The Journal of Agricultural Sciences - Sri Lanka
Vol. 21 No 1, January 2026. pp 200-213
https://doi.org/10.4038/jas.v21i1.12007

RESEARCH

Agronomic Strategies to Manage Soil Water Retention to Minimize Global Warming

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Received: 18th July 2025 / Accepted: 05th September 2025

ABSTRACT

Purpose: *This paper focuses on the problems of soil water depletion and greenhouse gas emissions caused by improper soil management practices in arable lands. The results of previous studies were analyzed and the effects of deep ploughing on highly and less compacted soil were discussed. In addition, the effect of organic matter incorporation on soil water retention, and greenhouse gas emissions was evaluated.*

Research Method: *To assess the impact of deep ploughing on soil moisture, two soil series (Andigama and Madampe) were selected. Moisture content was measured in ploughed and un-ploughed soil over a year using a neutron moisture meter. Coconut cultivations interplanted with nitrogen-fixing trees for eight years were used to assess soil improvement of the unproductive Andigama series. Soil compaction and water retention were measured using a cone penetrometer and neutron scattering technique in dry and rainy seasons. Palm oil sludge was mixed with sandy loam soil in various ratios and incubated for three months. Greenhouse gas emission was then analyzed using gas chromatography.*

Findings and Values: *The results indicated that deep ploughing significantly ($p<0.05$) improved soil water retention during both rainy and dry periods in compacted soils but had no significant ($p>0.05$) effect in less compacted soils due to disruption of natural pore structure. Alternatively, agroforestry systems with nitrogen-fixing trees enhanced the soil water retention in degraded lands. Furthermore, an optimal ratio (15%) of palm oil sludge incorporation into the soil under optimal water conditions reduced the emissions of greenhouse gases such as CH_4 and N_2O. Overall, the findings demonstrate that incorporating organic matter and adopting appropriate land management practices minimizes the emission of greenhouse gases, which is essential to reducing global warming and mitigating climate change impacts.*

Keywords: *Deep ploughing, Greenhouse gas emission, Organic matter incorporation, Nitrogen fixing trees, Soil water retention*

INTRODUCTION

Soil is one of the major natural resources for storing environmentally available rainwater and carbon dioxide (CO_2). Out of the several biological and physicochemical properties, soil pore structure and size distribution are essential attributes that determine the hydraulic properties, organic carbon dynamics, several other physical and chemical properties, microbial diversity (biota), and gas retention and exchange (Guo *et al.* 2020,

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Lu *et al.* 2020, Xia *et al.* 2020, Li *et al.* 2022). However, improper handling of arable lands deteriorates the naturally developed soil pore structure (Alskaf *et al.* 2021), which can lead to global warming and climate change due to the emission of greenhouse gases.

The impacts of climate change as a result of greenhouse gas emissions are global and widespread through all the components of the climate system, i.e., hydrosphere, biosphere, atmosphere, cryosphere and lithosphere. Climate change has a direct impact on many soil properties, including soil water, biota, organic matter and other physicochemical properties (Corwin 2021, Khan *et al.* 2021). Similarly, increasing temperature as a result of climate change increases soil microbial decomposition, releases more CO_2, which accelerates global warming and climate change (Knorr *et al.* 2005). Deep ploughing helps to alleviate soil compaction, but surface sealing due to deep ploughing of light-textured soil possibly creates an anaerobic situation that causes the emission of greenhouse gases (Vidhana Arachchi 2009).

Soil compaction is a common phenomenon in agricultural fields throughout the world (Batey 2009). The blocking of capillary fringes because of soil compaction (Vidhana Arachchi 2009, Luo *et al.* 2020) reduces water retention and infiltration, leading to reductions in both crop growth and productivity (Shah *et al.* 2017). The physical fertility of the soil will also be decreased with compaction as it hinders water and nutrient supply and retention. As a result, it increases the fertilizer and water (irrigation) demand, which leads to a higher cost of production (Hamza & Anderson 2005). Thus, to reclaim the soil compaction and enhance infiltration of water, deep ploughing can be used where it facilitates deep root penetration and soil water retention in drought-prone crop fields. While deep ploughing in poorly drained clay soils enhances root penetration, its effect on soil moisture status has received relatively less research focus.

The growth and activity of coconut roots depend on the aeration of the soil (Vidhana Arachchi 2009). In Sri Lankan coconut cultivations with less compacted, poorly drained soils, surface ploughing is typically used to encourage aeration (Vidhana Arachchi 2009). Poorly drained soils contain excess water that limits the air movement in the soil, resulting in improper root functions, lack of nutrients as a result of washout through runoff and finally, poor growth and yield (Hamza & Anderson 2005, de Lima *et al.* 2017, Nyéki *et al.* 2017, Correa *et al.* 2019). Not only that, but excess water also creates an anaerobic situation that results in greenhouse gas emissions. It was reported that deep ploughing of some soils (e.g., Regosol) increases soil strength and bulk density (Yavuzcan *et al.* 2005). Further, heavy machinery used in land preparation reduces pore volume in soil, which eventually decreases saturated hydraulic conductivity and porosity (Yavuzcan *et al.* 2005). Also, the gas exchange in the soil can be restricted by the excess water in the root zone (Lenzewski *et al.* 2018, Slamini *et al.* 2022).

Many studies have been undertaken to upgrade low-productive lands using agronomic practices, which improve the fertility status of soil (Lal 2006, LaFevor 2014, Ayub *et al.* 2020). However, the potential of multipurpose tree species to enhance physical conditions in degraded lands has received relatively little research attention. Rather than using deep ploughing to address soil compaction, planting crops with deep root systems, such as nitrogen-fixing trees (NFT), can be highly effective in reducing compaction while also enhancing green cover (Vidhana Arachchi & Liyanage 1997, Lawson *et al.* 2020). The presence of green cover substantially facilitates the assimilation of atmospheric CO_2. Species of NFT, including *Acacia auriculiformis* (Acacia), *Calliandra calothyrsus* (Calliandra), *Gliricidia sepium* (Gliricidia), and *Leucaena leucocephala* (Leucaena), exhibit significant potential as multifunctional tree species within agroforestry systems and can prove to be remarkably effective in enhancing the productivity of compacted soils that exhibit low fertility (Vidhana Arachchi & Liyanage 1997, Binayao III *et al.* 2021). In addition, the atmosphere can be polluted because of the improper amelioration of organic matter in arable lands, which also leads to decreased soil fertility. Anaerobic conditions in agricultural lands promote the production of methane (CH_4), while nitrous oxide (N_2O) is generated through the denitrification process, and the global warming potential of these two gases is greater than that of CO_2 (Chataut *et al.* 2023). Even though there are several recommendations, recent practices to minimize the emission of these gases are scant at the farmer level. Therefore, this study was conducted to evaluate sustainable soil management practices, such as deep ploughing, introducing NFT and organic matter incorporation, for improving degraded arable lands and mitigating their contribution to global warming.

MATERIALS AND METHODS

Experimental details

This study was conducted in Sri Lanka (7.8731° N, 80.7718° E), a tropical island located in the Indian Ocean. Sixteen major soil series in the country were classified into low and high productivity soils according to the coconut yield and the visual characteristics of the soil (Somasiri *et al.* 1994). As the initial step, the physical properties of the 0–10 cm layer in 16 soil series were assessed (Table 1). Based on the contrast in physical properties and moisture status as shown in Table 1, two soil series were chosen to assess the impact of deep ploughing on soil moisture status: the Andigama series (highly compacted and low productivity) and the Madampe series (less compacted and high productivity). According to the United States Department of Agriculture (USDA) soil classification, Andigama series and Madampe series belong to Rhodudults/Tropudults and Quartzipsamments, respectively (Mapa 2020). Field experiments were conducted separately in two soil series and their soil characteristics are mentioned in Table 1.

In the experimental site, a 5 × 5 m plots were selected at the center of the coconut square. Two days after the rainfall, this plot was ploughed up to 30 cm depth using a mouldboard plough connected to a two-wheel tractor (5 HP, YANMAR). Ploughing depth was selected according to the deep ploughing method used in Vidhana Arachchi (2009). In the Andigama soil series, the initial gravimetric moisture content (at ploughing) was 10.6±0.5%, while the value was 6.8±0.8% in the Madampe soil series.

The plots without ploughing and with grass were considered as the control, while bare soil treatments were the plots in which grass cover was cleared. Five replicates were allocated for each treatment resulting in a total of fifteen plots.

Depletion of soil water

A neutron moisture meter (Model 4302, SN. 166, Troxler) was used to measure the soil moisture. In every plot, aluminium access tubes were installed up to 1 m depth using a steel guide tube. A length of 20 mm of each tube was exposed above ground level, where rubber bungs were used to seal the tubes. Prior to the measurement, the instrument was calibrated for each soil horizon in both soils.

The measurements were obtained at weekly intervals in ploughed soil, bare soil and grass-covered soil of both Andigama and Madampe series for 12 months, covering the dry and rainy period in the year 1998. The method developed by Bell (1987) was used to calculate the fluctuation of soil moisture.

Evaluation of the effect of nitrogen-fixing trees

In another location of the Andigama series, 10 soil pits (1 × 1.5 × 1.5 m) were cut randomly, and the physical properties such as bulk density (undisturbed core method) and root growth of NFT species in soil horizons were evaluated. The 0–15, 15–50, and 50–100 cm depths were named as A, AB, and B, respectively. Coconut plots interplanted with 8-year-old NFT species (*Acacia auriculiformis*, *Calliandra calothyrsus*, *Gliricidia sepium* and *Leucaena leucocephala*) in Andigama series were used to evaluate the soil improvement. Pits of similar dimensions were cut near the root zone of NFT and the same physical properties were evaluated. This method was similar to the method used in Vidhana Arachchi & Liyanage (1997).

Organic matter incorporation and greenhouse gas emissions

As a soil conditioner, palm oil sludge (POS), the palm oil mill effluent rich in organic solids, was used. Different ratios of POS mixed with sandy loam soils were allowed to decompose for a period of three months (January to April 1998) under incubation conditions. Emissions of CH_4, N_2O, and N_2 were measured from soils amended with POS at higher (>20%) and lower (<5%) application rates, relative to the 15% amendment and the control.

To analyze the release of greenhouse gases, 300 μL of gas samples of the headspace of incubated soil mixtures were extracted with 1 mL syringes. A Shimadzu gas chromatograph (GC-14A) was used to analyze the gas extract, equipped with a flame-ionization detector (FID) and a 1.8 m $\times$ 0.3 cm OD glass "Poropak Q" column: 50–80 mesh. Helium was used as the carrier gas. The calibration graph was drawn using standard gases of CH_4, N_2O and N_2.

Data analysis

The data were analyzed using the JMP Statistical Discovery Software Package (Version 3.2.2) from SAS Institute. The Tukey–Kramer Honestly Significant Difference (HSD) test was employed to perform the analysis of variance and compare means at different probability levels ($p<0.05$, $p<0.01$, and $p<0.001$).

RESULTS AND DISCUSSION

Physical properties of major soil series

The summary of soil physical properties in coconut growing major soil series in Sri Lanka is shown in Table 1. The mean bulk density of the 0–10 cm depth (surface soil) was 1.49±0.05 g cm^{-3} with a range of 1.38±0.02 to 1.57±0.07 g cm^{-3}. The soil penetration resistance (SPR) varied from 55±10.0 to 315±16.4 N cm^{-2} (Table 1). The bulk density exceeded 1.5 g cm^{-3} in six soil series: Kuliyapitiya, Wariyapola, Wilpattu, Kurunagala, Andigama and Boralu (Table 1). According to Vidhana Arachchi *et al.* (2000), in the Andigama series, a substantial proportion of clay particles was observed to accumulate within the soil profile, which was interspersed with gravels, resulting in the formation of rigid strata that could detrimentally influence the growth of coconut root systems.

The present results show high SPR which exhibited a statistically significant ($p<0.05$) positive correlation with the bulk density (Fig. 1). In contrast, the total air-filled porosity experienced a significant decline ($p<0.05$) as a consequence of subsoil compaction (Table 2). The findings indicated that the volume of micropores (%) and the total available water (vol.%) exhibited a significant increase ($p<0.05$) in relation to the clay content (%) (Table 2). On the other hand, the total available water demonstrated a significant reduction ($p< 0.05$) as soil compaction intensified (Table 1). Subsoil compaction was found to diminish nutrient and water use efficiencies in wheat cultivated in sandy clay loam soil, with the reductions of 38% in the initial year and 9% in the subsequent year (Ishaq *et al.* 2001), which can also be expected in the study locations. Land preparation using heavy machinery can lead to soil compaction, which damages soil structure and reduces macropore volume (Yavuzcan *et al.* 2005, Bennett *et al.* 2019, Laker & Nortjé 2020, Gursoy 2021). It is evident from the results that highly compacted coconut growing soils resulted in a reduction of macropores, which decreases the aeration capacity.

Hence, the implementation of suitable management strategies is imperative to mitigate soil compaction and to enhance soil moisture levels. Given that compacted soil inhibits the absorption of water by coconut roots, an SPR threshold below 250 N cm^{-2} is considered favourable for efficient water uptake (Vidhana Arachchi *et al.* 1999). In this regard, two distinct soil series identified as marginal and highly suitable soil types (Somasiri *et al.* 1994) were selected to assess the impact of deep ploughing on the status of soil water. The low productivity soil series under consideration was the Andigama series (characterized by bulk density exceeding 1.5 g cm^{-3}; SPR greater than 250 N cm^{-2}), while the high productivity

Table 1. Soil physical properties in the surface (0–30 cm depth) of major soil series of coconut lands in Sri Lanka – adapted from Vidhana Arachchi (2009).

Soil series	BD[a] ($g\ cm^{-3}$)	PR[b] ($N\ cm^{-2}$)	TAW[c] (vol.%)	Macro[d] (%)	Micro[e] (%)	Sand (%)	Silt (%)	Clay (%)
Andigama	1.55 ± 0.08	300 ± 18.5	9.05 ± 1.23	26.40 ± 2.65	15.20 ± 2.45	80.85 ± 6.21	4.80 ± 1.13	14.32 ± 2.13
Kuliyapitiya	1.51 ± 0.06	280 ± 13.3	9.60 ± 1.65	27.21 ± 3.45	16.72 ± 3.12	78.12 ± 4.55	7.76 ± 2.31	14.12 ± 2.44
Kurunagala	1.52 ± 0.07	285 ± 15.7	9.45 ± 1.22	27.88 ± 4.31	16.11 ± 2.76	77.23 ± 3.56	8.21 ± 1.76	13.98 ± 1.99
Boralu	1.57 ± 0.07	315 ± 16.4	8.05 ± 0.98	28.34 ± 3.15	12.67 ± 2.46	80.97 ± 5.76	5.54 ± 2.11	13.34 ± 3.45
Madampe	1.48 ± 0.02	240 ± 16.3	5.71 ± 0.89	34.40 ± 3.21	9.80 ± 1.23	86.10 ± 5.43	2.68 ± 0.97	10.80 ± 2.63
Rathupasa	1.49 ± 0.03	248 ± 12.6	7.54 ± 0.98	32.67 ± 3.34	11.12 ± 0.96	84.54 ± 3.42	3.21 ± 0.67	11.98 ± 3.12
Katunayake	1.43 ± 0.02	225 ± 8.5	5.23 ± 0.87	38.12 ± 2.34	8.90 ± 1.20	88.45 ± 3.21	4.12 ± 0.23	9.87 ± 3.56
Pallama	1.48 ± 0.02	245 ± 10.2	7.89 ± 1.21	33.60 ± 3.70	10.24 ± 3.40	83.70 ± 4.23	4.45 ± 2.10	12.67 ± 2.45
Wariyapola	1.52 ± 0.03	275 ± 14.4	10.00 ± 1.42	25.32 ± 4.65	17.12 ± 3.33	76.12 ± 4.56	10.12 ± 2.10	13.76 ± 3.23
Melsiripura	1.49 ± 0.02	245 ± 16.5	8.92 ± 1.02	31.01 ± 2.10	12.96 ± 1.66	82.67 ± 3.24	5.43 ± 1.65	12.56 ± 2.11
Gambura	1.48 ± 0.01	248 ± 8.5	7.11 ± 1.54	32.10 ± 2.31	11.34 ± 1.32	83.70 ± 2.24	4.88 ± 1.99	12.11 ± 1.99
Wilpattu	1.52 ± 0.05	275 ± 12.2	9.97 ± 0.98	26.21 ± 1.23	16.18 ± 2.45	77.31 ± 4.65	10.21 ± 1.23	12.48 ± 2.12
Mavillu	1.48 ± 0.03	248 ± 8.5	7.23 ± 0.34	33.13 ± 0.98	12.88 ± 1.55	82.73 ± 3.65	4.32 ± 1.65	13.01 ± 2.66
Borupan	1.47 ± 0.01	245 ± 15.0	7.76 ± 1.20	33.90 ± 2.70	10.90 ± 1.33	83.10 ± 4.31	2.98 ± 0.96	13.13 ± 2.34
Welikatiya	1.38 ± 0.02	55 ± 10.0	1.38 ± 1.01	41.93 ± 2.54	6.82 ± 0.98	96.78 ± 2.43	1.98 ± 0.45	1.55 ± 0.45
Sudu	1.41 ± 0.02	60 ± 15.6	1.41 ± 0.32	40.12 ± 5.66	7.52 ± 1.33	96.12 ± 2.21	2.21 ± 0.98	1.67 ± 0.76

±SD; n = 10

[a]BD = Bulk density; [b]PR = Penetration resistance; [c]TAW = Total available water;
[d]Macro = macropores; [e]Micro = micropores.

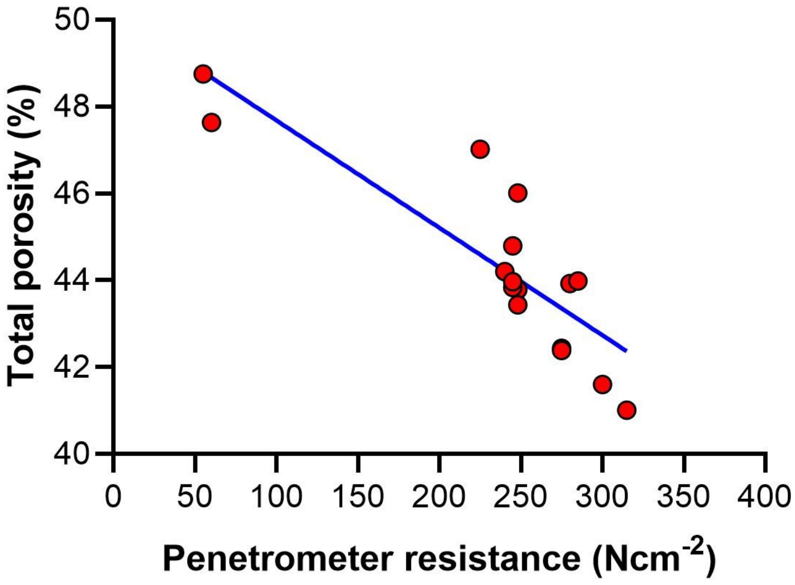

Figure 1. Correlation between total air-filled porosity and subsoil compaction.

Table 2. Correlation matrix of soil physical properties in the surface of major soil series of coconut lands in Sri Lanka.

Variable	PR[a] (N cm^{-2})	TAW[b] (vol.%)	Macro[c] (%)	Micro[d] (%)	TP[e] (%)	Sand (%)	Silt (%)	Clay (%)
PR[a] (N cm^{-2})	1.00	0.92	-0.86	0.76	-0.86	-0.91	0.58	0.98
TAW[b] (vol.%)	0.92	1.00	-0.93	0.89	-0.83	-0.98	0.76	0.94
Macro[c] (%)	-0.86	-0.93	1.00	-0.96	0.89	0.95	-0.82	-0.83
Micro[d] (%)	0.76	0.89	-0.96	1.00	-0.72	-0.93	0.89	0.76
TP[e] (%)	-0.86	-0.83	0.89	-0.72	1.00	0.82	-0.58	-0.80
Sand (%)	-0.91	-0.98	0.95	-0.93	0.82	1.00	-0.82	-0.93
Silt (%)	0.58	0.76	-0.82	0.89	-0.58	-0.82	1.00	0.56
Clay (%)	0.98	0.94	-0.83	0.76	-0.80	-0.93	0.56	1.00

[a]PR = Penetration resistance; [b]TAW = Total available water; [c]Macro = macropores; [d]Micro = micropores; [e]TP = Total porosity.

counterpart was the Madampe series (with bulk density below 1.5 g cm^{-3}; SPR less than 250 N cm^{-2}).

Effect of deep ploughing on soil water status

Highly compacted soil – *Andigama* Series: Compared to the *Madampe* series, which has a light-textured soil, the *Andigama* series exhibited high compaction as a major constraint to coconut cultivation, adversely affecting the total available water fraction (Table 1). Therefore, deep ploughing can be an effective method to improve the total available water fraction in this soil series. Fig. 2 illustrates the variations in soil moisture to a depth of 1 meter across rainy and dry seasons under conditions of deep ploughing, grass coverage, and bare soil.

In the *Andigama* series, bare soil demonstrated a lower capacity to retain water during the rainy season compared to grass-covered soil, likely due to reduced infiltration and increased runoff. However, soil water content significantly ($p < 0.01$) increased in deep-ploughed soil compared to both bare soil and grass-covered soil in the *Andigama* series. Deep ploughing disrupts compacted hard layers, promoting water infiltration into sub-horizons (Contreras 2003).

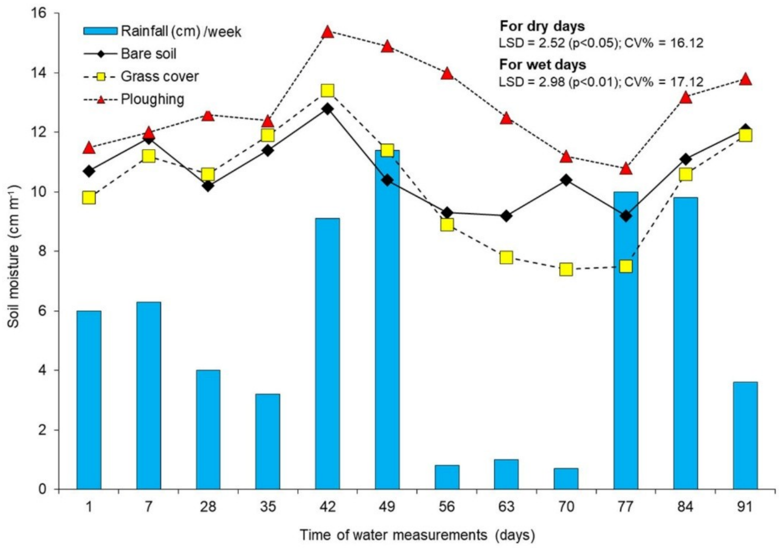

Figure 2. Variation of soil moisture with the effect of deep ploughing, grass cover and bare soil in highly compacted Andigama series.

During the prolonged dry spell (56–77 days), ploughed *Andigama* series soils exhibited significantly higher ($p < 0.05$) water retention, recording 10.4 cm m^{-1} and 16.9 cm m^{-1} greater retention compared to bare and grass-covered soils, respectively (Fig. 2). Reduced soil moisture levels observed in grass-covered plots in contrast to other treatments can be attributed to soil moisture depletion through the process of evapotranspiration during dry conditions. Furthermore, loosening compacted soil through intensive ploughing resulted in a statistically significant ($p < 0.05$) higher water conservation compared to other treatments, presumably due to increased water storage capacity within the soil profile during the wet season (Fig. 2). Previous studies have shown that deep ploughing of severely compacted soils promotes increased and more profound root development, thereby improving water utilization efficiency in comparison to conventional tillage (Guan *et al.* 2015).

Light textured soil – *Madampe* Series: The soil moisture fluctuations in the *Madampe* series were analyzed under deep ploughed, grass-covered, and bare soil conditions during both rainy and dry periods (Fig. 3). Following deep ploughing, soil moisture retention during the rainy season was not significantly higher than in grass-covered or bare soil. This may be due to the disruption of the natural pore structure during deep ploughing, which limits soil water retention. Additionally, water loss through deep percolation further reduces moisture conservation. Surface sealing accelerates soil erosion, potentially leading to environmental pollution and negatively impacting green cover (Tobias *et al.* 2018).

Apart from deep percolation losses during the rainy season, increased evaporation during dry periods also contributes to low soil water conservation in this soil series (Fig. 3). During the dry period (56 to 77 days), the ploughed *Madampe* series showed a water reduction of 6.55 cm m^{-1} compared to bare soil and 5.45 cm m^{-1} compared to grass-covered soil. It was reported that a higher volume of water can be conserved in deep ploughing, which can also induce evaporation (Stenitzer & Murer 2003, Yavuzcan *et al.* 2005). Complementary to our findings, Goldsworthy (1997) stated that deep ploughing of light-textured soil was not an economical management practice and did not show significant benefits on the yield of some of the crops such as wheat and barley. The treatment with the grass cover showed a higher soil water content than the bare soil during the rainy period, which may be associated with the infiltration. However, it was lower compared to bare soil in the dry period due to transpiration (Fig. 3).

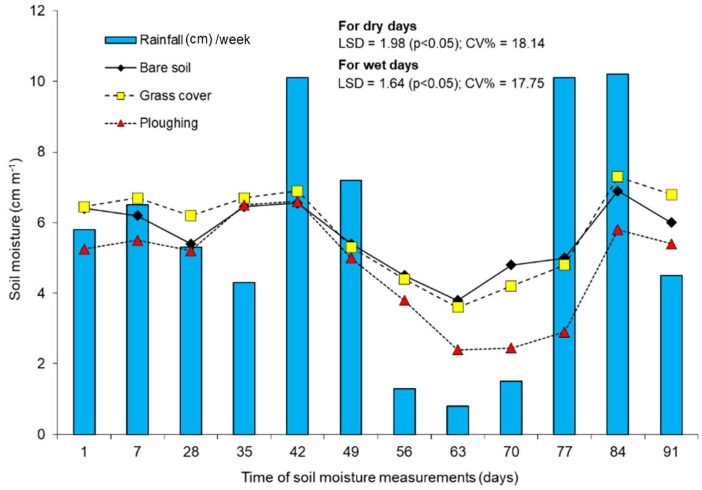

Figure 3. Variation of soil moisture with the effect of deep ploughing, grass cover and bare soil in less compacted Madampe series.

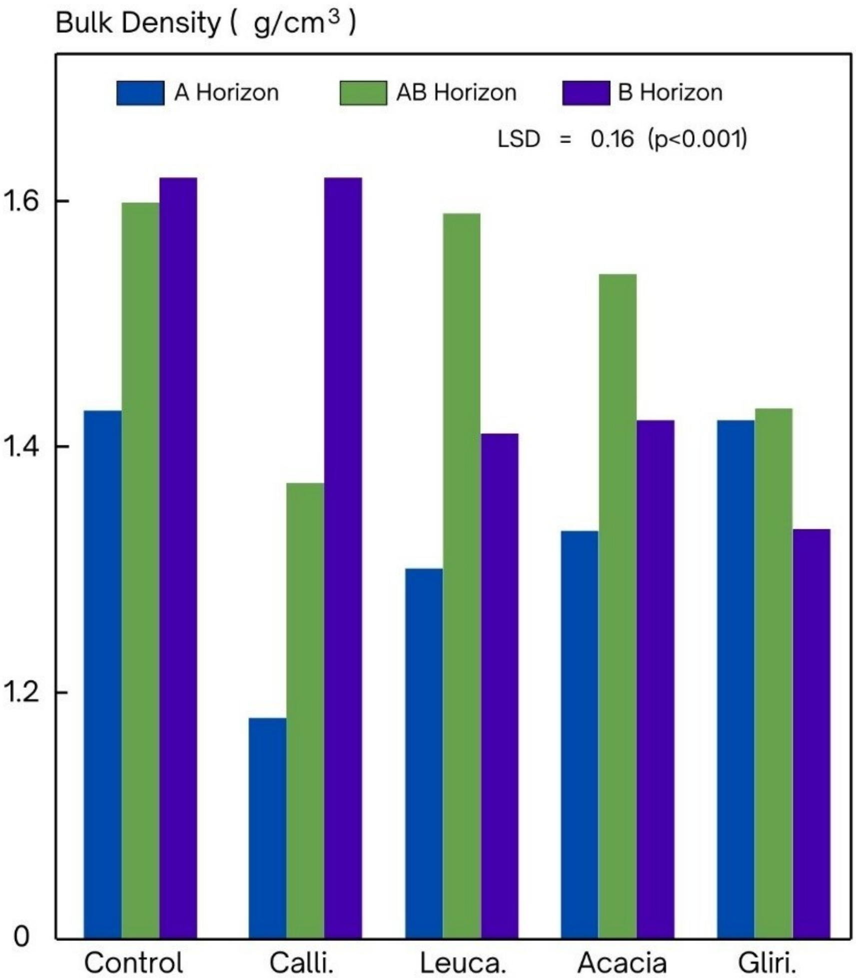

Figure 4. Coconut root growth in plots interplanted with NFT species in Andigama series.

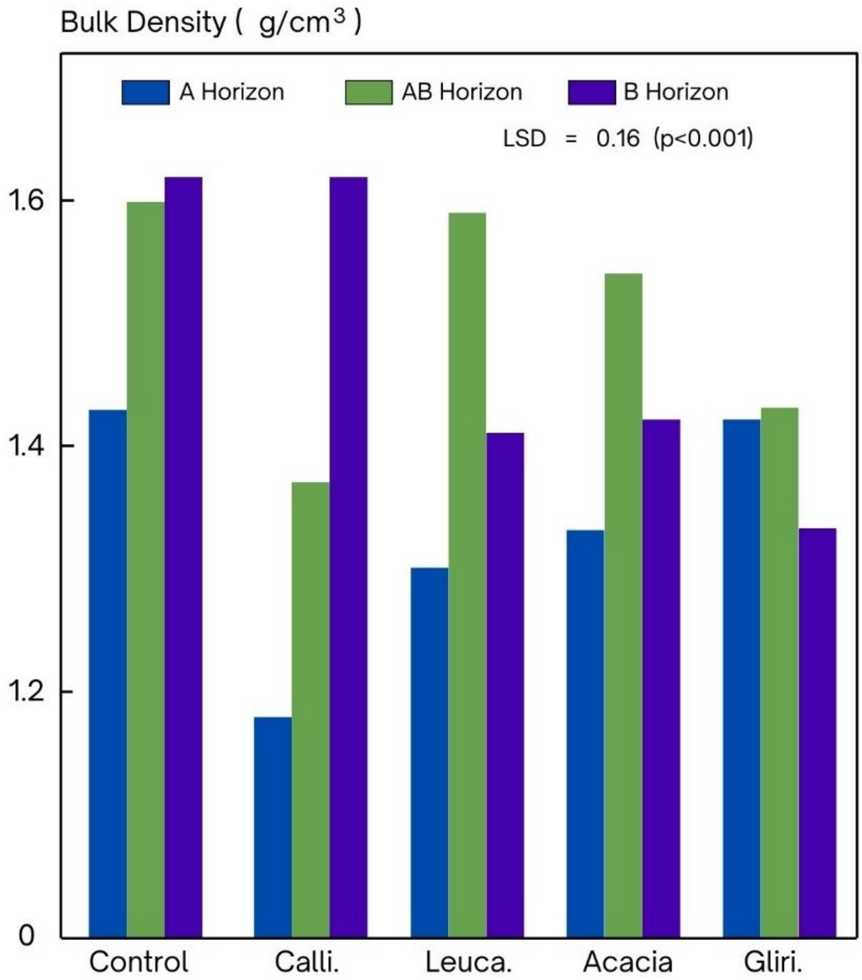

Figure 5. Effect of interplanting NFT species on bulk density of Andigama series soils.

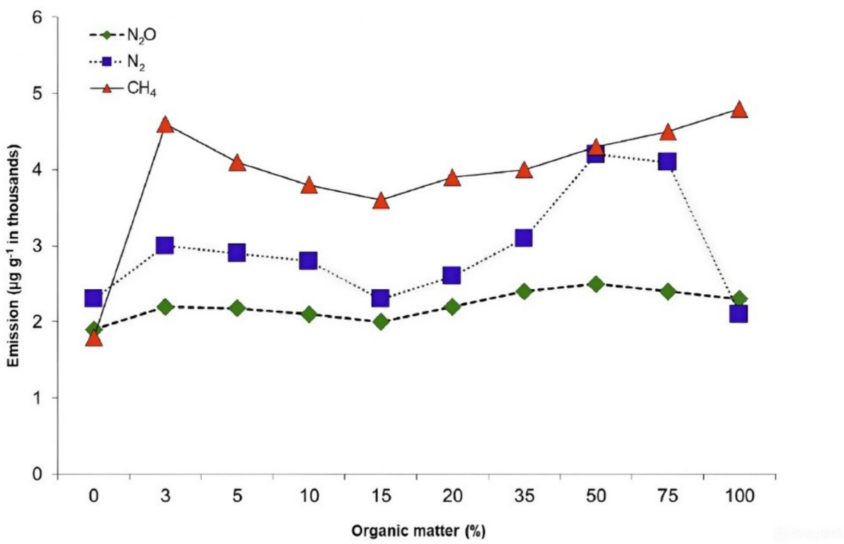

Figure 6. Greenhouse and nitrogen gas emission in palm oil sludge (POS) amended soil.

Nitrogen-fixing trees (Agroforestry) related to soil compaction

Vidhana Arachchi & Liyanage (1997) reported that root development of NFT species across the different horizons of the Andigama soil series, characterized by high compaction, was confined to a maximum depth of 1.25 m and a lateral spread of 1.5 m from the plant. Moreover, *Gliricidia* roots displayed a superior capacity to penetrate the B horizon (451 g m^{-3}) relative to the other species examined. The findings also indicated that *Calliandra*, *Gliricidia*, and *Acacia* were responsible for a greater proliferation of roots throughout the soil profile of the Andigama series. The penetrative action of roots was found to be exceptionally beneficial in ameliorating the compacted layers of the Andigama series, as shown in Fig. 4.

Bulk density, especially in the AB and B horizons, decreased in all plots where NFT species were interplanted (Fig. 5). Nevertheless, a significant reduction in bulk density ($p < 0.001$) was observed in the AB and B horizons of the plots interplanted with *Acacia* and *Gliricidia*, in comparison to the control group, while the A and AB horizons of the *Calliandra* plots demonstrated a significant ($p < 0.05$) reduction relative to the other species. Cumulatively, the findings indicated that the interplanting of *Gliricidia* and *Acacia* was notably more efficacious in enhancing the bulk density of the Andigama series (Fig. 5). This enhancement could be attributed to their substantial root growth and penetrative root systems.

Overall results showed that instead of deep ploughing, the establishment of agro-forestry systems such as NFT reduced the bulk density, improving soil physical properties of degraded lands. It is evident from the results that root penetration of NFT into degraded soil effectively ameliorates naturally developed hard gravelly conditions in low productive soils.

Emission of CH_4, N_2O and N_2

CH_4, N_2O and N_2 emissions were detected in different palm oil sludge incorporated soils (Fig. 6). Significantly ($p<0.05$) increased cumulative CH_4, N_2O and N_2 emissions were observed at both higher (>20%) and lower (<5%) rates of palm oil sludge amended soils when compared with the 15% amended and the control. Hence, lower and higher rates of organic matter amendment into soil create favorable anaerobic conditions for microbial growth that emit CH_4 and N_2O. Therefore, organic matter amendment into the soil at optimum ratios can minimize the production of greenhouse gases.

Impact of moisture and pore size distribution on CH_4, N_2O and N_2

As observed by Vidhana Arachchi & Nor (1994), the images from Scanning Electron Microscopic (SEM) of POS amended soils showed that sludge incorporation at higher rates (>35%) blocks the soil pores, inhibiting oxygen movement. This condition facilitates the anaerobic condition, leading to increased CH_4, N_2O, and N_2 emissions.

Further, the absorption of water by sludge particles is low at a lower POS incorporation (5%), which leads to a higher amount of freely available water, blocking micropores of the soil and creating an anaerobic condition. This is one of the reasons for the increased emission of the above gases at a lower POS mixture rate. It is also evident that a lower sludge incorporation rate resulted in more macropores compared to the higher rates of POS addition (Vidhana Arachchi & Nor 1994). Accordingly, incorporation of organic matter can be used to manage the higher emission of these gases, as which 15% POS soil mixture reduced the emission rates of greenhouse gases, compared to lower and higher rates of organic matter amendments.

It was evident that the growth of methanogenesis and denitrifying bacteria could be restricted due to the pore size distribution of the 15% POS amended soil, which eventually reduces the emission rates of greenhouse gases. Overall results of the study show that a proper amount of organic matter incorporation into the soil is favorable to minimize the denitrification and methanogenesis processes, which may be helpful in reducing environmental pollution through the emission of gases (Li *et al.* 2016, McGeough *et al.* 2016). The reduction of the emission of greenhouse gases eventually helps mitigate climate change.

CONCLUSION

It is evident from the results that soil compaction limits the available water in the soil profile of Andigama series. Deep ploughing promotes soil water conservation in such highly compacted soil, while deep ploughing depletes soil water in light-textured soil like Madampe series. Moreover, interplanting NFT in coconut fields improves the aeration status and available soil water. Root penetration of NFT into degraded soil is a "natural" phenomenon which, in turn, may effectively ameliorate naturally developed hard gravelly conditions in low-productive soils. In addition, incorporation of organic matter such as palm oil sludge into the soil at optimum ratios promotes soil water status and avoids emission of greenhouse gases. Improved soil moisture promotes the growth of green canopy which absorbs atmospheric CO_2 and reduction of greenhouse gases such as CH_4 and N_2O, minimizing global warming.

Acknowledgements

The Director, Technical and field staff of the Coconut Research Institute of Sri Lanka for providing facilities and invaluable support to conduct the study effectively, are greatly acknowledged.

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