Available online at http://scik.org

Commun. Math. Biol. Neurosci. 2025, 2025:49

https://doi.org/10.28919/cmbn/9185

ISSN: 2052-2541

SYSTEMATIC LITERATURE REVIEW OF OIL PALM ON SANDY SOILS

IDA BAGUS ARIMBAWA[1,*], AKHMAD R. SAIDY[2], FAKHRUR RAZIE[2], JOKO PURNOMO[2], HERMANTORO[3], TEDDY SUPARYANTO[3,4], BENS PARDAMEAN[4]

[1]Doctoral Program of Agricultural Science, Postgraduate Program, Lambung Mangkurat University, Banjarbaru 70714, Indonesia

[2]Faculty of Agriculture, Lambung Mangkurat University, Banjarbaru 70714, Indonesia

[3]Faculty of Agricultural Technology, Institute of Agriculture STIPER, Yogyakarta 55282, Indonesia

[4]Bioinformatics and Data Science Research Center, Bina Nusantara University, Jakarta 11480, Indonesia

Abstract: Sandy soils are marginal soils that have potential in the form of land availability and limiting factors that pose challenges to oil palm cultivation. We believe mapping and improving these limiting factors can increase the potential of sandy soils to support oil palm cultivation. This systematic review aims to summarise and collect data on the results of oil palm research on sandy soils to obtain information on the growth, yield and nutrition of oil palm plants grown on various sandy soils. Only 24 articles were screened according to this systematic literature review's inclusion and exclusion criteria. Most of the studies were conducted in Indonesia and then Malaysia, with the soil types being the object of research: Spodosols, Latosols, Entisols, and Regosols. It is hoped that the summary of results and evidence from the 24 articles found can be widely accepted and adopted to improve knowledge and find research gaps in oil palm crop management in sandy soils.

Keywords: oil palm; sandy soil; review.

2020 AMS Subject Classification: 62P12.

---

[*]Corresponding author

E-mail address: ibarimbawa68.01@gmail.com

Received February 06, 2025

1. INTRODUCTION

Sandy soils are widely distributed throughout the world. Based on the World Reference Base for Soil Resources, sandy soils consist of Arenosols, Regosols, Leptosols, and Fluvisols [1]. Meanwhile, according to the USDA Soil Taxonomy, sandy soils are found in Entisols. Sandy soils are also found in other soil orders, such as Alfisols, Aridisols, Inceptisols, Mollisols, Oxisols, Spodosols, and Ultisols. In this review, we define sandy soils as those with an average sand content greater than 50% and clay content less than 20% to a depth of 30 cm. Sandy soils generally have low organic matter content, which leads to low cation exchange capacity (CEC) and low nutrient availability due to runoff and nutrient leaching problems. Low Phosphorus availability worsens soil productivity [2]. Adding clay and organic matter to sandy soils can alter soil physical properties (such as soil aggregation, soil water content, and soil porosity) through cementation, cohesion, and replacement of soil particles. Better soil physical properties result in greater root distribution and penetration, hence greater uptake of nutrients and water, which can lead to improved plant growth [3], [4].

Oil palms (Elaeis guineensis) are monocots with a single seed and a fibrous root system that spreads downwards in search of nutrients and for the formation of a single trunk [5]. The oil palm crown is comprised of 25-40 mature fronds. The oil palm is native to West and Central Africa. It was introduced to Malaysia by British colonizers in the 19th century when the first commercial oil palm plantation was established in Selangor in 1917 [6]. Oil palm trees typically reach a height of approximately 10 meters and have a lifespan of 25-30 years before requiring replanting [5]. The yield of the oil palm plant, more commonly known as fresh fruit bunches (FFB), consists mainly of oil (25%), kernel/seed (5%), mesocarp fiber (13%), shell (7%), and empty fruit bunches (EFB) (23%) [5].

The extensive geographical distribution of the oil palm is likely attributable to its capacity to adapt to the challenging environmental conditions characteristic of its native African ecosystem, where it serves as a pioneer species. The oil palm can grow in a multitude of environments, including flooded areas, shallow lateritic or rocky soils, very sandy soils, peat, dry areas with less than 800 mm of moisture stress per year, areas with high slope angles, and altitudes of approximately 1,300 meters above sea level. Nevertheless, oil palms can flourish optimally in low-lying regions below 500 m in the humid tropics between 10 degrees north latitude and 10 degrees south latitude, with an annual rainfall of between 2,000 and 2,500 mm and no dry season (humidity less than 100 mm per year), and a minimum air temperature above 20 degrees Celsius. The optimal conditions for oil palm cultivation include a temperature range of 20 to 35 degrees Celsius, a minimum of five hours of effective solar irradiation per day, soil depths of 100 centimeters or more, loam to sandy loam textures, loose and well-drained soil, and slopes of less than 4 degrees [7].

This systematic review aims to collate and synthesize data on the outcomes of oil palm research conducted on sandy soils to acquire insights into the growth, yield, and nutritional requirements of oil palm plants cultivated on various sandy soil types. The research object is defined as broadly as possible to encompass results from studies conducted on sandy soils, regardless of the specific research methodology employed.

2. METHODOLOGY

A systematic literature review was conducted on oil palm on sandy soils. The criteria for inclusion in this review were that the material had to present original research on oil palm grown on sandy soils. The systematic review used PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses). Systematic reviews are carried out by groups of at least 2-3 researchers who specialize in the topic and have a basic knowledge of statistical data analysis. This reduces bias due to subjective errors in how individual research results are assessed and synthesized [8], [9].

Scope

The objective of this review is to respond to a specific question. The purpose was to ascertain the impact of sandy soil on oil palm growth, yield, and nutritional value. To gain insight into the subject matter, articles pertinent to utilizing sandy or alternative soil types for oil palm cultivation were identified. It was resolved that the Scopus (Science Direct) journal database would serve as the principal source of articles. Furthermore, a search was conducted for published systematic reviews on utilizing sandy soils with oil palm cultivation [8], [10].

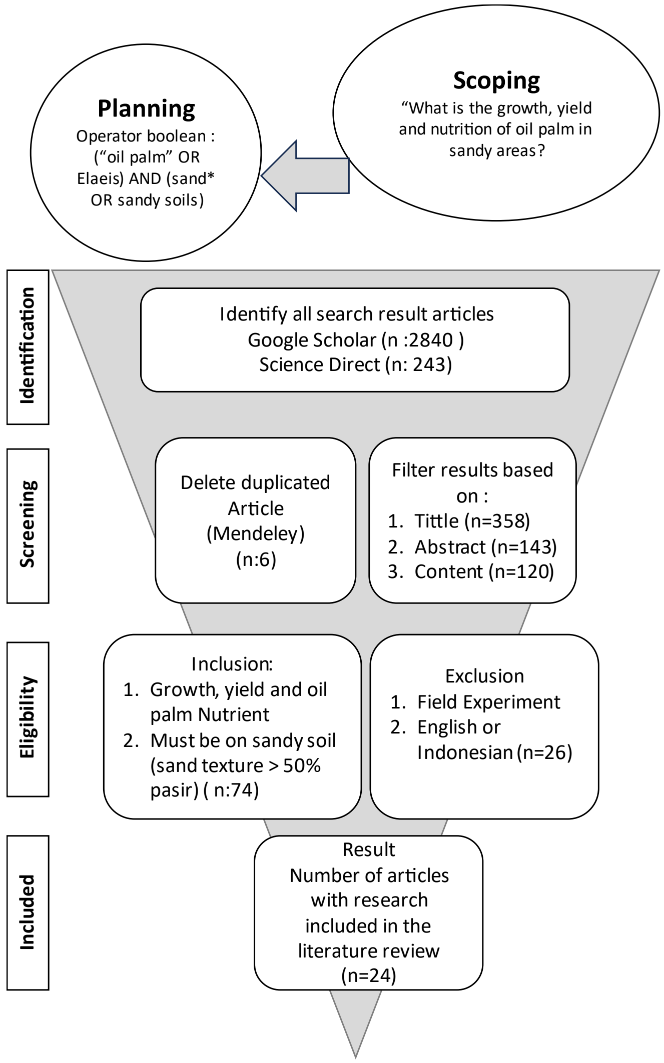

FIGURE 1. Systematic Literature Review Stage

Planning

The digital database chosen as the main source is Sains Direct. We obtain all article search terms using (Boolean operator) to be used as the main search term in the form of (oil palm OR Elaeis) AND (sand OR sandy soils).

Identification/Searching

Search strategies used in planning to identify/search for articles. Examine the results of some of the articles found to determine whether the articles are relevant or not. If necessary, make changes to the search strategy at this stage so that the articles found apply to the scope of the search, e.g., by changing keywords or adding digital database sources. The Boolean operator will be modified and updated to obtain relevant search results. Adding digital databases as search sources will be done if the number of articles obtained is still insufficient; it is possible to add grey literature from other unpublished source collections as a supplement [8]. Using keywords correctly is important, as they provide precise or too few search results, leading to misleading results and wrong conclusions [8].

Screening

Article screening starts by exporting all articles searched from the digital database (Scopus) in the form of citations and then importing the data using the citation application (Mendeley). The initial filtering in Mendeley is to remove duplicate articles. Updating article information (article properties) to facilitate the citation and filtering process. The most important filtering stage is to test the relevance of the article based on the article title, abstract, and content, respectively [8].

Eligibility/Assessment

The inclusion criteria are: 1) The plant species studied must be oil palm, focusing on growth, yield, and plant nutrition. 2) The soil type on which oil palm is grown is sandy (Alfisols, Aridisols, Inceptisols, Mollisols, Oxisols, Spodosols, and Ultisols) with a sand content more than 50%. The exclusion criteria applied are 1) articles must be field research and 2) articles published in accredited journal databases (Scopus) in English or Indonesian. In addition, all articles from the screening results will be read in depth.

Presentation and Interpretation

A synopsis and summary of the article search and screening process were presented to ensure that the selected articles had passed the procedural stages of the systematic review. Subsequently, an investigation was conducted into the heterogeneity of the articles obtained, with a mapping exercise based on the journal publishing category. The article review results were then presented in a grouped format based on the year of publication, length of research, and type of access status (open access or paid). Finally, the study's limitations were discussed, noting that the articles must be in English and Indonesian and published in the Scopus database. Recommendations for further studies to complement oil palm results on sandy soils were also provided.

3. RESULT AND DISCUSSION

The result of the search of 3,083 articles from the database (Science Direct n: 243 and Google Scholar n: 2840) (Figure 1). After the screening stage to determine inclusion and exclusion based on the title and abstract, 26 articles were obtained to be reviewed in-depth, finally eliminating two articles that did not mention soil parameters and oil palm plants. The final number of in-depth articles examined was 24 (Science Direct n: 1 and Google Scholar n: 23).

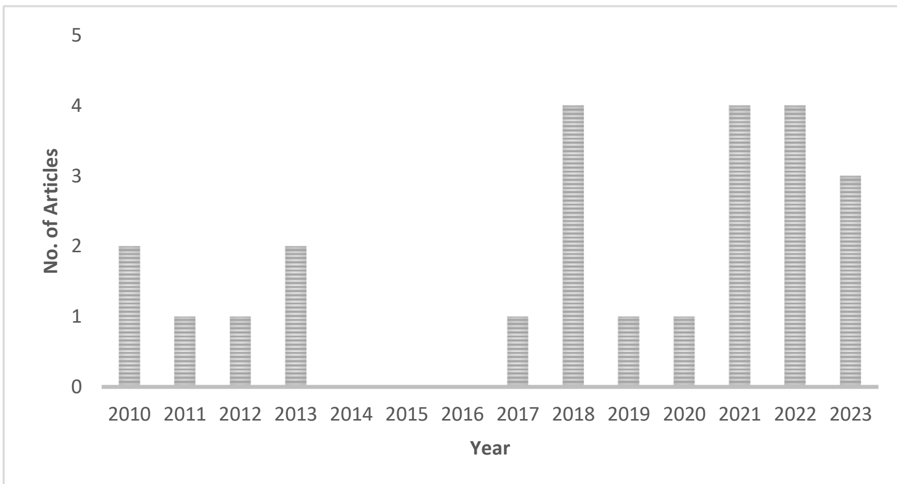

FIGURE 2. Historical Distribution of The Screened Literature

Figure 2 shows the literature results based on the publication year, from 2010 to 2023. From the screening results, we did not find any articles that fit the inclusion-exclusion criteria about oil palm plants on sandy soils in the 2014-2016 range.

The research methods used in the literature are grouped into three (Figure 3), namely literature review (n: 1), observation (n: 8), and the rest are experimental in the form of field or greenhouse experiments (n: 15). Observational research is suitable for agricultural studies related to climate change. It takes a long time [11]. In observational research, researchers observe the effect of a particular variable as it occurs naturally, without any intervention. In experimental research, Researchers manipulate the situation in an experiment and observe the effects in a more controlled environment.

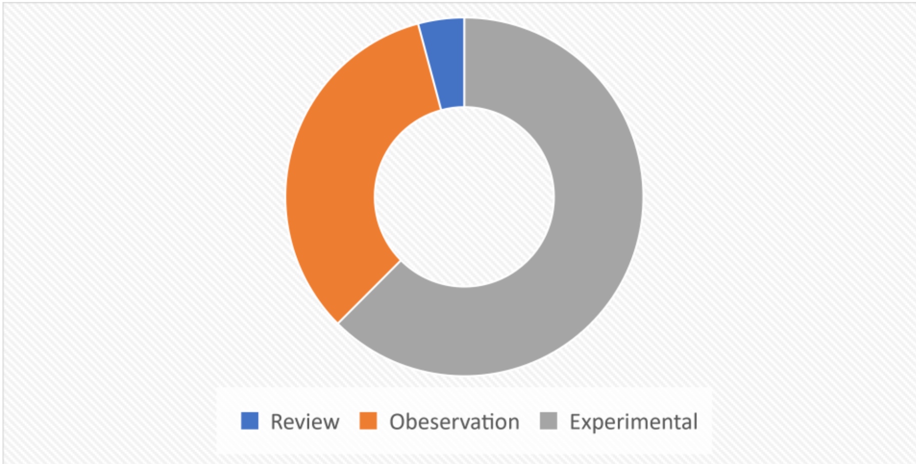

FIGURE 3. Literature Research Methods

The reviews were grouped (Figure 4) by plant age into nursery (8 articles), immature plants (3 articles), and mature plants (13 articles). This grouping focuses on the observation parameters measured in each article.

The soil chemical property identified from the review is soil pH. Soil pH was only mentioned in 9 articles, and no soil parameters other than pH were found. The soil pH values found in this review ranged from 3.5 to 7.12.

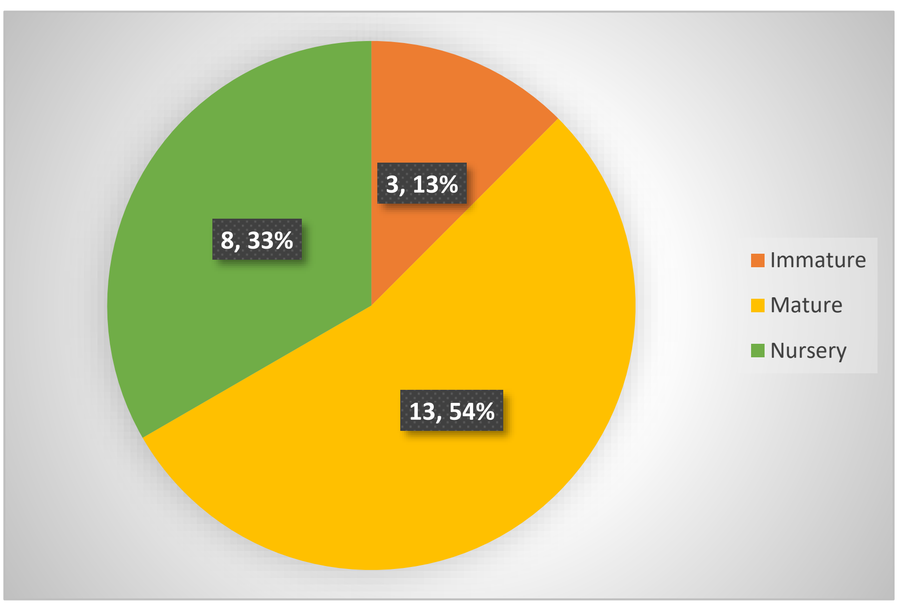

FIGURE 4. Literature Oil Palm Stage

This review summarises some of the findings of studies collected based on the age stage of the crop from nursery (pre-nursery and main nursery), immature crops, and mature crops.

Nursery

At the nursery stage, 8 articles were found when grouped by research topic, consisting of soil amendments (n: 4 articles), diseases (n: 2 articles), fertilizers (n: 1 article), and water (n: 1 article). A total of 50% of the articles discussed soil amendments (Table 1), which can be interpreted to mean that improving the physico-chemical properties of sandy soils as a planting medium for oil palm nurseries is essential. Hence, soil amendments are very important.

Zeolite increases the levels of Al-dd, CEC, K, Ca, Mg, and Na and decreases pH and P at a dose of 150 gr/polybag; an increase in Al-dd levels, a decrease in pH is thought to have caused inhibition of seedling growth [12].

Nutrient uptake in the leaves of oil palm seedlings tended to increase with zeolite at doses of 50 and 100 g per polybag, while the zeolite dose of 150 g per polybag caused a decrease in nutrient uptake in the ex-mining soil. Total dry weight and nutrient uptake were highest when applying palm empty fruit bunch compost. Relatively higher leaf nutrient uptake of N, P, K, Ca, and Mg were found in seedlings grown on topsoil and ex-mining media with palm empty fruit bunch compost [12], [13]. Leaf nitrogen content was highest in the NPK fertilizer treatment. Still, all organic fertilizer treatments increased leaf N content compared to the control, so it can be said that organic fertilizer application can increase plant nitrogen nutrient uptake [14]. The maximum field capacity of water in polybags for 11 kg soil-weight sandy loam oil palm seedlings was 1.68 L (100% FC). N nutrient uptake decreased significantly with soil moisture below 75% of field capacity. P nutrient uptake decreased significantly when soil moisture was less than 55% of field capacity. Similarly, when soil moisture was 65% of field capacity, K and Mg nutrient uptake decreased significantly [15]. The chlorophyll content of the leaves of the oil palm seedlings was higher in the oil palm empty fruit bunches compost treatment compared to poultry manure and NPK fertilizer treatments, while the N content was lowest in the cow dung treatment [14].

Zeolite is better at increasing plant dry weight than dolomite (Rahutomo et al., 2010). In another study, the application of cow dung (25%-100%) significantly affected plants' dry weight 12 weeks after planting. When the plants were 24 weeks after planting, only cow dung at a dose of >75% significantly affected plant dry weight compared to the dose of NPK fertilizer [16].

The trunk diameter best treated NPK fertilizer and cow dung compared to empty bunch ash and poultry manure [14]. Empty fruit bunch ash had the best effect on leaf number growth compared to NPK fertilizer, cow dung, and poultry manure [14]. The combination of 25% NPK fertilizer and 75% cow dung increased root growth at 12 weeks after transplanting compared to lower doses of cow dung treatments. Applying 100% cow dung increased root length growth by 56.61% compared to no cow dung. At 12 weeks after transplanting, there was no difference in root area, while root growth developed significantly at 24 weeks after transplanting due to the possibility that secondary, tertiary, and quaternary roots develop 24 weeks after transplanting [16].

Cow dung with a 50-100% dose provides growth in the number of leaflets, of which the best dose is 75-100% at the age of 12 weeks after planting. While the dose of cow dung >25% had a significant effect on the leaf surface area 12 weeks after planting, at 24 weeks after planting, only a 100% dose of cow dung had the highest significance to the leaf surface area. Plant height was significantly influenced by doses of 25-100% cow dung at the age of 12 weeks after planting, while at the age of 24 weeks after planting, only doses >50% gave significant results on plant height. The stem diameter at the age of 12 weeks after planting was influenced by the dose of cow dung >75%, while at the age of 24 weeks after planting, the dose of cow dung >50% dose only increased the diameter of the plant stem with 0% cow dung possibly due to nitrogen being converted into amino acids [16]. Lamtoro leaf compost and vermicompost did not have different effects on plant height, number of leaves, stem diameter, shoot dry weight, root length, and number of roots in the prenursery phase. However, each increased plant growth parameters compared to the control beach sand soil [17]. In that study, the recommended compost dose was 50 grams/polybag to meet the growth needs of plant observation parameters.

Soil moisture significantly affected the height of oil palm seedlings with a pattern of moisture levels of 65%, >55%, >45%, >35% of field capacity with a height difference of 20%, 27.9%, 27.9%, and 43.1% lower than the control (95-100% of field capacity), respectively. Leaf surface area and number of leaves significantly decreased when soil moisture levels were 60 to 65 %, 50 to 55%, 40 to 45%, and 30 to 35% compared to the control [15].

The first symptoms of Ganoderma infection appeared in the 3rd month (25% sand texture: 5% population and 75% sand texture: 15% population) and in the 6th month (75% sand texture: 55% population and 100% sand texture: 50% population). Mineral soil 100% without sand showed symptoms of root necrosis only in month 6. Stem base rot incidence was higher in sand-textured soils. Soil characteristics and the presence of the Ganoderma pathogen strongly influence the height of oil palm seedlings [18]. The rate of Ganoderma infection in the sand texture growing medium was 1.77 and 1.83 plants per month. The speed of the Ganoderma infection rate in sand soil is due to the loose physical properties of sand soil or high porosity, so plant roots move faster toward the source of Ganoderma inoculum. The chemical properties of the soil that affect the rate of Ganoderma infection in the soil are pH. The population of microorganisms in the soil affects the rate of Ganoderma infection in sand soil. The fertility of sand soil causes plants to decrease their resistance to pathogen infection [19].

Soils from different locations with different physical and chemical properties (clay content, nitrogen, potassium, CEC, and water holding capacity) were monitored for their respective effects on growth, chlorophyll content, and leaf nutrients in oil palm seedlings. Ganoderma-inoculated seedlings had lower vegetative parameters, leaf color survival, and chlorophyll content than non-Ganoderma-inoculated seedlings (control). G. Bioneensis inoculation did not affect the stem diameter of oil palm seedlings. In general, sand texture has the lowest plant growth (Kabu series) in healthy plants and plants inoculated with G. Bioneensis [20].

TABLE 1. Literature list on oil palm nurseries in sandy soils

Author	Years of Study	Subject
Rahutomo et al.	2004-2005 & 2008-2009	Soil Amendment
Uwumarongie-Iloria et al.	2010-2011	Soil Amendment
Susanto et al.	Na	Disease (Ganoderma)
Damansara	Na	Disease (Ganoderma)
Adileksana et al.	2018	Soil Amendment
Azwa Jamaludin et al.	Na	Fertilizer
Ovie et al.	Na	Water
Suryanti et al.	2020	Soil Amendment

Calcium Nitrate ($CaNO_3$) gave the best height and trunk diameter growth of oil palm seedlings on planting media with 95% sand texture compared to other calcium sources. Chlorophyll content was highest in Calcium chloride ($CaCl_2$). The best root growth in calcium sulfate ($CaSO_4$) treatment with a dose of 1000 ppm significantly impacts the dry weight of seedlings, so the best type of calcium fertilizer is calcium sulfate [21].

Immature

We collected 3 articles (Table 2) discussing research on oil palm in sandy soils during the immature plant period of 1-3 years after planting. Two of the three articles studied fertilizer types during the immature period. The need for effective and efficient fertilizer use during the immature period is very important, considering that nutrient adequacy for immature oil palm growth will affect oil palm yield. Providing each plant with balanced nutrients by increasing fertilizer frequency can ensure healthy vegetative growth and economically optimal FFB yield [22], [23].

Spodosols have distinctive characteristics such as low pH (3.5-4.2), a spodic layer, and sufficient soil nutrients. Based on observations in West Kalimantan, these characteristics are often found in plants with nutrient deficiencies of K, S, and Cu [24]. Making large holes and adding sufficient lime and organic matter are the initial recommendations for oil palm cultivation on spodosols, followed by increasing the frequency of fertilizer application to 3-4 times per year [25].

Observations of leaf area growth and plant stem diameter on sandy soil in Sarawak with a sand fraction content of 83% after 18 months of application of 3 different types of compound fertilizers, namely MBOP F1 (10:5.4:16:2), Ultra Slow release NPK (15:15:6) and Oil Palm Empty Bunch Compost (2:1:3) did not show significant differences [26]. This is similar to the results of Murugan [27] which state that the breadth of the leaf surface in pre-nursery is followed by the length of the stem diameter caused by the amount of photosynthate produced from the breadth of the leaf surface.

The 3 fertilizer treatments, namely MBOP F1 (10:5.4:16:2), Ultra Slow release NPK (15:15:6), and oil palm empty bunches compost (2:1:3), gave results in terms of high soil nitrogen (1738.5-1893.07 ppm). The available P content of the soil in the treatment (T1) Ultra slow release NPK 500gr N + composted oil palm empty fruit bunches 2000 g was significantly higher than ultra slow release NPK (15:15:6) 16 tablets + composted oil palm empty fruit bunches 2000 g, while there was no significant difference with the other treatments. Soil available P ranged from (0.89-1.00 ppm) and was not significantly affected by fertilizer-type treatment [26]. On a sandy soil in Kuala Lipis, Pahang, with 77-88% sand texture and soil pH ranging from 4.18-4.31, a trial application of regular fertilizer (T1) and biological fertilizer from University Putra Malaysia (T2) was conducted to determine the effect on growth, nutrition of immature oil palm plants. Regular fertilizer was applied 4-5 times yearly, and organic fertilizer was applied 3-4 times yearly. The use of fertilizer did not result in significant differences ($p > 0.05$) in soil chemical properties: pH, N-total, C-organic, P-total, P-available, CEC, K-exchange, Ca-exchange, Mg-exchange, Al-exchange, and B at both 0-15 and 15-30 cm depth [28].

Leaf N and P uptake did not show significant differences among the three types and combinations of compound fertilizers. Therefore, using USRF with or without oil palm empty fruit bunch compost can be an alternative application method [26]. The results of this study recommend reducing the number of applications by using compost and USRF.

The use of biofertilizer produced by University Putra Malaysia (UPM) also gave similar results with regular fertilizer on leaf N (optimum), Ca (optimum), Mg (optimum), B (optimum), P in leaves (optimum) and rachis (optimum), leaf K (optimum) and rachis K (optimum). Total leaf cations (TLC) did not differ significantly between the two fertilizer types with Mg deficient (<25%), Ca, and K above optimum values (>25%) [28].

TABLE 2. Literature list on immature oil palm in sandy soils

Author	Years of Study	Subject
Kasno & Subardja	2010	Land Cultivation
Siraj et al.	N/a	Fertilizer
Peng et al.	2015	Fertilizer

There were no significant differences in oil palm growth parameters such as frond length, frond number, canopy, frond width, frond thickness, and leaf chlorophyll when UPM Biofertilizer was used instead of regular fertilizer during the 48-month study period. Using UPM Biofertilizer on sandy soils during the study period can reduce total fertilizer costs for better nutrient management and vegetative parameters of immature crops in Malaysia [28].

Mature

During the mature phase of the oil palm, the most critical parameter is the plant's productivity in producing fresh fruit bunches. This review found 13 articles (Table 3) discussing oil palm yield on sandy soils. The use of biofertilizers from B. Cenocepacia strain KTG, combined with a reduction of the NPK 16-4-25 fertilizer dose by 25-50% of the recommended dose, is predicted to save fertilizer costs by 8.6-48.9% per ha per year (site-specific), with a higher or equal production level to the treatment with 100% of the standard garden dose of NPK 16-4-25 (control) on soils with sand texture of 63.5-68.1% [29].

The reference evapotranspiration (Eto) at the research site is not significantly different between crop age and soil type (3.87-4.18 mm/day) [30], [31]. Evapotranspiration was lowest in 7-year-old plants in Spodosols (3.07 mm/day). Water consumption of 13-year-old oil palm plants on Spodosols was highest (3.73 mm/day), followed by 8-year-old plants on Spodosols and 13-year-old Inceptisols (3.51 mm/day). Water uptake by roots was correlated with plant age, where oil palm plants on Spodosols absorbed more water due to high root density than those on Inceptisols and Ultisols. Root density and potential root extraction rate decreased as the oil palm rooting zone deepened. The contribution of the greywater footprint can be 0%, while the temporal greenwater footprint obtained will reach 100% of the total variable water footprint. The results obtained in this study show that oil palm has a low root water uptake rate compared to other oil-producing crops, such as sunflower and canola. In addition, the magnitude of maximum water uptake in the upper root zone also indicates that oil palm plants absorb a lot of rainwater (green water), which is fast cycling, compared to groundwater (blue water), which is long cycling [30]. Root distribution in Spodosols spread horizontally 6.5 m from the stem and penetrated vertically downward 9-28 cm deeper than roots in Ultisols 52-90 cm in 9-year-old plants and 150-200 cm in 13-year-old plants. Secondary roots spread further under empty bunch application than without empty bunch application [32] The water table in Spodosols is only 0.5 m deep due to the spodic layer at a depth of 0.57 m, while in Ultisols, it reaches 6-10 m [32].

Increasing the frequency of fertilizer application twice the regular frequency and reducing the fertilizer dose to 80% on soils with 77-88% sand texture in Kalimantan did not significantly affect production over the 4-year trial period (27.77 tonnes/ha/year) [33] Partial P-K productivity factor and partial P-K nutrient balance affected years 3 and 4 (standard frequency + 80% higher dose). During the trial period, there was no treatment effect on N, P, K, Mg, Ca, and Cl concentrations in leaves, midribs, and stems. Only S in stems was higher in year 4 of the trial (200% application + 80% dose > 200% application + 100% dose > 100% application + 100% dose = 100% application + 80% dose). The mean content of N, P, K, Mg, Ca, and Cl in leaves was above the optimum [33]. Soil water balance 28-30 months before harvest was positively correlated with monthly production and the number of bunches. This study's novelty is its large block-scale experimental design. Reducing the fertilizer dose increased the efficiency of Potassium nutrient use. Vegetative growth parameters such as petiole cross-section and annual frond production did not differ between treatments during the trial period. Changes in nutrient inputs may slow impact oil palm growth, as fruit bunches take 2-3 years to mature [5].

Long-term observations can help draw more definitive conclusions. Therefore, an additional experiment is Fertilizer treatment effects on nutrient use efficiency and nutrients in vegetative tissue. Nutrient losses through runoff and leaching may be limited during dry periods, limiting the potential positive impact of the fertilizer application distribution method on crop performance. Therefore, these conclusions are highly relevant for agronomists, plantation managers, and policymakers to optimize fertilizer management in oil palm plantations [33].

There were no significant differences in leaf K, Ca, and Mg nutrients after 5 months of application of oil palm empty fruit bunches either placed in a circle or palm inter-row on Spodosols in Kalimantan [34]. Unfortunately, this study did not provide leaf nutrient data before the experiment, so it is impossible to know the dynamics of leaf nutrients before and after the application of empty fruit bunches.

Estimation of the water balance using the Thornthwaite-Mather method in oil palm plantations in Kalimantan shows that the negative water balance (water deficit) is greater in Haplohumods soils than in Paleudults and lowest in Dystrudepts. The balance affecting the monthly FFB production of oil palm (tonnes/ha/month) was rainfall 4-29 months before harvest, rainy days 4-28 months before harvest, and water deficit 6-25 months before harvest. Based on their regression coefficient values, the parameters that most influence FFB production are rainfall 7 months before harvest, rainy days 11 and 28 months before harvest, and water deficit 10 months before harvest. The decrease in FFB production (tonnes/ha/month) for each 10 mm/month increase in water deficit on Dystrudepts, Paleudults, and Haplohumods soils in zone 3 was 11%, 2%, and 3%, respectively. In Area 5, the decreases were 12%, 4%, and 5%. In Area 6, the reductions were 5%, 18%, and 3% [35].

The high amount of rainfall 1 year before harvest caused a yield gap of -15.61% in 2011, indirectly affecting the low number of oil palm bunches. In 2012, there was a jump in production (23% above potential), which was caused by an increase in the number of bunches by 36.90% and a decrease in the average weight of bunches by 8.92%. Rainfall intensity is closely related to oil palm productivity on Spodosols [36].

Spodosols have distinctive characteristics such as low pH (3.5-4.2), a spodic layer, and sufficient soil nutrients. Based on observations in West Kalimantan, these characteristics are often found in plants with nutrient deficiencies of K, S, and Cu. Making large holes and adding sufficient lime and organic matter are the initial recommendations for oil palm cultivation on spodosols, followed by increasing the frequency of fertilizer application to 3-4 times per year [37].

During the 12 years of crop establishment, soil type affected oil palm productivity (yield, number of bunches, and weight of bunches). Compared to Ultisols (23.5 t/ha), Entisols had an annual production difference of -33% (-7.7 t/ha), followed by Spodosols -31% (-7.2 t/ha). The difference in bunch number compared to Ultisols (2104 bunches/ha) was -30% on Entisols and -22% on Spodosols. The average bunch weight produced on Entisols was -14% and Spodosols -18% lower than on Ultisols (12.23 kg/bunch) [37].

In the first year of the water deficit, oil palm productivity decreased by 5-22% (ultisols 12-22%, entisols 12-22%, spodosols 7-10%, histosols 5-15%) compared to the previous production year. In the second year after the deficit, the decrease in production ranged from 1-8% (Ultisols 3-7%; Entisols 2-4%; Spodosols 5-8%; Histosols 1-5%) compared to the previous production year. Spodosols and entisols showed more frequent production decreases than ultisols and histosols over the eight-year observation period (2014-2021). Entisols and Spodosols both belong to the sandy soil type, and Entisols showed a significant production decline compared to Spodosols, as there were three consecutive years of production decline compared to the previous year in 2019-2021, influenced by water deficits over the last two successive years (2018 and 2019). On the other hand, a review of some literature found that the limit of soil water deficit that can reduce transpiration in sandy loam/sandy soils is 5-30 mm [38].

Table 3. Literature list on mature oil palm in sandy soils

Author	Years of Study	Subject
Carr, 2011	2011	Review
Santi & Goenadi	2009-2011	Fertilizer a yield
Lubis et al.	2015-2016	Weevil and Yield
Safitri, Hermantoro, et al.	2017	Root growth and yield
Safitri, Suryanti, et al.	2017	Root
Tao et al.	2011	Fertilizer and Yield
Arryanto et al.	2019	Fertilizer
Ardiyanto et al.	2018	Water and Yield
Gunawan et al.	2012	Water and Yield
Sukarman et al.	2022	Abiotic and Yield
Suwardi et al.	2015-2022	Land Cultivation and Yield
Viegas et al.	2021	Fertilizer and Nutrient
Ramdan et al.	2021-2022	Disease

Monthly oil palm yield response to rainfall on the four soil types (ultisols, entisols, spodosols, histosols) showed stable dynamics. Water deficits in 2016 and 2018 reduced production in 2020 and 2021. The decrease in oil palm production in 2020 occurred only in Entisols and Spodosols, while in 2021, it occurred in all soil types. This is closely related to differences in each soil type's physical and chemical properties, which affect the water status of oil palm production through its influence on flower sex determination, flower abortion, and bunch failure. The effects occur approximately 2 - 2.5 years after the onset of water deficit, i.e., 27 - 30 months before harvest on Ultisols, 26 - 29 months before harvest on spodosols, 27 - 29 months before harvest on Entisols and 26 - 27 months before harvest on histosols. The effect of the water deficit on reduced productivity due to abortion occurred about a year after the water deficit, i.e., 14-15 months before harvest on Ultisols and 13-15 months before Entisols. However, it was not significant on Spodosols and Histosols. Accurate time lag information is very important for plantation management to mitigate the effects of climate change, as the impact of climate change is expected to be greater in the coming decades. The effect of water deficit on the bunch failure phase causes a decrease in average bunch weight. Bunch failure due to water deficit occurred 3 months before harvest in Ultisols, 3-4 months before harvest in Entisols, and 3-5 months before harvest in Spodosols. At the same time, histosols did not significantly affect bunch failure. Reduced productivity of oil palms occurs at 3-5 months (bunch failure phase), 1 year (abortion sensitive phase), and 2-2.5 years (sex differentiation phase) after water deficit [37].

With the mounding technique of 16-year-old oil palm plants on Spodosols in Central Kalimantan, the average soil moisture was 27% higher than in the block without mounding at 23%. Sap flow (fluid flow in plant tissue) was maximum in treatments Mounding first replicate (516.79 cm3 hour-1) and Mounding 2nd replicate (472.96 cm3 hour-1) with an average of 97.66 cm3 hour-1. In the control treatment, the maximum value of SAP flow was the Control first replicate (376.26 cm3 hour-1) and the Control 2nd replicate (386.16 cm3 hour-1) with an average of 80. cm3 hour-1 . (Suwardi et al., 2022). There is convincing evidence at both the single leaf and canopy levels that dry air reduces stomatal conductance, even when the soil is wet, with similar reductions in photosynthetic and transpiration rates [38].

The transpiration rate of oil palm plants with mounding was 1.56-2.30 mm per day, while the control was 0.80-0.86 mm per day. Production increased after two years of cultivation, with the mounding treatment increasing by 1.87-3.71 tonnes/ha (average 2.79 tonnes/ha) and the control only increasing by 1.04-2.22 tonnes/ha (average 1.66 tonnes/ha) [39].

During a 12-year study on Latosol soils in Brazil, the effect of P, K, and Mg fertilization on leaf micronutrients of oil palm was observed. Different P fertilizer sources (TSP and phosphine) did not significantly affect leaf B content in oil palms. Leaf B was affected by increasing the dose of P applied with P2O5 doses of 439 and 477 g per plant. Applying K and Mg fertilizers did not significantly affect leaf B content. However, adding K fertilizer tended to reduce leaf B due to the antagonistic relationship between Cl and B. High soil Cl- levels increase the leaching of soil B by mass effect and reduce its uptake by plants. Leaf Cl- concentration responded quadratically to P application in the third and fourth years and positively linear in the fifth and sixth years, especially with TSP sources. There were no differences in leaf Cl- levels between the K fertilizers, except for the control. Mg fertilisation did not alter Cl concentration [40].

A quadratic response was observed in the Cu concentration in the leaves in relation to the dose of P applied. The concentration of copper in the leaves exhibited a proportional decline with the increase in the dose of phosphorus, from 7.1 to 6.2 mg per kilogram of copper. The source of phosphorus did not affect copper concentration. Applying K and Mg fertilizers did not result in a statistically significant alteration in Cu concentration. The concentration of leaf Fe responded in a quadratic manner to the applied dose of P. The source of the fertilizer did not affect Fe, and the dose of K-Mg did not affect Fe. The concentration of leaf Mn exhibited a quadratic response to the P dose, declining from 499 to 415 mg kg-1 Mn. No significant response was observed for Mn to the P, K, and Mg sources. Antagonistic effects were evident between the K and Mg applications and Mn uptake. Leaf Zn was not significantly affected by the P dose, and the P, K, and Mg sources did not affect Zn [40].

Triple superphosphate is considered a P nutrient source that releases P faster, which can increase Cl. There is an antagonistic effect between Cu and P fertilizer application. A Zn concentration in leaves below the critical level indicates the necessity for nutrient replacement through fertilization to increase its concentration in the leaves of oil palm plants. The use of either triple superphosphate or natural phosphorus sources had no discernible impact on the micronutrient nutrition of oil palm plants, except the concentration of chloride in their leaves, which was observed to increase in response to the application of triple superphosphate, resulting in a synergistic effect. Phosphorus fertilizer enhanced oil palm nutrition about B, Cl, and Fe. However, this treatment also led to a reduction in Cu and Mn concentrations in the leaves. Potassium fertilization improved Cl nutrition, while Mg supply did not affect leaf micronutrient concentrations in oil palm. Regardless of the mineral fertilization applied to mature plants, oil palms have good nutrition in B, Cl, Cu, and Mn;

however, Fe and Zn nutrition is less satisfactory [40].

Ganoderma boninense infection in Lampung, Indonesia, on soils predominantly sandy in texture occurred at 10-54%, and the presence of low soil C-organic and CEC relationships increased the chance of Ganoderma boninense infection [41]. This is consistent with the infection of Ganoderma boninense in nurseries where the infection rate is high in sandy soil because of its physical properties and high porosity or loose soil properties, so plant roots move faster to the Ganoderma source [19], [42].

Research on Elaeidobius kamerunicus pollinating insects in Central Kalimantan, Indonesia, showed that the population of Elaeidobius kamerunicus (beetles/spikelet) was lower in sandy soil (25 beetles/spikelet) than in clay soil (72 beetles/spikelet) but higher than in peat soil (22 beetles/spikelet). The number of beetles visiting receptive female flowers on sandy soil was the lowest (113 beetles/female flower) compared to peat soil (119 beetles/female flower) and clay soil (219 beetles/female flower). Fruit set value was higher in clayey soil (58.9%) and significantly different from sandy soil (49.8%) and peat (46.4%). Fruit set value is influenced by Elaeidobius kamerunicus population per ha while Elaeidobius kamerunicus visit to receptive female flowers does not affect fruit set value [43].

4. CONCLUSION

Only 24 articles were screened according to this systematic literature review's inclusion and exclusion criteria. Most of the studies were conducted in Indonesia and then Malaysia, with the soil types being the object of research: Spodosols, Latosols, Entisols, and Regosols. This article still lacks information on when the study was carried out, considering that oil palm is an annual crop highly influenced by the climate. In certain years, weather anomalies affect the research variables.

The limiting factors of sandy soils are their physical, chemical, and biological properties. To enhance the growth, nutrition, and yield of oil palms in sandy soils, it is essential to address the limiting factors by introducing organic matter, nutrients, and physical treatments to improve drainage and aeration. This process should be initiated at the nursery stage, continued during the immature plant period, and finally completed during the mature plant period.

It is anticipated that the synthesis of findings and evidence from the 24 articles identified will be widely accepted and adopted to enhance knowledge and identify research gaps in the management of oil palm on sandy soils. Hopefully, this can serve as a reference point for improving the growth and productivity of oil palm plants on sandy soils.

AUTHOR CONTRIBUTIONS

Ida Bagus Arimbawa contributed to the conceptual design, data collection, data curation, and writing the original draft. Akhmad R. Saidy, Fakhrur Razie, Joko Purnomo, and Hermantoro contributed to the manuscript review. Teddy Suparyanto contributed to the manuscript review and editing. Bens Pardamean contributed to manuscript editing and supervision.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

REFERENCES

[1] S. Mantel, S. Dondeyne, S. Deckers, World Reference Base for Soil Resources (WRB), in: Encyclopedia of Soils in the Environment, Elsevier, 2023: pp. 206–217. https://doi.org/10.1016/B978-0-12-822974-3.00161-0.

[2] Y. Dady, R. Ismail, H. Jol, F. Arolu, Impact of Oil Palm Empty Fruit Bunch Biochar Enriched with Chicken Manure Extract on Phosphorus Retention in Sandy Soil, Sustainability 13 (2021), 10851. https://doi.org/10.3390/su131910851.

[3] Djajadi, B. Heliyanto, N. Hidayah, Changes of Physical Properties of Sandy Soil and Growth of Physic Nut (Jatropha Curcas L.) Due to Addition of Clay and Organic Matter, Agrivita, 33 (2011), 245-250.

[4] Hermantoro, W.I. Hutagalung, Suparman, et al. Low-Cost System of Automatic Water Level Recorder Tools Based on Microcontroller Arduino, Commun. Math. Biol. Neurosci. 2024 (2024), 104. https://doi.org/10.28919/cmbn/8811.

[5] R.H.V. Corley, P.B. Tinker, The Oil Palm, 1st ed., Wiley, 2015. https://doi.org/10.1002/9781118953297.

[6] H. Zulkifli, A.M. Tarmizi, Phosphorus Fractions in Soil Amended with Empty Fruit Bunches and Phosphate Fertilizer - An Incubation Study, J. Oil Palm Res. 22 (2010), 823-834.

[7] B. Thomas, D.J. Murphy, B.G. Murray, eds., Encyclopedia of Applied Plant Sciences, Elsevier, 2003.

[8] T.W. Cenggoro, F. Tanzil, A.H. Aslamiah, et al. Crowdsourcing Annotation System of Object Counting Dataset for Deep Learning Algorithm, IOP Conf. Ser.: Earth Environ. Sci. 195 (2018), 012063. https://doi.org/10.1088/1755-1315/195/1/012063.

[9] A. Liberati, D.G. Altman, J. Tetzlaff, et al. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Healthcare Interventions: Explanation and Elaboration, BMJ 339 (2009), b2700–b2700. https://doi.org/10.1136/bmj.b2700.

[10] T.W. Cenggoro, A. Budiarto, R. Rahutomo, B. Pardamean, Information System Design for Deep Learning Based Plant Counting Automation, in: 2018 Indonesian Association for Pattern Recognition International Conference

(INAPR), IEEE, Jakarta, Indonesia, 2018: pp. 329–332. https://doi.org/10.1109/INAPR.2018.8627019.

[11] Z. Yuan, F. Jiao, X. Shi, et al. Experimental and Observational Studies Find Contrasting Responses of Soil Nutrients to Climate Change, eLife 6 (2017), e23255. https://doi.org/10.7554/eLife.23255.

[12] R.E. Caraka, S.A. Bakar, B. Pardamean, A. Budiarto, Hybrid Support Vector Regression in Electric Load during National Holiday Season, in: 2017 International Conference on Innovative and Creative Information Technology (ICITech), IEEE, Salatiga, 2017: pp. 1–6. https://doi.org/10.1109/INNOCIT.2017.8319127.

[13] H. Capry, D.P. Putra, N.M. Titiaryanti, et al. Effect of Coal and Inorganic Fertilizers in Beach Sand Marginal Soil on the Growth of Oil Palm Seed in Pre-nursery, in: 2023 International Conference on Science and Technology, Lombok, Indonesia, 2023.

[14] E. G. Uwumarongie-Ilori, B.B. Sulaiman-Ilobu, O. Ederion, et al. Vegetative Growth Performance of Oil Palm (Elaeis guineensis) Seedlings in Response to Inorganic and Organic Fertilizers, Greener J. Agric. Sci. 2 (2012), 026-030.

[15] S. Ovie, A. Nwawe, O. Aondona, et al. Effect of Soil Moisture Level on Nutrient Uptake by Oil Palm Seedling in a Sandy Loam Soil, Int. J. Agric. Rural Dev. 26 (2023), 6668–6675.

[16] C. Adileksana, P. Yudono, B.H. Purwanto, R.B. Wijoyo, The Growth Performance of Oil Palm Seedlings in Pre-Nursery and Main Nursery Stages as a Response to the Substitution of NPK Compound Fertilizer and Organic Fertilizer, Caraka Tani: J. Sustain. Agric. 35 (2020), 89-97. https://doi.org/10.20961/carakatani.v35i1.33884.

[17] S. Suryanti, R. Firman Syah, I. Al Hafish, Utilizing Compost Soil Conditioner in Beach Sand Soil as a Palm Oil (Elaeis Guineensis Jacq) in Pre-Nursery Media, J. Agron. Tanam. Trop. 5 (2023), 232-238. https://doi.org/10.36378/juatika.v5i1.2464.

[18] Hermantoro, M.A. Kurniawan, J.P. Trinugroho, et al. Detecting Ganoderma Basal Stem Rot Disease on Oil Palm Using Artificial Neural Network Method, Commun. Math. Biol. Neurosci. 2023 (2023), 40. https://doi.org/10.28919/cmbn/7911.

[19] A. Susanto, A.E. Prasetyo, S. Wening, Laju Infeksi Ganoderma Pada Empat Kelas Tekstur Tanah, J. Fitopatol. Indones. 9 (2013), 39–46. https://doi.org/10.14692/jfi.9.2.39.

[20] C.K. Lim, Y.K. Goh, N.F. Marzuki, et al. Growth and Chlorophyll Contents of Oil Palm Seedlings Inoculated with *Ganoderma boninense* and Planted on Five Different Soil Types, Trans. Malaysian Soc. Plant Physiol. 25 (2018), 34-274.

[21] N.M.A. Jamaludin, M.H. Musa, I.A. Seman, et al. Nutritional Effects of Different Calcium Sources on Growth of Oil Palm Seedlings under Nursery Condition, Pertanika J. Trop. Agric. Sci. 45 (2022), 257–271. https://doi.org/10.47836/pjtas.45.1.15.

[22] K. Meng, S.J. Kim, S.K. Kong, A Comparative Study on The Selected Personal and Reproductive Characteristics of Rhythm Users in Korea, Ingu Pogon Nonjip. 5 (1985), 46-62.

[23] T.T. Tiemann, C.R. Donough, Y.L. Lim, et al. Feeding the Palm: A Review of Oil Palm Nutrition, in: Advances in Agronomy, Elsevier, 2018: pp. 149–243. https://doi.org/10.1016/bs.agron.2018.07.001.

[24] I.B. Arimbawa, A.R. Saidy, F. Razie, et al. Differences in characteristic of Spodosols, Inceptisols, and Ultisols towards oil palm productivity, Commun. Math. Biol. Neurosci. 2024 (2024), 78. https://doi.org/10.28919/cmbn/8678.

[25] A. Kasno, D. Subardja, Soil Fertility and Nutrient Management on Spodosol for Oil Palm, Agrivita, 32 (2010), 285-292.

[26] S.M.B. Mohammad, M.C.K. Yok, H.B. Mohidin, Effect of Slow-Release Fertilizer on Nitrogen and Phosphorus Contents in Immature Oil Palm (Elaies Gunineensis) in Sandy Coastal Soil, Int. J. Agric. Forestry Plant. 11(2021), 56–62.

[27] P. Murugan, S.Y. Ong, R. Hashim, et al. Development and Evaluation of Controlled Release Fertilizer Using P(3HB-Co-3HHx) on Oil Palm Plants (Nursery Stage) and Soil Microbes, Biocatal. Agric. Biotechnol. 28 (2020), 101710. https://doi.org/10.1016/j.bcab.2020.101710.

[28] S.H.T. Peng, K.H. Chee, H.M. Saud, et al. A Cost-Effective Novel Biochemical Fertilizer for Better Managing Nutrient Levels and Vegetative Growth in the Immature Oil Palm (Elaeis Guineensis Jacq.), Horticulturae 8 (2022), 758. https://doi.org/10.3390/horticulturae8090758.

[29] L. Prima Santi, D.H. Goenadi, Uji Potensi Burkholderia Cenocepacia Strain KTG Sebagai Bahan Aktif Pembenah Hayati Pada Tanah Tekstur Berpasir di Kalimantan Tengah The Potential Test of Burkholderia Cenocepacia KTG Strain as an Active Ingredient of Bio-Ameliorant in Sandy-Textured Soil at Central Kalimantan, Menara Perkebunan 81 (2013), 28-34. https://doi.org/10.22302/iribb.jur.mp.v81i1.52.

[30] L. Safitri, H. Hermantoro, S. Purboseno, et al. Water Footprint and Crop Water Usage of Oil Palm (Eleasis Guineensis) in Central Kalimantan: Environmental Sustainability Indicators for Different Crop Age and Soil Conditions, Water 11 (2018), 35. https://doi.org/10.3390/w11010035.

[31] L. Safitri, Hermantoro, V. Kautsar, et al. Sustainability of the Water Footprint of Various Soil Types on Oil Palm Plantations, IOP Conf. Ser.: Earth Environ. Sci. 998 (2022), 012004. https://doi.org/10.1088/1755-1315/998/1/012004.

[32] L. Safitri, S. Suryanti, V. Kautsar, et al. Study of Oil Palm Root Architecture with Variation of Crop Stage and Soil Type Vulnerable to Drought, IOP Conf. Ser.: Earth Environ. Sci. 141 (2018), 012031. https://doi.org/10.1088/1755-1315/141/1/012031.

[33] H.H. Tao, C. Donough, J. Gerendas, et al. Fertilizer Management Effects on Oil Palm Yield and Nutrient Use Efficiency on Sandy Soils with Limited Water Supply in Central Kalimantan, Nutr. Cycl. Agroecosyst. 112 (2018), 317–333. https://doi.org/10.1007/s10705-018-9948-0.

[34] D. Arryanto, Z. Nasution, A. Rauf, Dynamics of K, Ca, Mg in Spodosol Land That Is Applied Oil Palm Empty

Fruit Bunch on Oil Palm Cultivation Land (Elaeis Guineensis Jacq.) In Central Kalimantan, in: Proceedings of the The 3rd International Conference Community Research and Service Engagements, North Sumatra, Indonesia, 2019. https://doi.org/10.4108/eai.4-12-2019.2293832.

[35] R.E. Caraka, M. Tahmid, R.M. Putra, et al. Analysis of Plant Pattern Using Water Balance and Cimogram Based on Oldeman Climate Type, IOP Conf. Ser.: Earth Environ. Sci. 195 (2018), 012001. https://doi.org/10.1088/1755-1315/195/1/012001.

[36] S. Gunawan, M.T. Sri Budiastuti, J. Sutrisno, H. Wirianata, The Performance of Oil Palm Productivity and Management of Organic Materials at Various Rain Intensity in Sandy Soil, IOP Conf. Ser.: Earth Environ. Sci. 709 (2021), 012088. https://doi.org/10.1088/1755-1315/709/1/012088.

[37] S. Sukarman, A.R. Saidy, G. Rusmayadi, et al. Effect of Water Deficit of Ultisols, Entisols, Spodosols, and Histosols on Oil Palm Productivity in Central Kalimantan, SAINS TANAH – J. Soil Sci. Agroclimatol. 19 (2022), 180. https://doi.org/10.20961/stjssa.v19i2.65455.

[38] M.K.V. Carr, The Water Relations and Irrigation Requirements of Papaya (*Carica Papaya* L.): A Review, Exp. Agric. 50 (2014), 270–283. https://doi.org/10.1017/S0014479713000380.

[39] S. Suwardi, L. Sutiarso, H. Wirianata, et al. Mounding Technique Improves Physiological Performance and Yield of Oil Palm on Spodosols, SAINS TANAH – J. Soil Sci. Agroclimatol. 19 (2022), 221-229. https://doi.org/10.20961/stjssa.v19i2.65460.

[40] I.D.J.M. Viegas, M.G. Costa, E.V.D.O. Ferreira, et al. Micronutrients Concentrations in Leaves of Oil Palm Trees Fertilized with Phosphorus, Potassium, and Magnesium, J. Agric. Stud. 9 (2021), 377. https://doi.org/10.5296/jas.v9i1.18061.

[41] E.P. Ramdan, A. Hartono, G. Giyanto, et al. The Relationship Between Soil Fertility and Basal Stem Rot Disease in Oil Palm Plantations, AGROSAINSTEK: J. Ilmu Teknol. Pertanian 7 (2023), 32–39. https://doi.org/10.33019/agrosainstek.v7i1.384.

[42] H. Soeparno, A.S. Perbangsa, B. Pardamean, Best Practices of Agricultural Information System in the Context of Knowledge and Innovation, in: 2018 International Conference on Information Management and Technology, IEEE, Jakarta, 2018: pp. 489–494. https://doi.org/10.1109/ICIMTech.2018.8528187.

[43] F.I. Lubis, S. Sudarjat, D. Dono, Populasi Serangga Penyerbuk Kelapa Sawit Elaeidobius Kamerunicus Faust Dan Pengaruhnya Terhadap Nilai Fruit Set Pada Tanah Berliat, Berpasir Dan Gambut Di Kalimantan Tengah, Indonesia, Agrikultura 28 (2017), 39-46. https://doi.org/10.24198/agrikultura.v28i1.13056.