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GROWTH CHARACTERISTICS AND SUSTAINABILITY INDEX AT DIFFERENT DEVELOPMENT STAGES OF IMMATURE OIL PALM UNDER MONO- AND INTERCROPPING SYSTEMS

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ABSTRACT

*Oil palm (*Elaeis guineensis*) is one of Indonesia's important oil-based plantation crops. The problem with oil palm planting is the long duration from initial planting to harvesting of the fresh fruit bunches. A possible solution to improve farmers' income is to plant oil palm in an intercropping system. This research compared the monocropping and intercropping systems in the immature oil palm stage. This study aimed to evaluate the growth performance of oil palm in an intercropping system with maize using the Sustainability Index (SI) model. The experiment was conducted at the Ciparanje Experimental Field, Universitas Padjadjaran, Indonesia in February-May 2019, 2020 and 2021. In terms of treatment, a monocropping system and an intercropping system of oil palm with maize were replicated four times. The observation variables were plant height, frond number, stem diameter, leaf chlorophyll index, and stomatal conductance. The SI analysis was calculated to observe plant growth consistency. The evaluation results showed no significant effect on the growth performance of immature oil palms through monocropping and intercropping over three years. The SI value showed the variation level in the sustainability of immature oil palm. The majority of SI showed a moderate category, which led to the conclusion that immature oil palm in various cropping systems was stable for the first three years. The intercropping system with oil palm and maize showed similar result to the monocropping system in the three years of the immature oil palm phase.*

Keywords: intercroping, maize, oil palm, sustainability.

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INTRODUCTION

Oil palm (*Elaeis guineensis*) is a primary oil-producing crop in Indonesia, and nearly every part of the tree offers substantial advantages (Ibitoye *et al.*, 2011). Therefore, this plant holds a high economic advantage, leading to yearly expansion in cultivated areas (Setyamidjaja, 2006). In 2016, the oil palm plantation in Indonesia covered 11 300 307 ha, consisting of 22.74% immature, 75.20% mature, and 2.06% unproductive trees (Direktorat Jenderal Perkebunan, 2015).

The establishment of small-scale oil palm smallholdings has seen rapid growth, particularly in tropical climates such as Indonesia. These developments are prevalent in communities surrounding oil palm agro-industrial companies. Despite these improvements, several key production factors continue to pose constraints, including challenges related to land availability and the required investment for expanding oil palm cultivation among smallholder communities. The high costs associated with establishing new

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plantations, specifically expenses linked to field preparation and seedlings, as well as production expenses during the initial growth stages of immature trees, present significant challenges (Vermeulen and Goad, 2006). The time required for oil palm to start fruiting also presents a significant challenge for smallholders. Large companies investing substantial resources and labour also face similar issues before generating income from their plantations. Consequently, both smallholders and large plantation groups are turning to intercropping oil palm with faster-harvesting crops (Zen *et al.*, 2005). The generous spacing of oil palm trees, approximately 9 x 9 m, leaves gaps that can be used for growing other crops, such as annual cereals and legumes. Several studies have reported that intercropping could effectively control weed density within the plantations (Liebman and Davis, 2000; Liebman and Dyck, 1993; Tonye *et al.*, 2005). This cropping system is often implemented to take advantage of the 60%-75% of open space between the rows of oil palm trees, specifically during the initial 24 months (Nuraisah *et al.*, 2019; Suherman *et al.*, 2022). In the oil palm monoculture system, open spaces are reserved for planting cover crops such as legumes. Intercropping can enhance profits by incorporating edible plants compared to the monoculture system. This cropping system provides a multitude of benefits in both economic and ecological domains (Nchanji *et al.*, 2016). Maize, a significant cereal crop, is commonly intercropped with oil palm due to its ecological and economic advantages. Furthermore, this particular crop is an important staple food with high economic value in Indonesia (Ruswandi *et al.*, 2023). This shows that intercropping between oil palm and maize is recognised as a profitable undertaking.

Oil palm cultivation offers opportunities for intercropping with other crops beyond maize. Numerous studies have reported successful intercropping with soybeans, pueraria, cassava, banana, plantain, cocoyam, groundnut, ginger and turmeric (Dissanayake *et al.*, 2022; Dissanayake and Palihakkara, 2019; Nchanji *et al.*, 2016; Okyere *et al.*, 2014; Putra *et al.*, 2012). This indicates the versatility of this cropping system, particularly with profitable crop options.

Despite the potential benefits, intercropping remains untapped and not commonly practised by farmers and companies. The economic viability of intercropping on oil palm yield has often been questioned, even though several experiments have shown consistent positive results. However, environmental conditions can easily affect the profitability of intercrop when it is not effectively managed. Agricultural systems, including intercropping, are susceptible to environmental stress, and this complexity can worsen the situation (Okyere *et al.*, 2014). Additionally, the uncertainty of oil palm yield can deter farmers from adopting this cropping system (Pridham and Entz, 2008). Brainard and Bellinder (2004) explained that mismanagement of crop selection or plant life cycle variations can lead to competition for water and nutrient sources in the soil, affecting yield unfavourably. Furthermore, the planting density can also create conditions favourable to pests, diseases, and weeds, which can pose risks to plantations and neighbouring crops. This shows that careful selection of suitable intercrops is essential in the intercropping system.

Nuertey *et al*. (2009) reported that smallholders in Ghana successfully practiced intercropping by planting food and cash crops within oil palm smallholdings, particularly during the early growth stages, approximately the first three years after oil palm planting. Similar practices are observed in many oil palm producing countries, including Indonesia. Integrating oil palm cultivation with intercrops, comprising both food and commercial crops, serves the economic interests of the local community.

Oil palm demands substantial nutrients to sustain vigorous growth and high yields. According to Supriatna *et al*. (2022), managing these nutrients is essential to achieve optimal yields and this is necessary for establishing a sustainable and profitable planting pattern. It is important to combine scientific and practical efforts to evaluate oil palm productivity under various cropping systems, including intercropping. Therefore, this study aimed: (i) to evaluate the growth performance of oil palm in an intercropping system with maize, and (ii) to identify the most effective intercropping pattern for oil palm and maize using the sustainability index (SI) model.

MATERIALS AND METHODS

Plant Material and Field Experiment

This study was conducted at the Ciparanje Field Trial, Agricultural Faculty, Universitas Padjadjaran, Jatinangor, Indonesia situated at an altitude of ± 780 m above sea level. The soil in the experimental field fell under the Inceptisol classification. The climate was categorised as type C based on the classification of Schmidt-Ferguson. The experiment took place from February to May 2019, 2020, and 2021. The materials used included hybrid maize variety Pertiwi 3 and immature oil palm varieties at SEUM stages I (aged 12-16 months), II (aged 24-27 months) and III (aged 36-40 months). Additional materials used included NPK fertiliser and chicken manure as the base fertiliser. The NPK fertiliser dose for oil palm was 200 g per plant, and the chicken manure dose was 10 kg per plant; The NPK fertiliser dose for maize was 200 kg per ha, and the chicken manure dose was 0.5 kg per plant.

The field experiment consisted of two treatments, repeated four times each year. These treatments included monocultured oil palms and intercropping between oil palm and maize. The experimental plot size was 1 ha; the planting distance between oil palms was 8 x 8 m. Maize was planted within oil palm plantations, with a spacing of 1.5 m. Oil palm growth performance was assessed based on plant height, frond number, and stem diameter. Meanwhile, leaf chlorophyll index and stomatal conductance (gs) were measured using a chlorophyll meter (Opti Sci., US) and a porometer (Decagon Device Inc. US) respectively.

Data Analysis

The average value for each treatment was analysed using a T-test to evaluate variances between monocropping and intercropping of oil palm. The *p*-values ≤0.05 were considered significant for all growth parameters. Sustainability Index (SI) was calculated using the following Equation (1):

$$SI = (Y - \sigma n) / YM \times 100 \quad (1)$$

where Y represented the mean parameter of oil palm, σn was the standard deviation, and YM was the best performance of immature tree at any stage. SI values were arbitrarily classified into five groups, including deficient (up to 20%), low (21% to 40%), moderate (41% to 60%), high (61% to 80%), and very high (above 80%) (Atta *et al.*, 2009). SI calculations were performed using Microsoft Excel 2013.

RESULTS AND DISCUSSION

Growth of Immature Oil Palm in Different Cropping Systems

Growth of immature oil palm under monocropping and intercropping with maize was assessed across three stages, as presented in *Tables 1, 2* and 3. No significant differences were observed in any of the variables between the two-cropping systems across all stages. Variables such as plant height, frond number, and stem diameter continued to have consistent development in each phase. The result was supported by the statement of Maxiselly *et al.* (2022a) that growth parameters, such as leaves, stems, and branches, increased at each stage, indicating total plant development. Meanwhile, stomatal conductance and chlorophyll index showed fluctuating values per week after transplanting (WAT). The chlorophyll index indicated a decrease from stages I to stage III in both monocropping and intercropping treatments. Several factors, with soil nutrition being a prominent one, significantly influence oil palm growth. According to Almatholib *et al.* (2017), micronutrients such as Cu and Ca affect the leaf number, leaf length, and canopy size of the plant. These results indicated that intercropping oil palm with maize did not affect oil palm development. This observation was further supported by the results of Nuertey *et al.* (2009) and Nchanji *et al.* (2016), who reported that intercropping oil palm with annual plants had no adverse effects during the growth phase of the tree. Intercropping immature oil palm with annual plants such as maize not only had a positive impact on oil palm growth but also increased farmer income through the products derived from the intercrop (Dissanayake and Palihakkara, 2019). In summary, maize is one of the crops that does not have a negative impact on oil palm growth. So, it has the potential to become a useful intercrop for increasing farmers' economic benefits.

Sustainability Index (SI) on Oil Palm Cropping System

Tables 4 and *5* present SI for oil palm cropping system. *Table 4* outlines SI estimation for a monocropping oil palm system across three stages spanning from 2019 to 2021. The observed growth characteristics resulted in varying SI values, categorised as low, moderate, high, and very high (Filio *et al.*, 2023; Wicaksana *et al.*, 2022). Certain parameters had low sustainability, such as chlorophyll content at 8 WAT and stem diameter at 4 and 6 WAT. The majority of growth parameters expressed a moderate SI with values ranging between 41.45 (for plant height at 10 WAT) and 58.54 (for frond number at 10 WAT).

The frond number at 8 WAT, as well as stomatal conductance at 4 and 8 WAT, had a high SI, as opposed to the very high SI observed at 6 WAT. The presence of low SI values indicated that the tested traits had inconsistent values over the three-year planting period. Based on previous studies, a low SI value suggested that the characteristics being tested were inherently unstable (Atta *et al.*, 2009; Filio *et al.*, 2023; Utami *et al.*, 2023). A high SI value indicated that the traits under examination remained consistent despite environmental changes. Both chlorophyll content (8 WAP) and stem diameter (4 and 6 MST) had varying values across the three-year testing period, showing optimal performance in specific years only. To achieve the best chlorophyll content and stem diameter, selection should have been carried out during particular seasons that represented these traits optimally. In the monocropping system, traits falling within the moderate to high SI category, with values above the average represented the best and most stable conditions for three years. These traits incorporated plant height (at 4, 6 and 8 WAT), frond number (at 8 and 10 WAT), chlorophyll content (at 10 WAT),

TABLE 1. CROPPING SYSTEM EFFECT ON GROWTH PARAMETER OF IMMATURE OIL PALM STAGE I

Variable	Treatments	Means (WAT)			
		4 WAT	6 WAT	8 WAT	10 WAT
Plant height (cm)	Oil palm monocropping	92.45	106.49	112.69	122.43
	Oil palm + maize	107.09	114.00	121.56	126.36
Frond number	Oil palm monocropping	8.75	10.00	11.88	12.67
	Oil palm + maize	9.62	11.88	13.25	13.88
Stem diameter (cm)	Oil palm monocropping	16.74	20.15	22.75	23.54
	Oil palm + maize	20.38	22.71	29.25	29.85
Stomatal conductance (mmol $m^{-2} s^{-1}$)	Oil palm monocropping	140.97	139.10	209.46	229.46
	Oil palm + maize	132.89	168.78	241.81	251.18
Chlorophyll index (CCI)	Oil palm monocropping	57.50	59.77	62.88	65.25
	Oil palm + maize	56.60	60.67	61.09	64.53

Note: The T-test shows no significant difference in all parameters between monocropping and intercropping on immature oil palm stages I ($p \leq 0.05$).

TABLE 2. CROPPING SYSTEM EFFECT ON GROWTH PARAMETER OF IMMATURE OIL PALM STAGE II

Parameter	Treatments	Means (WAT)			
		4 WAT	6 WAT	8 WAT	10 WAT
Plant height (cm)	Oil palm monocropping	221.73	223.45	225.10	227.30
	Oil palm + maize	212.00	216.25	219.00	221.88
Frond number	Oil palm monocropping	12.25	13.00	13.50	13.50
	Oil palm + maize	14.75	14.50	15.00	15.50
Stem diameter (cm)	Oil palm monocropping	58.00	59.50	61.25	62.00
	Oil palm + maize	56.25	57.50	58.50	60.50
Stomatal conductance (mmol H_2O/m^2s)	Oil palm monocropping	132.75	128.83	127.30	115.50
	Oil palm + maize	130.35	97.00	115.75	145.50
Chlorophyll index (CCI)	Oil palm monocropping	45.00	40.25	48.75	47.00
	Oil palm + maize	45.00	40.00	48.00	44.25

Note: The T-test shows no significant difference in all parameters between monocropping and intercropping on immature oil palm stages II ($p \leq 0.05$).

TABLE 3. CROPPING SYSTEM EFFECT ON GROWTH PARAMETER OF IMMATURE OIL PALM STAGE III

Parameter	Treatments	Means (WAT)			
		4 WAT	6 WAT	8 WAT	10 WAT
Plant height (cm)	Oil palm monocropping	247.50	258.75	272.38	284.38
	Oil palm + maize	244.44	255.76	272.10	281.00
Frond number	Oil palm monocropping	114.00	119.18	123.15	126.26
	Oil palm + maize	113.50	118.62	122.84	125.72
Stem diameter (cm)	Oil palm monocropping	19.63	21.00	22.13	23.06
	Oil palm + maize	19.38	21.31	22.88	25.25
Stomatal conductance (mmol H_2O/m^2s)	Oil palm monocropping	177.60	155.38	164.01	211.54
	Oil palm + maize	178.38	157.20	168.73	216.20
Chlorophyll index (CCI)	Oil palm monocropping	20.58	19.38	18.55	22.03
	Oil palm + maize	20.13	19.48	18.08	21.95

Note: The T-test shows no significant difference in all parameters between monocropping and intercropping on immature oil palm stages III ($p \leq 0.05$).

Figure 1. a) Oil palm monocropping and b) oil palm intercropping with maize.

TABLE 4. ESTIMATION FOR SI ON MONOCROPPING IMMATURE OIL PALM DURING THREE STAGES (2019-2021)

Variable		Y	σn	YM	SI	Category
Plant height (cm)	4 WAT	187.22	247.50	67.83	48.24	moderate
	6 WAT	196.23	258.75	65.07	50.69	moderate
	8 WAT	203.39	272.38	66.98	50.08	moderate
	10 WAT	44.76	65.25	17.72	41.45	moderate
Frond number	4 WAT	13.54	19.63	4.53	45.89	moderate
	6WAT	14.67	21.00	4.64	47.73	moderate
	8 WAT	17.82	22.13	4.32	61.00	high
	10 WAT	18.28	23.06	4.78	58.54	moderate
Chlorophyll content (CCI)	4 WAT	41.03	57.50	15.33	44.69	moderate
	6 WAT	29.82	40.25	10.44	48.15	moderate
	8 WAT	33.65	48.75	15.10	38.05	low
	10 WAT	211.37	284.38	67.07	50.74	moderate
Stomatal conductance (mmol H_2O/m^2s)	4 WAT	150.44	177.60	19.50	73.73	high
	6 WAT	141.10	155.38	10.93	83.78	very high
	8 WAT	145.66	164.01	18.35	77.62	high
	10 WAT	163.52	211.54	48.02	54.60	moderate
Stem diameter (cm)	4 WAT	62.91	114.00	39.86	20.22	low
	6 WAT	66.28	119.18	40.71	21.45	low
	8 WAT	92.20	123.15	30.95	49.74	moderate
	10 WAT	94.13	126.26	32.13	49.11	moderate

Note: Y - the mean parameter of an oil palm; σn - standard deviation; YM - the best performance of the immature oil palm at any stage.

stomatal conductance (at 4 and 10 WAT), and stem diameter (at 8 and 10 WAT). The observation was supported by the results of Wicaksana *et al*. (2022), where moderate criteria with yield values above the average yield showed stable performance across diverse environmental conditions.

The intercropping system of oil palm with maize had distinct SI values, as presented in *Table 5*. Parameters such as chlorophyll contents at 8 WAT and stem diameter at 4 and 6 WAT showed low SI values. These traits consistently had low SI values in both monocropping and intercropping systems, implying that they could only be selected under certain conditions to attain the desired values. On the other hand, the high SI category included frond numbers at 6 and 8 WAT, along with all variables related to stomatal conductance.

Most variables showed moderate values for SI. Traits falling within the high SI category showed consistency in the face of environmental changes. Conversely, traits with low SI values indicated susceptibility to environmental changes (Maulana *et al*., 2023). Other studies have also reported that the high SI category had stability throughout three

TABLE 5. ESTIMATION FOR SI ON INTERCROPPING IMMATURE OIL PALM AND MAIZE DURING THREE STAGES (2019-2021)

Variable		Y	σn	YM	SI	Category
Plant height (cm)	4 WAT	187.84	244.44	58.62	52.87	moderate
	6 WAT	195.34	255.76	59.73	53.02	moderate
	8 WAT	204.22	272.10	62.34	52.14	moderate
	10 WAT	209.75	281.00	63.71	51.97	moderate
Frond number	4 WAT	14.58	19.38	3.99	54.68	moderate
	6 WAT	15.90	21.31	3.97	55.95	moderate
	8 WAT	18.94	22.88	3.94	65.56	high
	10 WAT	20.38	25.25	4.88	61.39	high
Chlorophyll content (CCI)	4 WAT	40.58	56.60	15.21	44.81	moderate
	6 WAT	29.74	40.00	10.26	48.70	moderate
	8 WAT	33.04	48.00	14.96	37.67	low
	10 WAT	43.58	64.53	17.39	40.58	moderate
Stomatal conductance (mmol H_2O/m^2s)	4 WAT	147.21	178.38	22.07	70.15	high
	6 WAT	140.99	168.78	31.47	64.89	high
	8 WAT	142.24	168.73	26.49	68.60	high
	10 WAT	180.85	216.20	35.35	67.30	high
Stem diameter (cm)	4 WAT	63.38	113.50	38.35	22.05	low
	6 WAT	66.28	118.62	39.64	22.45	low
	8 WAT	90.67	122.84	32.17	47.62	moderate
	10 WAT	93.11	125.72	32.61	48.12	moderate

Note: Y - the mean parameter of an oil palm; σn - standard deviation; YM - the best performance of the immature oil palm at any stage.

growing seasons, as observed in butterfly pea (Filio *et al.*, 2023). Traits categorised as having moderate SI values and high average values indicate stability across various locations and seasons (Tuteja, 2006; Verma *et al.*, 2013; Wicaksana *et al.*, 2022). In this study, frond number (at 8 and 10 WAT) and stomatal conductance (at 10 WAT) had optimal performance over three years of intercropping with maize. Frond number was an important trait associated with fruit sets, where a greater number of fronds correlated with a higher number of fruit sets (Balakrishna *et al.*, 2018). Stomatal conductance plays a significant role in metabolic processes such as respiration and photosynthesis, which indirectly enhance crop yield, particularly oil palm (Sales *et al.*, 2023; Suresh and Nagamani, 2006). Therefore, these two traits had substantial consistency in response to environmental changes, spanning both intercropping systems and various growing seasons.

Sustainability in the agricultural industry is important, particularly in the development of sectors such as oil palm plantations. Murphy *et al.* (2021) emphasised the importance of maintaining continuous oil palm production for the economies of key countries, including Indonesia and Malaysia, which are major oil palm exporters. As supported by Tang and Al Qahtani (2020), the sustainability of oil palm plantations depends on a multitude of factors, comprising policy-making, a conducive environment, and biodiversity. The monoculture system commonly used for oil palm cultivation has contributed significantly to declining biodiversity. In a broader context, sustainable agriculture becomes one of the important factors in the advancement of crops (Maxiselly *et al.*, 2022b). This shows that the use of the intercropping system holds promise for fostering sustainable agricultural practices and increasing biodiversity.

The results from this study indicated that intercropping with immature oil palm did not adversely affect future growth. In contrast, this cropping system could yield economic benefits for farmers even before oil palm starts fruiting. The right selection of crops for intercropping can reduce labour costs for maintenance during the growing period (Nchanji *et al.*, 2016). Intercropping in oil palm during immaturity appeared to offer substantial enhancements in both economic and environmental aspects. The use of this cropping system also indicated the multifunctionality of the land in use (Khasanah *et al.*, 2020). Therefore, the vacant land within the oil palm plantations could be effectively used, mitigating weed growth and offering numerous advantages.

CONCLUSION

The result showed no significant effect between monocropping and intercropping on immature oil palms over three years. The SI value showed the variation level in the sustainability of immature oil palm. The majority of SI showed a moderate category that led to the conclusion that immature oil palms in both cropping systems were stable. The intercropping system between oil palm and maize showed similar result with monocropping for three years during the immature oil palm phase. The oil palm cultivating system (mono and intercrop) showed yearly consistency based on the Sustainability Index on growth variables. Overall, oil palm can be cultivated by mono or intercropping systems, good intercropping will potentially elevate the farmers' income.

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