH, *Aeschynomene histrix*; CB, *Cassia bicapaueris*; CP, *Centrosema pascourum*; CR, *Chamaecrista rotundifolia*; CT, *Clitoria ternatea*; FM, *Flemingia macrophylla*; GS, *Gliricidia sepium*; LP, *Lablab purpureus*; MC, *Mucuna cochinchinensis*; SG. *Stylosanthes guianensis*; SH, *Stylosanthes hamata*; TC, *Tephrosia candida*

Total P accumulation of 0.2 kg/ha was realised in *Aeschynomene histrix, Chamaecrista rotundifolia, Clitoria ternatea, Stylosanthes guianensis* and *Lablab purpureus.* K accumulation was greatest in *Chamaecrista rotundifolia* (0.8 kg/ha). Following it were *Stylosanthes guianensis* (0.7 kg/ha) *Lablab purpureus* (0.7 kg/ha) *Stylosanthes hamata* (0.5 kg/ha) and *Aeschynomene histrix* (0.4 kg/ha). Total Ca accumulation was highest in *C. rotundifolia* and *Stylosanthes guianensis* (1.2 kg/ha), *Stylosanthes hamata* (0.9 kg/ha), *Lablab purpureus* and *Clitoria ternatea* (0.7 kg/ha) and *Mucuna cochinchinensis* (0.5 kg/ha). Accumulation of magnesium was highest in *Stylosanthes guianensis* (1.2 kg/ha) and *S. hamata* (1.1

kg/ha). It was 0.9 kg/ha in *Chamaecrista rotundifolia*, *Lablab purpureus* and *Mucuna cochinchinensis* and 0.8 kg/ha in *Clitoria ternatea.*

Table 1.6 Plot cover, legume biomass, grass weed biomass and broadleaf weed biomass of eight herbaceous species at Wenchi, Ghana in 2001

Legume species	Plot cover (%)	Dry matter yield in kg ha^{-1}	Weed dry matter yield at nine months after		
			Grass (kg ha^{-1})	Broadleaf (kg ha^{-1})	Total
Aeschynomene histrix	30	42	44	55	99
Centrosema pascuorum	50	46	14	17	31
Chamaecrista rotundifolia	64	112	43	17	60
Clitoria ternatea	62	102	24	8	32
Lablab purpureus	24	89	36	16	52
Mucuna cochinchinensis	31	142	103	33	136
Stylosanthes guianensis	71	96	39	23	62
Stylosanthes hamata	71	96	39	23	62
Grand mean	52	98	39	20	
LSD$_{5\%}$	24	120	NS	NS	

LSD, least significant difference; NS, not significant

1.3.5 Plot cover and weed control

Nine month growth gave an order of percentage ground or plot cover as *Stylosanthes hamata* > *Stylosanthes guianensis* > *Chamaecrista rotundifolia* > *Clitoria ternatea* > *Centrosema pascuorum* > *Aeschynomene histrix* > *Mucuna cochinchinensis* > *Lablab purpureus* (Table 1.4). There was significant difference ($P < 0.05$).

For legume biomass production, grass weeds and broadleaf weeds there were no significant differences. *Stylosanthes hamata* produced the highest DM followed by *Mucuna cochinchinensis, Chamaecrista rotundifolia, Clitoria ternatea Stylosanthes guianensis* and *Lablab purpureus Aeschynomene histrix* and *Centrosema* produced the least biomass.

Weed dry matter yield (both grass and broadleaf) was least on *C. pascuorum* plot. In an ascending order *Clitoria ternatea, S. hamata, L. purpureus. C. rotundifolia, S. guianensis, A. histrix and M. cochinchinensis* produced weed dry matter yield ranging from 31.44 kg/ha to 136.06 kg/ha.

1.4 Discussion

The aim of this study was to assess the adaptability of shrubby plants and herbaceous plants to local conditions. It was also to evaluate their potential contribution to soil fertility restoration and identify most suitable species for improved fallow. The results of the study highlighted the importance of improved fallow species in the Forest and Forest -Savanna Transition Zones of Ghana. Ecologically most adapted and most contributing species were sought to be selected.

1.4.1 Woody and shrub legumes

Gliricidia sepium (Jacquin) Steudel, a versatile fast-growing tree is reported to attain heights of 2 to 15 metres (Lavin, 1996) under climatic conditions similar to those of the experimental site. The prevailing conditions, therefore, tend to account for the overall growth performance of *G. sepium. Flemingia macrophylla*, on the other hand though native to Asia is considered naturalised in Sub-Saharan Africa and reported to grow up to 2.5 m, attained 3.9 m in 21 months in this study (Asare *et al.,*, 1984). *Tephrosia candida* (Roxb.) D.C. (Leguminosae family, Papilionoideae) which is native to the tropical foothills of the Himalayas in India is a cultivated and naturalised in South-East Asia (Oyen, 1997). It is promising for agroforestry in the tropics and has high biomass yield, dense vegetative cover, deep root system and nitrogen-fixing ability (Kadiata *et al.,* 1996; Gichuru, 1991). *T. candida* obtains its maximum growth in the second year after planting (Oyen, 1997) and in this study it attained 2.8 m height and started showing signs of death. This quality notwithstanding *T. candida* fallow gave positive N and P balances, increased soil N and tended to positively affect the release of labile P in Asia (Hoang Fagerström *et al.,* 2002)

1.4.2 Herbaceous legumes

Plant height, spread and ground cover were some of the criteria considered for the selection of fallow legume species. *Mucuna cochinchinensis, Lablab purpureus* and *Clitoria ternatea* had the widest spread. The superiority of *M. cochinchinensis,* in a sole cropping where it grew quickly and almost achieved 100% ground cover, has been reported elsewhere (Eilittä *et al.,* 2003). Same can be said of *L. purpureus* and *C. ternatea*. These species spread laterally as a result of their morphology (being creepers by nature) and particularly being planted as monocrops. Generally they would grow fast in order to complete their life cycles as non-perennials. Besides, *L. purpureus* adapts well to a variety of ecological conditions but excels in tolerating drought (Schaffhaussen, 1963). Naturally as a supple, climbing/spreading plant with pubescent stem and very widespread in the tropics of the entire world, *C. ternatea* is also drought resistant (Gohl, 1982).

Perhaps to show that cover crops are not limited to *Mucuna*, soil fertility and the control of *Imperata cylindrica,* this study has dealt with some herbaceous legume species that are still unknown to farmers and/or pastoralists. Probably the multiple uses of cover crops are not known and that is why adoption is low and yet cover crops play a very significant role in agronomic aspects such as organic matter, nitrogen fixation and erosion control. Results of this study may be useful to those involved in sustainable agriculture and in animal husbandry. *C. rotundifolia* performed well and could be used in fodder banks. *C. pascuorum* yielded well but failed to persist despite the good control of weeds. *A. histrix* looked quite promising with dry matter yield of 41.78 kg/ha even though it produced the lowest dry matter yield among all species screened in contrast with the finding of Peters *et al.,* (1994) who reported 6 t/ha.

1.4.3 Fallow biomass and nutrient accumulation

Biomass production of the fallow legume species screened in this study can be said be reasonably high. Optimum rainfall received during the growing season and P level (13.82 ppm) (Table 1.1) may have partially accounted for this. This somewhat tends to suggest that while screening for various qualities such as biomass production and nutrient (yields) rainfall and other climatic and edaphic factors during the screening or fallow phrase should be taken into account. The rainfall figures for the experimentation period were 713.7 mm (2000), 578.5 mm (2001) and 563.5 mm (January-August, 2002). The high biomass yields reported for *G. sepium, T. candida, F. macrophylla* and *C. bicapaueris* (woody and shrubby species) and *M. cochinchinensis, C. rotundifolia, C. ternatea, S. guainensis, S. hamata* and *L. purpureus* (herbaceous species) (Table 1.4) were somehow comparable to those reported for the same species in other studies. For example, Budelman (1989) reported that at 10 000 plants ha^{-1} density *F.*

macrophylla produced a yearly average of 12.4 tons of leaf dry matter yield over 4 quarterly cutting intervals. Furthermore, *G. sepium* is gaining popularity for planting in "biomass banks" to supply materials for biomass transfer techniques (Rao and Muthuva, 2000).

How long a species thrives and how long it can maintain net primary productivity are attributes worth considering for improved fallows. This study involved both herbaceous and woody species which implies that depending on soil fertility requires species such as *M. cochinchinensis, L. purpureus, S. guianensis, S. hamata*, *P. phaseoloides* and *C. ternatea* that complete their life cycles earlier than the tree/shrub species (*T. candida, G. sepium*, *F. macrophylla* and *C. bicapaueris*) can be used respectively for short-duration and long-duration fallows.

Nutrient accumulation varied with species and species type – whether woody or herbaceous. In terms of N accumulation *M. cochinchinensis, C. ternatea, L. purpureus*, and *S. hamata* can be considered as good candidates for short fallows looking critically at the amounts of recyclable nutrients they accumulate. On the whole, it appears that with exception of Soya bean (TGX-1740-2F), cowpea (IT 95M-118-1), cowpea (IT 95K-1090-12) and cowpea (93K-915), all the other fallow legume species evaluated are well-adapted to the Forest and the Forest-Savanna Transition agro-ecological zones

1.4.4 Weed control and plot/ground cover

One of the major effects of fallow legume species is reduction of weeds. This reduction is probably due to the complementary processes of litter drop from multipurpose tree and cover crop species as well as good spread providing a ground cover (Yamoah *et al.,* 1986; Kang, 1993), shading effects (Yamoah *et al.,* 1986; Jama *et al.,* 1991) and competition with weeds for growth resources (Rippin *et al.,* 1994) and exhibition in potential of allelopathy by fallow legume species (Obondo, 1987; Weston, 1996). There were differences observed in ability of fallow legume species to control weeds. These could be attributed to differences in biomass production and decomposition rates and particularly canopy spread. Species such as *Senna siamea* (added to species in the second year of experimentation), *F. macrophylla*, and *C. bicapaueris* which showed slower litter decomposition than *G. sepium* and *T. candida*. Similar observation was made by Yamoah *et al.,* (1986).

Even though Osei-Bonsu (1998) observed in Ghana that mucuna was effective in weed suppression on-farm and Akobundu and co-workers (Akobundu and Poku, 1984; Akobundu and Udensi, 1995), in researcher-managed trials in Nigeria in a bimodal rainfall zone just like the study area (Wenchi) also found mucuna to be efficient in *Imperata cylindrica* control the highest weed biomass was found in mucuna plot (Table 1.4). The rather high grass weed (predominantly *Rottboellia exaltata* in fewer stands but large biomass) on the mucuna plot could be due to the early senescing and fast decomposition of mucuna, nitrogen flush at the beginning of the major (first) rainy season in 2001 and upright nature of the weed species. Capturing of nitrogen flush that follows early rains by maize has been reported by a number of authors (Fakorede, 1985; Mutsaers, 1995; Weber *et al.,* 1995) and it was likely *R. exaltata* which is in the same family as maize benefited from this phenomenon. Weber *et al.,* (1995) give estimate of nitrogen in the flush to be between 8 and 120 kg N/ha.

1.4.5 Plant height, spread and ground cover

The figures reported in this study are in a range reported by Kanmegne *et al.,* (1999). The differences in these parameters for the initial 3 months of growth can be partly explained by the morphology and shrubby species have different growth habits. It can also be explained by the rainfall received during this period minor rainy season. Planting was done in September, 2000 which received only 64.5 mm rainfall with an annual figure of 713.7 mm. Kwesiga *et al.,*(1995), for instance, have found that biomass production was related to the amount of rainfall received in the initial establishment and growth.

The capacity for ready establishment confers to *Gliricidia sepium*, *Flemingia macrophylla*, *Tephrosia candida* and *Cassia bicapaueris* (and *Senna siamea* in 2002 when it replaced Soybean) in their fast-growth evident in crown diameter, height and girth and generally heavy biomass production. *G. sepium* in particular quickly produces a broad crown, explaining its capacity to give rise to a large basal diameter. Similarly, the herbaceous legume species performed quite well with *Mucuna cochinchinensis, Lablab purpureus, Clitoria ternatea* and *Aeschynomene histrix* are outstanding in their growth performance. So far data suggest that these species, particularly all woody/shrubby species, are better able to establish in the cleared sites within the components of the Forest and Forest-Savanna zones. On the basis of these results, it is important to consider these species in agroforestry combinations with crop production for fallow establishment and management.

1.5 Recommendations and conclusions

All the fallow legume species differed in terms of quality and quantity of biomass produced and growth performance, thus their potentials for enhancing soil fertility restoration. All four trees and shrubs, namely *Tephrosia candida, Gliricidia sepium*, *Flemingia macrophylla* and *Cassia bicapaueris* have a good potential to be selected as ecologically most adapted species. They also have the potential to contribute to the farming system in the Forest and Forest-Savanna Transition Zones of Ghana.

These, as well as the herbaceous species particularly *Mucuna cochinchinensis, Chamaecrista rotundifolia, Clitoria ternatea, S. guianensis, S. hamata and Lablab purpureus,0* have high biomass and high content of N P K Ca and Mg. They can act as green manure/cover crop species.

From agroforestry perspectives slow growth and low biomass productivity imply low nutrient recycling and less availability of nutrients to companion crops. High growth rate and biomass productivity are, therefore, essential (Duguma and Mollet 1997). It has been shown in the screening experiment that considering the results, biomass production, ground cover and nutrient dynamics, all the species can be used in short fallow management for the production of mulch, fuel wood and to control noxious weeds. Species such as *Gliricidia sepium, Flemingia macrophylla, Mucuna Lablab* and *Canavalia* have the potential to be used on permanent plantain production and other systems.

Research in improved fallows is likely to gain much more recognition in the near future. It is, therefore, essential that long-term trials are established to assess how sustainable such improved fallows are over a longer period. Nitrogen fixation species will certainly maintain soil N at high levels, but other nutrients such as P may become limiting after several cycles of fallowing. Furthermore, planted fallow species should include several contrasting species and more so mixed species in other to combine the beneficial attributes of rapid plot coverage, effective biological nitrogen fixation and cycling of nutrients and biodiversity.

2. ON-FARM PARTICIPATORY RELAY CROPPING MAIZE AND LEGUME COVER CROPS

2.1 Introduction and Justification

Farmers in West Africa are confronted with the phenomenon of intensification of land use and reduced fallow periods because of increasing populations (COMBS, 1992). These farmers experience such basic problems as maintenance of soil fertility and decreased land productivity under diverse ecological and economic conditions. Continuous cultivation of the land is resulting in soil fertility decline in most agricultural systems in Sub-Saharan Africa (SSA) (Stoorvogel *et al.,* 1993; Smaling *et al.,* 1993, 1997; Hartemink, 1997; Sanchez *et al.,* 1997).

In the past many Ghanaian farmers maintained soil fertility by practising shifting cultivation or applying chemical fertilisers and weedicides on their fields. The conditions have changed over the last decade. For example, increasing demand for land as a result of population increase has led to a breakdown of these soil fertility maintenance strategies and the productivity of traditional shifting agriculture systems has declined, while access to subsidised agrochemicals is declining in Ghana. Crop removal of 428, 700 t of N, 73, 100 t of P and 414, 900 t of K was estimated nationwide for a period of ten years in Ghana. As a result of the aforementioned scenarios, farmers are now moving to marginal lands.

Although the use of mineral fertilisers is recognised as a convenient way for rapid correction of nutrient deficiencies in soils, its prohibitive cost limits wide application by farmers. Farmers are, thus, unable to apply the required amounts of mineral fertilisers to replenish the soil with nutrients lost via crop removal and harvest. The continuous use of mineral fertilisers, on the other hand, can have detrimental effects on soil properties and crop yield. Kang and Juo (1986) have reported that on the strongly weathered and poorly buffered tropical soils continuous cereal monocultures using mineral fertilisers as the main source of nutrient input has resulted in significant yield decline and soil degradation. Therefore, there is the urgent need to develop alternative farming systems that could build up soil organic matter levels and improve the physical and chemical properties of the soil for sustainable production at affordable cost.

Farmers need technologies which can help ameliorate these problems. Today, the list of alternative strategies for improving soil fertility includes the use of compost, crop residues, animal manure, biomass, chipped wood, alley farming, and fallow legume and green manure cover crops Researchers have appreciated these problems as major constraints to sustainable crop production for decades. Therefore, they developed a range of technological options and increased efforts are being made to take the long-term maintenance of crop productivity into consideration (Kang *et al.,* 1981; Okigbo, 1990; Ehui and Spencer, 1990).

Legumes present the best potential to significantly contribute to the maintenance of nitrogen levels, organic matter content and physical properties of soils in intensified cereal-based cropping systems. Legumes usually play an important part in humankind's attempt to postpone fertility drain, and improve the productivity capacity of the soil in several systems of agriculture that have developed (Skerman, 1977). In Ghana, the use of legumes such as *Mucuna* species, *Pueraria phaseoloides, Lablab purpureus, Canavalia ensiformis* and *Stylosanthes species* are presently hardly known to farmers in the Forest, Forest-Savanna Transition Zones although extensive research activities on-station show their contributions to the productivity of food crop systems (e.g. Rinaudo *et al.,* 1988).

Legumes may be integrated into existing cropping systems as cover crops; the integration may be achieved through planted fallow or relay or relay-intercrops (Kang 1992, Jeranyama *et al.,* 1998). Legume cover crops can supply all or most of the N required by a subsequent crop if legume biomass is of sufficient quantity and N mineralisation is synchronous with crop demand (Griffin *et al.,* 2000).

Legume intercropping has been shown to enhance soil quality, porosity and soil tilth (Keisling *et al.,* 1994).

The identification of the most appropriate legume cropping system for the improvement of soil fertility and for weed suppression requires the involvement of farmers and researchers. Traditional agricultural research has been the preserve of scientists who have acted on behalf of farmers. This research resulted in many measurements of great precision which can be analysed according to standard procedures. However, no matter how good the science might be or how persistent the extension efforts, it has been found repeatedly that technological advances will not be adopted unless they are acceptable to farmers (Fielding and Riley, 1997).

The participatory approach to agricultural research and development attempts to overcome this problem and learn from the farmer. Fielding and Riley (1997) further explain that since agricultural research researchers have left the confines of research stations to pursue their investigations alongside farmers, new research techniques had to be developed, and others modified, in order to adapt to changes in location as well as to a more multidisciplinary approach. In order to evaluate various legumes on-farm jointly with farmers, trials need to be on-farm and participatory to provide more farmer access for adequate monitoring and evaluation (Hoefsloot *et al.,* 1994).

A participatory process is essential for the establishment of on-farm trials (Buzzard, 1989). Most successful trials include pre-trial participant training, farmer interaction throughout the trial period and group meeting following the trials to share observations, examine differing results and provide a forum for the exchange of information among farmers, researchers and extension agents. An informal "contract" with farmers collaborating in the trials can help to clarify their responsibilities and gain commitment.

It is important that researchers maintain the direct involvement. In the execution of field trials to ensure hat recommended procedures/methods are followed and that proper data are collected. Collaboration with extension services is a central aspect of on-farm trials and on-farm visits. Researchers, extension agents and cooperating agencies can work cooperatively for the benefit of all.

Hypothesis

Herbaceous legume crops such as *Mucuna pruriens*, *Canavalia ensiformis* and *Lablab purpureus* have been tested on-station and proven to increase yields of food crops. It was hypothesised, therefore, that in relay with food crops these herbaceous legumes would suppress weeds, recycle nutrients, restore lost soil fertility and consequently increase yields of subsequent food crops particularly maize.

Objective

The trend to shorter natural fallow in shifting cultivation calls for management alternatives to accelerate nutrient accumulation and aid in weed control. Substituting cover crop-based managed fallow is a possibility. The objective of this study was to compare the effectiveness of legume cover crops to control weeds, restore soil fertility and increase maize productivity.

2.2 Methods and Materials

2.2.1 Site Description

The experiments were conducted in farmers' fields, at Yabraso, in Wenchi District, Gogoikrom in Atwima District and Subriso No. 3 in Tano District.

Table 2.1 Site characteristics for Wenchi (Yabraso), Tano (Subriso No. 3) and Atwima (Gogoikrom)

	Site		
	Wenchi/Yabraso	Tano/Subriso No. 3	Atwima/Gogoikrom
Location			
Altitude (m asl)	30 - 61	290	77 - 94
Latitude	7° 30′ N and 8º 45'	7º 0′ N and 7° 25' N	5 ° 00′ N and 5° 02′ N
Longitude	2° 10′ W and 2° 45' W	1° 45′ W and 2° 20' W	1° 52′ W and 2° 09′ W
Mean annual rainfall (mm)	1140 - 1270	1500	1700 – 1850
Agro-ecological zone	Guinea savanna woodland	Moist semi-deciduous	Wet semi-deciduous
FAO-UNESCO classification	Savanna/forest ochrosols, lithosols and brunosols	Forest ochrosols	Forest ochrosols and forest ochrosols-oxisols intergrades

2.2.2 On-farm trial design

The three sites were selected for on-farm experimentation to represent a range of agroecozones from the Forest to the Forest-Savanna Transition Zones. The trial design used was one-field, one-replicate, with three plots per field (Fielding and Riley, 1998). Of the 108 participating farmers, data were collected from 49 of their on-farm trials to test the legume cover crops - 13, 20 and 16 at Gogoikrom, Subriso No.3 and Yabraso respectively. Forty-three of the trials were successfully implemented over two years with acceptable data quality. Three plots were laid out which allowed the comparison of two "best bet" cover crops from the following farmer-researcher screened herbaceous fallow legume species: *Pueraria phaseoloides, Mucuna pruriens* (black), *Mucuna cochinchinensis*, *Clitoria ternatea*, *Lablab purpureus*, *Stylosanthes guianensis, Stylosanthes hamata* and *Canavalia ensiformis* with common farmer practice, sole maize or mixed crop with maize as the main crop. Farmers were asked to choose which legume cover crops to include in the relay-intercropping systems based on their own assessment during two field days that had been organised for them on-station. Each site received all eight legume species. The legume species were supplied to farmers depending on the cropping system they adopted. Sole maize plots received either a creeping or an erect species whereas mixed crop plot received only erect species. This was necessary since in an intercrop/mixed cropping situation, the creeping legume cover crops might create problem by strangling the long-duration crops. These were under-sown in maize beginning in mid-June (eight weeks after sowing of test crop). The minimum size of a farmer-managed plot (control) was 15 m by 20 m. The legume cover crop plot also measured 15 m by 20 m. The maize was sown at a planting distance of 80 cm by 50 cm, while the legume cover crop was sown at planting distance of 80 cm by 50 cm but rows ran along the middle of the adjacent maize rows. The productivity of maize was measured at physiological maturity. Grain as well as stover yield per unit land area was estimated.

The maize was planted to all the treatment plots the following cropping season (2002) to see the effects of the trials on the soil as well as the crops where possible. Weeding was done once or twice (but only once, in most cases as was the farmers' practice). In some cases failure/refusal to do second weeding delayed seeding of legume cover crops. However, in 2002 due to insufficient seed availability, *M. cochinchinensis* and *C. ensiformis* dominated legume cover crops used across sites. In 2002, therefore, the treatments were: (1) Control of no cover crop but with either sole maize (*Zea mays* variety Abeleehi) or a mixture of crops with maize as the dominating crop, (2) a legume cover crop (*Mucuna cochinchinensis*) with either sole maize (*Zea mays* variety Abeleehi) or a mixture of crops with maize as the dominating crop and (3) a second legume cover crop (*Canavalia ensiformis*) with either sole maize (*Zea mays* variety Abeleehi) or a mixture of crops with maize as the dominating crop. Spacing in 2002 was 40 cm x 20 cm (i.e. two rows of cover crop between two rows of maize) following the poor ground cover realised as a result sparser legume population in 2001. Seeding was two seeds per hill for large seeds and drilling for small seeds. The control plot had only maize sown at 80 cm x 50 cm same spacing as the maize on the maize-legume relay intercrop planted plots. A core soil sample was taken from a depth of 15 cm in each farmer's plot before planting and after establishment of fallow legumes. Soil physical and chemical properties varied from site to site and from farm to farm (Table 2.2).

Trial management and measurements were conducted in strong collaboration with agricultural extension staff and farmers with instructions from researchers. Researchers chose collaborating farmers at village (group) meetings from farmers who volunteered to do the trials. Attention was paid to all categories of farmers including resource-poor as well as well-off, female-headed as well as male-headed household (Mutsaers *et al.,* 1997), natives as well as settlers and land owners as well as renters (Obiri *et al.,* 2000).

2.2.3 Trial implementation

At trial sites the farmer cleared his or her site of vegetation and prepared the land according to their management practice. After that the farmer sowed the maize when there was a fairly heavy down pour of rain. Researchers and AEAs (agricultural extension agents) based at the various locations provided supervision through regular visits.

Data collected from trial sites included rainfall, plot size measurement, planting date, plant population density, dates plots were weeded, plant height at physiological maturity, stover and grain yield. Maize grain and stover yields were determined for all trials. A 5 m x 5 m area was demarcated in the centre of each plot and maize hand was harvested and weighed with hanging scales in the field (±10 g accuracy). Sub samples of 1000 grains were collected and brought to the laboratory to determine grain moisture and to conduct dry weight to fresh weight conversions.

2.2.4 Legume sampling methodology

To capture legume intercrop performance, an estimate of legume and weed biomass, spread and ground cover was made. Samples were collected from all plots in August 2002. Above ground biomass of legumes and weeds was determined in the field. A quadrat measuring 0.5 m x 0.5 m was placed at random in inter- and intra-maize rows for the assessments. Biomass fresh weights of legumes and weeds were determined in the field and dry matter in the laboratory after oven drying at 105 °C for 24 hours. Legume plant samples were ground to pass a 2 mm mesh and total nitrogen determined by wet acid digestion and colorimetric determination of ammonia (Anderson and Ingram, 1989).

Soil samples were collected from the top 0-15 cm of all trial sites at the start of the experiment process in June and September 2001 and the same period in 2002. All soil and plant tissue analytical procedures followed those of the Royal Tropical Institute (1984, 1986).

Above-ground biomass of fallow legume species was taken at 90 days after planting the cover crop. Sub samples were taken from each treatment plot using a PVC frame quadrat of 0.5 m x 0.5 m in size. Samples were weighed and oven dried and weighed again before they were submitted to the Soil Research Institute for final dry matter determination. Fallow legume biomass and weed biomass were collected and analysed for macronutrients separately. Plant samples were taken with an electronic scale and dry matter determined after oven drying for 24 h at 105° C. Below ground biomass was not taken. The beaded string method described by Sarrantonio (1991) was applied to estimate the percent ground coverage. Maize plant height was taken at physiological maturity using a graduated pole and fresh weight of maize stover taken on the field using a spring balance.

2.2.5. Statistical Analysis

The entry of data and analysis were carried out using the Minitab 13.31 statistical package. Data were subjected to ANOVA (analysis of variance) employing the GLM (General Linear Model) aspect of the package. Descriptive statistics of variables, adjusted residuals and the least significant differences (LSDs) were computed and used to separate treatment means at the 5% level of significance.

2.3 Results

2.3.1 Soil characteristics

The fields at Yabraso had medium loam-clay loam soils largely above pH 5.2 and range from 6.9-7.1; 1.8-2.2 % organic carbon; 3.1-3.8 % organic matter; 4.2-4.9 ppm P; 178 – 202 ppm K and 14-16 me/100 g Ca. The fields at Gogoikrom had sandy loam textured soils which were generally forest ochrosols, forest oxisols or intergrades of these. They had a pH range, organic matter content and organic matter content of 6.7-7.0, 1.7-5.2, and 2.9-3.4% respectively. The analysis further revealed that the P K and the Ca contents were 5.8-7.2 ppm, 48.5-62.7 ppm and 11.9 - 15.2 me 100 g^{-1} respectively (Table 2.2). At Subriso, the farmers' fields had soils with textures varying from loam to clay with pH range of 7.0-7.2; organic matter content range of 3.3-3.8% and organic carbon range of 1.9 - 2.3%. Their P K and Ca contents were in ranges of 3.3-4.3 ppm, 175-191 ppm and 14.5 to 17.3 respectively.

Table 2.2 Chemical and physical properties of soil (0-15 cm) at sites of relay-intercropping in the Forest and Forest-Savanna Transition zones of Ghana

Property	Yabraso (Savanna ochrosols)			Subriso No.3 (Forest ochrosols)			Gogoikrom (Forest ochrosols)		
	Control	MC	CE	Control	MC	CE	Control	MC	CE
pH	7.09	6.99	6.95	7.00	7.19	7.13	6.73	6.95	6.88
Organic C (%)	2.20	1.82	1.87	2.05	2.29	1.93	5.19	1.97	1.70
Total N (%)	0.18	0.15	0.16	0.17	0.19	0.16	0.16	0.16	0.14
Organic matter	3.79	3.14	3.23	3.53	3.83	3.31	3.19	3.39	2.94
Ca (me/100 g)	16.37	14.53	14.02	14.57	17.33	15.23	13.48	15.21	11.90
Mg (me/100 g)	4.79	4.03	6.22	4.01	4.48	3.46	3.80	4.50	3.61
K (me/100g)	0.39	0.43	0.43	0.59	0.67	0.54	0.25	0.29	0.22
Na (me/100 g)	0.15	0.15	0.12	0.17	0.18	0.17	0.15	0.16	0.16
TEB	21.70	19.13	20.79	19.35	22.65	19.41	17.66	20.15	15.89
Exch. Acidity (Al + H)	0.11	0.10	0.10	0.21	0.10	0.10	0.14	0.13	0.10
CEC (me/100 g)	21.80	19.23	20.90	19.56	22.75	19.51	17.79	20.27	15.99
Base Sat. (%)	99.44	99.37	99.31	98.82	99.47	99.45	98.72	99.15	99.24
P ppm (avail. Bray's)	4.25	4.94	4.45	3.33	3.45	4.27	7.18	6.10	5.87
K ppm	193.90	178.80	202.00	175.80	188.1	190.6	59.11	62.73	48.59
Sand	45.36	50.17	49.43	55.89	55.50	54.16	55.38	54.55	53.63
Silt	40.41	36.21	37.54	30.43	31.15	31.59	38.78	39.70	40.03
Clay	14.23	13.63	13.03	13.68	13.31	14.25	6.00	5.75	6.33
Texture	Medium loam	Clay loam	Clay loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy Loam	Sandy loam

2.3.2 Maize/legume relay intercropping system

2.3.2.1 Maize performance in 2001

Relay - intercropping maize with fallow legume species did not clearly affect maize performance as there were no significant differences in maize plant height and grain and stover yields (Table 2.3).

Table 2.3 Fallow legume species and maize height, grain and stover yields at Yabraso, Subriso No. 3 and Gogoikrom during 2001 cropping season

Location	Treatment	Height (cm)	Grain yield (kg ha^{-1})	Stover Yield (kg ha^{-1})
Yabraso				
	Cover crop I	207 (12.2)	3902 (85.4)	3385 (551)
	Cover crop II	199 (10.9)	3847 (107)	3411 (563)
	Control/	194 (8.61)	3807 (113)	2800 (349)
	Grand mean	200	3852	3199
	LSD$_{5\%}$	ns	ns	ns
Subriso No.3				
	Cover crop I	222 (9.57)	3607 (86.3)	3257 (291)
	Cover crop II	224 (8.75)	3620 (83.3)	4000 (468)
	Control	229 (7.08)	3640 (86.8)	3826 (487)
	Grand mean	225	3622	3738
	LSD	ns	ns	ns
Gogoikrom				
	Cover crop I	249 (11.30)	3484 (122)	7637 (1240)
	Cover crop II	248 (8.92)	3444 (140)	8387 (1090)
	Control	247 (7.59)	3411 (129)	7890 (1188)
	Grand mean	248	3446	7971
	LSD$_{5\%}$	ns	Ns	Ns

ns = not significantly different at 5% level

2.3.2.2. Maize performance in 2002

In the following year farmers relay intercropped different fresh maize plots without following the previous plots with second maize. Hence response of subsequent maize could not be evaluated. The trend for these new fields with regards to maize performance followed a similar trend. The differences were significant between control and maize/legume plot in Yabraso, (Table 2.4), but not at Subriso (Table 2.5) or Gogoikrom (Table 2.6).

Table 2.4 Effects of relay-intercropping maize with legume cover crops on height, stover and grain yields of maize at Yabraso (Wenchi District), Ghana in 2002

Treatment	Height (cm)		Stover yield.(kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
MC	198	4.64	4188	563	2375	306
CE	203	5.39	3938	675	2525	203
Control	190	10.5	3737	562	1788	164
Grand mean	197		3954		2229	
LSD$_{5\%}$	NS		NS		527	

Table 2.5 Effects of relay-intercropping maize with fallow legume species on height, grain yield and stover yield of maize on farmers' fields at Subriso No. 3 (Tano District), Ghana in 2002

Treatment	Height (cm)		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
MC	213	5.12	4868	716	2773	301
CE	214	7.83	5400	593	2499	226
Control	204	5.23	5811	710	2820	329
Grand mean	210		5360		2698	
LSD5%	NS		NS		NS	

LSD, least significant; NS, not significantly different at $p = 0.05$

Table 2.6 Effects of relay-intercropping maize with fallow legume species on height, grain yield and stover yield of maize on farmers' fields at Gogoikrom (Atwima District), Ghana in 2002

Treatment	Height (cm)		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
MC	213	9.22	4137	354	3340	380
CE	222	9.65	5607	628	2768	582
Control	217	4.27	5123	657	2393	314
Grand mean	217		4955		2834	
LSD5%	NS		NS		NS	

LSD, least significant; NS, not significant

In 2002, while farmers were enthused about the performance of legume cover crops with regards to weed control and decided to relay intercrop new maize fields with legumes, those who repeated cropping on same plots or otherwise as 2001 noted better performance of maize plant height and grain yield with stover yield declining giving higher stover yield from control than maize/legume plots. Generally, there were no substantial changes in the performance of maize but weeds were less common on plots that received legumes in the previous year

2.3.2.3 Differences between years

The 2000 growing season, especially the minor cropping or second rainy season, suffered a drought and all the legumes failed to establish. However, the 2001 and 2002 seasons had normal rains and most legumes established stands and produced biomass. Planting legumes between maize rows did not significantly affect maize height, stover and grain yields. However, mean maize height across sites was higher from maize/legume plot than sole maize (control) plot. This was observed at Gogoikrom which received the highest rainfall during the period while at Yabraso control plot produced the lowest mean height probably as a result of the relatively low rainfall of the site. There was no clear-cut effect of intercropping on maize yield. There were also no significant differences in 2001 and 2002 maize productivity among sites. In 2001 the no cover crop control yielded 3442 kg ha^{-1} maize grain while intercropped plots yielded 3574 kg ha^{-1} and 3606 kg ha^{-1} for cover crops I and II respectively.

There was no significant or clear-cut effect of intercropped legume cover crop residue effect on yield of subsequent maize when maize followed 2001 maize/legume relay intercrop. Maize/legume cover crop studies do not often assess such an effect in a subsequent year, notwithstanding reports indicating an intercrop merit (Jerenyama *et al.,* 2002; Mariga, 1990; Rao and Mathuva, 2002) or demerit (Muza, 1998; Natarajan and Shumba, 1990) in the intercropping season. This study is a step to providing an assessment on effects of intercropped cover crops in the subsequent cropping season. Maize following maize/legume was insignificantly lower than that following maize alone (Table 2.7). Maize stover yield and height at physiological maturity were not significantly affected by the presence of a legume cover crop in 2001. In 2002 maize stover yield and height at physiological maturity following maize/legume cover crop were only slightly higher than those from the control plot

Table 2.7 Height, grain yield and stover yield of maize legume relay intercropping on-farm trials during 2001 and 2002 (all three sites) in the Forest-Savanna Transition Zone of Ghana

Treatment	Height of maize at physiological maturity (cm)				Maize grain yield (kg ha^{-1})				Maize stover yield (kg ha^{-1})			
	2001		2002		2001		2002		2001		2002	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
Cover crop I	212	13.9	215	5.47	3574	149	2737	291	4806	1668	4528	359
Cover crop II	231	15.3	222	762	3606	119	2416	265	5360	1818	5389	593
Control	218	11.8	207	6.68	3442	160	2372	219	4417	1357	5129	558
Grand mean	220		215		3540		2508		4861		5015	
LSD5%	NS		10.87		NS		NS		NS		NS	

s.e. = standard error; LSD, least significant difference; NS, not significant

Where same fields were re-cropped as the previous year or with maize without an intercrop, maize productivity over the two years was better than no cover crop plot. Maize stover yield was higher on control plot at Gogoikrom than a legume cover crop plot. This could probably be accounted for by the stifling of maize stalk by viney and climbing cover crops which rendered harvesting of maize difficult and retrieving of maize stover almost impossible. Similarly, maize grain yield was higher but not significantly so in no cover crop than intercropped plot at Subriso No. 3 (3640 kg ha^{-1} > 3606 kg ha^{-1}) respectively

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2.3.3. Legume cover crop agronomic performance

Biomass assessment of legumes and weeds was done on 2002 cropping. Legumes that were screened in an on-station trial at Wenchi were sown as relay intercrop into farmers' maize fields. After the harsh and unfavourable weather in the 2000 minor rainy season which made re-starting of experiment in the major rainy seasons of 2001 and 2002 necessary legume cover crops were evaluated for aboveground biomass, spread and ground, plot or soil coverage.

In this on-farm adaptive trial the following herbaceous species were sown: *Mucuna, Canavalia, Lablab, Clitoria, Stylosanthes and Pueraria.* The absence of any significant response to cover crops was consistent across fields and sites. It should be worth noting that above ground biomass production in some fields may have been unusually low because some legume cover crops established faster than others. For example, *Mucuna* species, *Canavalia* species, and *Clitoria ternatea* established faster than the *Stylosanthes* species, *Lablab purpureus* and *Pueraria phaseoloides*. In addition the faster growing cover crop species, particularly Mucuna and Canavalia, also senesced earlier at drier sites due to lower rainfall specifically at Yabraso.

Legume spread and ground cover assessment revealed that the trailing species, namely Mucuna, Pueraria and Clitoria gave a mean spread of 380 cm (Subriso No.3); 335 cm (Gogoikrom) and 310 cm (Yabraso), ground/plot cover was 88, 77 and 79 percent respectively in the year 2002.

2.3.4 Legume biomass

In the study there were system effects on total legume cover crop biomass production. In 2002, cover crop biomass was measured in all fields that received a second cycle of cropping or experimentation. The systems were maize/legume and/or maize/legume with control of no legume to compare. Mean highest aboveground biomass per site was Yabraso (4795 kg ha^{-1}) > Subriso No. 3 (4708 kg ha^{-1}) > Gogoikrom (2771 kg ha^{-1}). Mean lowest dry matter yield per site was 1935 kg ha^{-1} at Gogoikrom < 2958 kg ha^{-1} at Yabraso < 3484 kg ha^{-1} at Subriso No. 3. Cover crop biomass averaged 4198 kg ha^{-1} (Subriso No.3), 3888 kg ha^{-1} (Yabraso) and 2345 kg ha^{-1} at Gogoikrom. Average for the year 2002 was 2345 kg ha^{-1}. Higher aboveground biomass was captured intra maize row than inter maize row placement of quadrat during assessment. For maize-cover crop relay followed by maize-cover crop relay, weed biomass was measured in all fields and on all three plots. The highest legume dry matter yield across sites averaged 1207 and 3666 kg ha^{-1} for control and cover crop plots respectively and these were significantly different ($P = 0.000$).

Differences between control and legume/maize plots in weed infestation were clear. Higher weed infestation was observed in the control plots than legume/maize plots. Large variability in aboveground weed biomass seemingly is attributable to weed suppressing effect of cover crops especially *Mucuna* species which tended to spread to cover any available “bare” space. Particularly noteworthy were the significantly effective spread and ground coverage by the cover crops. Twelve WAS ground coverage was 76.34% at Subriso No.3 > 66% at Yabraso = 66% at Gogoikrom.

Combining the effect of legume spread with ground coverage would suggest that in relay-intercropping the cover crops competed effectively with and in most cases outgrew weeds. However, weeding of cover crops at the juvenile or early growing period is critical for this to be achieved. Variability in weed whether inter-maize or intra-maize row was caused mainly by within field and across site differences in weed pressure. Some weed species cut across fields and sites in their presence and appearance frequency in plots. Broadleaf as well as grass weeds were found. Weeds were visually observed as they appeared in sampling quadrats during assessment.

2.4 Discussion

Generally, maize growth performance, stover yield and grain yields were not statistically different at all three sites. Maize/legume plots at all sites except Subriso No. 3 produced superior maize height at physiological maturity to control plot of no legume cover crop. Maize height was, however, not significantly different between maize/legume and control plot. Mean height was legume/maize, 248 cm, at Gogoikrom and lowest, 194 cm, and from a control plot at Yabraso. This is an indication that the improvement of the soil is a long-term process which is not immediately noticeable especially in a relay intercropping.

Rainfall received at Gogoikrom was the highest and this favoured good legume cover crop growth. Ground cover and litter drop by legume might have also conserved moisture accounting for the better crop performance than the other sites.

As reported in some studies (Eilittä *et al.,* 2003), when major season intercropped cover crop, particularly mucuna, was slashed prior to second season maize planting, there was increase in maize growth performance including grain yield, despite low legume cover crop biomass. There was no clear-cut residual effect detected on the subsequent first season yield. In this study where intercropping was repeated in first season and allowed to mature in the field (e.g. *C. ensiformis, M. cochinchinensis* and *C. ternatea)* there was no increase in yield of subsequent maize despite the relatively high cover crop biomass. Annual maize production was low as a result of one cropping as against two some farmers do in a year – cropping in both major and minor seasons on the same plot. Lengthy time lag prior to 2002 major season maize cropping (some six months) to allow legume cover crop to grow fully could cause this. Rapid mineralization of legume cover crop residue and nutrient losses particularly *M. cohinchinensis* through various avenues (Carsky *et al.,* 1998; van Noordwijk *et al.,* 1995) might have occurred. In contrast, Ile *et al.,* (1996) reported maize yield increase in Nigeria though there had been long time lags prior to planting first-season maize.

Maize yield was significantly affected by legume intercropping, P = 0.03, at Yabraso in 2002 but not at Subriso No. 3 (P > 0.05) and Gogoikrom (P > 0.05). The viney and climbing species such as Mucuna, Clitoria, Canavalia and Lablab as intercropped legumes did not significantly affect maize grain yield. This is probably because they are associated with physical competition as they twined around the maize plants. The slower establishing *Pueraria* (2002), *Stylosanthes guianensis* and *S. hamata* (2001) and erect *C. ensiformis*, unlike the viney species, resulted in higher maize yield probably due to less physical competition with maize. *Pueraria* could result in similar competition to the above-mentioned species with time.

Lack of legume biomass in the control of no cover crop treatment was compensated by weed growth – highest weed dry matter yield was recorded on the control plot at all three sites. Considering the amount of biomass left on the field to be an indicator of soil conservation benefit, the nutrient status of the soil in the subsequent season was affected by decomposition before seeding of the plots with maize (Tian *et al.,* 1995).

Weeds were fewer on legume/maize plot than control plots. The cover crops suppressed weeds very well a quality that attracts farmers very much to adopt them. The denser plant population (cover crops + test crops: maize and other food crops) might have helped control weeds (FAO, 1986). In addition, because the plants mature at different times, intercropping may extend ground or soil coverage period of the year thus protecting the soil through leaf cover and root systems.

Successful relay intercropping involves consideration of the spatial arrangement, density, planting date plant architecture of the crops. Seeding rates of each crop are typically reduced to avoid overcrowding. Of course, seeding rates must also take into account desired yields for each crop. To take advantage of the difference in demands for nutrients, water, and sunlight among the individual crops, intercrops can be planted with crops having different maturity dates. Proper planning of planting dates can also minimise competition between crops, and help with staggered harvesting. Different types of plant structures of crops can be complementary (Kantor, 1999). The idea behind intercropping is growing two or more crops together in order to maximise beneficial interactions while minimising competition. The resulting beneficial reactions can lower the need for external inputs. Intercropping can also increase biodiversity, stability and financial diversification of the farmer's field.

Table 2.7 compares 2001 cropping with that of 2002. Plant height was higher on legume/maize plots than control plots. Maize had been planted into slashed/cut legume mulch. Grain yield decreased from 3606 kg/ha to 2737 kg/ha in 2002. Possible reason was late weeding or lack of weeding by farmers, poor 2001 legume biomass accumulation due to unfavourable rainfall. The trend, however, was different for stover yield. There was an increase of 0.54 percent in maize yield. Weeding was found to enhance intercrop yields in maize/bean combination by 35% in southern Africa in a similar study by Tembakazi and Lucas (2002) while in Ghana, Dapaah *et al.,* (2003) also noted maize yield reduction due to increased number of soya bean intercrop rows between rows of maize.

2.5 Conclusion and recommendations

The findings indicate that legume/maize plots did better than control plots with regards to maize growth performance, grain and Stover yields. The positive maize grain yield increases in the relay cropping maize and legume cover crops appear to be consistent with other reports by Costa *et al.,* (1990) and van Noordwijk *et al.,* (1995) that cover crops rapid mineralization and subsequent yield impacts on food crops. Tromphe (1996) has reported *Mucuna* having a positive impact on maize yield beginning with the first cropping cycle.

Experiences from this on-farm participatory research/collaboration with farmers suggest enormous potential benefits to be derived from the use of legume cover crops. As a sustainable system food crop yields can increase and the challenge for research and extension systems is to sustain the pursuit of further identification of cover crop species that are fast growing, nitrogen fixing, drought tolerant and multipurpose in nature for farmers' use. Mixed species incorporation in relay-intercropping possibly should do the trick.

Companion maize yields were not reduced significantly when various legume cover crops were intercropped into maize. This appears to be consistent with the findings of Rao and Mathuva (2000) that maize intercropped with pigeon pea gave similar yields to sole maize in comparable seasons but average yield over all seasons was significantly higher than that of continuously sole-cropped maize, because there was no maize failure in long rains unlike the case of other cropping systems. Agboola and Fayemi (1972) noted that legume intercropped with early maize gave a maize yield equal to that obtainable with 55 kg/ha N supplied as mineral fertiliser.

None of the fallow legume species taken alone appears to be an ideal candidate for or a panacea to soil fertility replenishment through improved fallows in the Forest and Forest-Savanna Transition Zones of Ghana. However, each one has desirable characteristics as fallow improving species. The best opportunity could reside in mixed cover crops. Mixtures can withstand drought, disease, fire etc better than sole-cover crops. Legume-legume mixture should be explored through future research (IDRC/ITTA/SG2000, 1998).

Mucuna species, *Lablab purpureus, Pueraria phaseoloides* and *Canavalia ensiformis* have great potential if planted at the appropriate time to boost biomass accumulation and at the same time ensure less competition by fallow species with main crop.

In whatever case a year fallow duration is not likely to bring about substantial change in soil fertility status and crop yield. The treatments did not have significant effects on parameters that were set up possibly due to the short-term nature of the research. This suggests that more research work for longer duration to include especially the shrubby and tree species that were screened and found to be ecologically adaptive to the region namely, *Gliricidia sepium*, *Tephrosia candida*, *Flemingia macrophylla* and *Cassia bicapueris*, in addition to the herbaceous species should be done. Research in intercropping should be geared towards increasing the productivity and returns in arable crops. Farmers' traditional cropping system will continue until an alternative is evolved that can fit into present technology, environmental constraints and at the same time maintain high crop yield. Relay cropping maize and legume cover crops research has the potential of offering an early and viable alternative.

3. RESIDUAL FERTILISER STUDIES ON MAIZE FOLLOWING TOMATO

3.1 Introduction and Justification

The Natural Resources Institute, a United Kingdom-based organisation, has been active since 1994 in the Brong Ahafo Region of Ghana. A component of its work was research and extension of several green manure species and animal manures as soil ameliorants on dry season vegetable farms. Their Integrated Food Crop Systems Project (IFCSP) has ended but as a continuation, trial plots at Wenchi Agricultural Station which they planted to test green manures and animal manures, either on their own or in combination with inorganic fertilizers, were re-planted with maize to test their residual effects. Farmers will normally follow vegetable crops especially tomato with maize for several reasons. Maize is an important crop for the Wenchi District especially when grown in rotation with tomato (*Lycopersicon lycopersicum*) the cash crop of the District. The advantages of rotating tomato with maize (*Zea mays*) include breaking the life cycles of major tomato insect pests and diseases and supplying additional residues to increase soil organic matter.

Aside from the above, maize is one of the most important cereal crops in Ghana. About 400 000 ha of maize is under cultivation and maize production has averaged around 375 000 tonnes per annum during 1970 – 85 (Coste, 1996) and even beyond. According to Obiri-Darko *et al.,* (2000) maize is produced and eaten by all categories of the inhabitants of the District. It is also a cash crop and has ready market. Aside from this the standing crop of maize can be used as collateral to obtain credit from traders to meet funeral, medical and other household expenses. Green maize is often grown where dry season vegetables including tomato are produced and is a source of cash and food.

Organic matter has a role to play in the mechanisms involved in freeing mineralised N, and hence in feeding the maize. It also has many other roles to play, however, in terms of improving or maintaining the physical qualities of the soil and its ability to store water, and in terms of developing microbial activity. The organic matter content of the soil is one of the keys to successful maize as it is a store of plant nutrients.

Bunch (2001), in putting in his 'Nutrient Access Concept' across, elaborated that organic matter can and does supply low-medium concentrations of nutrients, and almost always in well-balanced quantities. Furthermore, organic matter by its very nature has a slow – release mechanism, allowing the nutrients to be available to plants over a period of several months or years. And lastly, though this mechanism is somewhat slower and sometimes problematic in improving soil structure of heavily compacted soil, soil organic matter does serve to gradually improve soil structure. Soil organic matter does so both directly, through the provision of binding materials, to improve flocculation, and indirectly, by feeding earthworms and other soil organisms both micro and micro which also improve soil structure (Minnich, 1977).

It should be mentioned here that Nutrient Access concept does not necessarily support the total discontinuation of the use of chemical fertiliser (Bunch, 2001). While organic agriculture proponents may agree with this concept, the Concept does not necessarily support a totally organic approach hence the inclusion of combination of animal manure and N P K or complete fertilizer in the studies. What the Concept does do is open the door to greatly reduced use of chemical fertilizers in the short run, and the gauging of their use in the long run more according to replacement levels of net losses of nutrients for the purpose of sustainability (minus those nutrients supplied by organic matter and nitrogen fixation), rather than the much higher levels of use presently thought to be the only way to significantly increase productivity.

Chemical fertilizer use has been associated with significant increases in yield in some areas in the Brong Ahafo Region of Ghana. However, current levels are not sufficient to replace nutrients used during crop production and so mining of soil nutrients is occurring as crop yields decline (NRI/MOFA, 2000).

Chemical fertilizers alone, at the rates most farmers can afford, do not at present offer a sustainable system of soil fertility maintenance.

The use of organic fertilizers, in the form of animal manure, is a well established practice in the Sudan Savanna and other parts of northern Ghana; however it is not widely practised elsewhere. Possible reasons for this are their bulkiness and cultural barriers with farmers' scanty knowledge in manure management. Settler farmers of northern extraction in Wenchi District tend to bring along the custom, which therefore calls for the need to research into its use. The use of organic fertilizers is generally underdeveloped in Ghana and offers a less capital-intensive alternative to bought chemical fertilizer.

Therefore, the combined use of organic and inorganic fertilizers can be particularly beneficial, with the organic component helping to prevent loss of readily available inorganic nutrients, while providing an additional source of more slowly available nutrients.

Previous work by Mudra (1953) indicates that numerous tests and many years of experience have taught that farm yard manure with its long-effective nutrients is an ideal fertilizer for maize. Recently, Harris and Yusaf (2000) have also indicated that manure is a key input to smallholder farming systems especially in West Africa where cost and availability limit the use of inorganic fertilizers. Powell *et al.,* (1995) have emphasised the importance of livestock manure to the maintenance of soil fertility in low input farming systems in Sub-Saharan Africa.

In areas with negligible livestock or where these produce only small amounts of stable manures, above all in warmer regions where stabling is almost non-existent, green manuring can provide a valuable organic complement. Here, the profusion of partly wild legumes makes the choice of green manuring plants rather more difficult and it is better to select the most suitable among these growing in the country in question. Good results could be achieved trying various species hence the research at Wenchi involving several green manure species.

To conclude the relative merits of organic manures versus mineral fertilizers as sources of plant nutrients are not clear-cut mineral fertilizers alone can maintain production for up to 10 years, but organic manure is essential to sustain production for longer periods (Pieri, 1992). Co-application of both amendments produces better yields in the long terms (Bationo *et al.,* 1991*;* ICRISAT, 1989)

A full evaluation of a green manure/cropping system should take account of any residual effect operating on a succeeding crop or crops (FAO, 1994). In view of this transient nature of the expected benefits such as direct N-contribution, organic matter build-up and improvement of soil physical properties, second-stage residual effects are difficult to quantify or distinguish other than in terms of yield increase under a given set of cultivation conditions.

In a study in which green manure N content averaged 85 kg/ha, Morris *et al.,* (1996a) did not detect residual-N effects after four years. There was no residual effect of green manuring in West Bengal, but there were positive effects ranging from 141 kg to 221 kg rice /ha in other States, when Panse *et al.,* (1965) studied the residual effect of green manure applied to rice on a following rice crop. Meelu *et al.,* (1992) obtained no significant residual effect in the first year of a two-year evaluation of eight green manure crops, but in the second year, sesbania, the most productive species, gave a significant increase of 0,52 t/ha grain yield for a succeeding dry season rice crop. In Latin America, several green manures applied to maize showed marked residual effect ranging from 0.5 to 2.7 t/ha on the grain yield of the following wet season maize crop (Lathwell, 1990).

Furthermore, Frye *et al.,* (1985) found an increasing benefit of hairy vetch on maize yield with time, particularly at low rates of added N. Singh *et al.,* (1982) studied the residual effect of green manuring on succeeding wheat crop over three years and obtained an average increase of 0.28 t/ha grain over no green manure treatment. Bouldin (1988) reported that continued use of green manure over or more years have considerable residual effect.

The above past work results indicate a need for more in-depth and critical research into possible residual effects, particularly after long term use of green manures in food crops and in dry land, where the build-up of soil fertility is important. The amount of nutrients provided by green manures are determined by the production rate and nutrient concentrations, both depending on climate, soil type, green manure crop species, plant part, plant density (Palm, 1995) and the stage and state of incorporation. A large number of screening and alley cropping trials in different climate-soil environments indicate that prunings of several tree species contain sufficient nutrients to meet crop demand, with the notable exception of phosphorus. Palm (1995) further reported that field trials with agroforestry species ranging in quality show that as much as 80% of the nutrients are released during the course of annual crop growth but less than 20% is captured by the crop, a low nutrient-use efficiency.

The availability of N not captured by the crop to subsequent crops or how much of it is lost through leaching, volatilisation or denitrification cannot be adequately determined to lack of insufficient data. In Rwanda, green manuring proved to be a risky enterprise, due to highly variable biomass production and residual effects (Drechsel *et al.,* 1996). Even where biomass production was sufficient, residual effects were in most cases unsatisfactory due to rapid nutrient leaching (N, K) or inappropriate incorporation on-farm.

Despite numerous reports on the use of animal manure/green manure as fertilizers, their residual effects on subsequent crops have not been studied in Wenchi. This is particularly important because this system of tomato production has significantly decreased soil loss by erosion, which consequently increased the residual fraction of organic nitrogen**.**

Hypotheses

1. Residual manures from various sources have the potential of giving greater residual benefits to maize for the fact that they do not decompose completely but rather release nutrients slowly in the case of animal manure. Making use of them avails various amounts of nutrients to the succeeding crop, which is more so, a cereal (maize) following tomato in a rotation. Under-utilised manures would be fully used especially if they require a longer time to further decompose and release nutrients.
2. Residual green manures of *Sesbania aculeata*, *S. bispinosa*, *S. rostrata*, *S. sesban*, *S. speciosa* have different effects on the growth performance and yield of maize.
3. Co-application of organic and inorganic fertilizers results in greater maize yield than the application of either type only, because of the combination effect of both nutrient sources.

Objectives

1. To compare the effectiveness of various residual organic manures, with or without chemical fertilisers, to increase yield of succeeding maize crop.
2. To compare different application rates of fertilisers and organic manures on the growth performance of maize (variety: Abeleehi)
3. To determine the effect of residual green manures on the growth performance and yield of maize following tomato in crop rotation

3.2 Materials and Methods

3.2.1 Site description, rainfall and site characteristics

An on-station experiment was conducted at the Wenchi Agricultural Station. The station is located between latitudes 07°30 ‘N and 08° 45 ‘N and between longitudes 02° 10’ W and 02° 45 W. The site has a mean annual rainfall of 1140 – 1270 mm per annum with peaks in May and September. There are two cropping seasons. The major cropping season begins from March to August and the minor season from September to December.

The soil range from deep reddish brown fine sandy clays with occasional ironstone concretions on valley sides, to yellowish brown to Grey, poorly drained alluvial sand and clays in the valley bottoms. The experimental plots were cropped to tomato the previous dry season and irrigation was carried out to sustain crop growth.

3.2.2 Experimental Design

For all three trials randomised complete block designs were established them to match the three replications each, as was the case with the tomato cropping. Planting of maize (variety: Abeleehi) was done in June 2000. Treatments had been randomly assigned in each block by the IFCSP and this had to be maintained as residual effects were now the current treatments.

There were three trials in the study. The first trial was on the effect of residual animal manure with or without inorganic manure on maize growth performance and grain and stover yields, with 14 treatments and replicated three times. The treatments included 1. Poultry manure 25kg N/ha, 2. Poultry manure 50 kg N/ha, 3. Poultry manure 75 kg N/ha, 4. Poultry manure 40 kg N/ha + NPK15-15-15 40 kg N/ha, 5. Cattle manure 25 kg N/ha, 6. Cattle manure 50 kg/ha, 7.cattle manure 75 kg N/ha, 8. Cattle manure 40 kg N/ha + NPK15-15-15 40kg N/ha, 9. sheep 25 kg N/ha, 10. sheep 50 kg N/ha, 11. sheep 75 kg N/ha, 12. sheep 40 kg N/ha + NPK15 -15-15 40 kg N/ha, 13. NPK 15 -15-15 80 kg N/ha and 14. control (no animal manure/no chemical fertilizer).

Animal manures had been collected and stored under a tree at the Wenchi Agricultural Station to allow them to decompose prior to use. Sheep manure was delivered on 28th May, 1999 while cattle manure was delivered on 23rd June in the same year. In September the same year poultry manure was collected. The treatments (applications) were carried out on the 12th October, 1999.

The experimental plot size was 43.8 m by 27m with each treatment measuring 5.4m by 3.5m and a footpath, which is 1 m between plots. Tomatoes were planted on ridges and these were maintained with the maize (variety: Abeleehi) sown 70 cm inter-ridge and 60 cm intra-ridge or intra-maize spacing giving a planting distance of 70 cm x 60 cm.

The second trial examined the effect of residual green manures from different sources (green manure plants) on the growth performance and yield of maize. There were nine treatments, namely 1) *Mucuna pruriens* (light mottled), 2) *Canavalia ensiformis*, 3) *Mucuna pruriens* (cream), 4) *Crotalaria juncea*, 5) *Calapogonium mucunoides*, 6) *Mucuna pruriens* (dark mottled), 7) *Mucuna pruriens* (black), 8) *Crotolaria* species and 9) control. Each block/ replicate measured 12.5 m by 18.2 m breaking down to 5.4 m by 3.5 m a treatment plot and 1 m path between treatment plots.

The third trial looked at the effect of residual green manures from different species of *Sesbania* on the growth performance and yield of maize. Like the trials above this trial had three replicates as was in the case of tomato, which had been cropped the previous rainy season by the Agronomy component of

IFCSP. The land was cleared of bush through slashing and mulch left on the plot. The ridges, which contained the green manure, were retained.

The treatments, therefore, are (1) *Sesbania aculeata*, (2) *Sesbania bispinosa*, (3) *Sesbania rostrata,* (4) *Sesbania sesban*, (5) *Sesbania speciosa* and (6) control (no green manure).

The experimental lay-out indicates plot size as 28m x 18.2m with each treatment plot measuring 5.4 m x 3.5 m and footpaths which measured 1 m wide.

The trial plots in 3 above were weeded twice at 2 and 6 weeks after sowing (WAS) of maize. Manual weeding was done either with the hoe or the cutlass (machete) and cut weeds were left on the surface of the surface. All plots were irrigated as and when necessary as the trial was established too late to be described as a first (major) season and too early to be described as a second (minor) season cropping.

3.2.3 Maize growth performance measurement

Five maize plants in the central row of each treatment plot were marked and their heights taken regularly at 4 and 8 WAS and at physiological maturity of maize.

3.2.4 Maize Harvest

120 days after sowing the maize was harvested in October 2000. The procedure to harvest and estimate the yield of maize on each of the three trials was as follows: On each treatment plot whole plot was harvested. The maize plants were counted and number recorded. The ears of maize were plucked off and husks removed. The cobs with well-developed grains formed were counted and number recorded. These were weighed and weights recorded.

20 cobs were then randomly selected, weighed all together and weight recorded. The grains were shelled, weighed and grain weight recorded. The correction factor for shelling (CFS) was calculated using the formula:

$$\text{C F S} = \frac{\text{kg of shelled grain}}{\text{kg of maize cobs.}}$$

A thousand (1000) grains were randomly selected, weighed and weight recorded. The 1000 grains were dried in and oven at 80° C for about 24 hours. The dried grains were weighed and weight recorded. The percentage moisture content of the grains at harvest was calculated as follows:

$$\text{Harvest moisture} = \frac{\text{Fresh weight 1000 grains} - \text{Dry weight 1000 grains x 100}}{\text{Fresh weight of 1000 grains}}$$

Correction factor for moisture (CFM) was calculated to convert weight to constant moisture content from the following formula:

$$\text{C F M} = \frac{100 - \%\text{ harvest moisture}}{100 - \%\text{ constant moisture*}}$$

*The percentage of constant moisture of maize is about 13.

Correction Factor for Area (CFA) was calculated to convert harvest weight to kg/ha as follows:

$$C\,F\,A = \frac{10\,000}{\text{Harvest plot size}}$$

All the maize stover on the harvest plot was cut and weighed and weight of stover (stubble) recorded. To convert to stover yield per ha the recorded figure was multiplied by CFA.
Maize grain/ha was calculated using the formula below:

Kg grain/ha = kg grain/plot x CFM x CFA

Kg grain/plot = Weight of maize cobs/plot x CFS

3.2.5 Statistical Analysis

Statistical analysis was carried out on maize plant heights, at 4 weeks after sowing (WAS), 8WAS and physiological maturity, maize stover yield and grain yield. The statistical packages used were Minitab Release13.31 and GenStat 6.1 ANOVA (analysis of variance) was done using GLM (general linear model). All assumptions of ANOVA were checked by analysis of residuals. Statistical significance refers to $P < 0.05$ unless otherwise indicated.

3.3 Results

3.3.1 Crop performance

The average heights of maize under the treatments are shown in Tables 3.1, 3.2, and 3.3. The treatments effect was only significant ($p<0.05$) at 4 WAS for the animal manure study. The tallest plants were predominantly in plots under the residual NPK applied at 80 kg N/ha treatment and cattle manure applied at 25 kg N/ha (Table 3.1) with a mean height of 72 cm. Cattle manure applied at 50 and 75 kg N /ha treatment produced predominantly the shortest maize plants of 49 cm.

At 8 WAS sheep manure 50 kg N/ha treatment produced the tallest plants of 207 cm whereas cattle manure treatment 25 kg N/ha treatment produced predominantly shortest plants of 128 cm. At physiological maturity the tallest plants were predominantly in plots under residual sheep manure 50 kg N/ha treatment with mean height of 218 cm while the shortest of 160 cm were in plot under cattle manure 25 kg N /ha treatment.

Table 3.1 Effects of residual animal manure with or without mineral fertilizer on height, stover and grain yields of maize at Wenchi, Ghana in 2000

Treatment	Height at 4 WAS (cm)		Height at 8 WAS (cm)		Physiological Maturity (cm)		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	mean	s. e.	mean	s. e.	mean	s. e.	Mean	s. e.	mean	s. e.
PM25	65	11	186	12	187	11	2646	627	988	263
PM50	67	6	184	14	205	3	2222	461	952	183
PM75	52	10	152	25	195	5	2857	618	1111	291
PMNPK	67	1	163	30	208	11	3397	536	1270	153
CM25	72	4	128	30	60	6	3739	841	1393	329
CM50	49	6	155	19	205	15	2187	634	827	312
CM75	49	10	164	33	206	13	252	555	935	306
CMNPK	54	11	150	47	202	26	2275	1074	935	475
SM25	60	7	163	27	207	8	3016	827	917	362
SM50	50	8	207	21	218	14	2134	208	794	162
SM75	69	4	173	18	209	11	2469	969	917	354
SMNPK	71	4	196	4	213	11	1764	508	705	267
NPK80	72	5	166	28	211	5	2381	680	952	231
Control	62	7	158	16	214	14	1869	144	709	96
Grand Mean	61		168		203		2534		958	
LSD5%	16		NS		NS		NS		NS	

s.e ., standard error; LSD = least significant difference; PM25, PM50, PM75 = poultry manure applied at 25, 50 and 75 kg N/ha respectively; PMNPK = poultry manure and NPK 15-15-15 applied at 40 kg N/ha; CM25, CM50, CM75 = cattle manure applied at 25, 50 and 75 kg N/ha respectively; CMNPK = cattle manure and NPK15-15-15 (mineral fertilizer) each applied at 40 kg N/ha; SM25, SM50 and SM75 = sheep manure applied at 25, 50 and 75 kg N/ha respectively; SMNPK = sheep manure and NPK 15-15-15 (mineral fertilizer) each applied at 40 kg N/ha; NPK80 = NPK 15-15-15 mineral fertilizer applied at 80 kg N/ha and control (no animal nor mineral manure).

The average maize stover yield of 3739 kg/ha the heaviest was predominantly from cattle manure 25 kg N /ha treatment and the lightest, 1764 kg/ha, was from sheep manure 40 kg N/ha + NPK 40 kg N /ha treatment. The average maize grain yield was highest, 1393 kg N/ha, from cattle manure 25 kg N/ha and least, 709 kg N/ha from the sheep manure 40 kg N/ha + NPK 40 kg N/ha treatment

Table 3.2 shows the mean height of maize under residual green manures from herbaceous legumes. The treatment effect was not significantly different. However, agronomic efficiency of the various treatments for maize height at 4 WAS were *Crotalaria* species > *Calopogonium mucunoides* = control > *Mucuna pruriens* (dark-mottled) > *Mucuna pruriens* (light-mottled) = *Crotalaria juncea* > *Canavalia ensiformis* > *Mucuna pruriens* (cream)> *Mucuna pruriens* (black).

At 8 WAS the tallest plants 202 cm were predominantly in plots under *Mucuna pruriens* (dark mottled) treatment. The shortest 155 cm were in plots under *Mucuna puriens* (black) treatment. Mean maize plant height at physiological maturity was highest, 211 cm, under *Mucuna pruriens* (dark-mottled) treatment and least, 188 cm under *Mucuna pruriens* (black) treatment. Mean stover yield was highest, 2822 kg/ha under *Calopogonium mucunoides* treatment and least 1834 kg/ha, in *Canavalia ensiformis* treatment. Maize grain yields in the residual green manures from herbaceous legumes treatments were Crotalaria juncea > *Mucuna pruriens* (light mottled)> *Mucuna pruriens* (dark mottled) > *Calopogonium mucunoides* > *Mucuna pruriens* (cream)> *Crotalaria species* (local) > *Canavalia ensiformis* > *Mucuna pruriens* (black) (Table 3.2).

Table 3.2 Height, stover and grain yields of maize grown with residual green manures at Wenchi, Ghana in 2000

Treatment	Maize height at 4 WAS (cm)		Maize height at 8 WAS (cm)		Maize height at Physiol. maturity		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
MPDM	58	10	202	19	211	14	2575	534	1041	203
MPLM	55	5	167	39	203	26	2628	387	1058	191
MPB	43	6	155	48	188	23	1869	306	617	127
MPC	51	12	183	42	206	21	2452	338	847	81
CE	53	9	187	38	207	23	1834	521	723	229
CS	63	6	185	29	202	22	2275	397	829	116
CJ	55	12	168	41	207	20	2734	341	1129	77
CM	61	7	190	12	210	21	2822	274	988	93
Control	61	8	163	42	208	22	2011	53	952	0
Grand mean	56		178		205		2355		909	
$LSD_{5\%}$	23		NS		NS		NS		NS	

LSD, least significant difference; NS, not significant; MPDM, *Mucuna pruriens* (dark – mottled); MPLM, *Mucuna pruriens* (light – mottled); MPB, *Mucuna pruriens* (black); MPC, *Mucuna pruriens* (cream); CE, *Canavalia ensiformis*; CS, *Crotalaria* species; CJ, *Crotalaria juncea;* CM, *Calopogonium mucunoides*; Control, no green manure

Under Study 3, residual *Sesbania* green manures produced the following results. At 4 WAS the tallest mean maize plants were predominantly in plots under *S. rostrata* treatment (68 cm) and the shortest were under *S. sesban* (56 cm). The trend was somewhat different at 8 WAS. Mean maize plant heights were *S. aculeata* = *S. bispinosa* > *S. sesban* > *S. rostrata* > *S. speciosa* > control (Table 3.3).

Table 3.3 Effects of residual green manures from five *Sesbania* species on maize height, stover yield and grain yield at Wenchi in the Brong Ahafo Region, Ghana 2000

Treatment	Maize height at 4 WAS (cm)		Maize height at 8 WAS (cm)		Maize height at Physiol. maturity		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
S. aculeata	58	7	202	25	222	23	1940	517	617	157
S. bispinosa	66	4	202	32	215	25	2152	138	758	47
S. rostrata	68	13	194	34	213	30	1411	107	511	18
S. sesban	56	11	200	21	215	22	1235	294	441	93
S. speciosa	62	7	182	28	203	26	1199	460	459	144
Control	61	8	179	9	205	4	1728	314	617	144
Grand mean	62		193		212		1611		567	
$LSD_{5\%}$	NS		NS		NS		NS		NS	

LSD, least significant difference; NS, not significant

Sesbania aculeata treatment produced the tallest maize plants of 222 cm when the crop reached physiological maturity while *S. speciosa* treatment produced the shortest plants, 203 cm. Mean maize stover yield ranged from1199 kg/ha from *S. speciosa* treatment to 2152 kg/ha from *S. bispinosa* treatment. Finally mean kg grain yield/ha was *S. bispinosa* > *S. aculeata* = control > *S. rostrata* > *S. speciosa* > *S. sesban* (Table 3.3)

3.4 Discussion

Efforts at rehabilitating the degraded tropical soils and at utilising these soils for sustainable production must be based on a sound understanding of their major constraints. For West African soils in particular, the common constraints include low organic matter content, the annual decomposition rates being high owing to high temperature and high faunal activities. The soils are structurally fragile and with increasing adoption of commercial agriculture they are exposed to the degrading forces of the harsh climate, which lead to rapid deterioration in their physical, chemical and biological properties. Above all, it appears very important and necessary to plant crops early enough to allow for early use of nutrients by crops and to avoid losses due to time elapse when advantages are to be taken of residual nutrients.

Although indications are that inorganic or mineral fertiliser alone is not sufficient to arrest degradation or to maintain productivity at optimum levels in these soils, it is noteworthy that reliance solely on organic inputs would raise problems of procurement, transportation and toxicity, at high rates of application. It is broadly agreed that soil fertility replenishment in Africa requires increased use of both inorganic fertilisers and organic manures (e.g. Palm *et al.,* 1997; TSBF, 1995).

The results of these studies show encouraging improvements in the physical properties of a degraded Gleyic Lexisol with the application of organic manures in the form of animal manures, green manures and combination of both organic and inorganic fertilisers. As sources of organic matter, the organic manures promote soil activities and play a major role in the build-up and stabilisation of soil structure. Indirectly they influence certain physico-chemical determinants of soil productivity.

There was significant difference in maize height at 4 WAS only. This could be attributed to decomposition of the manures particularly the green manure at the early stage of maize growth. Decomposition rates of incorporated green manures and other organic manures might have differed (less between manure types superficially applied than incorporated ones). Incorporated manures are in a generally more favourable environment for microbial decomposition (e.g., close soil contact, adequate soil moisture, etc) (Wilson and Hargrove 1986). This could be due to nitrogen flush and/or immobilisation of the different green manure materials during the early stages of the experiment and improvement in soil porosity owing to the various manure treatments. Mgabwu *et al.,* (1989) noted that organic wastes incorporated into the soil at the rate of 10% increased the total soil porosity by 23%. Indications from the results of these studies are that application of nutrients, organic or inorganic manures or combination of both, ended up improving porosity due to more biological activities in all plots except the control. Work needs to be done in this direction.

From the standpoint of soil fertility, organic matter supplies appreciable amounts of essential nutrients than NPK such as Fe, Mn, Cu, Zn and S, and most of the CEC of the soil (Nayar and Chhibba, 2000). Of importance too, it reduces P fixation and micro-nutrient leaching (Obi and Ebo, 1995). It would appear that sizeable organic amendments are required to rectify the constraints to productivity. Higher rates of organic manures than were previously applied are needed for the rectification and attainment of sustainability of agricultural systems.

3.4.1 Animal manure and crop productivity

The beneficial impacts of animal manure are well documented and, the effects of applying manure to land, is well known. In certain areas arable farmers may still make arrangement with herdsmen to corral livestock on their land (Enyong *et al.,* 1999) or move homesteads from place to place so that crops can be grown on that land to benefit from manure left over by livestock (Ruthenberg, 1980). The use of animal manure can not only enhance immediate crop yields (Ali 1996; Karki, 1996; Drechsel and Reck, 1998), but can also provide some residual benefit for following years (Singh and Desai 1991; Karki, 1996). This was the case with the animal manure study. While inorganic fertiliser, NPK 15-15-15 applied at 80 kg N/ha, initially accounted for the tallest maize plants cattle manure produced the highest maize stover and grain yields even though it produced the shortest maize plants at early growth stage of maize. Some analysis in Ghana has estimated that the cattle manure contains about 17.4 kg N, 6.7 kg P_2O_5 and 24 kg K_2O (Kwakye, 1980). In addition numerous micronutrients released from animal manures (Hemingway, 1961; Olsen *et al.,* 1970) and also made available in the soil through the chelating action of humic acid formed by the decomposition the dung might have favourably influenced maize crop performance.

The nutrients are relatively slowly released compared with those from mineral fertilisers and therefore have residual effects on the maize. It is estimated that the efficiency of nitrogen in cattle manure is about 30 per cent of that of nitrogen in mineral fertilisers for the first year of application, but effectiveness increases in subsequent years due to slow release and, therefore a higher residual effect (Anane-Sakyi *et al.,* 1997; Harris 2002).

The residual effect of cattle manure is important for the maintenance of soil fertility. Musa (1975) obtained results showing that during the decomposition of cattle dung the main form of nitrogen release was NH_4^+ This could partly explain the positive residual effect of the cattle manure on the yield of maize.

A good number of experiments conducted in West Africa using cattle manure showed increase in crop yield (e.g. Kwakye, 1980). On-farm trials in West African countries indicated that animal manure is required to be applied at rates of 3.7 mg/ha every other year to replenish the nutrients taken off the farm through growth removal (Williams *et al.,* 1995) . Not all the nutrients will be released from animal manure in one season. In a two-year study in Ethiopia it was found that on the average, 28% of the N, 19% of the P and 90% of the K were released into the soil in the first season, Ca and Mg were immobilised (Lupwayi and Haque, 1999) implying the need for supplemental N and P for high crop yields.

3.4.2 Optimal quantities of organic and inorganic fertilisers

In this study combination of animal manure with mineral fertiliser was second to cattle manure in maize stover yield and NPK applied at 80 kg N/ha in crop yield. Sheep manure applied at 40 kg N /ha and NPK at the same application rate produced the tallest plant at 8 WAS but the least maize stover and grain yields. However, poultry manure applied at 40 kg N/ha combined with NPK at the same application rate produced the second highest maize yield and stover yields.

Notwithstanding the advantage of high crop performance with the mineral fertilisers logistically and logically inorganic fertilisers also have their disadvantages. For example, they can cause acidification of soils (Bache and Heathcote, 1969). But this effect can be counteracted if inorganic fertilisers are used in combination with organic fertilisers (Bache and Heathcote, 1969). Combination of mineral fertilisers with different types of organic materials is a widely recommended strategy to improve soil fertility and enhanced nutrient use efficiency. Applying and promoting this strategy is one of particularly importance in long-term continuous cropping systems as it results in better yields in the long term (Cakmak, 2002; Bationo *et al.,* 1998; ICRISAT, 1989). Organic manure could be enriched with mineral fertiliser, which might aid decomposition and reduce the quantity of organic manure required for nutrient supply. In line with the above results, Bationo *et al.,* (1998) reported that the highest crop yields were obtained where fertilisers were used in combination with organic inputs in soil fertility trials established at IFDC's benchmark sites in Togo. Elsewhere and specifically with maize it was shown that although application of mineral fertilisers is an effective means of increasing yields in arable farming systems mineral fertiliser alone cannot sustain yields in the long run (Bationo *et al.,* 1998). They further reported that when mineral fertilisers are combined with other technologies such as crop residue or manure, productive and sustainable production systems can be obtained.

3.4.3 Green manure from herbaceous legume species and maize productivity

The application of green manures to previous tomato crop did not significantly increase performance of maize over any green manure controls at least at the initial stages. Initial growth performance indicates tallest maize plants under *Calopogonium mucunoides* and control plots. A full evaluation of a green manure/cropping system should take into account of any residual effect operating on a succeeding crop or crops.

In view of the transient nature of the expected benefits such as direct N-contribution, organic matter build-up and improvement of soil physical properties second-stage residual effects are difficult to quantify or even distinguish other than in terms of yield increase under a given set of cultivation conditions. The significant differences due to treatments in height of maize at 4 WAS can be attributed to the fact that crops respond differentially to the addition of different organic matter to the soil. The differing nutrient contents of the materials and variety of effects other than nutrient supply complicate the interpretation of these results in terms of residual green manure effects. Some of these effects include the influence of the amendments on soil physical properties, micro-environmental changes and interactions with pest and disease organisms.

Residual nutrients in plots previously under tomato cultivation were not significantly different from each other. However, there were better and significant maize productivity (growth and yield); parameters exhibited by residual *Crotalaria juncea*, dark-mottled *Mucuna pruriens* and *Calopogonium mucunoides*. This outcome is in line with a report by Lathwell (1990) that several green manures applied to dry season maize showed marked residual effect ranging from 0.5 to 2.7 kg/ha on the grain yield of following wet season maize in Latin America. In addition, the response of maize to herbaceous legume green manure N treatments in this study compared to the control of no green manure, a phenomenon observed by several workers in the tropics (Gonzales, 1962; Manguiat *et al.,* 1989).

Naturally, much larger contributions of N are to be expected from crops planted solely as green manures and a wide range of legumes have been used for a wide range of subsequent crops including maize (Lathwell, 1990). But one problem is that legume residues can decompose quickly as soon as they are incorporated into the soil and may release organic acids or other compounds detrimental to germination and seedling of the following crop (Boddey *et al.,* 1997). The former is more likely to be the case in this study, most of the nutrients being used up by the tomato before the maize was seeded. This could explain why the control plot compares with the green manure plot especially at initial grow stage of the maize.

Furthermore, a large proportion of the N in green manure residues may be released before the roots of the next crop are established to absorb it (Yadvinder-Singh *et al.,* 1992). Large losses of N through leaching and even volatilisation from such residues have been reported (Costa *et al.,* 1990; Janzen and McGinn, 1991). The above might have accounted for the relatively closer grain yield of the control to green manure treated plots.

3.4.4 Residual green manure from *Sesbania* (woody) species and crop productivity

The favourable effect of green manure on maize crop performance was likely due to increased organic matter leading to better biological, physical, and chemical soil conditions (Boparai *et al.,* 1992) Yadav (2001) reported the use of S*esbania* green manure as a profitable practice but did not elaborate which species.

Green manures incorporated in the soil before rice transplanting had residual effect on the succeeding wheat crop and Substitution of 50% N with Sesbania green manure in rice exerted a significant effect on succeeding wheat yields (Mahapatra and Sharma, 1989).

Application of 30kg N/ha as green manure produced maize yield comparable with from 90kg N/ha on fallow plots indicating a substitution value of 60 kg N/ha from green manure. However, Manguiat *et al.,* (1989) observed that grain yield of maize was increased by 80% with stem inoculated *Sesbania rostrata* over control which was contrary in this study. Control of no green manure produced 617 kg/ha as against 511 kg/ha maize grain yield from *Sesbania rostrata* treated plot.

This could be attributable to the fact that *S. rostrata* lost 80% N from residues after 20 days of residue decomposition (McDonagh *et al.,* 1995b), a quite early mineralisation of green manure N. Conducting field experiments on farmer's fields McDonagh *et al.,* (1995a) examined the potential of *S. rostrata* among other several pre-rice green manures and realised that the application of P, K, and lime combined with *S. rostrata* resulted in a fivefold increase in legume N recovered by rice, indicating the importance of alleviating nutrient deficiencies through fertiliser application if green manures are to be used successfully.

The better maize growth and yield parameters of residual *Sesbania aculeata* and *Sesbania bispinosa* could be due to soil moisture conservation and improved soil organic matter. This result appears to be in agreement with that of Nyakatawa and Reddy (2000) and Nyakatawa *et al.,* (2001), who did a similar work.

The grain yield results somewhat showed that residual N applied to tomato was capable of meeting some of the N requirements of maize following it in a rotation. In addition to reduction in cost of inorganic fertiliser, this will reduce the amount of nitrate N available for leaching. Nitrate N release from mineral fertiliser occurs in a relatively shorter time period giving a high concentration of nitrate N which is susceptible to leaching than from organic residual fertiliser where nitrate N release occurs slowly over time (Nyatakawa *et al.,* 2001)

3.5 Conclusions and recommendation

Ghana's most important economic sector is agriculture and a large majority of the population depends on it for their livelihood. Nevertheless Ghana has to import a high proportion of food demand. Therefore, intensification of agricultural production is one of the aims of the Government of Ghana The results of the experiments as indicated below are as apt or even better alternatives compared with conventional fertilisers even as residuals. Higher yields can be obtained with treatments combining organic and mineral fertilisers.

The effects of N from residual animal manures and green manures from herbaceous and woody species on maize succeeding tomato were beneficial. Residual manures/fertilisers (animal manures, green manures in combination with inorganic fertilisers or on their own) from 2000 dry season tomato cropping increased growth, stover and grain yields of maize. However, they produced minimum of 459 kg/ha and maximum of 1128 kg/ha maize yields without additional application of fertiliser in the Wenchi District of the Forest-Savanna Transition Zone of Ghana.

In addition, the increased stover yield of maize (2288 kg/ha) will supply more residues which will lead to an increase in organic carbon in the long term further improving soil productivity and conserving soil nutrients left by the tomato crop. These nutrients would otherwise be at risk of being lost through leaching or other means. The residual manures also increased growth performance of maize (increase in plant height) and could meet some of the N requirements of the maize.

Further research in residual fertilisers could focus on the confirmation of these results, green manure decomposition and on specific N-uptake patterns by maize in contrasting environments to further understand gaps in meeting N needs of maize with organic manures.

4. FALLOW SPECIES DENSITY AND PLANTING DATE EFFECT ON MAIZE AND WEEDS

4.1 Introduction and justification

Declining maize yields in the smallholder cropping systems of Ghana present the need to develop sustainable production system. One of the most prominent cropping-systems alternatives is the use of leguminous cover crops to improve the quality of fallows (Balasubramanian and Sekayange 1992; Hoefsloot *et al.,* 1993). Cover crops have the potential to address this issue.

While improved fallow and systems have been introduced in the Forest, Forest-Savanna Transition Zones (FFSTZ) of Ghana to address the problems of declining soil fertility and increasing weed load following the little or no use of NPK fertilisers for maize production, the constraint now is timing (planting date) and planting density of the fallow species to get appreciable results (H. Loos, personal communication).

The trend to shorter natural fallow in bush fallow agriculture calls for management alternatives to accelerate nutrient accumulation and aid in weed control. Various workers including Buckles (1998) and Giller and Cadisch (1995) have suggested cover-based managed fallows as possible such management alternatives. The adoption rate of cover crops such as *Mucuna pruriens* var *utilis* increased from year to year in the Sedentary Farming Systems Project (SFSP) pilot districts of the zone. However, some farmers considered the difficulties to intercrop cover crops well with any other crop due to the competitiveness nature of some of these fallow species. Where farms are too small and land pressure too great for any fallows, research focuses on improving soil fertility without interrupting the cropping cycle. One of the most promising technologies for this niche appears to be relay intercropping. Relay-intercropped legumes are not likely to directly benefit the companion maize crop, but have the potential to increase yields of a subsequent maize crop (Jeranyama *et al.,* 1998) If legumes are intercropped in a timely manner, competition with the maize crop for light, water and nutrients can be minimised while legume herbage N can be accumulated and production increased (Jeranyama *et al.,* 2002).

It has been observed that planting cover crops under maize two to four weeks after sowing maize leads to serious competition between the cover crops and maize. Cutting or heading back of aggressive species such as *Mucuna* spp*, Lablab purpureus* and *Pueraria phaseoloides* to avoid the strangling requires extra labour from farmers. Ideally late relay intercropping maize between mid June and July or combining with the last (second) weeding of maize has been recommended (Anthofer, personal communication). Some experimental results indicate that the appropriate dates for planting cover crops or relay-intercrops particularly *Mucuna* are between July 22 and March 5 (Carsky and Eilittä, 2001).

Weeds are a major constraint to crop production in smallholder crop production in tropical Africa in general and Ghana in particular. In the FFSTZ of Ghana for instance weeds are becoming more and more of a problem due to soil and forest degradation caused by savannisation and intensive agriculture (Amanor, 1995) Farmers regard weeding problem to be the main bottleneck in farming. At present investment in labour for weeding is quite high and the weeding process should be a useful entry point for approaches to sustainable agriculture based on natural resource management as it appears to represent a node at which labour and environmental concerns coalesce.

Because of their high biological nitrogen fixation, rapid growth and high biomass production (Giller *et al.,* 1994; Mafongoya *et al.,* 1998; Niang *et al.,* 1996) legume cover crops are some of the most promising plant species for short-duration cover cropping. In addition, legume crops can improve soil organic matter and physical properties (Wall *et al.,* 1991; Giller and Cadisch, 1995) and decrease pest preference for the main crop (Lambert *et al.,* 1987).

4.1.1 Relay-intercrop design

Intercropping is defined as the growing of two or more crop species simultaneously in the same field, with interspecific interactions in both time and space throughout the growing period (Trenbath, 1976). Sole cropping is defined as one crop species grown alone in pure stands at optimal density. Relay intercropping is the planting of a second crop into a standing crop at a time when standing crop is established but before harvesting. In general two intercropping designs are commonly employed – the replacement and additive. Replacement design is replacing plants of one component with plants of the other. Additive design is when the density of the one or both components is the same as in the sole crop.

Using a replacement design the total density is held constant and the proportion of the total density allocated to each species is varied from 0 to 100% (De Wit, 1960; De Wit and van der Bergh, 1965). Thus in a dual intercrop one component is replaced with same relative number of plants of the other component, thereby maintaining the same overall density in the intercrop as in the respective sole crops (De Wit and van der Bergh, 1965). The rationale for using this principle is that the total plant density of the intercrop totals the total density of the sole crop (Trenbath, 1976). Thus it is ensured that the interaction between intercrop and components are not confounded by alternations in the plant density of the intercrop compared to sole crops However, crop responses and subsequent interpretation of the influence of proportion may change with different total densities.

In a dual intercrop using the additive design one of the components is grown using sole crop density and then supplemented with the other component at a certain density. Thus the overall density is higher in the intercrop than in the sole crop (Fukai and Trenbath, 1993; Snaydon, 1991) and confounding effects due to total density and species proportion may occur.

4.1.2 Mode of intercropping

The competitive interactions for available environmental resources for plant growth may be influenced by the mode of intercropping (such as mixed intercropping, row intercropping and relay intercropping), planting pattern (row distance, inter-component distance, relative frequency of components, etc), planting date of components, availability of resources, etc. Although many studies have demonstrated the positive effects of cover crops in smothering weeds, there is very little information on seeding rate and time of seeding fallow species and cover crops when undersown maize in the FFSTZ of Ghana.

Hypothesis

Legume fallow species will accumulate nutrients thus will restore soil fertility, suppress weeds and influence maize productivity depending on their planting densities and planting dates. The major management issue for herbaceous legume relay-intercropping is the need to avoid inter-specific competition for soil moisture and nutrients and solar radiation. The aggressive climbing habit of cover crops such as Mucuna, Pueraria and Lablab may result in smothering of companion crops, resulting in reduced crop yield through competition for solar radiation, increased disease incidence and difficult in harvesting. Manipulation of relative planting dates and densities of cover crops can reduce inter-specific competition.

Objectives

The objectives of this study were to: (1) quantify nutrient accumulation by four herbaceous legumes, namely *Lablab purpureus* (L.) Sweet, *Mucuna pruriens* (L.) DC, *Stylosanthes guianensis* (Aubl.) Sw., and *Pueraria phaseoloides* (Roxb.) Benth., grown as relay-intercrops. (2) evaluate the effects of planting dates of the legumes (4 weeks and 8 weeks after sowing maize) on the growth performance and yield of maize and (3) determine the effect of planting density of the four species on maintaining yield of maize.

4.2 Materials and methods

4.2.1 Experimental site

The experiment was conducted at Wenchi Agricultural Station located between 7° 30'N and 7° 45'N) and (2° 10'W and 2° 45'W) latitudes and longitudes respectively, from May 2001 to August 2002. The site represents the drier end of the bimodal Forest-Savanna Transition agroecological zone of Ghana with annual rainfall of 1140-1270 mm. Rainfall occurs in two seasons, the first from March to July and the second from September to December.

To determine the optimum fallow legume species planting dates and planting densities of the cover crops four species, namely *Lablab purpureus* (LP), *Mucuna pruriens* (MP), *Stylosanthes guianensis* (SG) and *Pueraria phaseoloides* (PP) were undersown maize (*Zea mays* L. variety Abeleehi) in June and July 2001. The large seeded herbaceous legume species (MP and LP) were sown at 2 seeds per hill in rows of 80 cm apart and within row spacing of 25 cm, 50cm, 75 cm and 100 cm to give 50 000, 25 000, 16 000 and 12 500 plants per hectare respectively. The small-seeded species, namely SG and PP were drilled in rows 80 cm apart at 0.5, 1.0, 1.5 and 2.0 kg seeds per hectare to give the same densities as above. The design was a split plot factorial with legume fallow legume species as main plots measuring 16m by 12m and seeding / planting densities as sub plots of dimension 4m by 6m completely randomised within sub plots which measure 8 m by 12 m. The test crop, maize (*Zea mays* L. variety Abeleehi) was sown at 2 seeds per hill spaced 80 cm by 50 cm in May. At four and eight weeks after sowing the maize (WAS), the planting date treatments were imposed.

4.2.2 Trial establishment

The land was double disc ploughed with the tractor at the beginning of the cropping season in 2001 and the crop sown where there was a heavy down pour of rains and the recommended cultivar and population were used for the maize (cv "Abeleehi", crop cycle 110 days). The planting distance for maize was 0.80 m x 0.50 m at 2 seeds per hill giving a total of about 25, 000 plants to the hectare. In the 2002 cropping season the fallow species were slashed (cut) and left as mulch on the surface of the same experimental plot and maize planted into the mulch to observe effects of the trials on maize productivity

4.2.3 Treatments

The following were the levels of plant density factor: For the large-seeded species namely *Mucuna pruriens* and *Lablab purpureus* (LP) 1) 0.8m X 0.25 m spacing (50,000 plants ha^{-1}) [ONE], 2) 0.8 m X 0.50 m spacing (25 000 plants ha^{-1}) [TWO], 3) 0.8 m X 0.75 m (16,000 plants ha^{-1}) [THREE] and 4) 0.8 m X 1.0 m (12,500 plants ha^{-1}) [FOUR]. For the small-seeded drilled species, namely *Stylosanthes guianensis* (SG) and *Pueraria phaseoloides* the seed rates were as follows: (1) 0.5 kg seeds ha^{-1}[ONE], (2) 1.0 kg seeds ha^{-1} (TWO), (3) 1.5 kg seeds ha^{-1} [THREE] and (4) 2.0 kg seeds ha^{-1} [FOUR]. The planting dates were four weeks and eight weeks after planting the maize. The fallow legume species were sown under the maize as relay-intercrops on these two different dates. In order to choose the most appropriate design for this study a 2-year on-station experiment conducted at Wenchi Agricultural Station from 2001-2002 was taken as the point of departure. Next it was decided that investigation should focus on maize-legume cover crops/intercrops with the legumes undersown the maize. Two main issues were addressed: planting dates and densities of four herbaceous legume species. The additive intercropping design was employed for all the cover crop treated plots.

4.2.4 Data collection

The measurements made were ground cover, spread, plant height vigour and leafiness of fallow species. Presence of chewing and or sucking insects on fallow species, leaf drop, dates to 50% flowering, podding and seed ripening of fallow species. Biomass yield and nutrient content of fallow species, physical and chemical soil properties, height of maize plants at four and eight weeks after sowing and at physiological maturity, maize stover and grain yields were determined. Dry matter yield of weeds was also evaluated. Five plants were chosen from the centre row of each sub plot and monitored for height at 4 and 8 WAS and at physiological maturity of maize. Maize was harvested after 120 days of planting and yields for stover and grain determined.

Destructive harvesting was done for all treatments after the plot cover, spread/height, vigour, condition of leaves score, leaf drop, presence of disease, pests/insects and reproduction (flower and pods) were measured and recorded for analysis on 30th October 2001. A 1m quadrat was thrown at random in the centre of each sub plot and plants within it cut at 10-15cm above the ground. Fresh weights were taken of samples (after weeds were separated from legume). Oven drying of weighed legumes and weeds to determine of dry matter was done.

4.2.5 Statistical analysis

Analysis of variance was used and the General Linear Model of the Minitab in carrying out statistical analysis on maize and legume fallow species. Genstat release 6.1 was also used as and when appropriate to determine the least significant differences between means.

4.3 Results

4.3.1 Maize plant height

Height of the test crop (maize) was used as a measure of its growth performance. The results in Table 4.1 show that the presence of legume cover crop species as relay-intercrops with maize did not depress maize height at 4 WAS, 8 WAS and physiological maturity in the first year of the experiment. Maize plant height in the different species was in the order maize/*Pueraria* = maize/*Mucuna* > maize/*Lablab* > maize/*Stylosanthes* at 4 WAS and 8 WAS in the first year (Table 4.1). There were no significant differences among treatments in the maize height at both stages in 2001.

Table 4.1 Growth performance of maize relay intercropped with four fallow legumes at Wenchi, Ghana (2001)

Fallow species	Height of maize at 4 WAS (cm)		Height of maize at 8 WAS (cm)		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
L. purpureus	62	1.59	210	5.31	1023	77.2
M. pruriens	64	1.93	210	5.39	886	114
S. guianensis	61	1.39	203	5.71	938	89.4
P. phaseoloides	64	1.44	212	7.58	252	81.9
Grant mean	64		209		525	
$LSD_{5\%}$	ns		ns			

The trend changed in the second year or after the short fallow. Maize height was *Stylosanthes* treated plot > *Pueraria* treated plot > control (no legume) > *Mucuna* treated plot > *Lablab* treated plot at 4 WAS and

Mucuna treated > *Lablab* treated > *Pueraria* treated plot > *Stylosanthes* treated > control plot at 8 WAS (Table 4.2). There were significant differences among treatments in 2002 for height at 4 WAS (P = 0.000) but only near significant (P = 0.054) at 8 WAS following sowing of maize into cover crop mulch. Maize height at physiological maturity of maize was *Mucuna* fallow plot (193cm) > *Lablab* fallow plot (189 cm) > *Pueraria* fallow plot (182 cm) > *Stylosanthes* fallow plot (179 cm) > control/no legume fallow plot (175 cm). There were no significant differences in maize plant height at physiological maturity of maize.

Table 4.2 Maize growth performances: height, stover yield and grain yield on four legume fallow plots at Wenchi, 2002

Type of fallow plot	Height of maize at						Stover yield		Grain yield	
	4 WAS (cm)		8 WAS (cm)		Physiological maturity		(kg ha^{-1})		(kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Lablab purpureus	52	2.10	167	4.12	189	3.10	2787	132	1978	163
Mucuna pruriens	59	2.56	182	4.57	193	4.10	2451	215	2448	159
Stylosanthes guianensis	69	2.00	163	4.25	179.	3.45	2870	192	1836	98.0
Pueraria phaseoloides	65	2.69	164	6.91	182	4.62	2508	170	1841	159
Control	65	7.88	149	10.6	175	4.58	2396	132	1500	954
Grant mean	64		165		184		2602		1921	
LSD$_{5\%}$					ns					

Table 4.3 Planting densities of fallow legume species versus maize performance at Wenchi in 2002

Planting density (plants ha^{-1})	Height of maize at						Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	4 WAS (cm)		8 WAS (cm)		Physiological maturity (cm)					
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
50,000	63	2.24	170	6.19	185	3.85	2575	225	1914	128
25,000	60	3.13	169	4.92	190	4.29	2826	166	2145	173
16,000	59	3.04	168	5.88	184	4.35	2487	158	1920	114
12,500	63	2.17	168	4.15	185	3.38	2727	169	2125	19
Grand mean	64		169		186		2654		2101	

4.3.2 Maize stover yield

Maize stover production was used as a measure of performance. Tables 4.1, 4.2, 4.3 and 4.4 indicate that relay intercropping fallow species did not affect maize stover yield significantly in year 1 (2001) even though stover could hardly be retrieved in year 1 (2001) as there was strangling of maize plants at harvest time. However, in year 2 (2002) when legume biomass was applied to maize (cut and left on plot), maize stover yield was *Stylosanthes* plot > *Lablab* plot > *Pueraria* plot > *Mucuna* plot > control plot. Stover yield was only significantly different between planting date of legumes (P = 0.002). Mean stover yield of maize was 4 WAS plot > control plot >8 WAS respectively 2927 kg/ha, 2396 kg ha^{-1} and 2381 kg ha^{-1} (Table 4.4).

Table 4.4 Maize versus planting date of fallow legume relay intercrops at Wenchi in 2002

Planting date of legume	Height of maize at 4 WAS (cm)		Height of maize at 8 WAS (cm)		Height of maize at Physiological maturity (cm)		Stover yield (kg ha^{-1})		Grain yield (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e
4 WAS	62	2.10	171	4.38	191	3.15	2927	137	2215	128.0
8 WAS	60	1.76	166	2.92	181	2.24	2381	105	1836	77.5
Control	65	7.88	177	10.60	175	4.58	2396	212	1500	95.2
Grand mean	63		171		182		2568		1850	

4.3.3 Maize grain yield

The effects of fallow legume species on grain yield of intercropped maize in 2001 are shown in Table 4.1, while Tables 4.2, 4.3 and 4.4 show results for 2002 where cover crops were not re-sown. The results show that with the exception of 2001 all the treatments, namely legume species, planting date and planting density, had significant effect on maize grain yield in 2002 with p-values of 0.003, 0.005 and 0.012 respectively. In the relay-intercropping LP treated plot resulted in the highest maize grain yield followed by SG, MP and PP treated plots. The control plot produced the least grain yield. *Lablab* treated plot resulted in the highest grain yield (1023 kg ha^{-1}) followed by *Stylosanthes* treated plot (930 kg ha^{-1}), *Mucuna* treated plot (900 kg ha^{-1}) and *Pueraria* treated plot (250 kg ha^{-1}) in year 1. The differences among treatments were significant.

Subsequent maize cropping after the fallow produced significantly different maize grain yields among treatments. MP plot resulted in the highest maize grain yield of 2 500 kg ha^{-1}, followed LP plot (2 000 kg ha^{-1}), PP (1 800 kg ha^{-1}) and SG (1 900 kg ha^{-1}) whereas the control plot resulted in the least of 1 500 kg ha^{-1}. Both 4 WAS and 8 WAS legume plantings produced 2 200 kg ha^{-1} and 1800 kg ha^{-1} respectively were superior to the control plot of no legume fallow (1500 kg ha^{-1}. In year 2 (2002), maize grain yield were significantly different on the basis of species, planting date fallow age and the interaction of both. P values were less than 0.05.

4.3.4 Legume growth performance

4.3.4.1 Legume spread and ground cover

These assessments were carried out on 28th June 2001 when legume cover crops were between 9 and 10 months of age. Cover crop establishment which was measured, as spread, from plant base to the farthest tip was of the order MP > LP > PP >SG was significantly different ($P < 0.05$) at species and planting date levels (Tables 4.4 and 4.7).

Table 4.5 Effect of legume relay intercropping of maize on plot cover and spread of four fallow legume species at Wenchi in 2001

Planting date	Plot cover (%)		Spread (cm)	
	mean	s.e.	mean	s.e.
Four WAS maize	75	4.14	258	22.4
Eight WAS maize	58	4.38	221	23.0
Grand mean	67		240	

WAS = week after sowing

Measured as percentage ground cover, cover crop establishment was of similar order to that of legume spread: 97, 68, 63 and 39% respectively (Table 4.4). Planting legume cover crops as relay-intercrops under maize at 4 WAS produced better cover crop spread and ground cover than at 8 WAS. Varying planting density of legumes resulted in no significant differences in both plot cover and legume spread (Table 4.6)

Table 4.6 Effect of planting density of four fallow legume relay intercrops on the ground cover and spread at Wenchi in 2001

Planting density (plants ha^{-1})	Ground cover (%)		Spread (cm)	
	mean	s.e.	mean	s.e.
50,000	66	6.5	252	30.0
25,000	67	6.4	248	35.6
16,000	68	6.2	223	33.6
12,500	66	6.3	236	33.6
Grand mean	67		249	

4.3.4.2 Legume biomass/dry matter yield

There were significant differences ($P < 0.05$) among the legume cover crop species above ground biomass (expressed in dry matter yield per hectare) at species and planting date levels ($P = 0.000$ and $P = 0.002$ respectively). MP produced the highest DM with 260 followed by SG with 176, PP with 143 and LP with 117 kg ha^{-1} (Table 4.8). Table 4.5 shows that 4 WAS legume planting produced a mean dry matter yield of 175 kg ha^{-1} whereas 8 WAS legume planting produced 150 kg ha^{-1} suggesting relevance of planting date of herbaceous legume cover crops.

Legume plant population density of 12 500 plants/ha produced the highest DM of 190 followed by 16 000 plants/ha of 185 (Table 4.9). When planting density was further increased to 25 000 and 50 000 plants to the hectare cover crop DM were respectively, 154 and 170 (Table 4.9).

Table 4.7 Percentage plot cover and spread of four fallow legume species undersown maize at Wenchi Agricultural Station Ghana in 2001

Fallow legume species	Plot cover (%)		Spread (cm)	
	Mean	s.e.	Mean	s.e.
Lablab purpureus	68	6.12	297	17.3
Mucuna pruriens	97	0.79	435	14.9
Stylosanthes guianensis	39	1.38	61	4.3
Pueraria phaseoloides	63	6.95	160	16.5
Grand mean	68		238	

4.3.4.3 Nutrient content

The aboveground biomass of all four-legume cover crop species were analysed for nutrient contents, namely, N P K Ca and Mg. These were then subjected to ANOVA and fallow legume species and planting date had significant effects on the total aboveground N accumulation with P values respectively as 0.000 and 0.006. The trend was similar for P with p-values as 0.000 and 0.003 for species and planting date treatments. K accumulation effect was only significant with fallow species treatment (Tables 4.8 and 4.10) while for Ca and Mg, accumulation was significantly different relative to fallow species and planting date (Table 4.8). N P and K contents were highest in MP > SG > PP > LP (Table 4.8) whereas for Ca content was highest in SG followed by MP, LP and PP. The fallow legume species that accumulated the most Mg was MP with SG, PP and LP significantly lower.

There were significant differences among species in the mean contents of mineral elements from aboveground dry matter all four fallow legume species. Accumulation of N, K and Ca in percentage on dry matter basis was significant among the legume species (Table 4.10)

Table 4.8 Dry matter (DM) yield and nutrient content of four fallow legume species at Wenchi in 2001

Fallow legume species	DM yield (kg ha^{-1})		Elemental nutrient content									
			Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Calcium (kg ha^{-1})		Magnesium (kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
L. purpureus	117	5.8	3.0	0.21	0.4	0.04	1.0	0.08	2.0	0.02	2.1	0.12
M. pruriens	260	15.2	8.8	0.61	0.8	0.09	2.7	0.27	2.6	0.33	2.4	0.18
S. guianensis	176	81.1	4.1	0.45	0.5	0.70	1.7	0.02	2.6	0.28	2.3	0.33
P. phaseoloides	143	19.1	3.7	0.47	0.4	0.07	1.2	.0.20	1.5	0.29	1.4	0.17
Grand mean	176		4.9		0.5		1.7		1.9		2.1	

Table 4.9 Dry matter (DM) yield and nutrient content of fallow legume species on planting density basis, Wenchi 2001

Fallow legume species planting density (plants ha^{-1})	DM yield (kg ha^{-1})		Elemental nutrient content									
			Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})		Calcium (kg ha^{-1})		Magnesium (kg ha^{-1})	
	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.	mean	s.e.
50,000	170	20.0	5.0	0.68	0.5	0.08	1.7	0.28	2.0	0.27	1.7	0.02
25,000	154	14.2	4.5	0.55	0.4	0.05	1.4	0.15	2.0	0.23	1.5	0.15
16,000	185	20.4	4.8	0.74	0.6	0.11	1.6	0.22	2.3	0.32	2.0	0.28
12,500	190	19.8	5.2	0.67	0.5	0.07	1.9	0.27	2.5	0.34	2.1	0.31
Grand mean	150		4.9		0.5		1.7		2.2		1.8	

4.3.4.4 Estimated weed pressure

Weed biomass assessment was done on all plots on 22nd August 2002. The weed aboveground DM production was significantly greater in the control plot than in any of the legume fallow plots both inter- and intra-maize rows. The control plot followed by SG, PP, LP and MP had the highest aboveground weed DM. It did not matter whether inter- or intra-maize row; weed suppression was positively affected by MP > LP > PP > SG > control plot. The longer the fallow period the lower the weed DM and the better the weed suppression as was evident in the highest weed aboveground DM produced by the control plot followed by nine month-old legume fallow plots and then the ten month-old legume fallow plots. Weed aboveground DM in the inter-maize row space in the control plot was the highest followed by the ten month-old legume fallow and then the nine month-old legume fallow plots. Plots with plant population density of 12 500 plants per hectare that produced the highest weed aboveground biomass and were the most effective in weed suppression

Table 4.10 Mean contents of mineral nutrients from aboveground dry matter of four fallow legume cover crop species at Wenchi Agricultural Station, 2001

Species	Aboveground mineral element content (% on dry matter basis)									
	N	s.e.	P	s.e.	K	s.e.	Ca	s.e.	Mg	s.e.
Lablab purpureus	2.64	0.14	0.34	0.02	0.94	0.05	1.70	0.12	1.11	0.13
Mucuna pruriens	3.53	0.19	0.30	0.03	1.10	0.09	1.00	0.12	0.94	0.04
Stylosanthes guianensis	2.41	0.12	0.28	0.02	0.98	0.05	1.60	0.08	1.22	0.07
Pueraria phaseoloides	2.70	0.13	0.28	0.03	0.84	0.06	1.02	0.21	1.04	0.05
SED	0.33		0.03		0.09		0.21		0.08	
LSD (0.05)	0.80		ns		0.22		0.51		ns	

SE= Standard error of difference; LSD = Least significant difference; ns = Not significant

4.5 Discussion

4.5.1 Interspecific competition and relay intercrop advantage

When plant species are relay-intercropped it is likely that yield advantages occur as a result of complementarities in the use of resources by the component crops. Soil water is probably one of the environmental plant growth factors most often limiting nitrogen fixation in herbaceous legume cover crops (Schubert, 1995). There was no indication of drought or moisture stress and it was assumed that water did not cause any major limitation to either maize or relay-intercrops in the experimental period. At 4 and 8 WAS and at physiological maturity of maize it was observed that maize plant height in the control plot was not significantly different from the relay-intercropped plots. This probably suggests that water availability was not a factor decreasing the outcome of competition.

Maize was a predominant component in the relay-intercropping showing that a high degree of vigour in growth when the legume planting density was varied and planting date was delayed by four weeks. Apparently, there was better utilization of plant growth factors by the relay-intercrops compared to the control of sole maize. The advantage is probably due to early maize establishment, different above- and belowground growth habits and morphological characteristics of the relay-intercrops causing a greater efficiency in the utilization of plant growth resources, namely water, nutrients and light (Willey, 1979; Ofori and Stern, 1987; Fukai and Trenbath, 1993).

Cereal-legume relay intercropping advantages are often presumed to be associated with the complementarities use of N sources by components (Trenbath, 1976; Ofori and Stern, 1987). It was possible for the herbaceous legumes to cover their N requirement by N_2 fixation and soil inorganic N to be utilized by maize in addition to N fixation by the legume. Even though these were not investigated root dynamics and competitive ability towards weeds might have influenced relay-intercropping performances.

Satell *et al.,* (1999) suggested that the selection of a cover crop and its management depend on many factors among them the cover's ability to accumulate DM (i.e. residues) and N. DM provides energy for soil organisms, contribute to SOM, improves tilth and acts as a sink for nutrients. When soil inorganic-N is accumulated cover crops during the growth period, it cannot leach to the groundwater with subsequent rains. Legume cover crops can convert atmospheric N to plant-available forms and can provide substantial amount to subsequent crops.

When choosing a cover crop, consideration should always be given to how the cover crop will affect the following crop. The choice of establishment treatment for cover crops should be based on environmental constraints to good establishment and what the requirements are in the establishment period. A companion cover crop suppresses the yield of maize in the establishment period but offers a higher herbaceous or vegetative yield, better erosion control and weed suppression. Herbaceous legume cover crops can be as effective competitors as companion species (Willey 1979). It is with these criteria in mind that companion cover crops such as MP, LP, PP and SG should be evaluated.

Over the establishment period there were results that are worth discussing; the effects of legume cover crop planting date and density on the productivity of maize. There were also some effects of the fertility of the soil and weed management that are worth noting and considering. However, some issues have been highlighted which need to be considered in future research. For example, N fixation by the cover crops, nodulation, mycorrhiza colonisation, and nutrient uptake by the test crop.

4.5.2 Maize height, and grain and stover yields

The difference in height of maize in years 1 and 2 was probably due to improved soil nutrient status attributable to biomass and nutrient accumulation by the legume cover crops. This tends conform to findings of Jeranyama *et al.,* (1998) that relay-intercropped legumes are not likely to directly benefit the companion maize, but do subsequent crop.

Maize grain yields in this study in 2001 were higher in some cases and lower in others than those reported in the literature. In the former case for instance, Ile *et al.,* (1996), whose experiment was located on a highly degraded ultisol in south eastern Nigeria, reported 314 kg ha^{-1} whereas Eilittä *et al.,* (2003) working in the Los Tuxtlas Region of Veracrux, Mexico, reported 970 kg ha^{-1} being first season maize after Mucuna as against 1023 kg ha^{-1} in this study. However, these researchers further indicated a maize grain yield increase to 1460 kg ha^{-1} in the second season. In the case of the latter, Fischler and Wortmann (1999) recorded 4800 kg ha^{-1}, following Mucuna biomass incorporation in the bimodal rainfall zone of Uganda and Sanginga *et al.,* (1999) recorded 6 000 kg ha^{-1} from a rock phosphate treated Lablab plot in a rotation, as compared to 2 500 kg ha^{-1} in this study. Comparing these results appears to suggest that the benefit of legume cover crops is relatively greater when soil fertility is reduced. Plus, fallow legume species relay intercropping, particularly with aggressive species such as Mucuna, Lablab and Pueraria, is difficult to manage, resulting in possibly in current maize grain yield reduction and smaller benefits than sole maize.

Maize grain yield differences among treatments in 2001 when maize was in companionship with fallow legume species are not attributable to relay-intercroping and more so to timing and planting densities of intercrops. Legumes could be relay-intercropped into maize without reduction in maize grain yield (Jeranyama *et al.,* 2000). In contrast several reports have been made of sole crop yield advantages over many intercropping systems in maize/soybean and canola/soybean (Ayisi *et al.,* 1997: Ghaffarzadeh *et al.,* 1994; West and Griffiths, 1992).

Generally, grain yields obtained in 2002 were higher comparable to some results of previous work and lower in others. Percentage in maize grain yield increase from year 1 to year 2 was as follows PP (631.5) > MP (276.5) > SG (95.8)> LP (93.0) realised when maize was planted in legume mulch. Apparently, nutrient contents, weed suppression properties, moisture conservation and other properties of fallow species accounted for the maize grain yield increase. The least grain yield from the control plot tends to agree with Roland Bunch (pers. comm.) that food crop productivity in green manure/cover crops does not occur until after the biomass of the legume cover crops has been applied to the soil. This means visible recognisable results/successes are not apparent until well into the second cropping cycle.

It has been indicated that grain yield increases in maize with improved versus natural fallow were as high as 112 % (Lathwell, 1990) with similar responses in Ghana (Jost *et al.,* , 1996). Further more, in research-managed trials on farmers fields in central Ghana obtained average grain yield of 3 000 to 4,000 kg/ha on field of previous MP without application of nitrogen fertilizer (Osei-Bonsu and Buckles, 1993) exemplifies instances when yields are higher than realised in this study. The relatively higher yields reported elsewhere could be attributed to supplementary N-fertiliser application, cropping maize on pure rotational basis in which case there was no competition of maize with intercrops.

In particular, the experimental site at Wenchi was not nutrient-depleted unlike surrounding farmers' fields judging from the maize grain yield of 1 500 kg/ha for the control and up to 2 500 kg/ha legume intercrops. The fairly high yields could be attributed partly to the good agronomic management under the control of researchers. The response of maize to N in the over crop biomass as the experimental site initially contained a good level of extractable P of 13.82 mg kg^{-1} and K of 54.68 mg kg^{-1}.

In 2001 maize stover yields were not significantly different within species of cover. However, maize/SG plot resulted in the higher maize stover yield than any other maize/legume treatments. This suggests that maize/ SG intercrop could yield high maize stover/residue materials that could be ploughed into the soil to improve soil conditions for sustainable crop production. Maize stover yield was significant between planting dates of legume cover crops ($P < 0 .05$). Strangling of maize by the viney legume species resulted in drastic reduction in stover yield. The aggressive intertwining and subsequent lodging of maize stalk by these cover crops reducing maize stover yield and created difficulty in harvesting of maize as ears were buried in legume vines. However, these problems can be minimized through further manipulation of relative planting date and density. Planting date of herbaceous legumes as relay-intercrops had a significant effect on maize stover yield in the second year when the same plots were re-cropped with maize. Ranking of the yields of maize stover between plots of the two planting dates and the control of sole maize in 2002 indicates that under-sowing maize with legumes eventually leads to increase in maize stover yield. The cover crop residues that were left on the soil surface might have suppressed weeds by shading and cooling the soil.

4.5.3 Performance of fallow legume species

Legume growth performance was significantly different at different planting dates of the fallow legume species. Better and faster legume establishment occurred when the cover crops were sown at 4 than at 8 WAS of maize. The characteristically conducive weather of the month of June, particularly rainfall, favourably affected legume growth and development. When seeding of legumes was done at 8 WAS of maize their ability to spread and cover the ground was probably adversely affected by moisture stress of July/August. This experience tends to be supported by results of other studies (e.g. Mohammed-Saleem, 1985; Fosu, 1999; Anthofer and Kroschel, 2000). Planting legumes in June fits better for biomass accumulation. The highest precipitation, which is being observed in the study area, makes the planting less risk prone and enables the establishment of a good root system ahead of the dry spell in August.

When Mucuna was sown in maize plots for off-season fodder production with the objective of identifying the most appropriate time in the Sudan zone in Northern Benin the last two weeks of August proved best (Sinsin and Holvoet, 1999). Earlier sowing dates (June/July as was in the case of this study) accounted for the premature legume biomass losses recorded under the form of litter in the fields or a few days after the rainy season in October. The highest aboveground Mucuna, biomass noted (11 kg/ha of dry matter) corresponds to July planting as against 5 kg/ha for planting in the second half of August.

Biomass production is the key to producing plant residues and plant residues are the key to improving both short and long-term benefits to the soil (Huxley, 1999). Legume biomass accumulation was linear to planting date and density. The highest DM yield from a plant population density of 12 500 plants/ha could be attributed to relatively wider spacing which favoured vigorous and lush growth of the legumes. Too dense planting tends to bring about competition among plants for light, nutrients, water and space, consequently affecting crop yield. As individual plants of a single cover crop are grown closer together the size of each plant becomes smaller, but, starting with plots well spaced apart, the yield per unit area will increase (Huxley, 1999). Legume aboveground biomass declines when planting density is increased (Cannell, 1983).

The use of fallow legume species for fallow management is advocated because of their capabilities to fix nitrogen (Fosu, 1999). *M. pruriens* was able to fix 8,807 kg ha^{-1} *S. guianensis* 4.071 kg ha^{-1}, *P. phaseolodies* 3.081 kg ha^{-1} and *L. purpureus* 3.018 kg ha^{-1} short fallow with trailing is erect legumes can furnish 5 to 6 kg ha^{-1} dry matter in one year in the Guinea Savanna Zone (Tarawali 1994 a b) but not in a relay-inter crop where food crop can be produced at the same time.

M. pruriens is a fast growing cover crop which can produce more than 10 kg/ha of dry matter in the humid zone but usually less than 5 kg ha^{-1} in the semi-arid zone (Carsky and Ndikawa, 1998) because of the short growing season. *S. guianensis* can be introduced into crop mixtures in the year before a piece of land is left fallow. The understorey of *Stylosanthes* increases the nutritional value and quantity of the succeeding crop residue and improves soil fertility faster than a natural fallow (Mohammed-Saleem, 1985). *P. phaseoloides* is a vigorous climbing hairy perennial legume whose effective ground coverage will conserve soil moisture as well as suppress weeds. *Pueraria* improves soil fertility through N fixation, nutrient cycling and the production of organic matter. *L. purpureus* is a short lived or annual legume and fixed the least nitrogen among all 4 species 3 kg/ha.

Generally Mucuna accumulated the most of the N P K and Mg *Stylosanthes* accumulated the highest Ca (2.6 kg ha^{-1}), which was almost the same as *Mucuna* (2.6 kg Ca ha^{-1}). Planting density impacted positively on dry matter outputs of all the four herbaceous fallow legume species, but more seeds are needed. Dry matter yields ranged between 150-190 kg ha^{-1} for the corresponding densities of between 12 500 to 50 000 plants/ha.

4.5.4 Cover crop dry matter and nutrient accumulation

Cover crop selection and management depend on several factors among them the cover crop's ability to accumulate dry matter and nutrients. Dry matter provides energy for soil organisms, contributes to soil organic matter, improves tilth and acts as a sink for nutrients. When inorganic soil N and other nutrients are accumulated by cover crops hey cannot leach to the groundwater with the rains. Legumes can convert atmospheric N, for example, to plant-available forms and can provide substantial amounts of N to the following crops (Satell *et al.,* 1999).

Cover crop dry matter (i.e. residues) provide many benefits such as indicated above; however, it is not always desirable to maximize dry matter production as excessive residue can negatively affect field operations such as tillage; carbon: nitrogen (C:N) ratios and pest interactions. The ideal amount of dry matter depends, in part, upon the type of residue, the tillage system used and planting schedules and limitation of the subsequent crop.

Legume residues decompose quickly because they are relatively low C:N ratio; therefore, excessive dry matter accumulation generally is not a problem.

Cover crop N accumulation depends on the amount of dry matter and its percentage of N (Satell *et al.,* 1999). Accumulated N nearly always increases as dry matter increases. However, the percentage in dry matter varies considerably with cover crop type, stage of growth, and soil N content. Legumes take up more N than they need (luxury consumption) if soil N levels are high, thus increasing the percentage of N in the dry matter.

Sowing legume species at four weeks after emergence of maize gave a higher N percentage than at eight weeks. Though not significantly different from the later planting earlier planting in this study earlier planting could increase N accumulated by the start of the next rainy season. This tends to conform to work done by Brandi-Dohrn *et al.,* (1997) who reported N accumulation of cover crop that had been planted at different dates with the earlier planting date achieving better N accumulation. They further suggested that if N scavenging is an important goal, cover crop should be planted as early as possible. Generally cover crop vigour increases with earlier planting date as was the case in this study.

4.5.5 Weed suppression and cover crops

The impact of weeds on crop yield is of significance in agriculture the world over. Estimates suggest that globally up to 12% of all agriculture crops are lost to weeds although this may be as high as 25% in the tropics. Much energy and expense may be involved in controlling weeds and if allowed to proliferate, weeds can make agriculture altogether unprofitable (Auld *et al.,* 1987).

Various methods are available to farmers to control weeds. These are grouped into physical, chemical, biological ecological and integrated methods. Resource poor farmers in the Forest- Savanna Transition Zone of Ghana tend to use physical and ecological methods. Physical methods, for example, may involve manual weeding of the plots cleared for cultivation or the use of fire whereas ecological method might rely on the use of plants to suppress weed development and to reduce weed seed viability by enforced dormancy over long period of time.

Weeding for many farmers may be one of the most laborious and time-consuming activities undertaken by farmers. Ruthenberg (1980) indicated that in Ghana weeding in a maize system required 31% of total labour, which are about 186 person-hours per hectare.

Although maize is a vigorous and tall growing plant it is susceptible to competition from weeds, with losses greater than 30% commonly reported (Rahman, 1985). The time from which maize yields are affected by weeds appears to be related to the time when weeds attain 100% ground cover. Weeds left completely uncontrolled for four weeks after emergence can significantly reduce crop yield (James *et al.,* 2000).

DFID's research on the Forest/Agriculture Interface has tended to focus on weed suppression with cover crops. Weed suppression is one of the most important contributions legume cover crops can provide for cropping systems particularly in maize/legume cover crop relay intercropping. The degree of weed control provided by cover crops can vary according to cover crop species, residue quality and weed species. Research has demonstrated that weed suppression by cover crop residue increases with increasing residue quantity; natural levels of typical cover crop residue can be expected to reduce weed emergence by 75 to 90%. It has also demonstrated that residues with large number of layers and amount of empty internal space will be most suppressive, and annual weed species that are small-seeded such as *Tridax procumbens* and *Boerhania diffusa* (pig weed) are sensitive to surface residue whereas large-seeded annual and perennial weeds are relatively insensitive.

Practical application of these results tend to suggest that the best weed control can be achieved by using cover crops that produce high amounts of biomass and/or do not decompose rapidly. Generally cover crop residue can be expected to provide early- season weed suppression but not full-season control. As a result early weed suppression provided by cover crop residue should permit crops to be established before weeds.

Used as living mulches cover crops can suppress weeds if they are well established before emergence of weeds and maintain uniform coverage of the soil; that is, if they become occupants of niche normally occupied by weeds. In almost every case where the legume cover crops functioning as living mulches are competitive enough to successfully displace weeds, they are competitive enough to reduce crop growth and yield as well.

Carsky *et al.,* (1988) and Osei-Bonsu and Buckles, (1993) have cautioned that MP intercropping, especially with a tall crop such as maize, often results in MP growing upwards as it climbs on the companion thus having less contact with the ground and exerting less positive effect as a cover crop and may have a negative effect on associated cereal crop. Three out of the four cover crops in this study, namely LP, PP and MP have the potential to climb companion crop and, when they do, are likely to allow high weed incidence inter- than intra-maize row space. It would appear that the findings of this study support the conclusions of these authors that the problems related to intercropping can be avoided or at least minimized through manipulation of relative planting dates and densities.

Cover crops are important in many different farming operations. In Ghana, particularly in the Forest-Savanna Transition Zone, NRI/MOFA (2000) found, in on-farm trials, that farmers noted and appreciated the ability MP and *Canavalia ensiformis* to suppress weeds.

Mucuna produced the highest biomass quickly and established canopy (spread). This growth habit enables the legume to smother weeds best among all four species. Both legume cover crop species were found to grow rapidly and to spread, thereby suppressing weed growth; a case the finding of this study tends to confirm.

Mucuna controlled weeds better than the control plot and plots treated with Lablab, Pueraria and Stylosanthes. Several work done in Ghana and also elsewhere (Osei-Bonsu and Buckles, 1993; Galiba, 1994; Anthofer and Kroschel, 2000; Tarawali *et al.,*1991) indicate that mucuna is one of the most promising fallow species for soil improvement and weed suppression. Its growth habit is such that it tends to spread out and cover every open space and, therefore, smothers weeds rather quickly. These attributes extend to the other cover crops particularly those investigated in th0is study, namely PP, LP and SG.

4.6 Conclusions

This trial revealed firstly, that, a maize/herbaceous fallow legume cover crop relay intercropping is capable of improving the performance of subsequent maize in the FFSTZ of Ghana. While MP, SG, LP and PP cover crops contribute N to maize it was clear from the growth performance of maize that seeding time (date) and legume cover crop density of these legumes were critical. Maize/fallow legume cover crop relaying is an attractive option for arresting soil degradation, suppressing weeds and increasing maize yield, which is a pre-requisite for sustainable food production.

This inference emanates from the two years of maize/legume relay-intercropping experimentation with maize growth performance, stover and grain yields increasing significantly following appropriate legume planting date and density. Under-sowing maize with legume cover crops after 8 weeks as against 4 weeks of maize emergence and allowing 25 000 cover plants to the hectare positively affected maize grain yield.

For the purpose of increased maize grain yield, improved soil conditions and weed suppression for sustainable maize crop production, LP is the best treatment followed by SG, MP and PP in the intercropping year based on this study. LP in the intercropping stage appears to compare with PP better than with MP in growth rate and ground coverage – an attribute that tends to allow less competition with the companion crop. However, after fallowing the land with legume cover crop species, maize/MP treatment gives the highest maize grain yield followed by SG, LP and PP. Maize/MP treated plot performing best in terms of plot cover, fresh biomass and DM production, and weed suppression in the second year of the experiment produced he second highest maize grain yield. In addition, MP had the highest contents in the following nutrients: N P K and Mg and placed second to SG in Ca content.

MP provides good under-storey ground cover for crops such as maize and is able to conserve soil moisture for use by the maize crop, improve microbial activity within the root zone of crops and contributes to soil organic matter and nitrogen through decomposition of plant materials and nodulating potential of the fallow legume species.

SG and PP are relatively slow growing but persist in the dry season while MP and LP had to complete their lifespan in one cropping season and regenerate through self-seeding at the start of the rains. Because as a leguminous plant SG persists in the dry season and the associated *Rhizobia* can fix nitrogen, it accumulates biomass comparable to MP and hence in this study maize/SG treatment places second in maize grain yield as a fallow species. PP is a slower grower than any one species of the fallow legume cover crop candidates. It is, therefore, not able to spread and provide as much ground cover, weed suppression as LP and MP is better than SG.

Planting fallow legume species at 4 weeks after maize emergence has the advantage of better spread, ground cover and weed suppression than at 8 weeks but has the disadvantage of interspecific competition (between legume and companion crop). Cover crop planting densities tend to have both intra- and interspecific competitions (among cover crops and between cover crop and companion crop) accounting for the less favourable influence on maize performance with densities above 25 000 plants ha^{-1}. Optimum density depends on purpose of cover cropping whether for biomass production or for weed suppression. Fallow legume species aboveground biomass influenced growth performance, stover yield and grain yield of maize. Planting of legume at 4 WAS of maize produced a dry matter yield of 175 kg ha^{-1} while at 8 WAS it produced 1512 kg ha^{-1}.

Maize stover yield was adversely affected by viney and climbing species. However this did not significantly reduce grain yield of maize. Early (4 WAS) planting of legumes favoured early canopy establishment and plot cover by legumes thus choking weeds out. In subsequent year maize grain yields were increased by between 90 and 700 % following the maize- fallow legume relay intercropping.

5. THE EFFECT OF ORGANIC AND INORGANIC PHOSPHORUS FERTILISER APPLICATIONS IN LEGUME FALLOW SPECIES AND THEIR COMBINED EFFECT ON WEEDS AND MAIZE

5.1 Introduction and Justification

Nutrient balance studies indicate that soils in small, food-crop-based landholdings in the tropics are frequently losing fertility as a result of greater export than import of nutrients (Buresh and Sinclair, 1999). Losses of phosphorus (P) can be particularly detrimental to plant growth because many tropical soils are inherently low in plant available P and there is no biological process comparable to nitrogen fixation by P added to the soil.

Studies in Africa have shown that P is important for cereal nutrition, yet few (e.g. Smaling *et al.,* 1992) report the obvious, that response to fertiliser depends on P levels. Fairhurst *et al.,* (1999) indicated that P deficiency remains a major constraint in rain fed upland farming systems throughout the tropics. They further explained that P deficiency results in reduced plant growth, delayed crop maturity, and reduced quality and quantity of crop yield.

The movement of crop products across national and continental boundaries and within nations has driven the depletion of soil P reserves in all tropical regions (Beaton *et al.,* 1995; Cooke, 1986). Present annual exports of cocoa beans from Ghana to Europe and North America result in an outward transfer of 1350 t P/yr, whilst annual P fertiliser consumption for the country is about 1760 t P yr^{-1}.

The recycling of P and other nutrients from urban centres is essential for the maintenance of national and global P cycles. However, much of the agricultural produce traded across national and international frontiers is consumed in the rapidly expanding centres of developing world, with very limited potential for the capture of residual P for re-use in agriculture.

With regards to movement of P in Fairhurst *et al.,* (1999) reported that most soils have some P sorption capacity and, therefore, most applied P remains within the zone of application. Except on very sandy soils with little or no sorption capacity, P contained in enriched surface horizons is exposed to loss by surface run-off unless protective soil conservation measures are used.

Soils in many parts of Africa and South America are inherently poor in phosphate (P) and this is a severe constraint to agricultural production, especially since most small farmers cannot afford to produce phosphate fertiliser. A further problem affecting many tropical soils is the phenomenon known as P fixation: a large proportion of added P rapidly becomes held on charged surfaces of soil minerals and is rendered unavailable to crops for many years. In this situation it is necessary to seek ways of increasing the plant availability of small quantity of P present or very small amount that may be added as fertiliser. Adding fresh organic matter, such as crop residues, to soil increases microbial activity.

Soil P is insufficient in most agricultural systems in tropics and P must be provided as an external input (World Bank, 1994; Buresh *et al.,* 1997). Nutrient balance studies, such as those by Stoorvogel *et al.,* (1993), indicate alarming losses of nutrients from Sub-Saharan Africa including annual rates of 2.5 kg P ha^{-1}, which is equivalent to approximately 2 million t of RP over the 110 million ha of cropped land included in the study. Above all, phosphorus is the most important nutrient element after nitrogen most frequently deficient in soils in Africa (Kwabiah *et al.,* 2003) and a major limiting factor in maize production due to low native soil P and high P fixation by iron and aluminium oxides (Jones and Wild, 1975; Batiano *et al.,* 1986; Warren, 1992; Mokwunye *et al.,* 1996). Unlike N, P cannot be added to the soil by biological fixation. For many cropping systems in the tropics, therefore, application of P from organic and inorganic sources is essential to maximise and sustain high crop yield potential in continuous cultivation systems. Phosphorus deficiency problems could partially be relieved by incorporating high quality organic materials to the soil through relay intercropping and the use of locally and readily available rock phosphate.

Furthermore and notwithstanding low tissue concentrations and slow release of rock phosphate, some plant materials such as *Tithonia diversifolia,* have been shown to provide short term P balance and productive use by crops (Nziguheba *et al.,* 2000) while some organic inputs have been shown to increase P availability in P fixing soils, thus expanding their potential to increase the availability of soil P beyond the amount contained in their tissues (Hue, 1991). *Tithonia diversifolia* produces large quantity of biomass which is not fully utilised and which can be harvested and used as mulch in order to provide nutrients particularly P to crops.

In addition incubating (or composting) rock phosphate with plant material before application to crops has been suggested to be able to increase P availability (Tian and Kolawole, 1999). The combination of *Tithonia* biomass with rock phosphate has been shown to be effective (Nziguheba *et al.,* 2002) When *Tithonia* leaves decompose in the soil, soluble carbon and nutrients are released to the soil, which in turn enhance P cycling and conversion of mineral forms of P into organic P forms (Nziguheba *et al.,* 1998)

Evidence from various parts of Africa indicates that growing maize after legumes with added RP will increase yield and organic matter in soils (IITA 1999 in Van Straaten 2002). *Mucuna* and other fallow legume species can immediately benefit from RP, but as they have only limited economic values (at least for now); these benefits are meaningful if yields of subsequent maize are improved (Vanlauwe *et al.,* 2000). Legume maize rotations supplied with RP during legume phase and minimal amounts of inorganic N during the maize phase are good examples of promising soil fertility management techniques alleviating N and P deficiencies. To be able to supply information farmers need to meet soil P requirements both organic and inorganic P nutrient sources need be explored through controlled experiments as appropriate selection of organic materials as P sources will depend on an increased knowledge of the relationship between P availability and crop yield.

Low available soil phosphorus and weeds are the major factors responsible for low maize yields which hardly exceed 1000 kg ha, in much of the FFSTZ of Ghana Fertiliser trials on-station and on-farm frequently show large maize yields to phosphorus. Many resource-poor farmers cannot afford to purchase inorganic P fertilisers. An alternative seems to be the use of organic materials. Some research issues emanate from the above background regarding the utilisation of organic materials such as: (1) the need to evaluate *Tithonia diversifolia* to determine its effect on fallow legume species/cover crops and maize, (2) the need to determine the effect of organic versus inorganic sources of P and their integrated use – as integration becomes necessary because of the amount of materials needed to apply adequate quantity of P through organic is too large to obtain, be it on-farm or on-station – and (3) the potential benefits of organic on weeds. This study examined the effect of organic and inorganic P fertiliser applications in fallow legume species and their combined effect on maize yield in the FFSTZ of Ghana.

Hypotheses

1. Grain crops deplete soil P and this is exacerbated when legume species are used to increase N and, therefore, grain yield. Therefore, it is expected in fallow species rotations that grain crops are increasingly P rather than N limited and so there will be a large grain response to P fertilization in grain/fallow species rotations; attributable to the P itself and higher N-fixation by the cover crops.

2. Alternative P sources (rock phosphate and organic material) will release P at different rates causing differences in plant available P during the crop rotation and hence differences in maize yield, legume growth and N fixation.

3. Mixtures of organic material and rock phosphate (RP) may result in higher release rate of available P from RP because of release of organic acids in plant decomposition. Adding fresh organic materials to the soil will increase the cycling of P through labile pools of soil organic matter that are less prone to fixation and will gradually become available to crops. Fresh organic matter may also protect P from fixation on mineral surfaces by blocking sorption sites which would otherwise fix P from soil solution

4. Yield response to P fertilization will be linear up to a critical level so that it will be economically rational for farmers to apply to a threshold (although they may be constrained to lower application rates by availability of inputs or capital to produce them).

Objectives

1. To determine the effect of organic and inorganic phosphorus fertilizers on growth and biomass yield of legume fallow species.

2. To determine whether the effect of phosphorus nutrient source on growth and biomass yield differs among legume species.

3. To determine the combined effects of legume fallow species and phosphorus sources on the growth and yield of succeeding maize crop and weed dynamics.

5.2 Materials and methods

5.2.1 Experimental Design

The study was conducted on-station at Wenchi Agricultural Station in 2001 and repeated in 2002. The experimental design was a randomised complete block (RBCD) using split plot arrangement of treatment factors with four replications There were two main treatment factors and levels, namely, 1. P sources: (a) Rock phosphate (RP), (b) Organic material/*Tithonia diversifolia* Hemsley A Gray biomass (TB), (c) Rock phosphate + Tithonia Biomass (RP + TB) and (d) No Phosphate (NP) and 2. Legume species: (a) *Canavalia ensiformis* (CE), (b) *Mucuna cochinchinensis* (MC), (c) *Stylosanthes guianensis* (SG), and (d) Control (*Zea mays*).

These factors combined to give 16 treatments. The main-plot treatment was legume fallow species at four levels whereas subplot treatment factor was phosphorus nutrient source also at four levels. There was a sole maize control plot to receive the four levels of phosphorus nutrient source treatment factors**.** It has been suggested by Sanchez *et al.,* (1996) that a single layer application of RP which slowly releases available P may saturate sites and be sufficient to supply crops with adequate P for many years.
Therefore, RP (applied at 30 kg P.ha^{-1}) was placed in furrows 10 cm deep; and 10 cm away on one side of the legume plant stand and covered with soil before sowing the legume fallow species at 4 weeks after sowing (WAS) the maize. The organic material (*Tithonia* biomass) was surface-applied and in the fresh/green state. The *Tithonia* was from one identified source and suitability assessed in the University of Wales, Bangor to determine the P content and dry matter yield prior to harvesting as cut and carry or biomass transfer to Wenchi from a locally abundant source — wasteland. Some important considerations in assessing the suitability of *Tithonia* for the study were availability, high total P content, and sufficiency of supply. The quantity of dry matter to apply was based on the estimated P content of *Tithonia*

diversifolia mulch (0.18%)and 13 tonnes of fresh material would correspond to 30 kg P ha which was equivalent to the quantity of inorganic P applied.

Measurement made were ground cover of legume fallow species, plant spread (length of vine), height, leafiness, vigour and presence of insects (chewing and sucking) on fallow species. Other parameters also taken include leaf drop, date of 50% flowering, date of 50% podding, biomass yield and nutrient content of fallow species. The IITA (International Institute of Tropical Agriculture) plant assessment form was used to record data on legume fallow species.

In addition, height of maize plants at 4 and 8 WAS and also at physiological maturity, grain yield, stover yield of maize crop were measured. Weed biomass was assessed to determine how effective each treatment was in weed control in 2002 only.

5.2.2 Trial establishment

Land was ploughed with tractor using a disc plough. Lack of adequate moisture delayed seeding and therefore weeds mainly (*Cyperus rotundus*/sedge), which had emerged, were killed with 'Round-up' herbicide prior to planting of maize. The 54 m X 34 m total trial plot was demarcated, pegged and lined by researchers and maize (*Zea mays* L.) variety: Abeleehi with maturity period of 120 days was planted in the first week of May in 2001 and 2002 when there was fair moisture in the soil. The fertiliser (RP) was applied before the legume species were sown in the second week of June in either year. Spacing for maize was 80 cm X 50 cm and the same for the legumes at two seeds and one seed per hill respectively in 2001 but was changed for legumes to 40 cm by 20 cm in 2002 following the poor legume performance firstly as a result of sparse plant population and secondly poor rainfall. The large seeded fallow legume species, namely *Canavalia ensiformis* and *Mucuna cochinchinensis* were sown while the small seeded *Stylosanthes guianensis* was drilled. Weeding of the experimental plot was done manually with the hoe.

Composite soil samples were taken from the experimental plot at 0-15 cm and subjected to laboratory analysis at Soil Research Institute at Kwadaso. On 19th September, 2002 one time assessment of legume standing biomass and surface litter were sampled, destructively assessed, with a quadrat, placed randomly on a plot 50 cm away from the end of the plot.

5.2.3 Statistical Analysis

The data were examined by ANOVA using the general linear model, and comparisons of treatment means were made by least significant difference (LSD) using Minitab Statistical Release 13.31 and/or GenStat Release 6.1 packages (Minitab Statistical Software, 2000).

5.3 Results

5.3.1 Soil characteristics

Results from the analysis of soil samples from Wenchi Agricultural Station are given in Table 5.1.

Table 5.1 a) Chemical b) physical properties of soil at Wenchi Agricultural Station, Ghana

a)

pH	Organic C (%)	Total N (%)	O.M. (%)	Exc. cations me/100 g				TEB	Exc. Acidity (Al + H)	CEC me/ 100 g	Base Sat. (%)	Available Bray's ppm P	K ppm
				Ca	Mg	K	Na						
6.4	1.13	0.1	1.9	7.4	1.4	0.3	0.1	9.1	0.1	9.24	98.9	5.86	117

b)

Mechanical Analysis			**Texture**
Sand (%)	Silt (%)	Clay (%)	
71	19	10	Sandy loam

5.3.2 Maize performance

In the first year (2001) relay-intercropping maize with *Mucuna*, *Canavalia* and *Stylosanthes* significantly reduced maize grain and stover yields but not maize plant height, while the application of rock phosphate and/or *Tithonia* biomass did not significantly increase maize performance probably due to competition for resource and the minor rainy season dry spell (Table 5.2) Growth performance of maize for height was not significantly different among treatments. Mucuna + RP plot produced the tallest plant of 197 cm at physiological maturity. This was followed by maize +TB plot 193 cm, and *Canavalia* plot without RP and TB 189 cm (Table 5.1). The least height of 159 cm was recorded on *Canavalia* + TB + RP plot when legumes were relay-intercropped. Grain yield was highest on Stylo + RP plot followed by Mucuna only plot and Maize only plot with respectively 3369, 3129 and 3001 kg ha^{-1} while the lowest yield was on Stylo + TB + RP plot (1673 kg ha^{-1}). Following are Mucuna + TB + RP plot with 1781 kg ha^{-1} and Maize + RP plot with 1792 kg ha^{-1}. Maize grain yields appeared not to be related to P application as neither mineral nor organic P influenced yield (Table 5.2). Mucuna + TB plot produced the largest amount of maize stover yield of 3517 kg ha^{-1}. Mucuna only plot and Mucuna + RP produced 3325 and 3200 kg ha^{-1}of stover yield respectively.

Table 5.2 Maize plant height at physiological maturity, grain yield and stover yield and organic and inorganic P relay intercropping at Wenchi in 2001

Treatment	Height		Grain yield		Stover yield	
	(cm)		(kg ha^{-1})		(kg ha^{-1})	
	Mean	s.e.	Mean	s.e.	Mean	s.e.
Canavalia + RP	195	68	2792	92	2750	179
Canavalia + TD	186	12	2931	496	2675	602
Canavalia+TD+RP	159	16	1971	631	1788	417
Canavalia only	189	17	1829	391	2125	379
Mucuna + RP	197	5	2649	297	3200	688
Mucuna + TD	171	2	1781	221	1988	406
Mucuna + TD + RP	173	4	2832	150	3517	495
Mucuna only	178	8	3129	260	3325	572
Stylo + RP	181	4	3369	160	2775	174
Stylo + TD	166	19	2196	787	2438	807
Stylo + TD + RP	168	4	1673	176	1863	304
Stylo only	169	15	2417	360	2238	166
Maize + RP	179	15	1792	23	2563	896
Maize + TD	193	8	2738	98	2850	388
Maize + TD + RP	163	3	2935	175	2700	207
Maize only	173	1	3001	594	2913	291
Grand mean	**178**		**2496**		**2607**	
LSD (0.05)	286 ns		1064*		1064*	

LSD = Least significant difference; ns not significantly different at 5%; * significantly different at 5% level

In the following year, 2002, the trend in maize growth performance was not any better than the previous season. Relay-intercropping maize with all the three fallow legume species the previous year, surface placement of biomass of the legumes and *Tithonia*, and the application of RP that year repeating the procedure in 2002 did not significantly affect maize performances At 4 WAS of maize the highest heights were recorded as 69 cm, 68 cm and 67 cm from *Stylosanthes* + TB +RP plot, *Mucuna* + TB, and Maize + TB or *Canavalia* + TB plots respectively. The least maize heights were recorded from *Stylosanthes* only, Maize only and *Canavalia* + RP plots as 53 cm, 56 cm and 56 cm respectively. When the maize was 8 WAS, the time at which the legumes were sown, heights taken were 245 cm on *Mucuna* + RP plot, 233 cm on Mucuna + TB + RP plot and 222 cm on *Canavalia* + RP as the highest. The least heights were produced by *Canavalia* + TB + RP plot (182 cm); Maize + TB + RP plot (184 cm) and *Mucuna* only plot (191 cm). At physiological maturity another look at the maize height gave the following results: *Mucuna* + RP and *Mucuna* only plots produced the tallest maize plant of 246 cm followed by 229 cm from *Canavalia* + TB and 228 from *Stylosanthes* + TB plots. Grain yield was highest on Maize only plot as 3150 kg ha^{-1} followed by *Stylosanthes* only plot as 3050 kg ha^{-1} and *Canavalia* + RP plot as 2693 kg ha^{-1}. The treatments that produced the least grain yield of maize were Maize + RP (1513 kg ha^{-1}), *Stylosanthes* + TB (2113 kg ha^{-1}) and *Canavalia* + TB + RP (2163 kg ha^{-1}). Table 5.3 further indicates maize stover yields as *Stylosanthes* + RP plot, *Stylosanthes* + TB + RP plot and Stylosanthes only plot with respectively 4038, 3650 and 3200 kg ha^{-1}. The least stover yields were recorded on Mucuna + TB + RP plot as 1963 kg ha^{-1}, *Mucuna* + TB plot as 1988 kg ha^{-1} and *Mucuna* + RP plot as 2188 kg ha^{-1}. However, there were significant differences among treatments for fresh, maize stover yield. In overall terms, looking at the effects of maize/legume relay-intercropping only without Tithonia or rock phosphate on maize grain yield, Canavalia, Stylosanthes and Mucuna ranked first, second and third respectively behind sole maize (control). RP application resulted in higher maize grain yield but lower maize stover yield while *Tithonia diversifolia* biomass did the reverse by producing higher maize stover than grain yield. The control of no legume or no P fertiliser treatment was superior in both maize grain and stover yields.

Table 5.3 Growth performances of maize: height, stover yield and grain yields as affected by legumes with and without organic and inorganic P at Wenchi, Ghana in 2002

Treatment	Height of maize at			Yield	
	4 WAS (cm)	8 WAS (cm)	Physiological maturity (cm)	Grain (kg ha^{-1})	Stover (kg ha^{-1})
Canavalia + RP	56	222	227	2962	3613
Canavalia + TB	67	218	229	2862	3588
Canavalia + TB + RP	60	182	206	2162	3375
Canavalia only	61	221	220	2675	2275
Mucuna + RP	63	245	227	1513	2188
Mucuna + TB	68	212	220	2388	1988
Mucuna + TB + RP	65	233	246	2175	1963
Mucuna only	57	191	246	2325	2600
Stylo + RP	56	220	196	2962	4038
Stylo + TB	64	195	228	2112	3038
Stylo + TB + RP	69	194	207	2750	3650
Stylo only	53	206	210	3050	3200
Maize + RP	64	204	204	2562	2800
Maize + TB	67	200	220	2575	2738
Maize + TB + RP	59	184	211	2163	3375
Maize only	56	209	202	3150	3694
Grand mean	**62**	**208**	**217**	**2524**	**3007**
$LSD_{5\%}$	15	42 ns	27 ns	1301 ns	1122 *

WAS = weeks after sowing; RP = rock phosphate; TB = *Tithonia* biomass; * significantly different ($p < 0.001$); ns; Not significantly different at 5% level

5.3.3 Legume growth performance

In September 2002 the fallow legumes were evaluated for spread and ground cover. The mean spread and percent ground cover during the 2002 season is given in Table 5.4. There were significant differences ($p<0.001$) in *Mucuna* spread and ground cover between the relay with and without P and *Tithonia diversifolia* biomass among treatments. *Mucuna* + TB plot produced the most spread of 600 cm, *Mucuna* only plot 458 cm and *Mucuna* + RP 455 cm. The least spread was produced by all *Stylosanthes* plots ranging from 48 to 66 cm. Ground cover of *Mucuna cochinchinensis* by living parts was between 95 and 100 % indicating how vigorous it is. Ground cover was significantly higher in *Mucuna* than in either *Stylosanthes* or *Canavalia*. Both spread and plot cover were significantly different among plots and species ($P < 0.001$).

Table 5.4 Fallow legume spread and ground cover effects of phosphorus treatments on three herbaceous species at the Wenchi Agricultural Station, Ghana in 2002.

Treatment	Spread (cm)		Ground cover (%)	
	Mean	s.e.	Mean	s.e.
Canavalia + RP	244	238	71	32
Canavalia + TD	244	88	70	7.1
Canavalia + TD + RP	224	339	74	4.7
Canavalia only	227	368	60	4.1
Mucuna + RP	455	323	100	0
Mucuna + TD	600	110	95	5.0
Mucuna + TD + RP	445	719	100	0
Mucuna only	458	243	100	0
Stylo + RP	66	11.1	12.5	5.9
Stylo + TD	44	8.9	7.8	3.0
Stylo + TD + RP	57	9.6	22	11.3
Stylo only	48	11.4	5.5	1.7
Grand mean	**258**		**60**	
$LSD_{5\%}$	120 *		13.9 *	

* = significantly different ($P < 0.001$)

5.3.4 Legume biomass accumulation, weed biomass and weed control

The mean dry matter production of the three fallow legume species during second year of the experiment is given in Table 5.5. There were significant differences ($P = 0.05$) in dry matter yield among species between relay-intercrops with or without RP and with or without *Tithonia,* implying that sources of P fertilisers had an effect on dry matter production of the fallow legume species. Canavalia only treatment produced the highest yield of dry matter of 8451 kg ha^{-1} followed by Canavalia with *Tithonia* biomass and rock phosphate producing 8478 kg ha^{-1} and Mucuna + TD (7541 kg ha^{-1}). The least dry matter yields were produced by *Stylosanthes* only (731 kg ha^{-1}), Stylo + RP 854 kg ha^{-1} and Stylosanthes + TD (1111 kg ha^{-1}).

Proportions of weed dry matter from each plot were as follows: Maize + TD > *Stylosanthes* + TD > *Stylosanthes* + RP > Maize + TD + RP > Maize + RP > Maize only > *Stylosanthes* only > *Stylosanthes* + TB + RP > Canavalia + RP > Canavalia only > Canavalia + TD > Canavalia + TD + RP > Maize + RP > Mucuna + RP = Mucuna + TD + RP = Mucuna only (Table 5.5). In the reverse order Mucuna plots controlled the most weeds followed by Canavalia plots, *Stylosanthes* plots and then Maize only plots. Legume dry matter was significantly different among treatment ($p<0.05$). Weed dry matter yield was also statistically significant among all treatments ($p<0.05$). The control plot of no legume, *no Tithonia diversifolia* biomass and no rock phosphate were the weediest while maize/Mucuna plots were the least weedy. Three out of the four of *Mucuna cochinchinensis* plots completely eliminated weeds with most plots being 100% weed free.

Table 5.5 Fallow legume and weed dry matter yields following P treatments on three legume species at Wenchi Agricultural Station, Ghana in 2002

Treatment	Dry matter yield (kg ha^{-1})			
	Fallow legume		Weed	
	Mean	s.e.	Mean	s.e.
Canavalia + RP	4340	476	2561	417
Canavalia + TD	4112	1210	1983	678
Canavalia + TD + RP	8478	1277	1373	602
Canavalia only	8541	554	2270	561
Mucuna + RP	6452	305	760	760
Mucuna + TD	7541	1106	0	0
Mucuna + TD + RP	7290	1131	0	0
Mucuna only	6542	617	0	0
Stylo + RP	854	355	3613	537
Stylo + TD	1111	559	3720	919
Stylo + TD + RP	1352	582	2609	241
Stylo only	731	253	2920	510
Maize + RP			2981	280
Maize + TD			4260	666
Maize + TD + RP			3480	317
Maize only			2966	348
$LSD_{5\%}$	1964		1398	

WAS, RP, and TD stand respectively for weeks after sowing, rock phosphate and *Tithonia diversifolia*

5.4 Discussion

5.4.1 Soil characteristics

Analysis of soil from the experimental plot prior to establishment clearly indicates that phosphorus probably is not a lacking nutrient and this tends to nullify the hypothesis that grain crops e.g. maize and legumes are increasingly P limited as far as this study is concerned.. The soil pH is 6.4, a level that hardly restricts soil P availability and the P content of the soil is 118 ppm a P level that clearly suggests that P is not limiting even though the experiment did not examine P availability/uptake in the soil or by the fallow legumes or maize crop. Available P levels of around 15 ppm is considered desirable for a cereal crop (Evans, 2003) on dry land mixed farms in Australia and 2.5 mg g^{-1} is the critical p value in Ghana below which point net immobilisation in the soil expected (Janssen, 1993)

5.4.1 Maize performance

Notwithstanding the poor rainfall distribution pattern in 2001 (the minor season rainy season dry spell) maize growth performance from maize/legume plots was generally better than sole maize without any significant influence by source of P. However, the significant differences in maize grain and stover yields among treatments could hardly be attributed to nutrient source nor the presence of legume cover crops as the highest grain yields came from *Stylosanthes* +RP, *Mucuna* only and Maize only plots. Legume cover crop treated plots produced the highest stover yields indicating positive effects of these N fixing species. In intercropping companion maize crops have been found not to benefit directly from relay intercropped legumes (Jeranyama *et al.,* 1998). In contrast the 2001 maize crops seemed to have had advantage in this intercropping system a finding that appears to be in line with those of West and Griffiths (1997), Ghaffarzadeh *et al.,* (1994) and Ayisi *et al.,,* (1997) when maize was intercropped with soybean.

A second season (2002) cropping received better rainfall but increase in maize performances was negligible except the presence of legume species, *Tithonia diversifolia* biomass (TB) and application of RP increased maize stover yield. A possible reason for not realising marked increase in maize performance is the mode of application of plant material. TB was surface placed. Decomposition rates have been reported to be higher for incorporation than for surface placement of plant material (Kayuki and Wortmann, 2001). Even though placement could not have affected maize as decomposition rates would have been similar for all plants materials with the same placement method, time lapse could, thus late decomposition as a result of late application could not benefit maize. Attempting to enhance the value of plant materials by balancing nutrient supply with rock phosphate appeared not to work out well as it is a slow releaser of nutrient coupled with the delay in decomposition of plant materials as a result of late application. High quality organic materials such as *Tithonia* biomass can increase maize production to a greater extent than mineral fertiliser (Nziguheba *et al.,* 2002).

Due to the laborious and time consuming nature of biomass transfer the Tithonia biomass was finally applied at 3 kg P ha^{-1} as against the 30 kg P ha^{-1} previously planned. This could be the reason for the low response of the test crop. Another possible reason is the fact that pH of the soil is 6.4 (Table 5.1) a value that falls near the range 6.5-7.0 where P availability is greatest (Penas and Sander, 1993) implying that the soil was not P-deficient.

5.4.3 Organic materials as sources of phosphorus

The availability of P soil is strongly influenced by the quality of added plant material. The addition or cycling of plant material with a P concentration < 2.4 g kg^{-1} results in net immobilisation of P by soil microbes and a decrease in plant, available P in soil (Palm *et al.,* 1999). This could account for the low response of maize and fallow legume species in this study as the Tithonia material that was added had a concentration of 1.8 g kg^{-1}. Green biomass of *Tithonia diversifolia* has been identified as a useful source of nutrient to maize (*Zea mays* L.) in western Kenya (Gachengo *et al.,* 1999). *Tithonia* tissue concentrations of phosphorus (P) and potassium (K) are higher than found in commonly grown legumes (Palm, 1995). Along with other criteria, the high tissue P concentration of *Tithonia diversifolia* makes it an effective source of plant-available P (Nziguheba *et al.,* 1998). The leaf tissue P concentration is greater than the critical threshold (Niang *et al.,* 1996; Nziguheba *et al.,* 1998) meaning that the addition of biomass to soil results in net mineralization (Blair and Boland, 1978; Palm *et al.,*1997 Palm *et al.,* 1999). It was further observed that *Tithonia diversifolia* green manure doubled maize yields compared to control or no P added plots. In contrast, this was not case in this experiment as the TB treated plots produced the least maize grain yield in the first year. This was probably due to the relatively smaller amount of TB applied as a result of bulkiness and arduous nature of cut-and carry or biomass transfer. The available source of Tithonia bush (or stand) from which assessed samples had been taken were some 70 kilometres away in Sunyani. This clearly indicates how arduous it is to supply organic materials off-farm.

5.4.4. Rock phosphate and plant response

The most logical approach to attaining the goal of building the fertility of tropical African soils to levels never before attained is to increase the phosphorus capital in the soils as about 80% of these soils have inadequate amounts of this critical nutrient element (Mokwunye, 2003). Both organic and inorganic sources of P can be explored to achieve this. These sources have one quality: ability to continue to supply P to crops beyond the initial year of application but rock phosphate residual effectiveness is a significant property which enables it to be used for long-term improvement of productive capacity of soils. Mokwunye (2003) has suggested that the use of local RP as an investment in the natural resource base is not a cure-all and that it is worthless unless the RP is highly active.

The RP used in this experiment comes from Togo (Hahotoe) and is low carbonate- substituted and has low specific surface area of 7.1 m^2 g^{-1} (Truong and Montange, 1998) making it inferior to the highly carbonate-substituted, high specific surface area Tilemsi RP from Mali, for example, in agronomic effectiveness. One way to increase the surface area as suggested by van Straaten (2002) is by grinding, which creates fresh surfaces that positively affect solubilities. In addition, the chemical reactivity or solubility (a measure of the RP's ability to release P for plant uptake) of the Hahotoe RP from Togo has a unit-cell a- value (Å) of 9.354 while that of Tilemsi RP is 9.331. There is a clear relationship between carbonate substitution and unit-cell a-values in sedimentary francolites and solubility: The lower the unit-cell a-value the higher the "reactivity" and solubility. What is not clear is the processes the RP used in the experiment went through.

The application of green manure is practised by incorporating organic matter directly in the soil without to increase RP dissolution. van Straaten (2002) has reported that in western Kenya reactive Minjingu RP from Tanzania and unreactive Busumbu RP from Uganda was incorporated into the soil along with various green manures and that the system is very complex and so are the results. However, field results from that part of the world indicating increased yield when combining Minjingu RP with *T. diversifolia* biomass have been reported by Sanchez *et al.,* (1997) and Nziguheba (2001). One of the explanations for the increased agronomic effectiveness of RP plus *T. diversifolia* is related to the role of organic anions that compete with phosphate ions for adsorption sites in the sols (Nziguheba, 2001). It is, therefore, most likely that green manure of *M.cochinchinensis*, *C. ensiformis* and *S. guianensis* plus RP are suitable as a preceding treatment for maize.

5.4.5 Fallow legume/cover crop species ground coverage, biomass accumulation and weed suppression

Except for *Stylosanthes guianensis* which, due to late planting, mid-July, 2002, arising out of late seed arrival, thus giving consistently less ground cover than Mucuna and Canavalia, the fallow legumes performed very well by way of spreading and ground coverage. *M. cochinchinensis* seemed to benefit most from addition of TB and/or RP. Both sources of P appear to influence legume performances positively as ground coverage ranged from 60-100% even though and spread. The use of cover crops is a potential way of suppressing weeds. Ideally, cover crops used for weed suppression need to grow quickly, and provide spatial coverage.

Mucuna dry matter accumulation has been reported the world over. Dry matter is accumulated at rates of 4900-8500 kg ha^{-1} in Brazil (Lathwell, 1990) and Nigeria (Sanginga *et al.,* 1996); 6000-8000 kg ha^{-1} in Cameroon (Klein, 1994) and 7000-12000 kg ha^{-1} in Honduras (Triomphe, 1996). In this on-station trial, the Mucuna dry matter was 6500-7500 kg ha^{-1} following the application of organic and inorganic P. C ensiformis accumulated 4100-8500 kg ha^{-1} whereas S. guianensis accumulated 700-1400 kg ha^{-1}.

Weeds flourish on bare soil. Cover crops take up space and light, thereby shading the soil, and reducing the opportunity for weeds to establish themselves. *M. cochinchinensis.* Treated plots achieved this by producing a lot of biomass and smothering weeds. Generally, the fallow legumes except *S. guianensis* choked out weeds.

5.5 Conclusion and recommendations

This testing on-station of legumes with and without phosphorus from rock phosphate and *Tithonia* biomass as companion crops did not statistically affect maize growth performance, grain and stover yields in the first year. A further season of experimentation indicated that organic and inorganic phosphorus fertilizers had no significant effect on maize grain yield. Applying P in the form of rock phosphate and *Tithonia diversifolia* biomass or their integration does not seem to be crucial for maize production in soils that are near neutral – pH 6.4. Both *Tithonia.diversifolia* biomass and rock phosphate treated legumes produced substantial of biomass. Legume spread and ground cover were also increased with the application of P from both sources. However, considering the constraints related to the availability of *Tithonia diversifolia* biomass and the need for biomass transfer and soil P replenishment, a higher rate of RP (than the 30 kg P ha^{-1} applied in these experiments) would be a more workable strategy. The goal here is to maximise the proportion of P that could be applied at higher rate of the locally available rock phosphate in the West African sub-region. Besides, a practical method to replenish soil P in soils is through integrating locally available organic resources with commercial P fertilisers or, even more practically, with rock phosphate in close proximity. Further work should be done to delve deeper into researching into labile P, N fixation, colonisation by arbuscular mycorrhiza fungi, fallow legume nodulation and the rhizosphere to enable a more complete investigation into the effect of organic and inorganic sources of P in cereal/legume systems.

6. GENERAL DISCUSSIONS AND CONCLUSIONS

6.1 The role of improved fallow systems in soil fertility replenishment and sustaining food crop productivity

The overall objectives of these studies were to evaluate residual fertilisers, agroforestry and herbaceous fallow legumes and cover crops, organic and inorganic sources of phosphorus and legume density and planting dates on soil fertility and maize crop performance. It was hypothesised that smallholder resource-poor farmers would prefer improved fallows, use organic amendments, incorporate rock phosphate and integrate legume cover crops in their farming systems to benefit food crop, particularly maize, productivity through weed suppression soil nutrient recycling and restoration of lost soil fertility. On-farm and on-station trials were used to gain a better understanding of improved fallow management in a participatory manner.

6.2 Residual effects of organic and or inorganic manures on maize productivity

There were significant differences in maize growth (plant height) at the end of the fourth week after sowing maize on a plot previously treated with animal manures without mineral fertilisers. There were no significant differences among treatments at the end of the eighth week after sowing maize or at physiological maturity of maize. There were no significant differences in either grain or stover yield. Fertilisation with cattle manure increased maize grain up to 96% whereas the increase was 34% in mineral fertiliser only application. Fresh maize stover yield was also increased through the application of cattle manure by 27% and 10% by mineral fertiliser only. The nutrient contents of animal manures and other organic materials vary considerably. Quantification of residual plant nutrients derived from the various fertilisers and remaining in the soil after the tomato crop had been harvested could have given a better picture of the residual value.

6.3 Green manures from cover crops

None of the herbaceous species showed any residual value as a green manure. Except for height of maize at the end of the first month of growth being significantly affected, none of the other variables showed a significant effect. Sepcies of Crotalaria green manure increased maize plant height by 10% but failed to rank highest in both maize grain and stover yields. *Calopogonium mucunoides* and light mottled *Mucuna pruriens* ranked highest respectively in stover and grain yields of maize Increasing maize grain yield by 20% and stover yield 40% *Crotalaria juncea* and *Calopogonium mucunoides* respectively ranked highest. This is in contrast with the findings of Lathwell (1990) which indicated Crotalaria resulting in slightly less maize yield (5800 kg/ha) than Mucuna or Canavalia (6100 and 6300 kg/ha respectively).

A prominent finding of this study was that the control (no green manure) compared very well with the green manure plots, particularly at the seedling stage of maize. This could be explained by the fast decomposition of green manures soon after incorporation, thus releasing nutrients too soon to be of benefit to any subsequent crop (Yadvinder Singh *et al.;* 1992 Costa *et al;,* 1990, Janzen and McGinn, 1991). The possible release of organic acids or compounds that are detrimental to germination and maize seedling performance might have adversely affected the maize (Boddey *et al.,* 1997).

6.4 Sesbania green manures and maize productivity

Following reports by Boparai (1992) and more recently Yadav (2001) that Sesbania (species not specified) green manuring is effective in correcting iron deficiency and increasing SOM, maize was grown to evaluate the residual value of this genus. There was no significant difference between any of the five Sesbania species and the control on maize productivity. The residual manures of *Sebania* *aculeata* and *Sesbania bispinosa* ranked highest in positively affecting maize productivity (section 3). This is contrast with the findings of Manguiat *et al.,* (1989) who reported an 80% maize grain increase with *Sesbania rostrata*. *S. rostrata* has been proven to lose 80% of its N after 20 days of residue decomposition (McDonagh *et al.,*1995b) - an indication of rapid mineralisation of N. This could have accounted for the generally poor effect of Sesbania residual green manures in this study However, alleviating nutrient deficiencies, such as in the finding of McDonagh *et al.,* (1995a) where phosphorus, potassium and lime were added to *S. rostrata* resulted in tremendous (fivefold) increase in legume N recovered by rice. Soil nutrient mineralisation and crop uptake would have given a clearer idea of any greater potential in our study.

6.5 Potential contribution of woody and shrub legumes to soil fertility restoration

The four woody and shrub species, namely *Gliricidia sepium* (Jacquin) Steudel, *Flemingia macrophylla*, *Tephrosia candida* and *Cassia bicapaueris* evaluated in the study appear capable of restoring soil fertility in the FFSTZ of Ghana. There were significant differences among species in terms of growth performance and biomass production. Screening for fallow species biomass productivity may increase the utilisation of soil nutrient stocks in the soil and buffer against negative nutrient balances by increasing N inputs and soil capital N (Giller *et al.,* 1997). In increasing the productivity of biomass more emphasis should be placed on light capture and subsoil N capture so as to increase facilitation of resources. Lavin (1996); Asare *et al.,* (1984); Kadiata *et al.,* (1996); Gichuru (1991) and Oyen (1997) have all reported heights of these species to be favoured by favourable weather conditions.

6.6 Contribution of herbaceous legume cover crops to soil fertility restoration and weed control

The multiple benefits of legume cover crops play an important role in agronomic aspects such as SOM replenishment, nitrogen fixation, moisture conservation and weed suppression. Results of this study indicate that herbaceous fallow legume species are good candidates for the above functions in the FFTSZ of Ghana. Plant height, spread and ground coverage assessments showed that *Mucuna cochinchinensis*, *Lablab purpureus* and *Clitoria* and virtually all the others are capable of thriving very well in the zone and should be promoted and utilised as short-duration fallow species.

Gohl (1982), Eilittä *et al.,* (2003), and others have indicated attributes such as fast spreading ground coverage, drought tolerance (particularly, *Stylosanthes guianensis* for use as forage/fodder) and dry matter yield of various legume species similar to or same as those evaluated in this study. For example, *Chamaecrista rotundifolia*, from giving very good ground cover through biomass production, has good potential as material for a fodder bank. Peters *et al.,* (1994) reported 6 t ha^{-1} dry matter accumulations by *Aeschynomene histrix* in contrast to 4.2 kg ha^{-1} observed in this study. Even so *A. histrix* looks very promising as a fallow species. Species nodulation, nitrogen-fixation, mycorrhizal colonisation and N, P and soil characterisation at the end of the first two rainy seasons were not evaluated in this study. This could confirm or otherwise results so far achieved.

6.6 Biomass and nutrient accumulation

Fallow species were evaluated for biomass production. Initial assessments revealed that there were significant differences among species. How long a species thrives and how long it can maintain net primary productivity are attributes worth considering in screening species for fallows. Biomass production and nutrient accumulation varied according to whether a species was woody or herbaceous. Thus, *G. sepium*, *F. macrophylla*, *T. candida*, C *bicapaueris* and later *Senna siamea* (which replaced soybean in the second year due to pest attack and lack of seeds) are long-duration whereas the herbaceous species: *M. cochinchinensis L. purpureus, S. guianensis, S. hamata, P. phaseoloides, C. ternatea* and *C. pascuorum* are short duration fallow species.

Sources of P significantly affected legume performance. Biomass production by legume species that received neither *Tithonia* biomass nor rock phosphate was inferior to that of those fallow species treated with rock phosphate and Tithonia biomass. *M. cochinchinensis* produced large amounts of dry matter and accumulated N, P, K, Ca and Mg. The nutrient accumulation varied among species with total N of 4.3 kg ha^{-1} from M. *cochinchinensis* declining to less than 0.5 kg ha^{-1} in *C. pascuorum, C bicapaueris* and *F. macrophylla*. Comparisons of nutrient content of foliage of the fallow species with other published work showed that the levels of N, P, K, Ca and Mg in *M. cochinchinensis* and *Lablab purpureus* were lower than those reported by Sanginga *et al.,* (1996) and Vanlauwe *et al.,* (2000). Lack of sequential evaluation of the fallow legume species hindered more in-depth characterisation as most of the data collected were one-time. Wild fire that ran through parts of the experimental plot adversely affected species as some died back and others were killed.

6.7 On farm trials

Fielding and Riley (1997) suggested that agricultural research should not be limited to research stations but that investigations should be alongside farmers to give it a multidisciplinary approach. This way would make it participatory to provide more access to farmers for adequate monitoring and evaluation and ultimate adoption of appropriate technologies (Hoefsloot *et al.,* 1994; Buzzard 1989)

Our on-farm trials in the three villages in the Forest and Forest Savanna Transition Zone of Ghana, which rigorously sought the active involvement of farmers as co-researchers and co-extension workers, successfully created an environment for joint monitoring and evaluation (Annex C).

6.8 Maize/Legume relay intercropping

Maize growth performance grain and stover yields were not statistically different in all three villages in the first year. The subsequent maize crop was not significantly increased with the introduction of legumes the previous year. Even though some works corroborate this (e.g. Muza, 1998) the critique could be that low cover crop biomass production as a result of low legume density and poor rainfall the previous year did not result in residual effects. In the second year maize height at physiological maturity and stover yield were slightly higher on maize/legume plots than controls. Intercropping advantages have been reported by Marija (1990), Jeranyama *et al.,* (2000) and Rao and Mathuva (2000) but in this study this advantage was limited to only one village, Yabraso. The positive grain yield increase in this village in 2002 appears to be consistent with other reports that show impact on food crops yields (Costa *et al.,* 1990; van Noordwijk *et al.,* 1995; Triomphe, 1996). A more qualitative investigation could have been achieved by monitoring of BNF (with and without P) and determination of N release of cover crop residues and N balance following the use of cover crop residue in these contrasting agro-ecological zones.

6.9 Legume species and short fallows

Cover crops seem to show some success in addressing problems of soil fertility and weed control. Short-term fallows of herbaceous cover crops such *M. cochinchinesis Canavalia ensiformis*, *Lablab purpureus*, *Stylosanthes guianensis* and *Clitoria ternatea* can help increase food crop yields compared with continuous cropping, and weed densities can be reduced (Tarawali *et al.,* 1999; Ikuenobe and Anoliefo, 2003). Attributes were high legume cover crop agronomic performance manifested in spread, ground coverage, biomass production and nutrient accumulation. The presence of legume cover crops in maize/legume plots depressed weeds as higher weed infestation was generally observed in the control plots. Mucuna was significantly effective in weed control due to superior spread and ground cover by living plant parts. *Canavalia ensiformis,* though comparable to *Mucuna* in growth performance, was not as persistent. Notwithstanding this difference in agronomic performance farmers preferred Canavalia as a second choice after Mucuna for the edible grains. The traditional food uses of Canavalia in Ghana make it an option for farmers, perhaps better put in farmers' parlance, "killing two birds with one stone". In the FFSTZ Osei-Bonsu (pers. comm.) indicated that in a "food-first tradition" both species were familiar to farmers as grain legumes and had been recognised as such. This might have accounted for farmers opting for *Mucuna* and *Canavalia* in their choice of cover crops for testing, a livelihood issue!

6.10 Biomass transfer/ "fertiliser banks"

Tithonia diversifolia was utilised as off farm biomass transfer. The objective was initially to introduce this "scavenger" plant believed to accumulate phosphate and inorganic source of (organic) P. Logistic constraints restricted the potential to introduce it *in situ*, and it was therefore introduced as an organic material. The application of Tithonia did not significantly affect maize grain yield nor did it show any detectable influence on *Canavalia*, *Stylosanthes* and *Mucuna* growth. Instead of applying *T. diversifolia* biomass to supply 30 kg P ha^{-1} only a tenth of that amount (3 kg P ha^{-1}) was supplied. It was hypothesised that *T. diversifolia* as an organic material will facilitate release of P from such a slow P releaser as rock phosphate particularly one which was coming from Togo characterised by low specific surface area and low carbonate substitution (Truong and Montange, 1998).

The evidence so far suggests that biomass transfer technologies can help increase soil fertility and sustain or increase maize yields (Rao and Mathuva, 2000). However, for the technique to be successful, the quality biomass needs to be high, very large amounts of biomass are required to supply 'ideal' quantities to crops (Gachengo *et al.,* 1997), and labour for the collection, transportation, and incorporation of organic matter into the soil must be plentiful (Gachengo *et al.* 1997; Jama *et al.,* 1999).

6.11 Legume planting date and density

Relay intercropping maize with herbaceous grain legume cover crops may provide additional nutrients without sacrificing land for the legume. There may be reduced inter and intra-specific competition and/or facilitation of the maize crop if relay intercropping is adopted. There were significant differences among treatments in 2002 in maize that was planted on the same plots as 2001. Both maize stover yield and grain yield were increased following surface placement of legume biomass. The percentage increases were 10% and 28% respectively for stover and grain yields resulting from the use of the legume cover crops. Cover crop by planting density interaction showed significant difference among treatments for maize height, grain yield and stover yield. Maize growth performance, grain yield and stover yield were significantly affected by legume planting date in plots planted to legumes four weeks after maize emergence. This was anticipated as early relay intercropping favours better cover crop performance and consequently soil fertility replenishment. However, soil improvement and improvement in companion food crops are not usually visible until the second cropping cycle or second year. Cover crops must either continue to grow or form mulch during the dry season, and grazing animals, agricultural burning, termites, and a host of other problems may prevent their persistence during this period (Bunch, 2001).

Biomass production is related to planting date and density and one of the most common uses of cover crops is weed control. Both functions were enhanced through early planting (four weeks after planting maize) and optional densities (growing cover crops at 12500 plants per hectare). Legume biomass declines when planting density is increased (Cannell, 1983) and cover crop yield is jeopardised when planting is too dense (Huxley, 1999). This was elicited in this study as planting legumes four weeks after maize emergence produced 197 kg ha^{-1} dry matter compared with 151 kg ha^{-1} produced when legumes were relay intercropped four weeks later. Similarly 12 500 plants ha^{-1} planting density was superior to higher densities.

Nutrient concentrations were influenced by planting date as well as the density of legume cover crops. Early relay intercrops produced more N, P, K, Ca and Mg than late relay-intercrops. For example, Brandi-Dohrn *et al.,* (1997) reported N accumulation of cover crops planted at different dates with the earlier planting date giving higher N concentration than later planting date. These authors further suggested that cover crops should be planted as early as possible if N scavenging is the ultimate goal.

6.7 Conclusions

- Residual fertilisers/manures (animal manures in combination with mineral fertilisers or on their own, cover crop green manures and woody species green manures) did not significantly increase growth and yield of maize.

- *Mucuna cochinchinensis*, *Mucuna pruriens*, *Chamaecrista rotundifolia*, *Clitoria ternatea*, *Stylosanthes guianensis*, *Stylosanthes hamata*, *Pueraria phaseoloides* and *Lablab purpureus* accumulate large amounts of biomass and N, P, K, Ca and Mg which are of great importance in the low external input agriculture of the smallholder and resource-poor farmers in the Forest and Forest-Savanna Transition Zones of Ghana.

- *Gliricidia sepium*, *Flemingia macropyhlla*, *Tephrosia candida*, *Senna siamea* and *Cassia bicapueris* have potential for utilisation in improved fallows for soil fertility restoration.

- Application of phosphorus in the inorganic form as rock phosphate and organic form as Tithonia biomass or their combination is not crucial for maize production is soils where P is not limiting.

- Fallow legume species are favourably affected with the use of rock phosphate and Tithonia biomass transfer, but the latter has serious repercussions for farmers' livelihoods as the biomass technique is arduous due to bulkiness and high labour requirement and probably not cost-effective unless for crops with very high commercial value and which give high economic returns.

- Maize/herbaceous legume cover crop relay intercropping is an attractive option for arresting soil degradation, suppressing weeds and increasing maize productivity, all of which is a pre-requisite for sustainable food production.

- Mucuna and Canavalia are very good candidates for relay intercropping and confirm farmers' preference for these and other cover crops that have multiple uses. Their value as fallow legume species (as green manures and cover crop as human foods) seems to indicate adoption by farmers.

- Although the benefits of strategies to augment soil productivity were evaluated for only a short period and residual value could not be determined, the results point out that in farmers' current situation with limited resources, it is probably better to invest in soil fertility replenishment where farmers have jointly tested and found the benefits of technologies.

6.8 Recommendations

Based on these studies, and building on recommendations of previous studies in the FFTZ of Ghana, there is a need to encourage further research on the role of fallow legumes or legume cover crops in replenishing lost soil fertility, suppressing weeds and consequently increasing maize productivity. However, there is further need to determine the effectiveness of mixed improved fallow species by as this has been found to benefit food crops (Graham and Vance, 2003; Gathumbi *et al.,* 2003). Further studies should include:

1. Research on decomposition of organic materials and their residual value and N uptake by maize in contrasting agro ecological zones.

2. The fates of phosphorus in long duration fallows and year after year relay intercropping legumes and cereals.

3. Phosphorus BNF and AMF in the rhizosphere of green manuring and cover cropping.

4. Validation of soil organic matter build-up arising from various fallow systems.

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