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Effect of Intercropping Mango with Lemongrass and Screwpine on the Soil Carbon Dioxide Flux and Soil Microbial Density

Iqbal Usamah[1], Lee Yit Leng[1], Noor Hasyierah Salleh[2], Norawanis Abdul Razak[1]

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ABSTRACT

Background: An intensification of mono-cropping system has been increasing greenhouse gas emissions and loss of biodiversity. Intercropping offers a potential alternative to mono-cropping in lowering the environmental influences on agriculture. Virtually, no information is available on how intercropping with aromatic plants influences soil agroecosystems and hence present study was conducted to evaluate the effects of intercropping mango (*Mangifera indica*) with lemongrass (*Cymbopogon nardus*) and screwpine (*Pandanus amaryllifolius*) on soil CO_2 flux and microbial density vis-a-vis mango monocrop.

Methods: The field trial involves mango-screwpine intercrop, mango-lemongrass intercrops and mango monocrop. The soda lime method was used for the measurement of soil CO_2 flux. Soil microbial density was assessed by using the spread plate method with *Beijerinkia* and *Pikovskaya* medium.

Result: The results indicated that intercropping with aromatic plants increased the carbon allocation in promoting the root growth and thereby reduced the soil CO_2 emission. In addition, intercropping plots had large number of phosphate-solubilizing microorganisms than the mono-cropping. To finetune the findings of the experiment on the dynamics of soil nutrients, further study in protected environment is required.

Key words: Aromatic plant, Lemongrass, Mango, Mono-cropping, Soil nitrogen.

INTRODUCTION

Mango (*Mangifera indica* L.) is widely cultivated in tropical and sub-tropical regions (Akin-Idowu *et al*., 2020) and extensively consumed globally. Approximately 50.65 million metric tonnes of mangoes were produced worldwide in 2027, spanning over 4.37 million acres (Akin-Idowu *et al*., 2020). In Malaysia, mango production in 2020 recorded an average yield of 4.0 metric tonnes per hectare, with a total output of 12,834.40 metric tonnes (Department of Agriculture, 2020).

In general, mango orchards are established as monocrop with wide spacing to accommodate the large size of the trees and also to facilitate agro-management. This practice of growing a single crop species simplifies management for farmers, allowing them to streamline cultivation practices effectively. However, this intensive monoculture farming method, depends largely on synthetic fertilizers and pesticides, can significantly degrade soil health and disrupt the surrounding ecosystem (Dias *et al*., 2020; Sharma *et al*., 2000). Moreover, mono-cropping practice was found to have negative effect on soil microbial density and diversity in long term (Lulie, 2017) and accelerate the soil CO_2 flux to atmosphere and in turn loss of essential nutrients into surrounding environment (Dyer *et al*., 2012). Indeed soil CO_2 flow is a good soil health indicator because it aids in determining the rate at which soil microorganisms degrade soil organic matter (Giacomo *et al*., 2014).

Intercropping can be an alternative to mono-cropping as it reduces the environmental impacts on agriculture. Intercropping is a multiple cropping technique that maximizes output from crops cultivated with little input use while utilizing existing resources more efficiently (Khomphet *et al*., 2021; Maitra *et al*., 2021). Kishore *et al*., (2021) reported that mango tree canopy provide shade to the pineapple and thereby increased the yield of pineapple. Zhong and Zeng (2019) reported that intercropping peanut with cowpea significantly enhanced microbial density compared to monocropping system. However, intercropping has drawbacks, including reduced availability of nutrients, water and light, but it nevertheless produces a lower yield (Murtaza *et al*., 2020). Abagandura *et al.* (2020) opined that intercropping of Prairie cordgrass with kura clover emitting higher cumulative CO_2 flux compared to Prairie cordgrass monocrop. Low temperature, carbon input and slow turnover time of carbon are the way to keep the soil CO_2 emission in check (Pries *et al*., 2017).

Aromatic plant intercropping is a novel strategy to be applied in an agro-ecosystem to keep the growing medium

[1]Faculty of Mechanical Engineering and Technology, University Malaysia Perlis, Malaysia.
[2]Faculty of Chemical Engineering and Technology, University Malaysia Perlis, Malaysia.

Corresponding Author: Lee Yit Leng, Faculty of Mechanical Engineering and Technology, University Malaysia Perlis, Malaysia. Email: yllee@unimap.edu.my

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healthy. Both screwpine (*Pandanus amaryllifolius*) and lemongrass (*Cymbopogon nardus*) can thrive in the warm, humid climate of the tropics, making them suitable companion plants for mango trees (Skaria *et al*., 2006; Wongpornchai, 2006). This promising approach should be widely adopted to enhance the regenerative capacity of aromatic plants for subsequent harvests and to facilitate their rapid expansion into surrounding areas. As the literature is virtually silent on how intercropping mango with pandan and lemongrass influences soil microbial density and CO_2 flux, the present study was undertaken to comprehend the system in relation to the above-mentioned activities.

MATERIALS AND METHODS

A field experiment was conducted during 2021 to 2023 in a mango orchard (941.88 m²) of Chuping, Perlis, Malaysia (6°31′21.9″N, 100°17′08.4″E) in collaboration with Universiti Malaysia Perlis. Data were collected at six (vegetative), 12 (reproductive) and 18 months (post-harvesting) from seven-year-old mango trees planted in fine sandy loam soil (Ultisol) at 15 × 5 m spacing. The orchard was fertilized with 30 kg of organic fertilizer biannually. Annual rainfall was 1318.38 mm (2021-2022) and 1111.29 mm (2022-2023), with temperatures ranging from 24°C to 33.86°C. A randomized complete block design (RCBD) was employed for the experiment, consisting of five replications distributed in plots size of 1125 m^2. Treatments included mango monocropping (T1), mango-pandan intercropping (T2) and mango-lemongrass intercropping (T3). Aromatic plants (*Pandanus amaryllifolius* and *Cymbopogon nardus*) were vegetatively propagated and transplanted between mango trees at 1 × 1 m spacing in 15 m rows.

Soil samples (20 g) were randomly collected at 0-15 cm and 15-30 cm depths using a soil auger. Soil available C and N were measured using a CHNS analyser (PE 2400 SERIES II, Perkin Elmer, USA). Soil CO_2 flux was measured using the soda lime technique (Keith and Wong, 2006) with five PVC chambers per plot. The efflux of CO_2 was calculated as:

$$CO_2 \text{ efflux} = (G\text{-}g \times 1.69)/A \times (24\ h)/H \times 12/44$$

Where,

G = Weight gain of sample.

g = Average blank weight gain.

A = Area of chamber and H is the exposure time.

Soil microbial analysis for *Azotobacter* and phosphate-solubilizing microorganisms (PSM) was carried out using the spread plate method with Beijerinkia's and Pikovskaya mediums, respectively (Motsara and Roy, 2008). Comparison of treatments was done with the use of Tukey's test at $p<0.05$ and the significant effects of the treatments were ascertained by analysis of variance (ANOVA). For the statistical study, version 9.2 of the Statistical study System (SAS) software was used.

RESULTS AND DISCUSSION

Soil carbon and nitrogen analysis

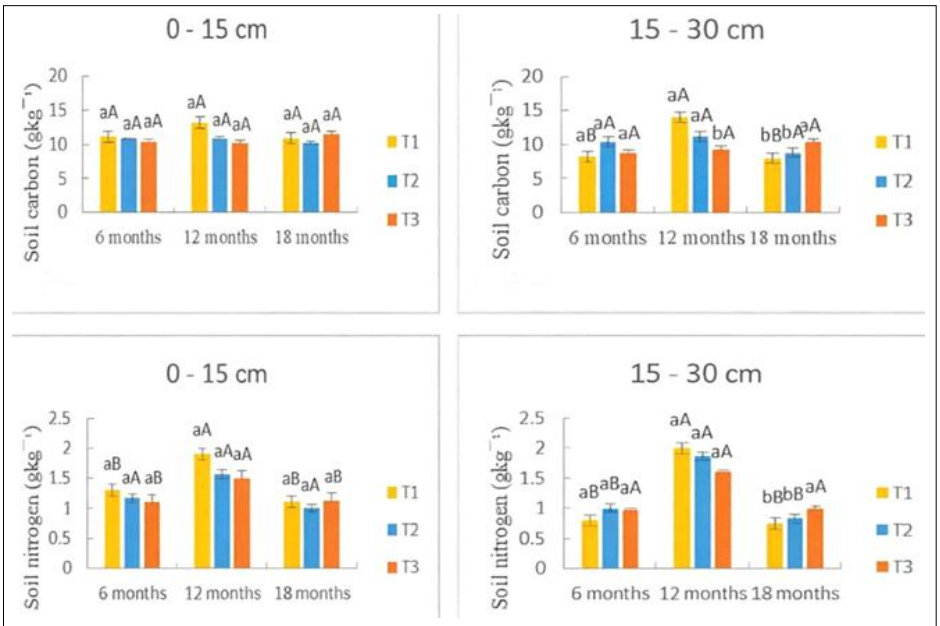
Utilising aromatic plants as companion plants is a novel strategy for an agro-ecosystem. It maximizes land usage and generates additional income for the grower. After 18 months of intercropping mango and aromatic plants, there were no discernible changes between any plots for soil C and N at both depths (Fig 1). When comparing planting months in the T1, mono-cropping system across soil depths, soil C content was lowest at six months, peaked at 12 months, but declined thereafter (Fig 1). Similarly, a comparable trend was noted for the soil N levels in both T1 and T3 at a depth of 0-15 cm. Nevertheless, T3 had a relatively high soil C and N content with depth compared with T2 and T1 after 18 months planting. The highest organic matter input by the high leafy biomass of lemongrass in T3 had increased the soil C and N with depth after 18 months planting. This finding is consistent with the increasing soil organic matter can enhance the soil C and N level (Saha *et al*., 2024; Malone *et al*., 2023; Bhatt *et al*., 2019). Pankaj *et al.* (2017) has also reported that the lemongrass cultivation can enhance soil C and N levels as the plants form dense clumps over time.

Soil bulk density, soil moisture and soil temperature analysis

Bulk density (BD) is commonly used to assess the soil's capacity for gas exchange, water retention and its suitability for supporting plant growth (Rabot *et al*., 2018). Between all plots, there were no variations in the soil's BD and soil moisture (MC) (Table 1). Comparing planting months, treatment T1 initially exhibits the lowest MC for the first 6 months, but thereafter, it displays a rising trend at 18 months after planting. Lower soil MC in monocrop also observed by Mendis *et al*. (2022). This implies that soils subjected to intercropping demonstrate an enhanced capacity to retain moisture over prolonged durations compared to mono-cropping treatments. High precipitation received during the post-harvest of mango tree could explain a relatively high soil MC across all the treatments. On average, there were no statistical differences in soil temperature across the treatments after 6 months of intercropping with aromatic plants (Table 1). However, treatment T2 had a lower soil temperature after 12 months of intercropping with screwpine. This suggests that the fast spreading and broad leaves of screwpine trees providing a shade and thereby resulting in a relatively low soil temperature in T2 after 12 months planting. After 18 months of planting, there were no variations in soil temperatures among the treatments. When comparing the planting months, the soil temperature was notably lower during the initial 6 months of planting across the treatments. This observation may be attributed to the reduced rainfall during the vegetative stage of the mango trees. Additionally, pruning activities, conducted for flushing induction, may have reduced shade coverage, consequently increasing soil temperature during this period.

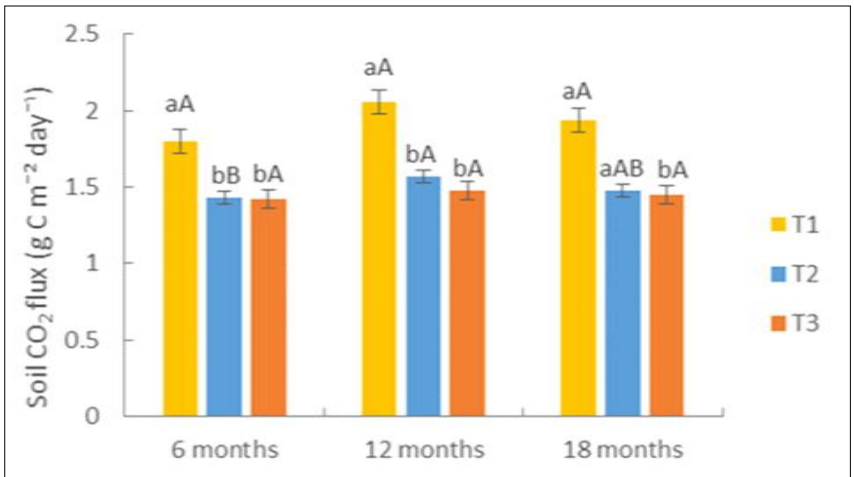
Soil carbon dioxide (co_2) flux and microbial density

Regulating the soil CO_2 emission is essential measure to mitigating global climate change (Ibrahim *et al*., 2023). Plot T1 had the highest soil CO_2 flux across all the plots throughout 18 months of planting (Fig 2). Our findings suggest that intercropping mango tree with the aromatic plants can sequester more carbon in the soil. Intercrops increase the carbon allocation in promoting the root growth and thereby reduce the soil CO_2 emission (Machado *et al*., 2016). It appears that the T2 intercrop with screwpine



Values are means of three replicates followed by ± standard error of means (n = 3). T1, T2 and T3 denote mango mono-cropping, pandan intercropping and lemongrass intercropping, respectively. Lowercase letters above error bars indicate significant differences between plots within the same planting months ($p<0.05$), while distinct capital letters show significant differences for the same plots across three planting months ($p<0.05$).

Fig 1: Impacts of various farming techniques on the soil carbon and nitrogen at depths of 0-15 cm and 15-30 cm.



Values are means of three replicates followed by ± standard error of means (n = 3). T1, T2 and T3 denote mango mono-cropping, pandan intercropping and lemongrass intercropping, respectively. Lowercase letters above error bars indicate significant differences between plots within the same planting months ($p < 0.05$), while distinct capital letters show significant differences for the same plots across three planting months ($p<0.05$).

Fig 2: Impacts of various farming techniques on the soil carbon dioxide flux.

Table 1: Impacts of various farming techniques on the soil bulk density (BD), soil temperature and soil moisture content (MC).

	Soil BD (g cm^{-3})			Soil temperature (^{o}C)			Soil MC (%)		
	6 months	12 months	18 months	6 months	12 months	18 months	6 months	12 months	18 months
T1	1.61±0.04aA	1.62aA	1.59±0.02aA	24.83±0.19aB	29.43±0.09aA	28.80±0.17aA	23.01±1.30aB	23.27±0.85aB	30.84±1.06aA
T2	1.56±0.11aA	1.54±0.02aA	1.51±0.01aA	24.90±0.35aB	28.20±0.25bA	28.63±0.26aA	25.69±6.03aA	19.57±1.06aA	32.47±1.84aA
T3	1.59±0.04aA	1.57±0.02aA	1.51±0.02aA	24.97±0.22aB	29.03±0.09aA	28.50±0.23aA	25.34±1.67aA	25.25±0.97aA	29.24±1.14aA

Different lowercase letters indicate significant differences among plots over the same planting months at p<0.05 per according to Tukey's test. Different capital letters indicate significant difference for the same plots over three planting months at p<0.05 per according to Tukey's test.

Table 2: Effects of different cropping practices on soil microbial density.

	Soil microbial (cfu ml^{-1})					
	Azotobacter spp.			PSM		
	6 months	12 months	18 months	6 months	12 months	18 months
			0-15 cm			
T1	3.74×10^{4}±1.36×10^{3} aA	3.83×10^{4}±1.08×10^{3} aA	3.70×10^{4}±1.62×10^{3} aA	2.91×10^{9}±1.37×10^{8} aA	3.11×10^{9}±1.54×10^{8} aA	2.97×10^{9}±2.77×10^{8} aA
T2	3.79×10^{4}±8.57×10^{2}aB	4.30×10^{4}±1.0×10^{3} aA	4.31×10^{4}±2.13×10^{3} aA	3.78×10^{9}±3.49×10^{8} aB	4.16×10^{9}±1.42×10^{8} aA	3.53×10^{9}±2.31×10^{8} aB
T3	3.74×10^{4}±1.69×10^{3} aA	4.10×10^{4}±1.60×10^{3} aA	3.84×10^{4}±1.72×10^{3} aA	3.26×10^{9}±2.03×10^{8} aA	3.61×10^{9}±2.09×10^{8} aA	3.57×10^{9}±3.01×10^{8} aA
			15-30 cm			
T1	3.02×10^{4}±1.49×10^{3} aA	3.67×10^{4}±2.57×10^{3} aA	3.11×10^{4}±2.28×10^{3} aA	3.10×10^{9}±2.07×10^{8} aA	3.00×10^{9}±2.24×10^{8} aA	2.63×10^{9}±2.05×10^{8} bB
T2	3.40×10^{4}±1.27×10^{3} aA	3.54×10^{4}±1.45×10^{3} aA	3.72×10^{4}±1.87×10^{3}aA	3.25×10^{9}±2.33×10^{8} aA	3.27×10^{9}±2.06×10^{8} aA	3.24×10^{9}±2.03×10^{8} aA
T3	3.25×10^{4}±1.27×10^{3} aA	3.03×10^{4}±2.11×10^{3} aA	3.53×10^{4}±1.55×10^{3}aA	2.94×10^{9}±1.63×10^{8} aB	2.93×10^{9}±1.38×10^{8} aB	3.79×10^{9}±2.54×10^{8} aA

Different lowercase letters indicate significant differences among plots over the same planting months at p < 0.05 per according to Tukey's test. Different capital letters indicate significant difference for the same plots over three planting months at p < 0.05 per according to Tukey's test.

exhibits a fluctuating trend in CO_2 flux over the planting months, as opposed to the more stable trend observed in T3 intercrop with lemongrass. This is also evidenced by the fluctuating pattern in microorganism activity observed in T2 over time (Table 2). Soil microbial community is a useful soil quality indicator and major driver of the elemental soil biogeochemical processes. No significant differences were observed in the density of Azotobacter spp. across the treatments regardless of planting stages at 0-15 cm depth but PSM shows the lowest density in T1 with increasing soil depth during the post-harvesting stage of mango trees (Table 2). At 15-30 cm depth, intercropping plots show more population of PSM over time compared with the mono-cropping which could be attributed to the increased biomass input in the intercrop plots improving the density of PSM. In general, intercropping improves the abundance of soil microorganisms (Zhao *et al.*, 2023; Zhang *et al*., 2021). Between months, plot T2 initially recorded the lowest density of *Azotobacter* spp. at 6 months after planting, but increased gradually over time (Table 2). Similarly, plot T2 exhibited a fluctuating trend in PSM over time. In contrast, Plot T3 had the lowest density of PSM at the initial 6 and 12 months but increased after 18 months of planting. The lower density of microorganisms at early planting suggests that they may require time to establish and colonize the rhizosphere of the newly planted intercrops.

CONCLUSION

The present study indicated that intercropping mango with lemongrass increases the soil C and N with increasing soil depth after 18 months planting. Our findings also suggest that intercropping mango with lemongrass and screwpine can sequester more carbon in the soil. In addition, intercropping plots show more population of PSM than the mono-cropping which could be attributed to the increased biomass input in the intercrop plots improving the density of PSM. However, further long-term analysis is needed to reinforce the findings for selecting the most beneficial cropping patterns for farmers to improve the soil nutrients.

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Disclaimers

The views and conclusions expressed in this article are solely those of the authors and do not necessarily represent the views of their affiliated institutions. The authors are responsible for the accuracy and completeness of the information provided, but do not accept any liability for any direct or indirect losses resulting from the use of this content.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish, or preparation of the manuscript.

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