EFFECT OF SLOW-RELEASE FERTILIZER ON NITROGEN AND PHOSPHORUS CONTENTS IN IMMATURE OIL PALM (*ELAIES GUNINEENSIS*) IN SANDY COASTAL SOIL

Siraj Munir Bin Mohammad
Faculty of Plantation and Agrotechnology
Universiti Teknologi MARA Sarawak Branch, 94300 Samarahan, Sarawak, Malaysia
Email: sirajmunirmohammad@gmail.com

Margaret Chan Kit Yok
Faculty of Plantation and Agrotechnology
Universiti Teknologi MARA Sarawak Branch, 94300 Samarahan, Sarawak, Malaysia
Email: drmchan@uitm.edu.my

Hasmah Binti Mohidin
Faculty of Plantation and Agrotechnology
Universiti Teknologi MARA Sarawak Branch, 94300 Samarahan, Sarawak, Malaysia
Email: hasmah@uitm.edu.my

ABSTRACT

Encroachment of oil palm (Elaies guineensis) into coastal sandy soil previously deemed as unsuitable has been an increasing trend due to prime land scarcity. Major limiting factors are poor water retention and high leaching of nutrients from granulated chemical fertilizers. The effect of slow-release fertilizer (SRF) on nitrogen (N) and phosphorus (P) contents in two years old oil palm in coastal sandy soil was studied at a smallholder estate using a Randomized Complete Block Design with five treatments of equivalent 1000g N replicated four times. The treatments were 100% NPK (T1), 50% NPK + 50% SRF (T2), 100% SRF (T3), 50% NPK + EFB Compost (T4), and 50% SRF + EFB compost (T5). There were no significant differences in the mean leaf area and mean bole diameter. There were significant differences in soil Total N ranging from 1333.10 to 1523.15 ppm as ANOVA indicated p = 0.026. T5 was significantly different from T1 and T4 but not from T2 and T3. In addition, there were no significant differences among T1, T2, T3 and T4. However, no significant differences were obtained in plant N ranging 1738.50 to 1893.07 ppm with ANOVA indicating a p= 0.336. Mean soil available P (0.89 - 1.00 ppm) and plant P (1056.04 - 1165.97 ppm) showed no significant differences with the ANOVA indicating p values of 0.370 and 0.161, respectively. The study concluded the combination of SRF and EFB compost is recommended as an alternative fertilizer for oil palm in the coastal sandy soil area.

Key words: coastal sandy soil, EFB compost, *Elaies guineensis*, NPK fertilizer, slow-release fertilizer

INTRODUCTION

Oil palm industry is one of the most important contributors toward the Growth Domestic Product (GDP) in Malaysia’s economy and an important agricultural sector in creating job opportunities. Nambiapan (2018) stated the area of oil palms planted has grown over 100 times more for the past 56 years. The export had tremendous increased by more than 50% from 2016 to 2018 despite experiencing reduction in the production of yield (Kushairi et al., 2019). More lands are being cleared to be used for planting this valuable crop. Facing scarcity of fertile soil, marginal soils, coastal sandy and peat areas are being exploited with enormous challenges.

Coastal sandy soil has been categorized as problematic soil, not only has poor nutrient status, but also prone to leaching (Pirker and Mosnier, 2015). Several studies reported that coastal sandy soil has known to have low cation exchange capacity, high porosity and low water holding capacity (Bell and Seng, 2007; Tao et al., 2018). This indicates that a potential loss of over 50% of nutrients applied (El Sharkawi et al., 2018). Nevertheless, coastal sandy soil could give good return if properly managed at a higher cost. Cultivation of oil palm requires a proper balance between fertilizer and water ratio to ensure not only the quality of the harvest but also production of yield (Ros, 2019). Goh & Po (2005) reported that almost 85% of the production cost is the cost of fertilizers in oil palm cultivation. Without proper sustainable agronomic practices applied, detrimental impact will not only be causing loss in farm profitability but also reduction in soil productivity and environmental quality (Ramesh et al., 2014). The usage of slow-release fertilizer (SRF) can be implemented to improve in minimizing the impact of nutrient loss in sandy soil through leaching as well as improve the productivity of oil palm (Bah et al., 2014). This is attributed to the characteristics of SRF properties of nutrients slowly being released based on the nutrient requirement of the crop (Singh et al, 2010). As oil palm demands large amount of nutrients to sustain growth, usage of appropriate fertilizer application is essential to improve palm oil production (Tiemann et al., 2018).

Empty fruit bunches (EFB) have been considered as a waste by-product in oil palm plantations. EFBs are the residue resulted after processing fresh fruit bunches (FFB) in the mill and contributing to the sustainable management of oil palm cultivation (Tang and Al Qahtani, 2020). The beneficial effects of applying EFB compost on the improvement of soil retaining water as well as reducing soil compaction have been reported by Wu et al. (2017). In addition, EFB compost is also reported to be able to improve soil chemical properties and store nutrients as organic fertilizer, and improve soil biological properties including microbial abundance, structure, and activity (Tahir et al., 2019). According to Indah et al. (2017), the usage of EFB as compost has the potential to substitute most of the nutrients needed by the plants.

The main objective of this research was to determine the viability of using SRF fertilizer with EFB compost as an alternative method of fertilizer application in two years' old oil palm in sandy coastal area. The research focuses on the growth rate of oil palm, as well as the nitrogen, and phosphorus content in both soil and plant.

MATERIALS AND METHODS

Site Description

The study was conducted on coastal sandy soil in a smallholder estate in Sampadi, Lundu, Sarawak. The soil composition of the area is loamy sand with 83% sand, 10% silt, and 7% clay. Throughout the 18 months' study, field maintenance was done in accordance with the standard field maintenance.

Experimental Design

A Randomized Complete Block Design with five treatments replicated four times was used with two oil palms per plot for each treatment. Three types of fertilizers were used: MPOB F1, a compound fertilizer (N: P: K: TE-10:5:4:16.2) manufactured by Malaysian Palm Oil Board (MPOB); ULTRA SRF, a slow-release compound fertilizer (N: P: K-15:15:6) manufactured in Korea and distributed by Kiel Energy Sdn Bhd, and EFB compost (N: P: K-2:1:3) manufactured and distributed by Daitoku Sdn Bhd. The N was calculated at the equivalent rate of 1000g for the five treatments based on the formula as follows:

$$\text{Amount of fertilizer (kg)} = \frac{\text{Nitrogen(kg)}}{\text{\% Nitrogen content x 100}}$$

Treatment (T1 – 100%NPK) of MPOB F1, a granulated compound chemical fertilser was the control being the conventional fertilizer application currently practised by the estate. The application of treatments of MPOB F1 with or without EFB compost were carried out every four months, while the applications of ULTRA SRF with or without EFB compost every six months over a duration of 18 months. The first data collection was carried out prior to the application of treatments. Table 1 indicates the rate of each fertilizer type with 1000g N equivalent.

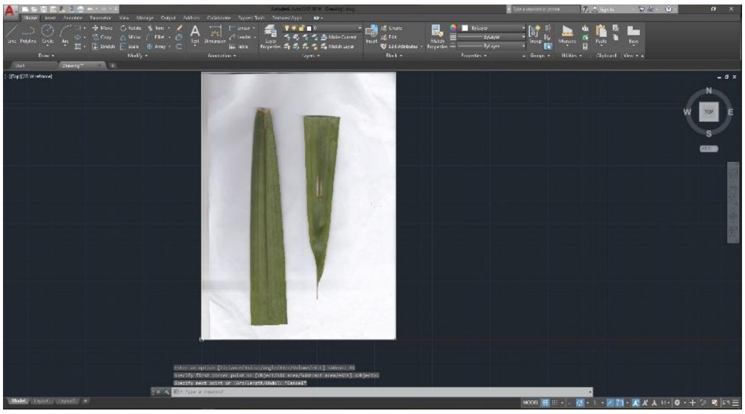
Table 1: Rate of fertilizers with 1000g N equivalent

Treatment	Rate and Type of Fertiliser
T1	1000g of N fertiliser (MPOB F1 Fertilizer 10:5.4:16.2)
T2	500g of N fertiliser (MPOB F1 Fertilizer 10:5.4:16.2) and 16 pellets of ULTRA Slow-Release Fertiliser (15:15:6)
T3	33 pellets of ULTRA Slow-Release Fertilizer (15:15:6)
T4	500g of N (MPOB F1 Fertilizer 10:5.4:16.2) and 2500g of EFB compost (2:1:3)
T5	16 pellets of ULTRA Slow-Release Fertilizer (15:15:6) and 2500g of EFB compost (2:1:3)

Growth Parameters

Two growth parameters determined were leaf area and bole diameter. Leaf area was taken from leaflets of Frond 9 identified as the frond counting from the terminal shoot following either towards the left or the right of the spiral motion, based on the protocol for immature oil palm (Rankine and Fairhurst, 1999). The frond was then segmented equally into three parts: six leaflets were taken from mid segment, while three from each top and bottom segments of the frond. The leaf area was then determined using Autodesk AutoCAD 2017 as described by Affif (2015). The leaflets arranged on a piece of A4 paper were digitally scanned and saved as JPEG images. The images were uploaded into the software and digitally traced as shown in Figure 1.

Figure 1 Leaf area determination of Frond 9 of oil palm using Autodesk AutoCAD 2017



The bole diameter was determined by measuring the circumference (C) of the bole of the oil palm by using metre tape. The diameter (d) was calculated by using the formula:

$$\text{Diameter (d)} = \frac{\text{Circumference (C)}}{\pi}$$

Soil Nutrient Analysis

Soil samples were collected from two sampling points below the canopy edge of the oil palm on opposite side using a soil auger of 5.4 cm core diameter. Samples were taken at depth of 10, 20, and 30 cm referred as Soil Depth A, B, and C, respectively. The samples were then sealed in a zip lock bag and brought to the laboratory. Soil samples were left to be air-dried for two weeks, ground and sieved through two mm sized mesh. These samples were further analysed for total N and soil available P.

The content of total N was determined by Vario EL III CHNS Elemental Analyser. Two mg of the soil samples were packed into tin boats and folded as pellets which were loaded onto the sample carousel. Each separate sample dropped into the analyser, undergone catalytic tube combustion in an oxygenated, high temperature CO_2 atmosphere. Helium gas was used to carry N through the adsorption columns. Concentrations of N component were determined by a thermal conductivity detector.

Soil available P were extracted using Bray (II) extraction method described by Seraphina and Chan (2018) and determined using UV-Vis Spectrophotometer Lambda 35 at 660 nm wavelength.

Plant Nutrient Analysis

Air-dried grounded and sieved leaf samples from Frond 9 were used for plant nutrients analysis. Plant N content was determined using Vario EL III CHNS Elemental Analyser. Two mg of the plant samples were packed in the tin boats and pelleted. The process was similar to soil N analysis. Plant P was analysed and determined using the UV-Vis Spectrophotometer Lambda 35 described by Seraphina and Chan (2018). Sample of 0.5 grams was placed into a digesting tube. Five ml of concentrated nitric acid (HNO_3) were then added into the tube. The tube was then covered using a watch glass. The samples were left overnight, before heated up on a hot plate at 125°C for an hour to allow digestion. Thirty percent of hydrogen peroxide (H_2O_2) was added several times until the digestion sample turned clear. After the digestion was done, the watch glass was then removed, and the clear digestion transferred into a beaker and dilution of 1:10 of HNO_3 was added until it reached the final volume of 10ml.

RESULTS AND DISCUSSION

Growth Parameters

Table 2 shows the mean leaf area and mean bole diameter of oil palm from the five treatments over 18 months' period. Treatment T3 recorded the highest leaf area of 1159.72 cm^2 while T4 recorded the lowest leaf area of 1072.52cm^2. There were no significant differences as ANOVA indicated p value of 0.969 at $\alpha = 0.05$. For bole diameter, Treatment T2 recorded the highest total mean of 42.60 cm and T3 recorded the smallest diameter of 37.78 cm with 11.31% difference. However, there were also no significant differences as ANOVA indicated p value of 0.577 at $\alpha = 0.05$.

Table 2: Mean leaf area and bole diameter of two years' old oil palm for five treatments over 18 months: T1 – 100% NPK; T2 – 50% NPK + 50% SRF; T3 – 100% SRF; T4 - 50% NPK + 50% EFB Compost; T5 – 50% SRF + 50% EFB Compost

Treatment	Leaf area (cm^2)		Bole diameter (cm)	
	Mean	SD	Mean	SD
T1	1121.53	420.02	40.28	12.76
T2	1103.07	486.17	42.60	13.41
T3	1159.72	452.53	37.78	11.17
T4	1075.52	452.83	41.27	10.05
T5	1104.18	386.95	42.13	12.19
ANOVA (p value) $\alpha = 0.05$	0.969		0.577	

The results showed that there were similar growth responses to the treatments. However, it is indicative that there is an association between the leaf area and bole diameter. This was supported by Murugan et al. (2020) who reported that highest value for leaf area at pre-nursery oil palm seedling were shown to have highest stem diameter due to the increase of surface leaf enabling production of photosynthates.

Soil Total Nitrogen Analysis

Mean soil total N analysis in Table 3 shows the highest total N in soil was from T1 at 1523.15 ppm followed by T4 (1480.06 ppm), T2 (1438.81 ppm) and T3 (1392.15 ppm), respectively. The least total N content was from T5 at 1333.10 ppm. There were significant differences as ANOVA indicated $p = 0.026$ at $\alpha = 0.05$. Duncan Multiple Range Test analysis indicated that T5 was significantly different from T1 and T4 but not significantly different from T2 and T3. In addition, there were no significant differences among T1, T2, T3 and T4.

Table 3 Mean soil total N contents in the coastal sandy soil for five treatments: T1 – 100% NPK; T2 – 50% NPK + 50% SRF; T3 – 100% SRF; T4 - 50% NPK + 50% EFB Compost; T5 – 50% SRF + 50% EFB Compost

Treatment	Soil Total N Analysis (ppm)	
	Mean	SD
T1	1523.15^{a}	353.55
T2	1438.81^{ab}	344.51
T3	1392.15^{ab}	303.06
T4	1480.06^{a}	321.33
T5	1333.1^{b}	248.28
ANOVA (p value) **$\alpha = 0.05$**	0.026	

Note: Common letters indicate no significant differences based on Duncan Multiple Range Test at α **= 0.05**

The four treatments consisting of EFB compost and SRF in combination or alone except T1 had some slow-release nutrients properties. Jouquet et al. (2011) stated that EFB compost had plausible mechanism in retaining the nutrients in the growing media by surface adsorption and increased nutrient recovery. The releasing of N from the organic matter of EFB depends on the microbial activities which was reported to take longer time to breakdown the binders (Ransom et al, 2020). Bah et al. (2014) demonstrated that the slow-release compound fertilizers reduced the runoff risks of nutrient loss possibly due to their slow-release properties. This was also supported by the results of Hanifah et al. (2019) showing SRF nutrient release increased over time when binders were actively broken down.

Soil Available Phosphorus Analysis

Table 4 shows the mean available P in the soil. Highest available P content was observed in T4 at 1.00 ppm. This was followed by T5 (0.99 ppm) and T3 (0.94 ppm). Lowest content of available P was observed in T1 with 0.89 ppm. No significant differences were observed between the treatments as ANOVA indicated p = 0.370 where α = 0.05.

Table 4 Mean soil available P analysis in coastal sandy soil for five treatments: T1 – 100% NPK; T2 – 50% NPK + 50% SRF; T3 – 100% SRF; T4 - 50% NPK + 50% EFB Compost; T5 – 50% SRF + 50% EFB Compost

Treatment	Soil available P Analysis (ppm)	
	Mean	SD
T1	0.89	0.58
T2	0.91	0.59
T3	0.94	0.60
T4	1.00	0.62
T5	0.99	0.69
ANOVA (p value) **α = 0.05**	0.370	

Direct comparison of P content in the soil could not be made as the rates of P depended on the types of fertilizer which were different in their original formulations. In general, the P content in the formulation of the ULTRA SRF was highest as compared to MPOB F1 and EFB compost with EFB compost having the lowest P content. However, this was not reflected in the soil P content as there were no significant differences among the treatments. This could be attributed to P still being bound in the original form of SRF and EFB compost (Bah et al., 2014; Ransom et al. 2020) and the P release increased over time when binders were actively broken down (Hanifah et al., 2019). The higher P content in T5 as compared to T3 indicated EFB compost had introduced microorganisms into the soil facilitating in the breakdown of the resin in the SRF (Sempeho et al., 2014).

Plant Nitrogen and Phosphorus Content

Table 5 shows the mean plant N for all treatments. T2 gave the highest value of mean plant N content with 1893.07 ppm, followed by T1 with 1865.79 ppm, and T5 with 1813.79 ppm. The lowest value mean plant N content was in T3 with 1738.50 ppm. There were no significant differences as ANOVA obtained p = 0.336 at α = 0.05.

Table 5 Mean plant nitrogen for five treatments: T1 – 100% NPK; T2 – 50% NPK + 50% SRF; T3 – 100% SRF; T4 - 50% NPK + 50% EFB Compost; T5 – 50% SRF + 50% EFB Compost

Treatment	Plant Nitrogen Analysis (ppm)	
	Mean	SD
T1	1865.00	348.38
T2	1893.07	398.36
T3	1738.50	341.87
T4	1744.82	295.49
T5	1813.7	392.84
ANOVA (p value) **α = 0.05**	0.336	

Table 6 showed the total mean of plant available P. T5 showed the highest concentration of available P with 1165.97 ppm while T4 showed the lowest mean with 1056.04 ppm. The treatments however showed no significant differences between one another as ANOVA shows p = 0.161 at α = 0.05.

Table 6 Mean plant phosphorus for treatments: T1 – 100% NPK; T2 – 50% NPK + 50% SRF; T3 – 100% SRF; T4 - 50% NPK + 50% EFB Compost; T5 – 50% SRF + 50% EFB Compost

Treatment	Plant Phosphorus Analysis (ppm)	
	Mean	SD
T1	1091.07	178.90
T2	1119.74	200.94
T3	1080.37	228.81
T4	1056.04	191.42
T5	1165.97	229.75
ANOVA (p value) **α = 0.05**	0.969	

The uptake of nutrients in the palm is dependant on the nutrient availability in the soil. Despite significant differences found in the soil, the plant N did not show similar result. T2 indicated the efficiency of N uptake was highest even over NPK with or without EFB compost. The efficiency in P plant uptake was also shown to be from the SRF treatments with or without EFB compost.
AlShamaileh et al. (2018) stated that the major drawback of conventional fertilizer is their fast dissolution in soil relative to their absorptivity by plants, consequently, water runoff results in the loss of fertilizers materials and contamination of surrounding environment. The SRF has improved the efficiency reducing the loss of the nutrients they supply and minimizing the differences between solubility and uptake of the plants (NotariodelPino et al., 1995). Regardless of the soil nutrient status, the rate of all formulations of the treatments in different types of fertilizer, although recorded different values in the soil, had provided adequate N and P to support oil palm growth as no significant differences in growth parameters was obtained. Goh & Po (2005) recommended treatments of soil nutrients under moderate status to be maintained according to the needs of the plants. AlShamaileh et al. (2018) reviewed that SRF whether synthetic or organic demonstrated advantages that nutrients are better utilized from slowly released throughout the seasons rather than applied in 'burst' or instantly soluble applications, thus increasing nutrient use efficiency and more closely synchronizing release rates with plant demand. In addition, the quantity of fertilizers used is also reduced. The presence of EFB compost is attributed to improving water retention in soil as well as through microbial activity accelerating the breakdown of coatings of SRF (Bah et al., 2014).

CONCLUSION

The different formulations of the three types of fertilizers: granulated compound fertilizer, SRF and EFB compost with equivalent N content recorded significant differences in total soil N contents, attributed to the treatments with granulated chemical fertiliser, MPOB F1. However, there were no significant differences in available soil P content despite different rates. Nevertheless, with recorded different values in the soil, they had provided adequate N and P to support oil palm growth as no significant differences in growth parameters were obtained. It was also noted that highest plant N contents did not come from the treatments with MPOB F1 but from the combination of MPOB F1 and ULTRA SRF while the highest P plant content was from the combination of ULTRA SRF and EFB compost.

The usage of 100% NPK can be reduced to 50% by combining EFB compost. Despite the reduction in frequency of application in treatments with SRF, the plant available N and P were observed to perform on par with the conventional fertilizers. This research concludes, SRF either in combination with the conventional fertilizer or EFB compost can also be recommended as an alternative application method for the cultivation of oil palm in the coastal sandy soil. This not only involves in the improvement of the effectiveness of fertilization but the mitigation of the negative impact of fertilizers on the environment and the reduction of labour.

ACKNOWLEDGEMENTS

This project received a grant from Kiel Energy Sdn Bhd. Acknowledgement is also due to the management of the Pantu Plantation Sdn Bhd where the study was conducted.

REFERENCES

Affif M. (2015). The Effect of empty fruit bunches-based compost on the growth response of oil palm (Elaeis guineensis), Final Year Project Thesis in fulfilment of the requirements of Bachelor of Sciences (Hons.) Plantation Management and Technology in the Faculty of Plantation and Agrotechnology, Universiti Teknologi Mara.

AlShamaileh, E., Al-Rawajfeh, A.E., & Alrbaihat. M. (2018). Mechanochemical synthesis of low release fertilisers: A Review. The Open Agriculture Journal, 12, 11-19.

Bah, A., Husni, M. H. A., Teh, C. B. S., Rafii, M. Y., Syed Omar, S. R., & Ahmed, O. H. (2014). Reducing runoff loss of applied nutrients in oil palm cultivation using controlled-release fertilizers. Advances in Agriculture, 2014, pp. 1–9.

Bell, R. W. & Seng, V. (2007) The management of agro- ecosystems associated with sandy soils. In: Management of Tropical Sandy Soils for Sustainable Agriculture: Symposium on the Management of Tropical Sandy Soils, 27th November – 2nd December 2005, 298–304.

El Sharkawi, H. M., Tojo, S., Chosa, T., Malhat, F. M., & Youssef, A. M. (2018). Biochar-ammonium phosphate as an uncoated-slow-release fertilizer in sandy soil. Biomass and Bioenergy, 117, 154-160.

Goh, K. J., & Po, S. B. (2005). Fertilizer recommendation systems for oil palm: estimating the fertilizer rates. In Proceedings of MOSTA Best practices workshops-agronomy and crop management. Malaysian Oil Scientists' and Technologists' Association, 1-37.

Hanifah, Windia., Purnomo, C. W., & Purwono, S. U. R. Y. O. (2019). Slow release NPK fertilizer preparation from natural resources. In Materials Science Forum (Vol. 948, pp. 43-48). Trans Tech Publications Ltd.

Indah, S. P., Hermansyah, H., Hasanudin, H., & Marwanto, M. (2017). Effect of oil-palm-empty-fruit-bunch granular organic fertilizer on the yield 0f oil palm fruit. Akta Agrosia, 20(2), 61-65.

Jouquet, E. P., Bloquel, E., Doan, T. T., Ricoy, M., Orange, D., Rumpel, C., & Duc, T. T. (2011). Do compost and vermicompost improve macronutrient retention and plant growth in degraded tropical soils?. Compost science & utilization, 19(1), 15-24.

Kushairi, A., Ong-Abdullah, M., Nambiappan, B., Hishamuddin, E., Bidin, M. N. I. Z., Ghazali, R., Subramaniam, V., Sundram, S., & Parveez, G. K. A. (2019). Oil palm economic performance in Malaysia and R&D progress in 2018. Journal of Oil Palm Research, 31(2), 165–194.

Murugan, P., Ong, S. Y., Hashim, R., Kosugi, A., Arai, T., & Sudesh, K. (2020). Development and evaluation of controlled release fertilizer using P(3HB-co-3HHx) on oil palm plants (nursery stage) and soil microbes. Biocatalysis and Agricultural Biotechnology, 28(June), 101710.

Nambiappan, B., Ismail, A., Hashim, N., Ismail, N., Shahari, D. N., Idris, N. A. N., Omar, N., Salleh, K. M., Hassan, N. A. M., & Kushairi, A. (2018). Malaysia: 100 years of resilient palm oil economic performance. Journal of Oil Palm Research, 30(1), pp. 13–25.

Najihah, T. S., Ibrahim, M. H., A'fifah Abd Razak, R. N., & Wahab, P. E. M. (2019). Effects of water stress on the growth, physiology and biochemical properties of oil palm seedlings [J]. AIMS Agriculture and Food, 4(4), 854-868.854-868.

NotariodelPino, J.S., ArteagaPadrón, I.J., González, M.M., & GarcíaHernández M.J.E (1995) Phosphorus and potassium release from Phillipsite-based slow-release fertilizers. J Control Release 1995; 34: 25-9.

Pirker, J., & Mosnier, A. (2015). Global oil palm suitability assessment. International Institute for Applied Systems Analysis. 1–33.

Ramesh, Rana, S.S. and Negi, S.C. (2014). Improved agricultural practices to mitigate the effect of climate change. Himachal Journal of Agricultural Research, 40(1): 1-13.

Rankine, I. R., & Fairhurst, T. H. (1999). Field Handbook: Oil Palm Series Volume 3√ Mature. Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and 4T Consultants (4T), Singapore.

Ransom, C. J., Jolley, V. D., Blair, T. A., Sutton, L. E., & Hopkins, B. G. (2020). Nitrogen release rates from slow- and controlled-release fertilizers influenced by placement and temperature. PLoS ONE, 15(6 June), 1–21

Ros, A. R. (2019). Slow-release fertilizer hydrogels: A review. Polymer Chemistry, 10(45), 6073–6090.

Rosenani, A. B., Rovica, R., Cheah, P. M., and Lim, C. T. (2016). Growth performance and nutrient uptake of oil palm seedling in prenursery stage as influenced by oil palm waste compost in growing media. International Journal of Agronomy, 2016, pp. 1-8.

Sempeho, S.I., Hee, T.K., Mubofu, E., & Hilonga, A. (2014) Meticulous overview on the controlled release fertilizers. Advances in Chemistry, Vol 2014, Articles ID 363071, 16 pages.

Seraphina, D.G., & Chan, M. (2018). Sustainability and Good agricultural practices on soil properties and yield of oil palm (Elaeis guineensis). 1st International Conference on Innovative Sciences and Technologies for Research and Education (InnoSTRE). 18-20 December 2018

Singh, R. P., Ibrahim, M. H., Esa, N., & Iliyana, M. S. (2010). Composting of waste from palm oil mill: A sustainable waste management practice. Reviews in Environmental Science and Biotechnology, 9(4), pp. 331–344.

Tang, K. H. D., & Al Qahtani, H. M. S. (2020). Sustainability of oil palm plantations in Malaysia. Environment, Development and Sustainability, 22(6),4999–5023.

Tao, H. H., Donough, C., Gerendas, J., Hoffmann, M. P., Cahyo, A., Sugianto, H., Wandri, R., Rahim, G. A., Fisher, M., RötSter, R. P., Dittert, K., Pardon, L., & Oberthür, T. (2018). Fertilizer management effects on oil palm yield and nutrient use efficiency on sandy soils with limited water supply in Central Kalimantan. Nutrient Cycling in Agroecosystems, 112(3), 317–333.

Tahir, A. A., Barnoh, N. F. M., Yusof, N., Said, N. N. M., Utsumi, M., Yen, A. M., Hashim, H., Noor, M.J.M.M., Akhir, F.N.M., Mohamad., S.E., Sugiura, N., Othman, N. A., Zakaria., Z., & Hara, H. (2019). Microbial diversity in decaying oil palm empty fruit bunches (OPEFB) and isolation of lignin-degrading bacteria from a tropical environment. Microbes and Environments, ME18117.

Tiemann, T. T., Donough, C. R., Lim, Y. L., Härdter, R., Norton, R., Tao, H. H., Jaramillo, R., Satyanarayana, T., Zingore, S., & Oberthür, T. (2018). Feeding the palm: A Review of oil palm nutrition. Advances in Agronomy, 152, 149–243.

Wu, H., Lai, C., Zeng, G., Liang, J., Chen, J., Xu, J., Dai, J., Li, X., Liu, J., Chen, M., Lu, L., Hu, L., & Wan, J. (2017). The interactions of composting and biochar and their implications for soil amendment and pollution remediation: a review. Critical Reviews in Biotechnology, 37(6), 754–764