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Evaluation of Coconut Based *Gliricidia sepium* Agroforestry Systems to Improve the Soil Properties of Intermediate and Dry Zone Coconut Growing Areas

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***Abstract* – This study was intended to assess the potential of using coconut based *G. sepium* agroforestry systems to improve soil fertility of degraded coconut lands in intermediate and dry zones of Sri Lanka. Study locations were Rathmalagara Estate and Pallama Estate of Coconut Research Institute of Sri Lanka, which belong to Andigama soil series in low country intermediate zone (IL_1) and Ambakele soil series in the low country dry zone (DL_3) respectively. Experiment was conducted in a randomized complete block design with five treatments and three replicates. Main treatments were coconut based agroforestry systems intercropped with *G. sepium*, and sole coconut. A fallowed land and a sole *G. sepium* land were used as benchmarks. Soils from three depths i.e. 0-15 cm, 15-30 cm and 30-45 cm were analysed for its' chemical, physical and biological properties. Results showed a significant ($p<0.05$) accumulation of soil organic matter (SOM) due to incorporation of *G. sepium*. Mean SOM in top soil of *G. sepium* intercropped fields were 0.87% compared 0.49% in sole coconut, however values were quantitatively low compared to typical fertile soils. Higher soil total nitrogen (TN) was observed in *G. sepium* intercropped lands in both estates compared to sole coconut in same climatic zone, however quantity varied on degree of management of *G. sepium* such as lopping frequency. Exchangeable potassium (K) and magnesium (Mg) were observed in significantly high quantities in *G. sepium* intercropped fields than sole coconut. Significantly higher soil microbial activity (SMA) was observed in *G. sepium* managed and unmanaged conditions in both estates in contrast to sole coconut. This study reconfirms the promising results of integrating *G. sepium* for replenishing soil fertility of degraded coconut growing soils in intermediate and dry zone.**

***Keywords* – Agroforestry, Coconut, Dry Zone, *Gliricidia Sepium*, Intermediate Zone.**

I. Introduction

Low land productivity in intermediate and dry zone coconut plantations is highly associate with loss of fertile topsoil through accelerated erosion due to poor land management. Numerous studies have been undertaken to achieve this task through several agronomic practices, especially by improving fertility status of soil (Liyanage et al., 1993). Incorporation of tree species producing substantial amounts of biomass is recognized as a solution for enhancing soil organic matter in cost effective way and with alternative uses (Costa and Sangakkara, 2006).

Gliricidia sepium base agro-forestry system producing substantial nitrogen rich biomass, leaves are useful as fodder enriched with proteins for livestock and fuel wood for electrifying national power grid though dendro-thermal energy (Wijethunga et al., 2006). It has a great potential as a multipurpose tree in agroforestry systems, and could be useful in improving the gravelly soils (Liyanage, 1994). Gunasena et al., (1991) observed that by growing *Gliricidia sepium*, soil bulk density was reduced and steady infiltration rate increased. Such improvements through breaking of hard-pan by *G. sepium* roots would help to improve poor physical conditions of soil that restricts growth and development of coconut roots.

In addition, Liyanage et al., (1993) reported that *G. sepium* also has an ability to improve nutritional status of the soils. A well-established Gliricidia intercrop is capable of producing about 8 to 10t ha^{-1} of fresh loppings from three prunings per year (Liyanage, 1994). *G. sepium* loppings is an ideal green manure for coconut palms that supply significant amounts of N and K. Quantitatively, application of at least 30 kg loppings around each palm can completely replace nitrogen input and about 20% of phosphorus and potassium requirement of recommended adult palm mixture (APM) (Liyanage, 1994). However, for coconut, inclusion of a *G. sepium* based agroforestry system is possible using available spacing efficiently. In addition to the green manure incorporation *G. sepium* can enrich the subsoil through nitrogen fixation and mining nutrients from subsoil with its deep root system. Systematic incorporation of *G. sepium* in either hedgerows or alleys is an effective barrier for reducing the momentum of raindrops and overland flow but diminishing the risk of erosion. Nonetheless, with several advantages of *G. sepium*, it is essential to test its rate of soil fertility improvement and contribution for low country intermediate zone where Andigama soil series is predominant. Especially, there are no sufficient scientific evidences of the efficacy of *G. sepium* coconut based agroforestry systems that are proposed in this research. Moreover, low cost agronomic methods of growing nitrogen fixing trees to improve soil fertility are economically viable and environmentally sound. Therefore, this study was design to assess the potential of using coconut based *G. sepium* agroforestry systems to improve soil fertility of degraded coconut lands in intermediate zone and dry zone of Sri Lanka.

II. Materials and Methods

The study was conducted at Agronomy Division of Coconut Research Institute (CRI), Lunuwila, Sri Lanka, situated in North Western Province of Sri Lanka, (7° 20' 37" N, 79° 51' 42" E). Study was carried out in established experiment fields for intercropped coconut. The first field experiment was conducted at Rathmalagara Estate, Madampe in the low country intermediate zone (08^0 02' N, 79^0 E; 35 m from mean sea level). Agro ecological zone of this area is IL_1 (Punyawardena et al., 2003)**.** Soils belong to the Andigama series which categorized into great soil group of Red Yellow Podzolic (Mapa et al., 2005) (Ferric Acrisols; FAO/ UNESCO, 1998). The mean annual rainfall and ambient temperature range were 1660 mm and 23.8 ^{0}C - 30.4 ^{0}C, respectively.

The second field experiment was conducted at Pallama Estate, Pallama in the low country dry zone. Agro ecological zone of this area is DL_3 (Punyawardena et al., 2003)**.** Soil at the location belongs to the great soil group of Red Yellow Podzolic (Mapa et al., 2005) with soft or hard laterite (70-90%). The mean annual rainfall and ambient temperature range were 1200 mm and 28 ^{0}C – 32 ^{0}C, respectively. In both locations, *Gliricidia sepium* trees were cultivated in between coconut rows on double hedge rows. Soils of coconut based *G. sepium* agroforestry systems were evaluated through a soil fertility analysis by measuring soil physical, chemical and biological properties. Experiment was designed in a Randomized Complete Block Design (RCBD) including five treatments with three replicates.

T_1. Coconut cultivation with Gliricidia under management: Coconut was established with 8 m x 8 m spacing and Gliricidia was established in between coconut rows of 2 m x 1 m on double hedge rows. Gliricidia was repeatedly lopped to a 1.5 m height in four months intervals and incorporated to the manure cycle of coconut palms.

T_2. Coconut cultivation with Gliricidia without management: Coconut was established with 8 m x 8 m spacing and Gliricidia was established in between coconut rows of 2 m x 1 m on double hedge rows. Lopping and incorporation of Gliricidia was not practiced.

T_3. Coconut: Coconut was established with 8 m x 8 m spacing. There was no any intercropping.

T_4. Fallowed land

T_5. Gliricidia: Gliricidia was established in 2 m x 1 m spacing on double hedge rows.

Soil Sampling, preparation & analysis

In April 2012, three soil samples were randomly collected from each experimental plot at depths of 0-15cm 15-30cm and 30-45cm, respectively. Simultaneously, an undisturbed soil sample was collected using a core-sampler from desired depths (0cm, 15cm and 30cm) for bulk density determination. Samples were processed under laboratory conditions by air drying separately at room temperature for 48-72 hours without any contaminations. Air dried soil samples were crushed and sieved through 2 mm sieve. In addition, undisturbed soil samples were collected from same locations to determine microbial activity. For physic-chemical characterization the following soil parameters were considered: organic carbon of the samples were measured by Walkey-Black method (Walkley and Black, 1934); the N was estimated by the Kjeldahl method (Jackson, 1973), and the P and K contents of the samples were analyzed by calorimetric method (Anderson and Ingram, 1993) and flame photometric method (Simard, 1993), respectively.

III. Results

Soil organic matter content

Soil organic matter (SOM) of all three depths in Rathmalagara site was higher when compared to Pallama site irrespective of the agroforestry system (Table 1). Interestingly, lowest SOM content of topsoil in Rathmalagara Estate i.e. 0.97% in T_2 was greater than the highest SOM value of Pallama Estate. Highest SOM content observed was 1.71% from the topsoil in T_5 in Rathmalagara Estate. Furthermore, topsoil SOM in T_5 in Rathmalagara Estate was not significantly different from other four treatments (Table 1). Lowest value was observed in T_2. In contrary, treatments with *G. sepium* (T_1, T_2, T_5) resulted significantly greater SOM in Pallama Estate compared to treatments without *G. sepium.*

Table 1: Effect of different treatments on soil organic matter content (%) at different soil depths in Rathmalagara and Pallama Estates

Treatments	Organic Matter (%)					
	Rathmalagara			Pallama		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	1.13^a	0.76^c	0.61^a	0.71^{ab}	0.62^a	0.53^a
T_2	0.97^a	1.48^a	1.03^a	0.87^a	0.53^a	0.66^a
T_3	1.39^a	1.05^{bc}	0.68^a	0.40^b	0.36^a	0.40^a
T_4	1.50^a	1.22^{ab}	0.85^a	0.49^b	0.38^a	0.38^a
T_5	1.71^a	1.09^{abc}	0.70^a	0.83^a	0.72^a	0.51^a
Significance	ns	*	ns	*	ns	ns
LSD	-	0.42	-	0.30	-	-

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
*Denote the significant difference at p<0.05; ns denote the non-significance

Subsoil SOM showed different dynamic compared topsoil in both sites. Intestinally, SOM did not showed any significant difference in subsoil from 15-30 cm depth and 30-45 cm depth in Pallama Estate. In both depths SOM ranged between 0.38 - 0.87 %. In Rathmalagara Estate, T_2 showed the highest SOM in subsoil between15-30cm and was in lined with T_4 and T_5. Subsoil below 30 cm did not show any significant difference between treatments. There was a general trend of reducing SOM with increasing soil depth in both estates except T_2 in Rathmalagara Estate.

Soil total nitrogen

Highest total N content was observed 814.3 ppm in T_2 from the topsoil of Rathmalagara Estate. However, T_2 did not show any significant difference between rests of the treatments at same depth (Table 2). Nevertheless the lowest total N was 420 ppm and observed in T_1 despite it was intercropped with *G. sepium.* In contrary, in Pallma Estate highest topsoil total N of 780.33 ppm was observed in T_1. Interestingly, total N of T_2, T_3, T_4 and T_5 were less than half of total N of T_1. Furthermore, lowest was observed in T_3 and T_5 and T_4 was not significantly different of T_3, while T_2 showed greater total N. Although, in Pallama Estate, T_1 showed 780 ppm total N, total N of rest were lower than the lowest TN of Rathmalagara Estate (Table 2). Subsoil TN dynamics showed a certain degree of variation compared to topsoil in both locations. The highest subsoil TN was recorded in Rathmalagara Estate, and now it was T_3. In contrast, highest TN in Pallama Estate was observed in T_1. Generally, TN was diminishing with increasing depth, especially for topsoil to subsoil at 15-30 cm. However, in T_3 TN content of topsoil was lower than the TN of subsoil at 15-30 cm (Table 2) in both locations. Further, in Pallama Estate, T_2 and T_5 showed a small increase in TN in subsoil at 15-30 cm compared topsoil. Despite greater TN in subsoil at 15-30 cm in T_3, it followed a similar pattern aligned with other treatments at 30-45 cm depth.

Table 2: Effect of different treatments on soil total N content ppm at different soil depths in Rathmalagara and Pallama Estates

Treatments	Nitrogen ppm					
	Rathmalagara			Pallama		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	420.0^a	251.0^b	242.3^b	780.3^a	510.3^a	570.3^a
T_2	814.3^a	632.3^a	595.7^a	394.0^b	400.3^{ab}	361.3^b
T_3	644.0^a	672.3^a	603.0^a	300.0^c	322.3^b	260.0^b
T_4	514.3^a	485.7^{ab}	181.0^b	370.3^{bc}	342.3^b	361.7^b
T_5	565.7^a	260.7^b	265.7^b	330.0^{bc}	348.3^b	302.7^b
Significance	ns	*	*	*	ns	*
LSD	-	257.89	161	88.11	-	156.29

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
*Denote the significant difference at $p<0.05$; ns denote the non-significance

In addition, the reduction of TN from topsoil to subsoil up to 45 cm was approximately 200 ppm except T_3 in Rathmalagara Estate. However, in Pallama Estate, reduction of TN in to the soil profile was marginal except T_1.

Soil available phosphorus

Available P in topsoil showed a similar dynamics in both estates. Highest available P content observed was 3.77 ppm, in topsoil in T_1 in Rathmalagara Estate. Although, T_1 showed the highest available P, T_2, T_4 and T_5 did not show any significance difference (Table 3). Lowest value was observed in T_3 and was significantly different from rest. Similarly, in Pallama Estate highest available P in topsoil was observed in T_1. Lowest value was observed in T_5. Unlike in Rathmalagara Estate, available P of T_1 was significantly higher than the rest. Again, both highest values were observed in Gliricidia intercropped fields.

Table 3: Effect of different treatments on soil available P content ppm at different soil depths in Rathmalagara and Pallama Estates

Treatments	Available Phosphorus ppm					
	Rathmalagara			Pallama		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	3.77^a	1.25^a	2.58^a	2.94^a	1.96^a	1.47^a
T_2	2.78^a	1.51^a	1.96^a	1.51^b	1.05^a	0.81^a
T_3	1.44^b	1.60^a	0.91^a	1.83^b	1.82^a	1.21^a
T_4	2.65^{ab}	1.52^a	1.77^a	1.65^b	0.73^a	0.63^a
T_5	3.43^a	1.43^a	2.37^a	1.23^b	1.01^a	1.41^a
Significance	*	ns	ns	*	ns	ns
LSD	1.31	-	-	0.85	-	-

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
* Denote the significant difference at $p<0.05$; ns denote the non-significance

Available P content did not showed any significant difference in two subsoil depths tested, in either Rathmalagara or Pallama Estates. Interestingly, subsoil at 30-45 cm depth in T_1 showed much higher available P compared to the soil above (Table 3). In both locations, substantially higher available P was observed in T_1 in all three depths compared to even treatments with Gliricidia.

Soil exchangeable potassium

In general, exchangeable K contents observed in Rathmalagara Estate were greater than that of Pallama site in top and subsoil. According Table 4, highest exchangeable K was observed in T_2 in both locations. Highest was observed in Rathmalagara Estate that was quantitatively 320. However, a difference of approximately 130 was observed between two estates (Table 4). Again, lowest exchangeable K contents were observed in T_3 and T_5 in Pallama Estate, whereas T_3 showed the lowest in Ratmalagara Estate. Nevertheless, in topsoil, treatments T_1, T_4, T_5 did not show a significant difference compared to T_3 in Rathmalagara Estate while the rank order was T_2, T_1, T_4, T_3 and T_5 in Pallama Estate. However, the general trend of decreasing K with increasing depth was evitable in all treatments irrespective of location.

Table 4: Effect of different treatments on soil exchangeable K content (meq 100 g^{-1} soil) at different soil depths in Rathmalagara and Pallama Estates

Treatments	K^+ (meq 100 g^{-1} soil)					
	Rathmalagara			Pallama		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	0.167^b	0.100^a	0.070^a	0.138^{ab}	0.075^a	0.052^a
T_2	0.320^a	0.143^a	0.103^a	0.182^a	0.112^a	0.092^a
T_3	0.147^b	0.100^a	0.066^a	0.071^c	0.063^a	0.052^a
T_4	0.173^b	0.100^a	0.103^a	0.094^{bc}	0.090^a	0.078^a
T_5	0.187^b	0.123^a	0.100^a	0.070^c	0.056^a	0.047^a
Significance	*	ns	ns	*	ns	ns
LSD	0.082	-	-	0.062	-	-

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
* Denote the significant difference at $p<0.05$; ns denote the non-significance

In subsoil, contents did not showed any significant differences in both estates. Exchangeable potassium in subsoil of both locations was not influenced by the either intercropping of Gliricidia or keeping fields as sole coconut.

Soil exchangeable magnesium

The highest exchangeable Mg in Rathmalagara Estate was observed in T_5 in topsoil and was quantitatively 0.538 (meq 100 g^{-1} soil). In contrary, in Pallma Estate highest topsoil total exchangeable Mg of 1.269 (meq 100 g^{-1} soil) was observed in T_1. Unlike in Rathmalagara Estate, there were some significant differences between exchangeable Mg among different systems. Mainly, T_1 showed a substantial high Mg and was more than 0.6 meq 100 g^{-1} soil from that of 2nd highest i.e. T_2. Interestingly, topsoil Mg content was higher in corresponding treatments in Pallama Estate compared to Rathmalagara Estate except T_5. Exchangeable Mg in subsoil at 15-30 and 30-45 cm depths in Pallama was always higher than to Rathmalagara Estate in corresponding treatments, which was again parallel to topsoil (Table 5).

Table 5: Effect of different treatments on soil Mg content (meq 100g^{-1} soil) at different soil depths in Rathmalagara and Pallama Estates

Treatments	Mg^+ (meq 100 g^{-1} soil)					
	Rathmalagara			Pallama		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
T_1	0.408^a	0.184^a	0.134^a	1.269^a	1.386^a	1.317^a
T_2	0.497^a	0.224^a	0.200^a	0.658^b	0.607^b	0.392^b
T_3	0.228^a	0.135^a	0.128^a	0.255^c	0.378^b	0.501^b
T_4	0.346^a	0.178^a	0.277^a	0.381^{bc}	0.530^b	0.430^b
T_5	0.538^a	0.249^a	0.309^a	0.499^{bc}	0.427^b	0.605^b
Significance	ns	ns	ns	*	*	*
LSD	-	-	-	0.334	0.599	0.616

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
*Denote the significant difference at $p<0.05$; ns denote the non-significance

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Generally, exchangeable Mg was diminishing with increasing depth, especially for topsoil to subsoil at 15-30 cm in Rathmalagra Estate. However, in Pallama Estate, the trend was other way round in Pallama Estate. Especially, T_1, T_3 and T_4 showed a greater accumulation of Mg in subsoil compared to topsoil (Table 5). In general, exchangeable Mg was in a same range in both estates in all depths irrespective of treatments, with exclusion of extreme values recorded T_1 in Pallama Estate.

Bulk density

Mean soil bulk density (SBD) of in Rathmalagara Estate was lower when compared to Pallama Estate irrespective of the agroforestry systems (Table 7). Mean SBD was ranging from 1.41-177 (g cm^{-3}) and 1.60-1.88 (g cm^{-3}) in Rathmalagara and Pallama Estates respectively (Table 7). Highest value of SBD was observed in T_4 in both estates. Lowest SBD was 1.41 (g cm^{-3}) in T_1 in topsoil of Rathmalagara Estate and was significantly different from T_1, T_2 and T_5 (Table 7).

However, T_2 recorded the lowest topsoil BD in Pallama Estate and was in-lined with rest excluding T_4. Furthermore, treatments with *G. sepium* showed lower SBD in contrast to sole Coconut in both locations. Generally, BD in subsoil was higher, than topsoil except T_2 in 30-45 cm depth. Interestingly, SBD did not show any significant differences in subsoil in both depths in both locations. Generally, SBD values were not significantly different in subsoil due to the different agroforestry systems. Moreover, there was no detectable impact on *G. sepium* in subsoil SBD in both estates.

Table 7: Effect of different treatments on Bulk density (g cm^{-3}) at different soil depths in Rathmalagara and Pallama Estates

Treatments	**Bulk density (g cm^{-3})**					
	Rathmalagara			**Pallama**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
T_1	1.41^{d}	1.71^{a}	1.67^{a}	1.63^{b}	1.73^{a}	1.81^{a}
T_2	1.48^{dc}	1.71^{a}	1.64^{a}	1.60^{b}	1.76^{a}	1.83^{a}
T_3	1.68^{ab}	1.68^{a}	1.62^{a}	1.79^{ab}	1.81^{a}	1.85^{a}
T_4	1.77^{a}	1.74^{a}	1.58^{a}	1.83^{a}	1.88^{a}	1.82^{a}
T_5	1.60^{bc}	1.65^{a}	1.62^{a}	1.66^{ab}	1.78^{a}	1.87^{a}
Significance	*	ns	ns	ns	ns	ns
LSD	0.1411	-	-	-	-	-

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
*Denote the significant difference at $p<0.05$; ns denote the non-significance

Soil microbial activity

Soil microbial activity (SMA) in topsoil showed similar dynamics as the highest values were observed in T_5 in both estates. Highest SMA was 91.58 (mg day^{-1}), in topsoil in T_5 in Rathmalagara Estate and it was significantly different from other four treatments (Table 8). At the same location, lowest value was in T_2 and was significantly different from rest. Further, it was lower than the SMA at 15-30 cm subsoil in same treatment and from rest. However, excluding T_2, other treatments with Gliricidia i.e. T_1 and T_5 were ranked at highest SMA. Similarly, in Pallama Estate highest SMA 61.48 (mg day^{-1}) was observed in T_5 from topsoil and was significantly different from rest (Table 8). T_3 showed the lowest value of topsoil in Pallama estate and was in lined with T^1 and T_4. Again, treatments with Gliricidia showed the highest SMA activity compared to no Gliricidia in Pallama Estate. However the highest value in subsoil at 30-45 cm depth was greater than the SMA in 15-30 cm depth in Pallama Estate. Lowest SMA 8.06 (mg day^{-1}) was observed in T_3 in 30-45 cm depth in Pallama Estate; however it is common to all three depths. In both locations, substantially higher SMA was observed in T_5 in all three depths except T_2 in 15-30 cm depth in Pallama Estate.

Table 8: Effect of different treatments on soil microbial activity (mg day^{-1}) at different soil depths in Ratmalagara and Pallama Estates

Treatments	**Microbial Activity (mg day^{-1})**					
	Ratmalagara			**Pallama**		
	0-15 cm	**15-30 cm**	**30-45 cm**	**0-15 cm**	**15-30 cm**	**30-45 cm**
T_1	67.42^{b}	43.55^{a}	41.42^{a}	39.89^{bc}	21.56^{a}	18.77^{b}
T_2	34.32^{d}	48.55^{a}	13.25^{b}	42.68^{b}	27.72^{a}	20.09^{b}
T_3	51.60^{c}	48.40^{a}	39.61^{a}	25.22^{c}	11.14^{b}	8.06^{c}
T_4	54.97^{c}	54.53^{a}	42.37^{a}	34.76^{bc}	19.94^{ab}	18.33^{b}
T_5	91.58^{a}	67.67^{a}	50.29^{a}	61.48^{a}	23.32^{a}	29.93^{a}
Significance	*	ns	*	*	*	*
LSD	8.21	-	16.23	14.77	9.261	8.14

In each column, values with the same letter are not significantly different at $p<0.05$(LSD)
* Denote the significant difference at $p<0.05$; ns denote the non-significance

Soil Nutrient Stock

Generally, SOM stocks were higher in Rathmalagara Estate compared to Pallama Estate and were more prominent in corresponding treatments (Table 9). Highest SOM stock was observed in T_4 in Rathmalagara Estate. T_1 showed the lowest SOM stock and was approximately 44% lower than T_4. Nonetheless, treatments with *G. sepium* showed higher SOM stocks compared to sole Similarly in Pallama Estate, higher SOM stocks were recorded in T_2 and T_5. Again, coconut intercropped with *G. sepium* showed higher SOM stocks in Pallama Estate. Highest TN stock of 4.9 t ha^{-1} was observed in T_2. TN stock of T_3 i.e. sole coconut was similar to T_2 (Table 9 in Rathmalagara Estate. In contrary, highest TN stock of 4.8 t ha^{-1} was observed in T_1 and was approximately 60% higher than the second highest observed in T_3 and T_4 in Pallama Estate.

Table 9: Different nutrient stocks in different agroforestry systems based on coconut in Rathmalagara and Pallama estate

Treatment	Rathmalagara					Pallama				
	OM (tha^{-1})	N(tha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})	OM (tha^{-1})	N (tha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Mg (kg ha^{-1})
T1	58.8	2.1	17.7	307.6	203.6	47.6	4.8	16.3	263.0	1248.0
T2	84.9	4.9	14.9	520.2	263.8	53.0	3.0	8.6	384.9	517.4
T3	78.0	4.8	9.9	306.2	149.1	31.6	2.4	13.2	197.6	376.8
T4	91.7	3.0	15.2	376.5	247.7	34.5	3.0	8.3	283.4	451.7
T5	84.9	2.6	17.5	388.8	322.6	54.3	2.6	9.7	178.5	497.0

Generally, soil available phosphorus (AP) stocks in coconut intercropped systems were higher in Rathmalagara Estate compared to Pallama. The highest SAP stock of P (17.7 kg ha^{-1}) was observed in T_1 and was 44% higher than sole Coconut. Like in Rathmalagara Estate, the highest SAP stock of 16.3 kg ha^{-1} was recorded in T_1. Unlike in Rathmalagara Estate, T_2 showed lower SAP stock in Pallama Estate and was approximately 53% lower to sole coconut. Conversely, T_5 showed lower SAP in Pallama Estate. However, greater heterogeneity of SAP stocks was observed in Pallama even among agroforestry systems with *G. sepium.* Generally, soil exchangeable K stocks were higher in Rathmalagara Estate compared to Pallama Estate and was more prominent in corresponding treatments. Highest soil exchangeable K stock was observed in T_2 in Rathmalagara Estate, which was 520 kg ha^{-1} quantitatively. In both estates, T_2 resulted the highest K stocks, while lowest were observed in T_3 in both locations.

Soil exchangeable Mg stocks in Pallama estate were substantially greater than that of Rathmalagara Estate. Interestingly, Mg stocks were few times greater (Table 9) in corresponding treatments, while this was more pronounced in fields intercropped with G. *sepium.* The highest soil exchangeable Mg stock of 1248.0 kg $ha^{-1}$was recorded in T_1 in Pallama. Mg stocks of two reference lands i.e. T_4 and T_5 were higher than the T_3, which is a sole coconut field

IV. Discussion

This study was intended to assess the potential of using coconut based *G. sepium* agroforestry systems to improve soil fertility of degraded coconut lands in intermediate zone and dry zone of Sri Lanka. Present study revealed that fields intercropped with *G. sepium* showed a positive influence on soil microbial activity, bulk density, organic matter, total nitrogen, available phosphorus, exchangeable potassium and magnesium. Gunasena and Silva (1995) clearly showed that the incorporation of *G. sepium* trees into farming systems could improve chemical, physical and biological properties of the soil. In addition, Handawela and Kenderagama (1991) reported that application of *G. sepium* leaves as mulch specially decreased bulk density of soil. However, results in the present study showed significant differences in topsoil when compared to the all properties of subsoil. Furthermore, results revealed different dynamic in newly established Rathmalagara Estate that is located in the intermediate zone compared to Pallama Estate established earlier that is located in the dry zone. Higher SOM status under the coconut intercropped with *G. sepium* compared to the sole coconut and bare land irrespective to the locations (Table 04). This result reconfirms that organic inputs from *G. sepium* leaf prunings have a constructive effect on SOM in Andigama series soils. Liyanage (1989) also reported that incorporation of *G. sepium* leaves and the decomposition of leaf litter fall could improve the SOM content. Moreover, Utomo et al., (1990) and Reddy et al., (2003) reported that SOM amelioration following green manure incorporation up to 1% of total soil mass. Nonetheless, substantial SOM stocks were recorded from Rathmalagara Estate compared to the Pallama Estate. This may associate to inherent low SOM in dry zone soils and rapid oxidation process in dry regions (Srinivasarao et al., 2008). All the treatments showed an accumulation of SOM in surface soil as compared to subsoil in both locations that in lined with the study by Rudrappa (2006), who reported that SOM was found stratified along the soil depth.

In Pallama Estate, higher TN status was recorded in *G. sepium* intercropped fields under managed condition compared to the rest (Table 05). Being a nitrogen fixer, biomass of *G. sepium* is a rich source of N. Liyanage

(1994) reported that a well-established *G. sepium* intercrop is capable of producing about 8-10 tha^{-1} of fresh loppings from three prunings per year. Besides, it produces a very high quality green manure, and may contain as much as 4% nitrogen in its leaves (Makumba, 2003). Furthermore, N leaching from *G. sepium* agroforestry systems may lower than in the other agroforestry systems due to the ability of nutrient mining via deeper and extensively spread root system of mature plants (Harawa *et al.*, 2006). Relatively high levels of TN in topsoil observed in treatment with *G. sepium* possibly due to recycling of N by decomposing leaves which are only incorporated to upper layers of soil (De Costa et al., 2005). The present results are further confirmed by the findings of Sangakkara (1989) and De Costa et al, (2005) who reported possibility of enhancing topsoil N using *G. sepium.*

In both locations, substantially higher available P was observed in coconut intercropped with *G. sepium* under managed conditions in all three depths compared to treatments even with *G. sepium*. Although *G. sepium* is a poor source of P organic acids derived from decomposing *G. sepium*, which may accelerate mineralization of P (Egodawatta et al., 2012). Beedy et al., (2010) also reported that *G. sepium* intercrop had a positive effect on available P in soil. Hence, greater availability P in soil due to the incorporation of plant materials has been attributed by direct P release from the decomposing materials (Palm, 1995). This phenomenon is evident in Rathmalagara Estate, where subsoil at 30-45 cm depth in coconut with *G. sepium* under managed conditions showed much higher available P compared to the soil above. Deeper soils are rich in P than the topsoil because of the inherent soil characters and absorption by the vegetation from topsoil as reported by Silva et al., (2005). However, in Pallama Estate, higher available P contents were recorded in topsoil compared to the subsoil (Table 06). This may clearly related to the higher level of organic matter and clay content in the topsoil (Jayakody et al., 2007).

Treatments with *G. sepium* were ranked high with greater exchangeable K compared to treatments without *G. sepium* in both locations. Exchangeable K contents were always higher in topsoil, when compared to the subsoil irrespective of the location or depth. These observations may due to the K content in *G. sepium* leaves that are approximately 19 kg K t^{-1} of dry leaves (De Costa et al, 2005). Zaharah and Bah (1999) reported that *G. sepium* leaves release nutrients especially K and Ca most rapidly. Hence, accelerated releasing may be the reason of observing high K in coconut intercropped with *G. sepium* under managed conditions compared to unmanaged condition in both estates, where only litter fall was the input for topsoil. Moreover, exchangeable K contents were always higher in topsoil, when compared to the subsoil irrespective of the location or depth. Recycling of considerable quantities of K by *G. sepium* may be a reason for observing relatively high levels of exchangeable K in the surface soils (SenevirathneBanda et al., 1992). Furthermore, loss of K by leaching may be another reason for observing relatively low levels of exchangeable K in subsoil. Hence, a general trend of decreasing K with increasing depth is possible in both locations.

In Rathmalagara Estate, sole *G. sepium* showed higher soil exchangeable Mg contents, while in Pallama estate; higher soil exchangeable Mg contents were observed in coconut with *G. sepium* under managed conditions (Table 08). *G. sepium* foliage contains 2.55% of Mg (Ngulube, 1994) and results concurs with the findings of Akinnifesi et al, (2006) who showed higher soil Mg levels were maintained through *G. sepium* prunings. However, in general exchangeable Mg was in a same range in both estates in all depths irrespective of treatments, after excluding the extreme value recorded in coconut with *G. sepium* under managed condition in Pallama Estate. As an estate with and older establishment date, *G. sepium* trees in Pallama Estate may store more Mg in the stems, later translocated to leaves and then to soil with a high frequency of lopping In addition, well developed deep root system of older trees in Pallama Estate may more efficient in mining more Mg compared to the recent establishment in Rathmalagara Estate.

Treatments with *G. sepium* showed lower SBD in contrast to sole coconut in both locations. The results are in harmony with Handawela and Kenderagama (1991) who reported that *G. sepium* mulch decreased the bulk density of soil. In corporation of *G. sepium* as a mulch including leaves and twigs may reduce bulk density more than when leaves are added alone, because of the higher lignin content of the former (Sangakkara et al., 2008). Gunasena et al, (1991) observed that by growing *G. sepium*, soil bulk density was reduced and steady infiltration rate was increased. Higher SMA values of all three depths were recorded from treatments with *G. sepium* in both locations. However, a contrasting trend observed in *G. sepium* that might be attributed to higher microbial activity by inducing the tree rhizosphere due to greater soil organic matter (Paul and Clark, 1989), and most likely due to the influence of general amelioration of soil conditions with incorporation and surface application of prunings (Lawson and Lal, 1979; Wilson et al., 1986). However, this study showed that treatments with higher SMA recorded higher SOM as well despite insignificant correlation coefficients. Furthermore, Munkholm et al., (2002) reported that effects of soil organic matter on crop production, through mechanisms such as improving aggregates and microbial activity. For plant materials, decay occurs through initial fragmentation by soil macrofauna (earthworm, millipedes, termites, etc) with further transformations being accomplished by microbial activity via enzyme production (Anderson et al., 1983). Thus, difference between the two locations may attributed by different ages after establishment, while within a same location maturity of leaf material especially in unmanaged conditions. The incorporation of organic resources into soil leads in general to an increase in soil microbial activity (Burket and Dick, 1998). Present study showed that SMA was decreasing with increasing in depth in corresponding treatments in both locations. The variation may due to the fact that the SOM content is highest in topsoil when compared to the subsoil. High soil respiration in topsoil than the subsoil, due to because of stratification of above ground biomass with litter fall and lack of energy supporting greater biomass in deeper soils. However the results are concurs with the findings of Menon et al., (2005) that SMA of topsoil was greater than the subsoil.

V. Conclusion

Intercropping coconut with *G. sepium* is an effective strategy to improve soil chemical, physical and biological properties. Most of soil properties i.e. soil microbial activity, bulk density, organic matter, total nitrogen, available phosphorus, exchangeable potassium and magnesium dynamics of coconut growing soils. Andigama series can be enhance by either incorporating *G. sepium* trees or incorporating leaves as a green manure. Even, the trees are unmanaged, i.e. without frequent lopping and without deliberate leaf incorporation than natural litter fall SOM can be improved in Andigma series soils in the intermediate zone. Therefore, just by including *G. sepium* trees to coconut cultivation is beneficial. Although, the impact was not pronounced as much as in intermediate zone, *G. sepium* can be effectively use in enhancing SOM in dry zone and scheduled management of crops would be beneficial in return. In contrary, total N content in coconut growing soils of dry zone can be improved by *G. sepium* under management, where deliberate incorporation can help slow amelioration of N. Being a K, Mg and Ca rich material, *G. sepium* also proved its efficiency in enhancing former chemical elements. Either managed or unmanaged trees, can be effectively use in both intermediate and dry zone. Especially, for soil exchangeable Mg, age and maturity is a significant factor as well as the climate. In this study, observed changes of soil bulk density was a little, and confined to topsoil in the intermediate zone coconut growing soils, although lopping were added. Fields in Pallama suggested that a long-term tree incorporation might have an impact to the bulk density into deep layers as well. Similarly, soil microbial activity can be improved by *G. sepium* managed and unmanaged conditions in intermediate and dry zone respectively.

Present study concluded that the coconut based *G. sepium* agroforestry system can be effectively use to improve soil fertility of degraded soils in Andigama series, thus enhance the productivity and longevity of coconut production in intermediate zone and dry zone of Sri Lanka.

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