Improving short fallows with legumes for soil fertility replenishments in the Papua New Guinea highlands

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Abstract

In the Papua New Guinea (PNG) highlands, fallow periods have been reduced from 20 years to less than 12 months due to increased population pressure on land use resulting in declined soil fertility. The shortened natural weed/grass fallow management is often not sufficient to restore soil fertility, leading over time to noticeable declines in crop yields. A replicated short fallow management trial using four herbaceous legume treatments against natural weed fallow practice as control was carried out from September 2004-October 2005 at NARI Highlands Regional Centre, Aiyura, to determine soil fertility replenishment between two cropping seasons. Maize *(Zea mays)* was used as an indicator crop. The mean marketable cob yields in the first season before imposing the treatments, ranged from 9.8-11.7 t/ha and was at par between treatments. However, significant differences were observed in dry matter biomass yields amongst the fallow treatments including control, ranging from 2.2- 7.2 t/ha after 20 weeks of fallow. The dry matter were used as mulch to plant the succeeding crop and its mean marketable cob yields almost tripled numerically compared to first season yields. Yields ranged from 30.1-31.7 t/ha for plots fallowed with legumes while 26.5t/ha for control. This preliminary study indicated the potential of incorporating legumes as short fallow crops in subsistence farming, not only to replenish soil fertility, but also for other uses such as weed control and food/feed for both humans and livestock.

Key words: Legumes, biomass, mulch, fallow periods, cropping seasons, natural grass/weed fallow, soil fertility and PNG highlands

1. Introduction

Long Casuarina tree fallow periods of over 20 years and rotations of traditional legumes such as wing beans (*Sophocarphus tetralongonobus*) with taro and yams to replenish soil fertility were the common practice in the rural PNG highlands for more than 5,000 years ago (Walker and Flenley, 1979). Such practices were applied to overcome the inherent soil fertility problems of volcanic ash soils dominated in this region and also to offset the lower soil pH levels that affects nutrient availability for plant uptake. These fallow periods have declined to >12 months of natural weed/grass fallows over the recent decades (Kirchhof, 2006; Taraken and Ratsch, 2009), while the short fallows at Kandep in the Enga Province has declined to an average of 8.2 months (Wohlt, 1986). This is due to population pressure on land use as the highlands region has a burgeoning population of over 2 million, which grows at an average rate of 3.7% annually compared to the national

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average growth rate of 2.7%. The shortened natural fallow management could not cater for such pressures as it is often not sufficient to restore soil fertility, leading over time to noticeable declines in crop yields. Brook (1992) suggested that although soil management techniques such as fallow management using legumes and crop rotations are indigenous to PNG, major improvements could still be made in the areas of soil fertility maintenance, soil erosion control and fallow managements leading to increased productivity per unit of land.

One of the means of improving the production and the productivities of soil and crops is to incorporate N-fixing legumes into the shortened fallow systems. The improved biomass available from this system can be used as mulch/compost to plant the succeeding crop. In relation to this hypothesis, Bourke (1975) evaluated 23 legumes with one non-legume specie at Keravat in the East New Britain Province. Their parameters such as growth rates, ground cover and competitiveness were measured and concluded that legumes in the humid lowland tropics were of little importance in maintaining soil fertility. However, in his trail, no crops were planted following the fallow periods to see what residual effects, if any, the legumes had had on soil fertility. In Honduras where the environmental conditions are similar to that of PNG, farmers plant velvet bean (*Mucuna pruriens*) as a fallow crop, which has doubled their maize grain yield of succeeding crops Reijntjes et al. (1992). This study was aimed at improving the short natural weed/grass fallow practices with legume crops for soil fertility replenishments and to improve the yields of succeeding crops, in the rural PNG highlands.

Therefore, the shortened natural grass/weed fallow (control) was tested against the legumes: Everlasting Bean (E. bean) (*Phaseolus spp*.), Peanut (*Arachis hypogaea*) Desmodium Silver Leaf (*Desmodium uncinatum*) and Cowpea (*Vigna ungularis*) for soil fertility replacements. Peanut, E. bean and cowpea are food legumes, while Desmodium is a pasture species. Of these food legumes, peanut is a four month crop compared to the latter two, which are perennial. Peanut is commonly rotated with vegetable crops, especially sweetpotato in the PNG highlands. These legumes can grow at altitude ranging from zero to over 2500 m in PNG. However, the potential of E. bean in terms of growth and adaptability in the coastal areas is yet to be explored. Maize cultivar BA01-2138, which is known for its vigorous growth and high yielding was used as a soil fertility indicator crop. Maize generally is a 16-week cereal crop and a better soil fertility indicator than other crops, growing at altitudes ranging from sea level to over 2500 m in PNG. The results are presented in this report.

Materials and Methods

Trial location

The trial was conducted at National Agricultural Research Institute's (NARI) Highlands Regional Centre (HRC) at Aiyura Valley in the Obura Wonenara District of Eastern Highlands Province (EHP) in PNG at an altitude of 1,620 m. The trial site had been left under fallow for two years after sweet potato cultivation and had 100% vegetation cover when this trial was established. Aiyura's is generally cool with some seasonality giving fairly distinct wet and dry seasons. The average annual rainfall is 2074 mm and the temperature ranges between 12°C (min) and 24°C (max). Average daily solar radiation is 17 MJ/m^2 and evaporation is 3 mm. The valley experiences a dry season between June and September followed by a wet season between October and May. The wettest time of the year is between November and April (Taraken, 2007, unpub). The trial was implemented from September 2004 to October 2005.

Establishment of the trial

The treatment, control was tested against the legumes: E. bean, Peanut, Desmodium Silver Leaf and Cowpea. They were replicated four times in a complete randomised block design. The plots sizes were 5 x 4 m with 1 m spacing in between plots and replicates. Maize cultivar BA01-2138 was used as a soil fertility indicator crop at 50 x 40 cm spacing. The trial had two cropping seasons with an intervening fallow period: Season 1 (S1) was planted with maize, followed by a 20 weeks fallow period (FP) of the treatments, and the succeeding Season 2 maize crop (S2) after the fallow. Composite soil samples were taken at three different stages for nutrient analysis to determine the soil fertility status of the trial site. The first one was taken before establishing S1, followed by the second sample when establishing the fallow treatments. The final one was taken when slashing or harvesting all of the five treatments after allowing them to grow for 20 weeks. The seeds of the same maize cultivar were used to plant both cropping seasons. Season 1 maize was planted on October 2004.

Figure 1. (a). E. bean planted under 14-weeks old S1 maize and (b). S2 after S1 harvest

Four weeks prior to harvesting S1 maize, the fallow treatments were planted into the existing S1 plots (Fig. 1.a.). This was done purposely to allow the legumes to get well established, thus enabling them to out-compete and suppress weeds that might emerge during the FP (Fig. 1.b.). Though the treatments were not established together with S1 maize, the plots were labelled according to the treatment names for easy management, recording and reporting purposes. The legume seeds were planted at 25 cm x 40 cm spacing except Desmodium, which was planted as cuttings from mature vines, 20-30 cm in length. About 15-25 cm of the cutting was pushed into the soil leaving the remainder above ground to germinate. On the control plots, whatever weed or grass that emerged were allowed to grow. The biomass from each of the treatments was slashed or harvested after the 20 weeks and used as dried mulch for the succeeding S2 maize crop, planted at same density to that of S1 (Fig.2). To mimic standard farmer practice in the rural PNG settings, all the biomass, including the remaining debris of S1 were left lying on their individual plots without standardizing them to a certain weight when planting S2 crop.

Trial husbandry
Apart from the minor husbandry practices such as seed refilling, earthing up and thinning, the main husbandry practice applied after the establishment was weeding. Both maize crops were weeded at three weeks intervals after planting till the establishment of the FP. Similar practice was applied on the fallow treatments except the control. This was because peanut was used as one of the treatments, and had special management requirement. Karate at 1ml/L of water was sprayed at 4 and 8 weeks after planting of the maize seasons to control Oribius weevils, (*Oiribius destructor* and *O.enimicus*) and cutworms on the plants. However, hand picking was done at all stages to remove the pests as it was a minor problem. Hand removal was also practiced on other minor pests and diseases such as Blister smart on maize and leaf spot disease, caused by the fungus *Phoma exigua* on cowpea during wet seasons and Root chaffer beetles (*Melolonthinae spp*) on the legumes, especially peanuts.

Figure 2. (a). Slashing S2 after 20 weeks and (b). S3 planted using S2 biomass as dried mulch

Measurements of the yields and their components
Both maize seasons were harvested as fresh dry cobs. The yields and their components were measured. Season 2 treatments were slashed or harvested at 20 weeks of growth. The fresh weights of their biomass were recorded. Composite samples were taken and were oven dried at 65 ^{o}C to estimate the total dry matter content.

Soil and plant nutrient analysis
The two earlier composite soil samples were sent to NARI Kila~Kila Laboratory (KKL) for soil nutrient analysis. The composite samples of the dried biomass and the latter soil sample were sent to the University of Queensland Laboratory (UQL) in Australia for the analysis of various plant and soil nutrients, including nitrogen, because KKL had a fire incident and was not operating.

Data Processing
Analysis of variance (ANOVA) was done on the data collected. Differences between individual means were compared using the LSD (Least Significant Difference). A scatter

graph was plotted to determine relationship between the maize yields of S3 and the increasing amount of S2 biomass, applied per plot.

Results

Table 1. Mean maize yields and the components for Seasons 1 and 3 and S2 biomass yields in t/ha

Fallow treatments	**S1 total marketable fresh dry cobs**	**S1 biomass sample TDM**	**S2 treatment biomass TDM**	**S3 total marketable fresh dry cobs**	**S3 biomass sample TDM**
Control	11.1	0.41	7.24a	26.5	25.9
Desmodium	11.1	0.47	4.56b	31.7	23.3
E. Bean	11.7	0.49	3.82c	30.3	27.9
Cowpea	11.7	0.39	2.23c	30.1	26.4
Peanut	9.8	0.47	1.59c	30.5	28.0
LSD (P<0.05)	ns (1.852)	ns (0.175)	s (1.865)	ns (3.94)	ns (8.47)
CV %	ns (17.0)	ns (25.4)	31.10	ns (8.6)	ns (20.6)

ns = non-significant and s= significant. TDM = total dry matter. CV = percentage coefficient of variance. Means, followed by a similar letter are not significantly different from each other.

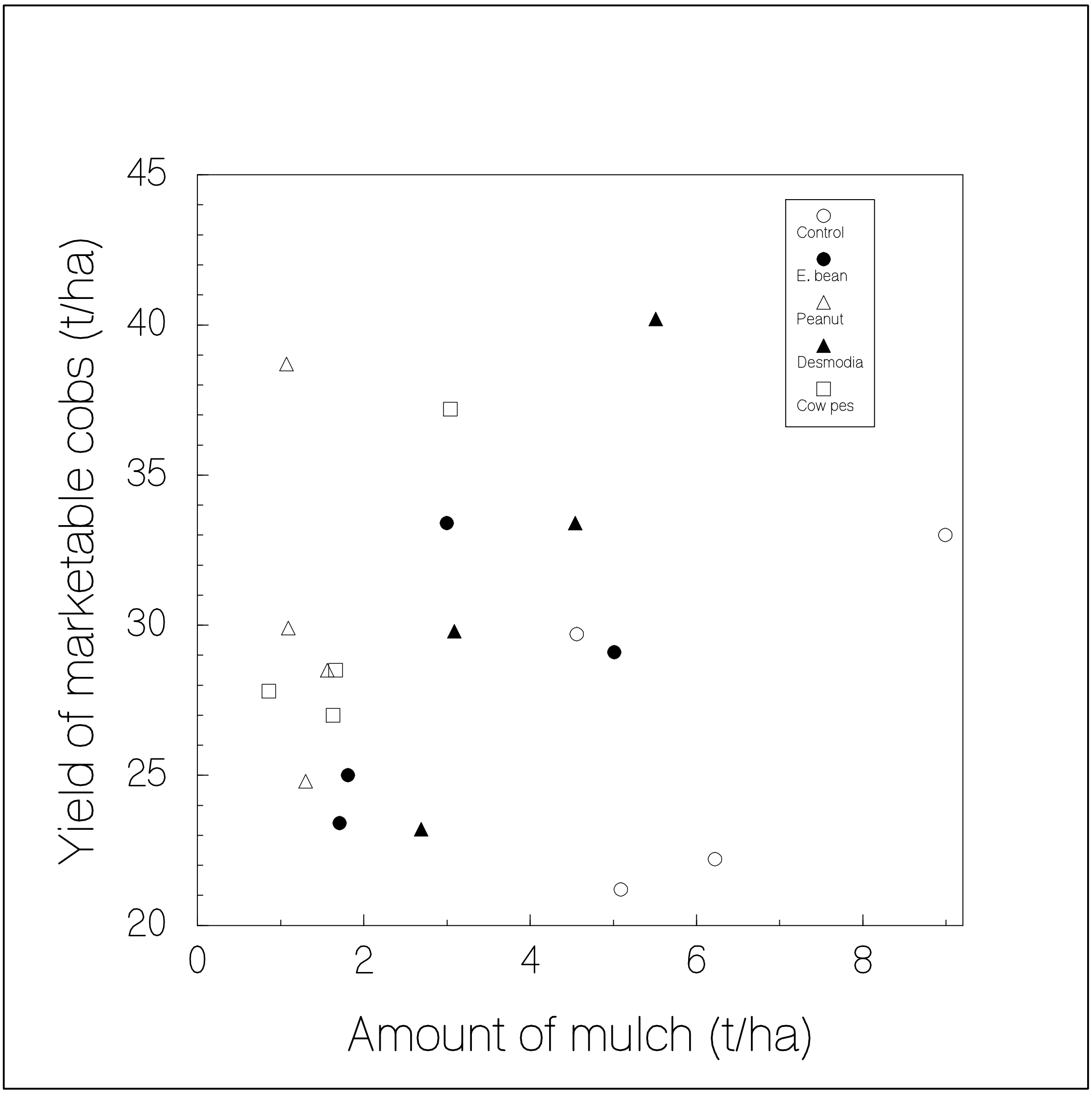

Figure 3. Scatter graph showing the S3 maize yield increase in relation to the increasing amount of the treatment biomass mulch applied per plot

Table 2. Mean TDM yield and nutrient off-takes in Season 2 treatment biomass at harvest in Kg/ha

Fallow treatments	S2 TDM treatment biomass	N	P	K	S	Ca	Mg	C/N
Control	7240	169	14	164	12	72	27	18
Desmodium	4560	117	8	84	6	37	10	17
E. Bean	3820	99	6	63	5	70	21	17
Cowpea	2230	92	7	55	5	31	12	10
Peanut	1590	58	3	39	3	15	12	11

Table 3. Soil nutrient Status of the experimental site before S1 and the fallow period

Property	Original Status (Sample 1*)	Status at maize S1 (Sample 2*)	Critical Values	Soil status/ratings
pH	5.3	5.5	<5.5	Strongly acidic
Ca (Extract. Base) (meq 100g^{-1})	5.2	5.5	<5.0	Medium
Mg (Extract. Base) (meq 100g^{-1})	2.5	2.5	<1.0	Medium
K (Extract. Base) (meq 100g^{-1})	0.6	0.6	<0.3	High
Na (Extract. Base) (meq 100g^{-1})	0.1	0.1	>0.7	Very low
CEC (meq 100g^{-1})	36.8	28.6	<6.0	High
BS (%)	23	30	<30	Low
Olsen P (mg/kg)	5.8	7.4	<5.0	Very low
Organic C (%)	7.1	5.7	<3.0	Medium
Total N (%)	0.79	0.8	<0.3	High
C/N ratio	9	7	<10	Very low
Mg:K ratio	4	4	>10	Very low

Table 4. Soil nutrient status of the trial site during harvest of the fallow treatments at 20 weeks

	Fallow treatment type						
Property	Control	E. Bean	Peanut	Desmodium	Cowpea	Critical value	Soil status or ratings
C (Wt %)	11.3	11.9	11.7	11.8	11.9	<3.0	High
N (Wt %)	0.92	0.92	0.90	0.90	0.88	<0.3	High
Colwell P (mg/kg)	66	68	69	70	67	20.0	Very high
S (mg/kg)	8.5	9.5	10.0	10.2	9.5	?	Low
Ca (meq 100g^{-1})	5.6	5.4	5.9	5.0	5.4	<5.0	Medium
K (meq 100g^{-1})	0.7	0.6	0.6	0.6	0.7	<0.3	Medium
Mg (meq 100g^{-1})	2.4	2.0	2.2	2.1	2.2	<1.0	Medium
Na (meq 100g^{-1})	0.1	0.1	0.1	0.1	0.1	>0.7	Very low
pH	5.91	5.86	5.70	5.22	5.42	<5.5	Strongly to moderately acidic
EC (dS/m)	0.05	0.04	0.06	0.11	0.03	?	Very low

? = critical vale not identified

Discussions

Soil Fertility Status

The results of the first two soil samples, Table 1 shows that by the time FP had been established 12 weeks after planting the S1 maize, minor changes had occurred in the soil fertility status of the trial site, compared to what it had been originally. These changes were probably owed to soil tillage. Soil pH improved from 5.3 to 5.5 but was still quite acidic as this is typical of PNG highlands soils where pH ranges from 4.0-5.5. Plants struggle to absorb soil nutrients as the availability of major nutrients for plant uptake is usually pH dependent. Nitrogen, P, K, S, Ca and Mg are most being available to plants in the pH range between 6.0 and 7.5 (Lucas and David, 1961; McKenzie, 2003). At lower or higher pH, not only are these nutrients less available to plants, but potentially toxic elements including Al and Mn increase in concentration which affect plant growth (Brady, 1974). However, plants that are tolerant to such pH levels thrive. The cation exchange capacity (CEC) declined by 8.2 meq $100g^{-1}$ but was still well above the critical level (<6.0 meq $100g^{-1}$). The percentage base saturation remained at the critical level (<30%). Organic carbon decreased by 1.4%, which indicates mineralisation of organically combined nutrients including N. This drop in soil organic C content may also have been responsible for the accompanying decline in CEC, since carboxyl and phenolic hydroxyl groups on organic matter contribute significantly to soil CEC (Brady, 1974). Soil C/N ratio remained low, indicating a high potential for N mineralisation (Haynes, 1986). Thus soil N content improved by 0.01%. The major elemental nutrients, N, P and K were all present in concentrations above their respective critical values. There was no indication therefore that S1 maize had depleted the soil fertility status of the site

The analytical data for the soil samples taken following the 20 week fallow period showed that fallowing in general had some positive impacts on the soil fertility status. The soil pH status changed from strongly acidic to moderately acidic. Minor improvements also occurred in the N, K, S, Ca, Na, C and plant micro-nutrient status. However, the results revealed that fallow species had little effect on the soil nutrient status of the site as the high pH level could have affected the growth of the legumes and fixation of N. The soil N concentrations were 0.92, 0.90, 0.90 and 0.88% for treatments 2-5 respectively, compared to the concentration of 0.92% on the control. The amounts of Cowell P extracted from the different treatments only ranged from 66 to 69 mg P/kg. This suggested that the natural fallow practice had been as good as the legume treatments, in maintaining soil fertility. This was because wild legumes were also growing on the control plots as they were untouched while weeding was done on the legume treatments. Major differences could have been observed in the soil nutrients status if there was a continuous cropping of maize for 3-4 seasons before imposing the fallow treatments, rather than just after the one season. Thurston (1997) suggested that legumes could fix large amounts of N as long as they are adapted to the prevailing soil and climatic conditions. Reijntjes et al. (1992) reports that Velvet beans when sowed 4-8 weeks after sowing maize perform well in the humid tropical regions of Honduras, Central America, at altitudes ranging from sea level to over 2500 m. The Velvet beans produce 50-70 t/ha of biomass giving 2.7-3.25 t/ha of grain yields in the succeeding maize crops, which is more than double their national average. In the second year, velvet bean seeds volunteer from the year before and the cycle continues with sowing of new maize. Thus, the legumes in this trial would have performed better and improved soil fertility through biomass production and fixing atmospheric N if they had been planted 4-8 weeks after sowing the S1 maize crop instead of after 12 weeks.

Maize and fallow biomass yields

The mean marketable cob yields in the first season before imposing the treatments, ranged from 9.8-11.7 t/ha and was at par between treatments (Table 3). Significant differences were observed in the dry matter biomass yields among the fallow treatments (including control, ranging from 2.2- 7.2 t/ha after the 20 weeks FP). The biomass yield of the control was significantly greater than that of Desmodium followed by the other three legumes: E. bean, cowpea and peanut respectively. There was no statical significant difference observed among the biomass of these three treatments. Dry matters of the biomass were used as mulch to plant the succeeding crop (S3 maize) and its mean marketable dry cob yields almost tripled numerically compared to S1 yield. The TDM content of S3 biomass was about 58 times greater than S1 yields. The cob yields ranged from 30.1-31.7 t/ha in plots fallowed with the legumes whilst 26.5t/ha for control.

The scatter graph (Fig. 3) illustrates that the numerical increase in cob yield of S3 is not related to the total amount of mulch, but more on the different types of mulch. It also shows that different quantities of mulch produced by each crop (e.g., relatively low amounts for peanut). Relying on the natural different amounts of mulch produced in each plot, and having only 4 points for each crop, only basic 'trends' can be identified. For instance, there seems to be a very rapid response in yields (23-40 t/ha) to an increased rate of mulch (2.8- 5.8 t/ha). Statistical significant differences would have been observed on the S3 dry cob yields if the treatment biomass weights were standardized to a certain kilogram rather than mimicking the standard farmer practice in allowing whatever that came up to remain on the individual plots when sowing S3 maize.

Nutrient off-takes of treatment biomass returned as mulch

The important fact about these results is that although higher quantities of nutrient containing biomass were returned as mulch (Table 2) on the control treatment, the legume supported numerically higher cob yields as against the control. For example, cowpea and peanut with 2000 kg/ha of dry mater each, containing N off-takes of 99 and 58 kg/ha respectively; and in S2, each of them gave cob yields of 4 t/ha greater than the control with biomass of 7000 kg/ha containing N off-takes of 169 kg/ha. This indicates that the effect of mulch is dependent on the quality of the material as it is on its quantity. The grass fallow material is likely to have higher lignin content (high C/N ratio) and decomposed more slowly in releasing its nutrient contents than the softer legume mulch materials. This possibly explains why the cob yields from the legume treatments were as good as that on the control. Plant material with high lignin contents are known to decompose very slowly and are considered poor quality sources for soil organisms that recycle carbon and nutrients (Brady and Weil, 2002).

Yet, a good mixture of such biomass as compost in soil mounds or mulch on flat beds and ridges can be used in the PNG highlands. This can improve the availability of soil nutrients which is a major constrain for plant growth due to volcanic ash inherent and low soil pH. The slow nutrient releasing biomass from the natural grass/weed fallow and the legumes would provide nutrients for the late and early maturing crops respectively, depending on their decomposition rates. Such practice might best suit the sweetpotato composted mounding zone of the highlands (Enga, and parts of Southern and Western Highlands Provinces) where mix cropping and sequential harvesting of sweetpotato and other vegetables are practiced on the mounds. The use of such biomass as compost or mulch is also important for the other parts of PNG as it is a tropical nation where bulk of the soil nutrients are retained in the vegetation, unlike in temperate soils (Oliver et al, 2001). This is clearly reflected in the nutrient off-takes, contained in the treatment biomass of these treatments in this trail. Velvet bean (*Mucuna spp*.) biomass has proved effective in short-term fallow management for growing vegetables and maize in Guatemala (Fernandes et al. 2001) and Honduras in Central America (Reijntjes et al. 1992). Then, can the use of biomass from legumes such as Desmodium and E. bean cheaply boost the production and productivities of soil and crops per unit of land in the rural settings of PNG highlands? The concept could probably suit the resource poor farmers of the tropical PNG, who could not be able to afford inorganic fertilizers as all soil nutrients are in the biomass.This will further alleviate the ever-increasing demand exerted on food and cash income by the growing population.

General performance of the legumes and their other importance

Of the legume treatments, Desmodium performed well and produced the greatest biomass dry matter followed by E. bean, cowpea and peanut. Desmodium and E. bean also tolerated the effects of pests and diseases such as Oribius weevils and fungus. Desmodium, however, is a wild perennial pasture legume that is considered as an environmental weed. Yet, if utilised can improve soil fertility under the short natural grass/weed fallow through biomass production and fixation of atmospheric N. Thus, it is a challenge for the rural highlanders to appreciate the importance of such wild legumes and other high nutrient accumulating plants species such as Wild sunflower (*Tithonia diversifolia*) and Wild daka (*Piper aduncum*) in their natural surroundings. These plants should be respected and utilised in soil fertility and fallow management practices to minimise the population pressure on land use and for optimum crop production. If biomass of these three plants: legumes (either wild or cultivated), sunflower and daka are either used as compost or mulch in gardening, would release the major soil nutrients, N P and K respectively upon decomposition for plant growth.

Everlasting bean, apart from its N-fixing characteristic, has pods or seeds and forages that are edible. It has become one of the common income generating beans for families in the highlands, even though it was recently introduced from the Southern Highlands Province after the 1997/8 drought. It tolerates dry conditions and is a perennial legume, but its potentials are yet to be tested in the lowlands of PNG. Cowpea performed well, but was affected by fungus *Phoma exigua* during the wet seasons. It is also a perennial edible legume that can help improve the natural fallows in the PNG lowlands as it performs well in that region. Peanut is a 4-month crop, which is rotated with sweetpotato and other vegetables to maintain soil fertility and crop yields, both in the PNG highlands and the lowlands, but is a weak competitor against weeds and needed high management inputs.

These results indicate that at least the relative amounts of organic biomass material each treatment could potentially contribute to the soil organic matter pool, which is very important for soils in the tropics. Such legumes can be used to improve the organic matter content of sandy soil, which can eventually enhance their fertility levels. Ayanlaja and Sanwo (1991) state that soil organic matter is the key to successful agriculture and sustains the productivity of tropical soils. It positively affects the structure, aggregation, porosity, microbial activity, pore size distribution and water retention capacity of the soil. It is also the major nutrient storage site for the low-activity-clay soils of the tropics and so affects nutrient retention capacity, availability and mobility of macro and micronutrients. The legumes are also good cover crops in suppressing of weeds and minimize soil erosion. Their root exudates can also break the pests and disease cycles in the soil during fallows (Thurston, 1997).

The legumes are not only important for fallow improvements, but are also important in family food security and income generation. Their leaves are good source of food for both human and livestock. The seeds of the edible legumes such as peanut, cowpea and E. bean are important protein sources and their dried seeds if stored can remain for longer periods, as drought preparedness. Livestock such as goats and rabbits if reared on the improved fallow lands with legumes can provide meat or milk and can generate family income.

Conclusion and recommendations

The control-natural fallow treatment produced greater quantity of fallow biomass/compost with high nutrient off-takes than any of the four legume treatments. Yet the compost produced by the latter treatments was of superior quality, particularly in respect of its decomposition and nutrient supplying/releasing characteristics. Therefore, they supported maize yields equally as good as that produced on the control. Furthermore, if the legumes had been planted 4-8 weeks after sowing the S1 maize crop instead of after 12 weeks, they would probably have produced significantly more nutrient-rich biomass and hence supported significantly higher maize yields than the control. Statical significant differences would have been observed in the dry cob yields of S2 if the dry biomass from the FP, used as mulch were standardised to a certain weight.

Among the legumes tested, Desmodium and E. bean performed well in terms of biomass production, plant nutrient content and pest or disease resistance. These legumes clearly have the potential for boosting the productivity of soil and crops in the highlands of PNG if integrated with crops in short-term fallows. Peanut, although important for crop rotations, cannot be used in integrated fallow, as it is a weak competitor with weeds and can be out-shaded by the main crop. Cowpea is good for improving short fallow management in the lowlands, but could be of limited value in the highlands, as it is very susceptible to fungus diseases during the wet seasons. In general, however, legumes if incorporated into short-term natural fallow should yield additional benefits such as improved food security, minimise inorganic fertiliser costs, increased house-hold incomes, and the provide quality forage material for livestock.

Dedication

This paper is dedicated to my mother Makadale Wambion L. Taraken, cousins Neon A. Abel, brother Gabriel A. Kiyowai and late aunties Akim L. Kiin and Agnes A. Minapi, brother Joseph K. Kiyowai, uncles Aron A. Lapai and Tipingi Kiin, who tirelessly funded my education and raised me successfully to the type of person that I am. I wish to extend this dedication to Debbie Kapal as my immediate Line Manageress in NARI, who brings to my attention what is good and positive and encourages me tirelessly for my personal and professional developments, despite the hardships that we face. Without her efforts, this paper together with the other papers that I have either authored or co-authored since 2004 would not have eventuated.

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[2] *ACNARS = Australia's Contribution to Agriculture Research Systems.*

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