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The potential of *Nephrolepis biserrata* fern as ground cover vegetation in oil palm plantation

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Abstract. *Satriawan H, Fuady Z, Ernawita. 2021. The potential of* Nephrolepis *biserrata fern as ground cover vegetation in oil palm plantation. Biodiversitas 22: 4808-4817.* Nuisance plants or weeds are commonly found in agricultural landscapes including in oil palm plantations. Despite being considered as weeds, several of them have the potential to be used as ground cover vegetation including *Nephrolepis biserrata* (Sw). Schott. This fern species exhibits beneficial characteristics as a ground cover plant, especially in terms of the contribution of organic matter and soil moisture through the prevention of evapotranspiration. The objective of this research is to explore the potential of *N.biserrata* as ground cover vegetation in oil palm plantations based on the assessment of its ecological characteristics regarding the growth and decomposition rate, tolerance to shade, organic contents and carbon accumulation. The split-plot experimental design was used with the age of oil palm plants was used as the main plot while in the sub-plots, the spacing of *N. biserrata* was used at three varying distances 10x10cm, 20x20 cm, and 30x30 cm, each treatment had three replicates. Nine parameters observed were the percentage of growth, the percentage of ground cover, plant height, fronds number per plant, leaves number per plant, Leaf Area Index, dry weight (g), nutrient content in plant tissue, and potential carbon stock. Results showed that *N. biserrata* showed rapid growth in covering the ground surface (8-12 weeks after planting), had rapid decomposition rate (30-60 days), tolerant to shading which was characterized by the highest percentage of growth up to 81.16% and covering the area up to 95.9%, accumulated organic contents of N (1.23-1.53%), P (0.18-0.22%), and K (1.4-1.67%), respectively. In addition, total dry weight biomass obtained was 27.1 ton/ha, accumulated carbon in a plant of 0.9 tons C/ha/year, and amount of soil carbon stock 76.4-97.4 tonnes/ha/year. The results of this study suggest that *Nephrolepis biserrata* is a potential plant to be utilized as a ground cover plant in oil palm plantations.

Keywords: Biomass, carbon plant, cover crops, *Nephrolepis biserrata*, soil carbon stock

INTRODUCTION

The rapid growth of the human population and consumption has triggered the expansion of agricultural lands globally (Bonhommeau et al. 2013; Godfray et al. 2010; Tilman et al. 2001). Tropical regions, which harbor a great level of biodiversity and forest covers, show the most rapid change of land uses along with its socioeconomic conditions (Laurance et al. 2014). Among agricultural crops, oil palms (*Elaeis guineensis*) of Arecaceae are widely planted across large areas in Southeast Asia to produce palm oil. Between 2000-2010, it is recorded that the total oil palm plantations area in Southeast Asia increased by 87% in just ten years (Wilcove et al. 2013).

Indonesia and Malaysia have the largest share of global palm oil producers, contributing to over 80% of the total world's supply (over 46 million tonnes per year) (FAO), 2017). In Indonesia, oil palm is the largest export commodity compared to other estate crops with a total value of over US$ 14.7 billion (Statista 2020). In 2016, around 35.3 million tonnes of crude palm oil (CPO) were produced (Ditjenbun, 2017). The total plantation area in the country increased from 9 million ha in 2010 (Putra et al. 2012) to more than 15 million hectares in 2021 (Rodríguez et al. 2021) with the rate of land conversions was 450,000 ha/year between 1995 and 2015 (Austin et al. 2017). At a provincial level of Aceh, oil palm plantation areas are close to 400 thousand ha with a composition of 50.41% is owned by the company while 49.59% is smallholder plantation (BKPM, 2017) with a total production of crude palm oil (CPO) reached 0.73 million tonnes (Ditjenbun, 2017).

Besides the land conversion problem, the expansion of oil palm also causes the widespread of weeds with some of them being invasive alien species. Studies have reported up to 60 species of plants categorized as weeds in oil palm plantations such as *Asystasia gangetica*, *Clidemia hirta*, *Dyrnaria cordata*, *Imperata cylindrica*, *Trema cannabina*, and *Oxalis barrelieri* (Ali et al. 2021; Norlindawati et al. 2019). While considered as a nuisance, weeds in oil palm plantations can serve as cover crops that provide various ecological functions, including reducing the speed of run-off water, preventing soil erosion and nitrogen leaching, improving soil organic matter, prohibiting the presence of other weeds through competition and reducing soilborne pathogens (Kanders et al. 2017; Larkin et al. 2015; Liu et al. 2021; Wen et al. 2017). However, several conditions have to be met so that weeds can be used as cover crops, i.e., simple propagation, rapid growth and covering ability, abundant leaves and branches, ability to grow in low fertility soil, non-competitive with main crops in terms of nutrient absorbance (Department of Agriculture, 2013), high biomass production (Satriawan and Fuady 2014), high nitrogen upturn, nutrient balance ability, and soil structure improvement ability (Kruidhof et al. 2009).

One of the most common types of weeds reported in oil palm plantations in Indonesia is fern *Nephrolepis biserrata*. Satriawan and Fuady (2019) stated that *N. biserrata* is generally found under oil palm stands with the age of more than five years old. *N. biserrata* is useful as a ground cover plant since it grows slowly in the form of shrubs and its presence does not cause much harm or disturbance to the oil palm planted so that *N. biserrata* tends to be maintained in oil palm plantations. Its serves as a cover plant that can improve water and soil capacity. The rhizomes of *N. biserrata* are able to enhance the space of soil pores particularly at the subsoil level which influences groundwater upsurge. In such conditions, the presence of *N. biserrata* can mitigate water shortages during the dry season. With good administration, *N. biserrata* has a great potential to be utilized as a ground cover crop in well-developed oil palm plantations. It has preferable characteristics such as being able to grow well in poor soil conditions (Samedani et al. 2013) and in shaded conditions (Adeleye et al. 2017). Thus, the study aimed to examine the potential of *N. biserrata* as a cover crop in oil palm plantation based on the assessment of its ecological characteristics regarding the growth and decomposition rate, tolerance to shade, organic contents and carbon accumulation.

MATERIALS AND METHODS

Study area and experimental design

The experiment was conducted at oil palm plantations located in South Peusangan Sub-district, Bireuen District, Aceh Province, Indonesia. Oil palms were aged eight, seven, and six years old (planted in 2012, 2013 and 2014, consecutively). A split-plot was used as an experimental design in which the main plots were the age of oil palm plants (8, 7, and 6 years old), while the spacing of *N. biserrata* was determined as a subplot (10×10 cm, 20×20 cm, and 30×30 cm). Each treatment was conducted in triplicates.

The experimental land was loosened using a hoe on a 20 cm high tillage layer. Furthermore, experimental plots measuring 2.5 x 2 m were made, and stem cuttings of *N. biserrata* (15 cm or two segments) were planted between rows of oil palm plants according to determined spacing treatment.

Parameters

Parameters observed were growth parameters of *N. Biserrata*, biomass and soil carbon parameters. The growth parameters of *N. biserrata* consisted of five measurements. First was the percentage of growth observed at 4, 8, and 12 weeks after planting (WAP). The second was the percentage of land covered by *N. biserrata* at 4, 8, and 12 WAP. This parameter was measured using a wire measuring 1 m x 1 m in which there were small meshes measuring 10 cm x 10 cm. The following formula was used to measure land cover:

$$\% LC = A / B \times 100\%$$

Where: LC: land cover; A: number of meshes covered by *N. biserrata*; B: total meshes

Third was plant height (cm) at age 2-20 WAP. And fourth was the number of fronds per plant at age 8-20 WAP. Fifth was total Leaf Area per plant (cm^2) using the gravimetric method as follows: leaf pattern (leaf replica) was drawn on plain paper and leaf replicas were weighed using an analytical balance; then a piece of paper measuring 10 cm x 10 cm was made and weighed. Leaf Area was calculated using the following formula:

$$\text{Leaf Area} = (\text{weight of leaf replica}/\text{weight of paper } 10 \times 10 \text{ cm}) \times 100 \text{ cm}^2$$

Sixth was Leaf Area Index, using the formula:

$$LD = LD/A$$

Where: LD is the leaf area above the soil surface with a certain area (e.g.: 1 m^2), A is the land surface area. Seventh was dry weight (g) in which all plant parts collected were dried in an oven at a constant temperature of 80°C for 48 hours. Dry weight was measured from sample plots measuring 1 m x 1 m, for example, dry weight per experimental plot was 100 g × 1 m^2 = 100 g/plot).

The rate of decomposition was determined by the weight loss of the decomposed plant material. Determination of the sample was carried out by taking about 50 g of plant material and then placing it in a 20 cm x 30 cm litter bag with fine holes made of nylon netting. The plant samples were placed between rows of oil palms aged 8, 7 and 6 years. Observation of the rate of decomposition was carried out at 30 days and 60 days after treatment. The decomposition rate was then measured using the equation:

$$R = (W0 - Wt) / t$$

Where: R: decomposition rate (g/day), W0: initial biomass dry weight (g), Wt: dry weight of biomass after observation time t(g), t: observation time (days). This unit was then converted to kg/ha to determine the total biomass weight of *N. biserrata* in oil palm plantations.

Analysis of the content of carbon organic, nitrogen, phosphorus and potassium contained in plant tissue was carried out using the wet digestion method according to technical guidelines provided by the Indonesian Soil Research Institute. Furthermore, the stored carbon content of the *N. biserrata* biomass was converted by calculating the carbon content as follow:

$$\text{C content} = \text{biomass (kg/ha)} \times \text{carbon content (C) in the plant}$$

Calculation of soil carbon stock as follows:

$$C\_Stok = BV \times C\_org \times D \times A$$

Where: C_stok: soil carbon stock (t ha-1), BV: soil bulk density (kg/m3), C_org: soil organic C content (%), D: soil layer depth (m), A: land area (ha).

Analyses of dry weight, plant organic contents and chemical properties of the soils were conducted in Integrated Agriculture Laboratory, Almuslim University, Aceh, Indonesia.

RESULTS AND DISCUSSION

Growth percentage

The results showed significant differences in the growth percentage of *N. biserrata* between all groups of planting years (Table 1). The older the oil palm age, the wider the canopy coverage. Thus, the areas under the canopy are highly shaded. This indicated the ability of *N. biserrata* to grow either in low or high shade conditions.

Table 1 presents the growth percentage of *N. biserrata* at various spacing and oil palm ages. At 4 to 8 WAP, the growth percentage was mainly below 50%, especially at six years old oil palm plants at all spacing treatments. While at 7- and 8-years old oil palm plants, at 30 x 30 cm spacing, the growth percentage was >50%. At 12 WAP, all spacing treatments showed >50% growth percentage, but the highest growth percentage at all ages of oil palms was found at 30 x 30 cm spacing treatments, and the results were statistically significant at eight years old oil palm plants.

Table 1 also highlights *N. biserrata* potentials as a ground cover crop. It showed a rapid development rate in which within 12 WAP the growth percentage recorded at 73.99 - 81.16% at all oil palm stand ages observed. Furthermore, a significant difference was also observed at the spacing treatment of 30 x 30 cm compared to 10 x 10 cm and 20 x 20 cm. In 2012 stands (8 years old), the spacing treatments of 10 x 10 cm, 20 x 20 cm, and 30 x 30 cm produced an increase of 60.26%, 50.48% and 63.99%, respectively. Increasing growth rate trends (58.8-69.9%) were also observed in 7- and 6-years old oil palm stands in all spacing treatments where the highest percentage increase in growth was found in 6-year-old oil palm stands of 69.9%. The significant difference in the growth percentage was confirmed using further statistical analysis, which resulted in 30 x 30 cm spacing treatment producing the highest growth in all planting ages.

The rapid development of *N. biserrata* in the 30 x 30 cm spacing compared to other treatments at all planting years suggests the importance of spacing in ensuring optimal plant growth. It is known that spacing reduces the competition between plants on nutrition and sunlight; thus, the best result was exhibited at 30 x 30 cm spacing. Growth percentage was obtained by calculating the ratio of the number of living plants and the population per planting area. Closer spacing resulted in competition in sunlight which is very important in photosynthesis and root development. Afterward, the roots will compete in water absorption. Hence, wider spacing lessens the competition and the plant will grow adequately.

Cover percentage

Statistical analysis on land cover percentage of *N. biserrata* at 8-, 7- and 6-years old oil palm stands were significantly different (Table 2). Spacing treatments showed significant differences instead of oil palm stands age. At 4 WAP, *N. biserrata* growth was not considered satisfying as the land cover percentage was in the range of 24.89-40.13% at all oil palm stands observed. At this initial stage, spacing of 30 x 30 cm showed the highest land cover percentage at eight years old oil palm stand (40.13%). At 8 WAP, a significant increase was observed at land cover percentage in which at a spacing of 10 x 10 cm resulted in the highest increase of 51.97%, 51.39% and 50.85%, respectively in 8-, 7- and 6-years old oil palm stands. Data collected at 12 WAP showed a maximum of >75% land cover percentage at the spacing of 10 x10 cm and 20 x 20 cm in all oil palm stand ages observed. While the largest percentage of land cover was found in the 10 x 10 cm spacing treatment at all ages of the observed oil palm stands.

Table 1. The growth percentage of *Nephrolepis biserrata* under various ages of oil palm stands at different spacing treatments at 4, 8, and 12 WAP

Observation time	Spacing treatments of *N. biserrata* (cm)	Age of oil palm plants (Year)		
		8	7	6
4 WAP	10 × 10	29.22^{bA}	28.88^{bA}	20.75^{aA}
	20 × 20	37.42^{bB}	37.12^{bB}	24.89^{aA}
	30 × 30	49.61^{bC}	48.9^{bC}	33.9^{aB}
8 WAP	10 × 10	40.52^{aA}	40.12^{aA}	38.95^{aA}
	20 × 20	44.71^{bB}	43.16^{bA}	40.22^{aA}
	30 × 30	62.05^{bC}	59.33^{bB}	49.68^{aB}
12 WAP	10 × 10	73.54^{bA}	70.14^{aA}	69.15^{aA}
	20 × 20	76.13^{bA}	71.75^{aA}	70.31^{aAB}
	30 × 30	81.16^{bB}	75.23^{aB}	73.99^{aB}

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

Table 2. Percentage of land cover by *Nephrolepis biserrata* under different ages of oil palm at various spacing treatments at 4, 8, and 12 WAP

Observation time	Spacing treatments of *N. biserrata* (cm)	Age of oil palm plants (Year)		
		8	7	6
4 WAP	10 × 10	32.23^{bA}	30.12^{bA}	24.89^{aA}
	20 × 20	33.1^{bA}	33.01^{bA}	29.64^{aB}
	30 × 30	40.13^{bB}	38.56^{abB}	37.97^{aC}
8 WAP	10 × 10	66.31^{cC}	62.72^{bB}	50.65^{aB}
	20 × 20	59.92^{bB}	50.84^{aA}	48.72^{aAB}
	30 × 30	53.85^{cA}	49.99^{bA}	46.88^{aA}
12 WAP	10 × 10	95.9^{bC}	92.9^{bC}	86.7^{aC}
	20 × 20	86.4^{bB}	84.1^{bB}	80.1^{aB}
	30 × 30	78.6^{cA}	75.4^{bA}	71.9^{aA}

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

The high land cover percentage of *N. biserrata* at 10 x 10 cm spacing treatment was in line with a large population per unit area. Therefore, as a high number of *N. biserrata* was recorded, then *N. biserrata* population became the largest spacing. Land cover percentage of *N. biserrata* was recorded to be much higher than that of our previous finding on *Asystasia intrusa*, which were 74.67- 82.59 % at 10 x 1 cm spacing and at 12 WAP (Satriawan et al. 2020).

Asbur et al. (2018) stated that land cover percentage indicates plant's speed in covering an area of cultivated land. Alonso-Ayuso et al. (2014; 2018) proposed that cover crop regulates soil moisture content and inhibits other weeds growth, which would be detrimental for parent crops. Yet, the development of land cover crops is highly dependent on plant height/length, the number of branches and leaves and growth percentage (Suryana et al. 2019; Kaye et al. 2019).

Plant height

Due to its ease of observation, plant height has been used as a common indicator in studying plant growth. For this parameter, the observations in this study were conducted at 4-20 WAP. Data collected on various ages of oil palm stands indicated that spacing treatments of *N. biserrata* influenced plant height at 4, 8, 12, 16, and 20 WAP (Table 3). At 16 WAP, homogeny of plant growth was observed at 7- and 8-years old oil palm stands, while the spacing treatment with the bigest influence was 30 x 30 cm.

Table 3. Height of *Nephrolepis biserrata* under various ages of oil palm stands at different spacing treatments. Data was collected at 0, 4, 8, 12, 16, and 20 WAP

Observation time	Spacing treatments of *N. biserrata* (cm)	Age of oil palm plants (year)		
		8	7	6
0 WAP	10 × 10	12.5	12.4	12.1
	20 × 20	12.6	12.5	12.4
	30 × 30	12.8	12.4	12.4
4 WAP	10 × 10	16.24^{aA}	15.15^{aA}	14.43^{aA}
	20 × 20	17.3^{bA}	15.3^{abA}	14.97^{aA}
	30 × 30	17.87^{bA}	15.71^{abA}	15.1^{aA}
8 WAP	10 × 10	18.77^{bA}	17.24^{abA}	15.69^{aA}
	20 × 20	19.16^{bA}	17.65^{abA}	16.33^{aA}
	30 × 30	20.1^{bA}	17.91^{aA}	16.89^{aA}
12 WAP	10 × 10	20.15^{aA}	19.13^{aA}	18.22^{aA}
	20 × 20	21.11^{bAB}	19.34^{abA}	18.97^{aA}
	30 × 30	22.35^{bB}	19.78^{aA}	19.12^{aA}
16 WAP	10 × 10	23.13^{aA}	22.37^{aA}	21.43^{aA}
	20 × 20	24.24^{aA}	22.89^{aA}	21.76^{aA}
	30 × 30	24.88^{bA}	23.15^{abA}	22.01^{aA}
20 WAP	10 × 10	26.82^{bA}	24.77^{aA}	23.44^{aA}
	20 × 20	27.13^{bA}	25.23^{abA}	23.86^{aA}
	30 × 30	28.34^{bA}	25.89^{abA}	24.1^{aA}

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

May et al. (2020) stated that access to light, nutrients, and water compete among individual plants, and is crucial in plant development. Table 3 indicates that at wider spacing, *N. biserrata* showed tolerance to shade and showed no growth etiolation even at narrow spacing.

Number of fronds

The significant difference resulting from spacing treatments affected the growth of *N. biserrata* fronds in all ages of oil palm stands observed (Table 4). The highest number of fronds was obtained at the spacing treatment of 30 x 30 cm compared to that of 10 x 10 cm and 20 x 20 cm at all oil palm stand's ages observed.

Based on Table 4, the number of fronds of *N. biserrata* per plant increased with increasing plant age. In WAP 4-24, the increase in the number of fronds of *N. biserrata* per plant at all spacings and ages was almost the same, especially in oil palm stands of 6 and 7 years. Meanwhile, at the age of 8 oil palm stands showed little difference. Then due to the tight spacing, competition for sunlight, water, and nutrients cannot be avoided so that it inhibits plant growth, while at a rare spacing it can be avoided so that plants grow better.

Table 4. The number of *Nephrolepis biserrata* fronds under various ages of oil palm stands at different spacing treatments. Data collected at 4, 8, 12, 16, 20 and 24 WAP

Observation time	Spacing treatments of *N. biserrata* (cm)	Age of oil palm (years)		
		8	7	6
4 WAP	10 × 10	3.2^{bA}	2.3^{aA}	2.1^{aA}
	20 × 20	3.5^{bA}	2.4^{aA}	2.3^{aA}
	30 × 30	3.7^{bA}	2.7^{aA}	2.5^{aA}
8 WAP	10 × 10	4.5^{bA}	3.5^{aA}	3.4^{aA}
	20 × 20	5.3^{bAB}	3.6^{aA}	3.3^{aA}
	30 × 30	5.8^{bB}	3.9^{aA}	3.8^{aA}
12 WAP	10 × 10	5.9^{aA}	5.1^{aA}	5.2^{aA}
	20 × 20	6.8^{cAB}	4.8^{aA}	5.5^{bA}
	30 × 30	7.1^{bB}	5.2^{aA}	5.9^{aA}
16 WAP	10 × 10	6.8^{aA}	6.2^{aA}	6^{aA}
	20 × 20	7.8^{bB}	6.6^{aA}	6.2^{aA}
	30 × 30	8.2^{bB}	6.5^{aA}	6.8^{aA}
20 WAP	10 × 10	7.3^{aA}	7.1^{aA}	7.2^{aA}
	20 × 20	8.4^{bB}	7.7^{aAB}	7.1^{aA}
	30 × 30	9.7^{bC}	8.1^{aB}	7.7^{aA}
24 WAP	10 × 10	9.2^{aA}	9.1^{aA}	8.8^{aA}
	20 × 20	10.3^{bAB}	9.9^{abAB}	8.9^{aAB}
	30 × 30	11.6^{aB}	10.2^{aB}	10.1^{aB}

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

Total leaf area and leaf area index

Leaf Area Index quantifies the amount of a leaf area in a certain ecosystem and has such an important effect on processes such as photosynthesis, respiration, and interception of precipitation (Fang et al. 2019). Total Leaf Area of *N. biserrata* at all ages of oil palm stands was influenced by the spacing in which the 30 x 30 cm spacing produced the highest Leaf Area, and Leaf Area Index. Figure 1 show that both parameters of the leaves of *N.biserrata* on oil palm plants aged eight years are larger and wider than those at the age of six and seven years. This result suggests that *N. biserrata* has the ability to grow in shaded conditions, and is not affected by light competition with the main crop (oil palm).

Dry weight and decomposition rate

Determination of dry weight indicates plant growth; thus, the determination was conducted on the whole plant. Therefore, the heavier the dry weight, the normal the plant growth. Plant dry weight analysis per treatment plot is presented in Table 5. A significant effect of spacing treatments on the dry weight of *N. biserrata* was found at 4, 12, and 20 WAP in all oil palm stands age observed. The highest result was observed at 10 x 10 cm spacing treatments which were significantly different compared to other spacing treatments (Table 5). The result might be in correspondence with fronds number and Leaf Area Index (Figures 1, 2, 3) in which the highest Leaf Area Index was also observed at 10 x 10 cm spacing treatments in all oil palm stands. Gotoh et al. (2018) stated that plants with wider Leaf Area contain a higher chloroplast number, thus a higher photosynthesis rate as it has wider sunlight receiving surface area. Therefore, additional dry weight resulting from the photosynthesis activity in the form of carbohydrates was observed.

Table 5. A dry weight of *Nephrolepis biserrata* under various ages of oil palm stands at different spacing treatments. Data collected at 4, 12, and 20 WAP

Observation time	Spacing treatments of *N. biserrata* (cm)	Age of oil palm (years)		
		8	7	6
4 WAP	10 × 10	192.4^{bC}	179.5^{bB}	132.7^{aB}
	20 × 20	139.7^{bB}	128.9^{abA}	109.8^{aAB}
	30 × 30	119.8^{aA}	116.3^{aA}	103.2^{aA}
12 WAP	10 × 10	705.3^{bB}	620.3^{bC}	488.7^{aB}
	20 × 20	571.4^{bA}	494.2^{bB}	370.3^{aA}
	30 × 30	468.9^{bA}	380.8^{aA}	301.5^{aA}
20 WAP	10 × 10	1054.20^{cC}	774.70^{bC}	653.70^{cB}
	20 × 20	838.60^{bB}	623.10^{aB}	580.80^{aAB}
	30 × 30	709.60^{bA}	520.30^{aA}	486.50^{aA}

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

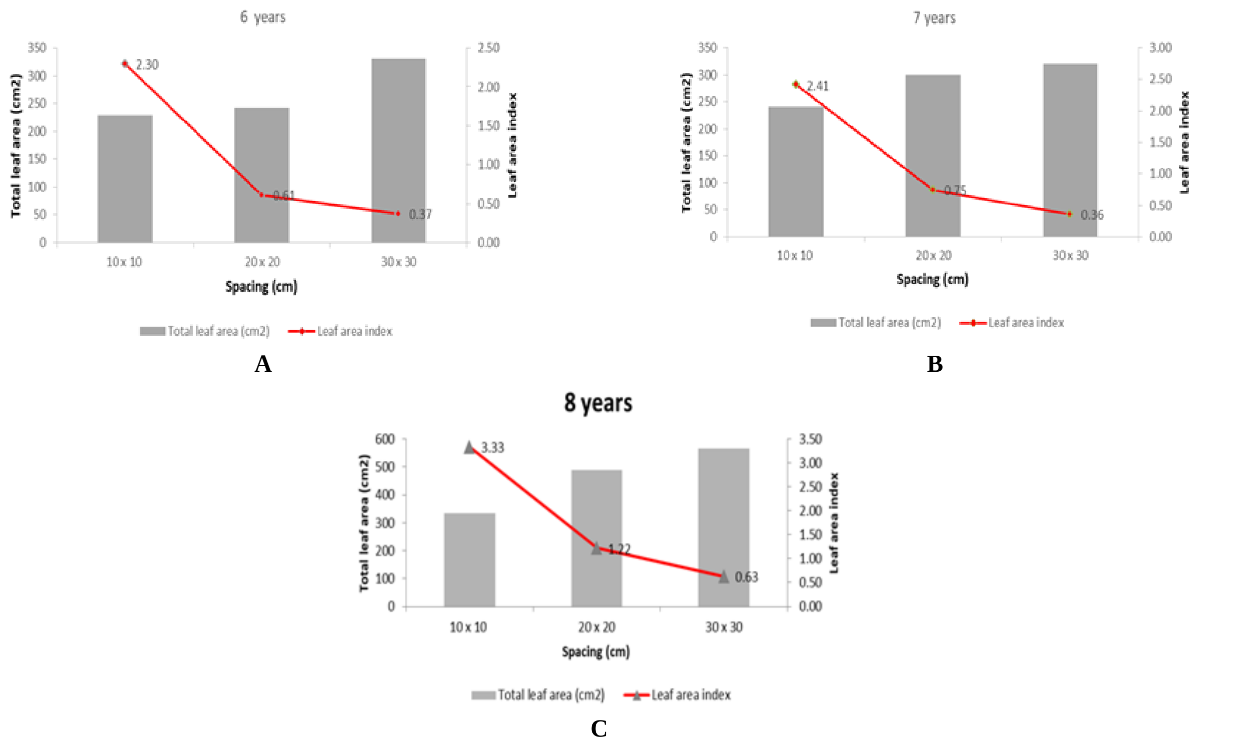

Figure 1. Total leaf area and leaf area index of *Nephrolepis biserrata* under various ages of oil palm stands at different spacing treatments. A. 6 years; B. 7 years; C. 8 years oil palm stands

Conditions of oil palm stand at all observation ages influenced decomposition rates of *N. biserrata*. The highest and fastest decomposition rates were observed at six years old oil palm stands. Within 30 days, only 52.4% of total biomass was disintegrated at the rate of 1.75% per day. While at 60 days, a total of 73.2% of *N. biserrata* were decomposed. It can be concluded that *N. biserrata* is not quickly decomposed. Meanwhile, lower results were found at 8 and 7 years old of oil palm stands, which were 65.8% and 67.6% (Table 6). The results imply that plant age lowered the decomposition rate of plant litter below the canopy area. It is of importance as a slow decomposition rate enhances the sustainability of organic deposits which is important in sustaining the fertility of the soil. Our previous finding on other cover crop weeds of *A. intrusa* reported greater decomposition rates with 2.43% per day and 94.6% of total biomass (Satriawan et al. 2020).

Biomass weight loss of *Melastoma malabathricum* L. and oil palm fronds were reported to be greater than that of *N. biserrata*, which were 14 months of decomposition periods and loss of biomass were 83.1% and 87.6%, respectively. Sulistiyanto et al. (2005) studied the decomposition of low pole forest and mixed swamp which found a longer decomposition time (18 months) than that of *N. biserrata* and *A. gangetica.* It is possible that fluctuations in environmental conditions such as light intensity and air temperature play an important role in affecting the decomposition rate of plant litter (Heviaa et al. 2003; Quideau et al. 2001).

Plant tissue nutrient content and potential carbon stocks

Statistical analysis of nutrient content of *N. biserrata* plant tissues indicates that organic carbon, N, P, and K contents were different in plant parts. Data indicated that the highest organic C content was found in the roots, while the highest contents of N, P, and K were found in the leaves. While the difference in oil palm stands age did not significantly affect nutrient contents in plant tissue (Table 7). It is interesting to note that the rate of decompositions is in correlation with macrofauna diversity and abundance (especially litter feeders) (Ashton-Butt et al. 2018). Since there is no data available on macrofauna composition in the study sites, further research will be needed.

The average of C-organic, N, P and K contents of *N. biserrata* in the 8-year-old palm stand was 52.3%, 1.53%, 0.22%, and 1.67%, respectively (Table 7). At 7-year-old oil palm stand, the average of organic contents was 51.6% C-organic, 1.40% N, 0.18% P, and 1.59% K. Meanwhile, in a 6-year-old oil palm stand, the C-organic, N, P, and K levels were 49%, 1.23%, 0.20% and 1.44%, respectively. Likewise, similar nutrient contents were reported in *Thitonia diversifolia* (Paitan) although at higher levels (Hartatik 2007). The results of this study are also in correspondence with the previous study on *N. biserrata* (Ariyanti et al. 2016), as well as *Ageratum conyzoides*, and *A. gangetica* (Asbur et al. 2018).

Nephrolepis biserrata plant tissue analysis that measured C-organic content and macronutrients (N, P, K) indicates its capacity to enrich soil through litter decomposition (Table 7). Ground cover crops are considered to be an ample substitute in generating nutrient supply and biomass to the soil (Landriscini et al. 2019). A previous study reported organic contents of *A. gangetica* are 33% C-organic, 3% N, 0.2% P, and 2% K. Then, *Paspalum conjugatum* organic contents were 36% C-organic, 3% N, 0.3% P, 2% K, while *A. conyzoides* reported to be comprised of 37% C-organic, 3% N, 0.2% P, and 2% K. The result of this study is in accordance to that of Ariyanti et al. (2016) which reported 51% C-organic, 1% N, 0.2 P, and 2% K of *N. biserrata* in oil palm plantations in South Lampung. While another study in oil palm plantations in South Lampung reported 49% C-organic, 2% N, 0.3% P, and 5% K from *A. gangetica* (Asbur et al. 2016). This suggests that location is an important factor in organic matter and plant nutrient content.

The amount of carbon deposited in an ecosystem in biomass, soil carbon, or dead plants at a certain time is called carbon stock (Agus et al. 2011). The carbon stock potential of the dry weight of biomass is approximately 45-50%. Hence, half of the total dry weight of the biomass is considered as plant the carbon stock (Hartoyo et al. 2019). In this study, a sample plot of 1 m x 1 m was used to calculate carbon stock of *N. biserrata* plant biomass. Calculation shows that the amount of carbon stock stored on each part of it is as much as half of the total dry weight (Figure 2). A higher amount of biomass in a plant will elevate the carbon stock in an ecosystem. Biomass deposited in plant tissue can be as much as 0.6-0.9 tonnes C/ha/year. *N. biserrata*'s biomass carbon stock was meager compared to oil palm fronds, *M. malabathricum* and *Cycas* sp. which reported to be as much as 9.4-12.2 ton/ha/year (Maswar 2009; Maswar et al. 2011), and tropical forest in Asia of 40-250 ton/ha (Lasco 2002).

Table 6. The decomposition rate of *Nephrolepis biserrata* under various ages of oil palm stands

Oil palm plant age (years)	Initial weight (g)	Weight after 30 days (g)	Weight after 60 days (g)	Decomposition rate after 30 days (%/day)	Decomposition rate after 60 days (%/day)	Biomass decomposition after 30 days (%)	Biomass decomposition after 60 days (%)
8	50	31.31^{c}	17.1^{a}	0.62^{a}	0.55^{b}	37.38^{a}	65.8^{b}
7	50	27.5^{b}	16.2^{a}	0.75^{b}	0.56^{ab}	45^{b}	67.6^{b}
6	50	23.8^{a}	13.4^{b}	0.87^{c}	0.61^{a}	52.4^{c}	73.2^{a}

Note: The numbers followed by the same letter were not significantly different in the LSD test at α 5%

Table 7. Nutrient content percentages of various *Nephrolepis biserrata* plant tissues under various ages of oil palm stands

Nutrient (%)	Plant organs	Age of oil palm (years)		
		8	7	6
C-organic	Roots	48.23[abA]	49.71[bA]	46.55[aA]
	Stems	56.42[bC]	54.99[abB]	53.22[aB]
	Leaves	52.36[cB]	50.02[bA]	47.34[aA]
N	Roots	1.3[aA]	1.25[aA]	1.2[aA]
	Stems	1.1[aA]	1.05[aA]	0.9[aA]
	Leaves	2.2[bB]	1.9[abB]	1.6[aA]
P	Roots	0.2[aAB]	0.2[aB]	0.18[aA]
	Stems	0.15[aA]	0.12[aA]	0.13[aA]
	Leaves	0.3[bB]	0.23[aB]	0.3[bB]
K	Roots	1.1[aA]	0.96[aA]	1.01[aA]
	Stems	1.8[aB]	1.6[aB]	1.62[aB]
	Leaves	2.1[bC]	2.2[bC]	1.7[aB]

Note: the numbers followed by the same letter notation in the same column and row are not significantly different on the 5% LSD test. Lowercase notation is read horizontally, uppercase notation is read vertically. (WAP: weeks after planting. LSD: least significant difference)

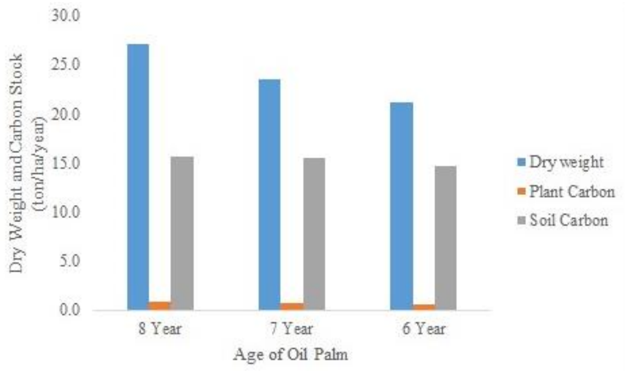

Figure 2. Biomass carbon stock of *Nephrolepis biserrata* under various ages of oil plant stands

Soil carbon stocks

Carbon and biomass are stored naturally in terrestrial ecosystems (Tarnocai et al. 2009). Carbon stored in the land significantly contributes to the reduction of greenhouse gas emissions and serves as an important indicator of soil's quality since it influences the physical, chemical, and biological properties of the soil (Bationo et al. 2006; Follet et al. 2009; Hou et al. 2012; Islam & Weil 2000; Liu et al. 2011;). Our study found that *N. biserrata* under 8-year-old oil palm stands increased soil carbon stock by 127.72%, 99.43%, and 68.36% at various depths observed (Figure 3). At a 7-year-old oil palm stand, the ability of *N. biserrata* in improving soil C organic content was 123.87%, 92.38%, and 79.86% at various depths observed. While at 6-year-old oil palm stands, the increase of C organic stocks recorded at 111.25%, 74.95%, and 58.07% at a depth of 0-10, 10-20 and 20-30 cm, consecutively. Hence, it can be concluded that *N. biserrata* is able to increase carbon stock 1-2 times for every depth profile observed.

Factors, such as physical properties and the type of vegetation that grows on it, contribute to soil carbon contents (Ohkura et al. 2003; Shofiyati et al. 2010). Carbon which is produced during photosynthesis will be stored by plants and become the constituent materials of the tissue. When the whole plant, leaves, or twigs are dead, then it will be redelivered to the soil to be decomposed. The procedure will release CO_2 gas into the air and some of it will be retained in the ground (Fujisaki et al. 2018).

The accumulation of soil carbon stock at 8-, 7- and 6-years old oil palm stands at all soil profile depths was as much as 97.4, 84.6, and 76.4 tonnes/ha/year, consecutively. This result is in comparison with those recorded in tropical forests at comparable depths (5-180 tonnes/ha) (IPCC, 1997). However, a much lesser value (0.1 tonnes/ha) was reported in oil palm plantations in East Kalimantan (Sugirahayu and Rusdiana 2011). It is known that the physical and chemical properties of the soil are certainly impacted by the aggregation of carbon stock as well as groundwater upsurge. Plants will absorb the rest of total CO_2 from the air and it will penetrate the soil again through plant litter, roots, and other organisms' decompositions (Hikmat 2005; Ruddiman 2007).

In conclusion, *N. biserrata* is an ideal ground cover crop due to its rapid growth in covering the landscape (12 WAP), fast decomposition (30-60 days), tolerance in shaded conditions (81.16% growth percentage, 95.9% area covering in all ages oil palm stands observed), high nutrient contents i.e. N (1.23-1.53%), P (0.18-0.22%), and K (1.4-1.67%), potential biomass (0.9 ton C/ha/year), soil carbon stocks (76.4 - 97.4 tonnes /ha/year), and able to increase soil carbon stock up to 127.72%. Thus, certain weeds such as *N. biserrata* can be used as part of an environmentally friendly oil palm cultivation technology, with the advantage of being able to contribute soil carbon and nutrients so that the need for fertilizer for oil palm can be reduced. Moreover, the recommendation of the most optimum spacing treatments of *N. biserrata* from this study is also need to be applied in order to get the intended result when the method wants to be applied widely.

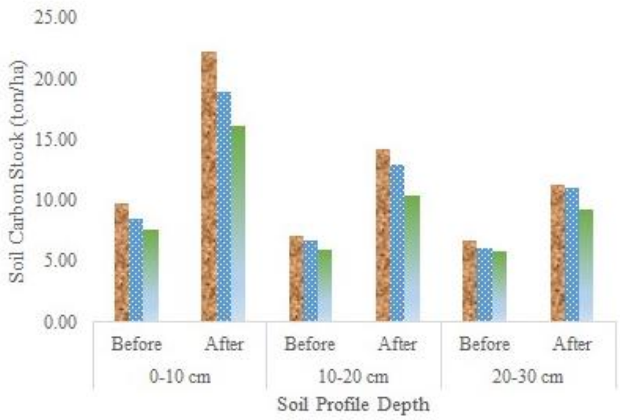

Figure 3. Soil carbon stock (ton/ha) at various soil profile depths (0-30 cm) under various ages of oil palm stands

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