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Effect of Present and Treated *Turnera ulmifolia* L. on Bagworm and Natural Enemies Population in Oil Palm Plantation

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Abstract: Bagworm is the most serious threat to Malaysia's oil palm industry, causing up to 40% crop loss after two years of defoliation. In response to the concomitant decrease in pesticide use, nectariferous plants such as *Turnera ulmifolia* are increasingly being planted as biological control for bagworm. To fill in the knowledge gap, studies were conducted to determine the effects of field fertiliser application on nectar and flowering of *T. ulmifolia* and its subsequent effect on parasitoid and bagworm population. Treatments T1 (0.2 g NPK) and T2 (0.2 g NPK + 3.9 g silicon) from semi trial study were further tested on a ten-year-old oil palm plantation in the Samarahan area with a moderate infestation of *Metisa plana* since early 2017. Data on the number of bagworms and natural enemies were collected weekly during two sampling rounds (February to March and August to September 2020). All data were subjected to Analysis of Variance (ANOVA) using the Statistical Analysis System (SAS) and means for significant treatment effects were separated by LSD tests at a $P<0.05$ significance level. Improvement in the number of flowers and nectar value was observed seven months after *T. ulmifolia* was administered with 0.2 g NPK. Consequently, increasing the amount of food is available to parasitoids. As a result, bagworm parasitism, and thus bagworm mortality was higher in the 0.2 g NPK and with silicon plot. The number of live bagworms was greatly reduced in plots with the presence of *T. ulmifolia* supplied with 0.2 g NPK compared to plots without co-plantation of *T. ulmifolia*. Fertiliser application positively affected the flowering, and nectar of *T. ulmifolia*.

Keywords: bagworm, natural enemies, beneficial plant, fertiliser, flower

1. Introduction

Malaysia's rapid development of oil palm plantations has inevitably resulted in the emergence of various oil palm-related pests that threaten oil palm production (Yap, 2005; Tan et al., 2008; Kok et al., 2012). Sarawak, being the largest state in Malaysia, holds 22% of the nation's oil palm plantations, making it the second largest contributor to palm biomass production (Aghamohammadi et al., 2016). While, Sarawak's oil palm plantings have grown over time, and the total area planted for oil palm in 2018 was 1.57 million ha (MPOB, 2018). However, being planted largely as a monocrop, the oil palm is prone to the infestation of endemic insect pests such as bagworm. With the increase in hectarage of oil palm plantations, there is a major concern on potential bagworm outbreaks, which would result in significant loss of yields. Such outbreaks are common in Malaysia and have a significant economic impact on oil palm yield. Bagworm infestations cause 10% to 13% of leaf defoliation in oil palm plantations, resulting in crop losses of up to 40% (Benjamin, 2012). According to Chung (2012), a bagworm-infested palm experiences increased foliage damage until all the fronds are stripped and bared.

The widespread use of chemical pesticides has resulted in serious implications such as pest resistance leaving dangerous residue to the environment, and the annihilation of beneficial insects (Wood & Norman, 2019a). To reduce the impact, the Integrated Pest Management (IPM) has been recommended as a viable option to control agricultural pests (Wood & Norman, 2019b). The IPM approach conserve natural enemies of pests and increase production of pollen and nectariferous plants in the field. Growers have started to increase the use of biological control agents by conserving

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natural enemies by planting beneficial plants as it one of four core components for bagworm control other than the use of *Bacillus thuringiensis* (Bt) based bioinsecticides, to attract beneficial insects, and the installation of pheromone traps.

Incorporating nectar producing host plants into oil palm plantations is one way to enhance natural enemy populations and subsequently regulate bagworm infestation. Flowering plants attract beneficial insects via their nectar production (Norman & Othman, 2016). Among the flowering plants, *T. ulmifolia* is gaining popularity as the common flowering plant being incorporated into oil palm plantations owing to its ease of culture, wide adaptability, and increasing demand in the Asian subcontinent (Gilman, 2011).

There are yet to be official reports on bagworm infestation in Sarawak, even though bagworms were spotted in certain oil palm plantations. The current method of bagworm control involves the application of cypermethrin via spraying if the number of bagworms reaches economic threshold level (ETL). At present, biological conservation at oil palm plantations is being practised by planting *T. ulmifolia* around the compound. However, based on observation, the *T. ulmifolia* was not well managed and some were killed off as weed using herbicide. The increasing quality of nectar of *T. ulmifolia* may positively affect nectar feeding insects and thus enhance the parasitism rate. Previous study showed fertilisation with 0.2 g NPK in a 1:1:2 ratio, silicon, and their combination had a similar effect on *T. ulmifolia* nectar production when compared to untreated plants (Sidi et al., 2022). Therefore, this study aimed to determine the effect of fertiliser application on *T. ulmifolia's* nectar and flowering to the bagworm population.

2. Materials and Methods

2.1 Study Area Description

The study area was in the Samarahan state of Sarawak (1°28'54" N, 110°32'25" E). This area was a 10-year-old oil palm plantation with the peat soil type. Oil palm was grown using a triangular system of planting with a 9 x 9 x 9-metre spacing. Based on the previous history record since early 2017, the plantation was chosen due to a moderate infestation of *Metisa plana*, which is less than 10 larvae of bagworm per frond. This plantation used biocontrol based IPM to control bagworms. There would be no insecticidal application intervention throughout the study. Other standard practices, such as pruning dry leaves and weeding, were regularly conducted.

2.2 Experimental Design and Treatment Description

The field was laid out according to a randomized complete block design (RCBD) with four replications. Four blocks were chosen as replicates: Blocks B3, B4, A4, and A5 for this study. The total area cultivated with oil palm for each study block is: B3: 36.0 ha; B4: 42.0 ha; A4: 49.0 ha; and A5: 54.0 ha. Each block was divided into four equal plots.The plots were separated by 100 metres, which served as a border. The replicates were stratified by grouping all treatments into blocks to minimise local directional effects. Treatments were randomly assigned within each block. Ten two-month-old *T. ulmifolia* plants were planted on the ground 30 cm apart along the row in each plot of treatments 1, 2, and 3. The *T. ulmifolia* strip was located along the edge of the field. For treatments 2 and 3, fertiliser was applied two weeks after plants at a distance of 10 cm from *T. ulmifolia.* Throughout the study, the fertiliser was applied at a monthly interval. Details of each treatment are shown in Table 1.

Table 1: Fertiliser application to *Turnera ulmifolia* grown at study area

Label	Treatment Description
T0	No *T.ulmifolia* planted
T1	*T. ulmifolia* (no fertiliser applied)
T2	*T. ulmifolia (*fertilised with 0.2 g NPK blue)
T3	*T. ulmifolia* (fertilised with 0.2 g NPK blue + 3.9 g silicon)

2.3 Flower Density and Nectar Sampling

Flower density was measured by recording the number of flowers per plant on each plot for all blocks on every sampling day. The sugar content of the flowers was also measured. Three flowers were selected and collected randomly between 9.30 a.m. and 12.30 a.m. from each plot treatment: 1, 2, and 3 within each block. Each flower was put into a falcon tube, which contained 10 mL of distilled water. After labelling, samples were immediately stored on ice in the field, and the samples were kept in a -20°C freezer in the laboratory until further analysis.

2.4 Nectar Sugar Analyses

The phenol-sulfuric acid method (Chen & Huang, 2019) was used to determine the sugar content, with glucose serving as a standard. To prepare the standard curve, 10 mg of pure glucose (GR Merck) was dissolved in 100 ml of distilled water. Pipette aliquots of this stock solution of 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 mL into numbered test

tubes. The final volume in each tube was set to 1 mL. In the blank test tube, distilled water was used instead of pure glucose. Then, in each tube, 1 mL of a 5% (v/v) phenol solution was added, followed by 5 mL of concentrated 98% (w/w) sulfuric acid to act as a catalyst for the colour development process. For 5 minutes, the final solution was agitated in a tube shaker. After 45 minutes, absorbance at 490 nm was measured against a blank. On Excel, the standard curve was created by plotting the absorbance at each designated glucose concentration. The total sugars in the nectar were quantitatively estimated using a standard curve preparation procedure. For the analysis of nectar sugars, 3–4 replicates and a blank were used. The sugar content of nectar was measured in milligrams of glucose equivalent.

2.5 Bagworm and Natural Enemies Sampling

Two sampling rounds of bagworm and natural enemies were conducted. The first-round sampling was carried out weekly for six weeks from 19th February until 11th March 2020, four weeks following the establishment of the *T. ulmifolia* strips. Thirty-three weeks following the establishment of the *T. ulmifolia* strips, a second round of sampling commenced for four weeks at a weekly interval from 26th August until 16th September 2020. The palm was sampled to assess the number of bagworms and their natural enemies. On each sampling date, two palms freshly damaged were chosen at random: one palm from the fifth row and one palm from the sixth to tenth row. Palms were tagged with a nylon strip to avoid being tagged twice. A frond was cut from a selected palm, and leaflets with bagworms on their fronds were collected by cutting the leaflet using scissors. The bagworms were brought to the laboratory, where they were counted and observed for predator and parasitoid activity. The total number of bagworms and parasitoids from the four replicates was recorded for each sampling occasion. Bagworm larvae and pupae were counted and recorded after being sorted into various life stages. The outer bag was measured to determine the stage of live larvae Each stage of live bagworm larvae was kept separately in a clear plastic container (11.8 cm wide x 8.5 cm base x 6.0 cm height) and fed fresh oil palm leaves daily until pupation. Female pupae were distinguished from adults by examining the posterior end of pupal bags; female pupae had no opening, whereas an adult opening was present. Live pupae were kept in plastic containers (75 cm wide x 25 cm base x 76 cm height) to observe parasitoid emergence.

2.6 Determination of Parasitism and Predation on Bagworm

All dead bagworm specimens were subjected to a post-mortem examination to determine the actual level of mortality caused by natural enemies. In preparation for parasitoid emergence, dead bagworms with small holes in their bags were separated and stored. The newly emerged parasitoid adults were individually transferred into glass vials with an aspirator and fed 50% honey. Following sorting of the samples, all parasitoids were counted, recorded, and identified to the species level using the keys, manual, and descriptions provided by Norman et al. (1996), as well as Parator Software.

2.7 Data Analysis

The effects of different treatments on the number of flowers, nectar content, number of live and dead bagworms, and parasitoid occurrence were analysed using ANOVA and subsequent post hoc LSD tests for pairwise differences among means. The results are presented as the weekly mean (± SEM). Data analysis) was performed with SAS Version 9.4.

3. Results

3.1 Effect of Fertiliser on Number Flowers of *Turnera ulmifolia* L

The mean number of flowers differed between study periods, and more flowers were noted in the August-September sampling period (Tables 2a, 2b). The mean number of flowers in the fertilised treatment was not significantly different from that of the unfertilised treatment during the first sampling period (Table 2a). For the first three weeks (5th to 7th week) of the first sampling period, the number of flowers was in the range of 1.8 ± 0.48^{a} to 5.5 ± 0.96^{a}. Subsequently, the number of flowers increased to a range of 9.0 ± 1.73^{a} to 13.0 ± 2.16^{a} in the following two weeks. The number of flowers was significantly affected by the application of 0.2 g NPK + 3.9 g silicon (T3) on 35th and 37th week, thirty-three weeks after *T. ulmifolia* was established. Plants subjected to fertilisers (T2) produced 45% more flowers than control (T1) ($F = 3.04$, $P = 0.1040$ and $F = 6.09$, $P = 0.0241$; Table 2b).

Table 2. Number (Mean ± SE) of *Turnera ulmifolia* flower after subjected to fertiliser application at weekly intervals after four weeks *T. ulmifolia* was planted

a) first round sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T1	4.8 ± 0.85[b]	2.5 ± 1.50[a]	1.8 ± 0.48[a]	9.0 ± 1.73[a]	12.8 ± 2.25[a]	11.0 ± 2.04[a]
T2	5.5 ± 0.96[a]	5.0 ± 1.78[a]	2.0 ± 0.71[a]	8.8 ± 1.97[a]	12.5 ± 2.36[a]	10.5 ± 1.26[a]
T3	5.0 ± 0.71[a]	4.5 ± 1.04[a]	2.3 ± 0.63[a]	9.0 ± 1.47[a]	10.8 ± 1.11[a]	13.0 ± 2.16[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T1	10.3 ± 5.25[a]	9.5 ± 2.53[b]	17.0 ± 3.2[a]	13.3 ± 0.25[b]
T2	10.8 ± 0.85[a]	19.8 ± 3.32[ab]	20.5 ± 4.1[a]	36.8 ± 1.38[a]
T3	18.8 ± 5.31[a]	24.3 ± 1.38[a]	27.0 ± 5.5[a]	25.8 ± 6.00[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).
Note: Means within columns followed by the same letter are not significantly ($P < 0.05$) different according to LSD test

3.2 Effect of Fertiliser Application on Sugar Content in Nectar *Turnera ulmifolia* Flower

During the first round of the sampling period, analysis on the 5th and 6th weeks after *T. ulmifolia* establishment showed that the sugar content of *T. ulmifolia* when 0.2 g NPK was applied (T2) was significantly different compared to treatment with no fertiliser (T1) (F = 6.47, Pr>F = 0.0208; Table 3a). However, from the 7th to the 10th week, there was no significant difference in sugar content between all treatments, and all treatments gave lower sugar values (0.8 to 0.9 mg/flower) than the values obtained during the first four weeks of sampling. Subsequent evaluation of sugar content 33 weeks after the establishment of *T. ulmifolia* (second round of sampling) did not reveal any significant differences in the sugar content between all the treatments, except on the 35th week (Table 3b). On the 35th week, nectar content was significantly higher (F = 3.00, P = 0.1068) when *T. ulmifolia* was added with 0.2 g NPK + silicon (T3) compared with 0.2 g NPK (T1) and an untreated plant (T0; no fertiliser applied).

Table 3: **Sugar content (Mean ± SE) in *Turnera ulmifolia* flowers produced by fertilised and controlled plants was measured at weekly intervals after four weeks after *T. ulmifolia* was planted**

a) first round sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T1	1.41 ± 0.05[b]	1.08 ± 0.04[b]	1.36 ± 0.08[a]	1.07 ± 0.16[a]	0.80 ± 0.04[a]	0.82 ± 0.02[a]
T2	1.67 ± 0.03[a]	1.41 ± 0.12[a]	1.43 ± 0.05[a]	1.09 ± 0.10[a]	0.86 ± 0.02[a]	0.87 ± 0.04[a]
T3	1.50 ± 0.04[b]	1.36 ± 0.07[ab]	1.20 ± 0.19[a]	0.92 ± 0.18[a]	0.81 ± 0.02[a]	0.83 ± 0.01[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T1	0.92 ± 0.61[a]	1.01 ± 0.46[b]	1.17 ± 0.53[a]	0.69 ± 0.22[a]
T2	1.22 ± 0.39[a]	1.57 ± 0.37[ab]	1.27 ± 0.40[a]	0.85 ± 0.35[a]
T3	0.87 ± 0.42[a]	2.42 ± 0.22[a]	1.75 ± 0.43[a]	0.82 ± 0.28[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).
Note: Means within columns followed by the same letter are not significantly ($P < 0.05$) different according to LSD test

3.3 Effect of Present and Treated *Turnera ulmifolia* on the Number of Live Bagworms

The mean number of live bagworms was not significantly different between all treatments at the 5th week of sampling (F = 2.70, P = 0.0879) (Table 4a). However, on the 6th, 8th, and 8th weeks, T0 (no *T. ulmifolia* planted) produced the highest mean number of alive bagworms and was significantly different from T1 (no fertiliser applied) and T2 (0.2 g NPK) (F = 4.35, P = 0.0245; F = 85.68, P < 0.0001; F = 6.72, P = 0.0061; Table 4a). During the sampling period from the 6th to the 8th week, T3 consistently showed the lowest number of bagworm infestations and was significantly different from the control (T0). There was no significant difference between all treatments on the 9th week, and the infestation occurrence was lower compared to the first three weeks of sampling. The trend of infestation changed on the 10th week, when the mean number of bagworms at plot T2 was the highest among all treatments and was significantly different from T0 and T1 (F = 12.70, P = 0.0872. Sampling continued for four weeks after thirty-three weeks *T. ulmifolia* was established. During this second round of sampling, the infestation of bagworms was lower compared to during the first sampling period, and there was no significant difference among all treatments. All treatments consistently reduced bagworm infestation by almost 65–85% compared to the first sampling period (Table 4b). Of all the species of bagworms, *P. pendula* and *M. plana* were the most dominant species in the study area in both sampling periods (Tables 5a and 5b).

Table 4: Mean number of alive bagworms (Mean ± SE) after subjected to different treatments at weekly intervals after four weeks after *T. ulmifolia* was planted

a) first round of sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T0	1.5 ± 0.96[a]	16.0 ± 3.24[a]	1.3 ± 0.75[a]	4.5 ± 1.67[a]	14.3 ± 3.61[a]	10.8 ± 2.10[b]
T1	12.3 ± 5.20[a]	2.5 ± 1.32[b]	0.0 ± 0.00[a]	0.0 ± 0.00[b]	2.5 ± 2.00[a]	14.0 ± 2.03[b]
T2	7.3 ± 3.28[a]	11.0 ± 1.78[a]	1.3 ± 1.25[a]	0.0 ± 0.00[b]	7.8 ± 0.58[a]	32.3 ± 2.91[a]
T3	3.3 ± 0.83[a]	2.8 ± 1.89[b]	1.0 ± 0.58[a]	4.0 ± 1.33[a]	8.5 ± 1.20[a]	19.0± 4.73[ab]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round of sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T0	5.5 ± 3.59[a]	2.3 ± 1.93[a]	5.8 ± 3.82[a]	2.5 ± 0.88[a]
T1	6.3 ± 1.65[a]	2.5 ± 1.32[a]	7.3 ± 2.50[a]	19.5 ± 0.33[a]
T2	1.3 ± 0.75[a]	6.0 ± 3.67[a]	3.8 ± 1.60[a]	4.0 ± 0.33[a]
T3	1.0 ± 1.00[a]	2.3 ± 1.03[a]	4.5 ± 1.04[a]	1.3 ± 1.33[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

Note: Means within columns followed by the same letter are not significantly ($P < 0.05$) different according to LSD test

Table 5: Species of alive bagworms subjected to different treatments at weekly intervals after four weeks after *Turnera ulmifolia* was planted

a) first round of sampling

Week observation	**Treatment**	**Species bagworm**				
		Metisa plana	***Pteroma pendula***	***Mahasena corbetti***	***Clania* sp.**	***Unknown* sp.**
5th Week	T0	46	20	0	0	0
	T1	32	17	0	0	0
	T2	6	23	0	0	0
	T3	7	6	0	0	0
	T0	125	35	0	0	0
	T1	62	38	0	0	0
	T2	61	35	0	0	0

6th Week	T3	8	3	0	0	0
7th Week	T0	128	57	0	0	0
	T1	24	35	0	0	0
	T2	40	18	0	0	0
	T3	73	43	0	0	0
8th Week	T0	18	0	0	0	0
	T1	0	0	0	0	0
	T2	0	0	0	0	0
	T3	16	0	0	0	0
9th Week	T0	50	7	0	0	0
	T1	121	20	0	0	0
	T2	15	16	0	0	0
	T3	26	8	0	0	0
10th Week	T0	42	1	0	0	0
	T1	50	6	0	0	0
	T2	86	13	0	0	0
	T3	67	0	0	0	0

b) second round of sampling

Week observation	**Treatment**	**Species of bagworm**				
		Metisa plana	***Pteroma pendula***	***Mahasena corbetti***	***Clania* sp.**	***Unknown* sp.**
35th Week	T0	18	4	0	0	0
	T1	11	14	0	0	0
	T2	1	4	0	0	0
	T3	2	2	0	0	0
36th Week	T0	27	6	0	0	0
	T1	7	3	0	0	0
	T2	0	24	0	0	0
	T3	4	5	0	0	0
37th Week	T0	5	4	0	0	14
	T1	18	6	0	0	5
	T2	8	5	0	0	2
	T3	4	6	0	0	4
38th Week	T0	1	5	0	0	4
	T1	56	4	0	0	18
	T2	10	0	0	0	6
	T3	18	2	0	0	4

3.4 Effect of Present and Treated *Turnera ulmifolia* on the Number of Dead Bagworm

The overall trends in the mortality of bagworm in response to present and treated *T. ulmifolia* after one-month planting are illustrated in Table 6a. Mortality of bagworm in plots of *T. ulmifolia* treated with no fertiliser (T1), 0.2 g NPK (T2) and 0.2 g NPK + silicon (T3) was not significantly different from plots without *T. ulmifolia* (T0-control) on 5th, 8th, and 9th week. On 6th week, plots that were planted with *T. ulmifolia* (T2-0.2 g NPK) showed the highest mortality (9.3 ± 4.03^{a}) of bagworms compared to treatment with no fertiliser applied ($F = 2.15$, $P = 0.1456$; Table 6a). While on 7th week, the number of mortalities of bagworms in T3 (0.2 g NPK + 3.9 g silicon) plots increased significantly (12.5 ± 5.00^{b}) compared to plots with no *T. ulmifolia* planted ($F = 1.08$, $P = 0.4401$). During the 10th week of sampling, bagworm mortalities were significantly higher in T2 (19.0 ± 5.8^{a}, $F = 3.74$, $P = 0.0379$) in comparison with other treatments. The mortality of bagworms in all treatments increased further thirty-three weeks after the establishment of *T. ulmifolia* treatment (Table 6b). The weekly mortality of bagworms was not significantly different between all treatments on 34th, 36th and 37th week. On 35th week, the highest bagworm mortality (54.8 ± 2.50^{a}) occurred in T2 and was significantly different from T0 (2.8 ± 0.95^{d}, $F = 73.79$, $P < 0.001$). Among dead specimens, *P. pendula* and *M. plana* remained the two highest species found in the study area (Tables 7a and 7b).

Table 6: Mean number of mortality bagworms (Mean ± SE) after subjected to different treatments at weekly intervals after four weeks after *Turnera ulmifolia* was planted

a) first round of sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T0	1.3±0.25^{a}	5.5±1.04^{ab}	1.3±0.95^{b}	1.5±1.19^{a}	4.0±0.91^{a}	4.0±1.83^{b}
T1	1.0±0.41^{a}	2.3±0.75^{b}	4.5±0.87^{ab}	3.8±1.89^{b}	6.0±1.47^{a}	7.3±1.70^{b}
T2	0.3±0.25^{a}	9.3±4.03^{a}	9.5±3.38^{ab}	6.3±4.13^{b}	12.5±2.78^{a}	19.0±5.80^{a}
T3	1.0±0.71^{a}	4.3±2.14^{ab}	12.5±4.97^{b}	4.8±2.06^{a}	7.0±4.26^{a}	6.3±3.57^{b}

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round of sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T0	31.8 ± 3.82^{a}	2.8 ± 0.95^{d}	5.8 ± 2.78^{b}	17.5 ± 2.72^{a}
T1	25.5 ± 2.25^{a}	10.0 ± 2.68^{c}	19.3 ± 3.50^{a}	21.0 ±5.01^{a}
T2	11.3 ± 5.96^{a}	54.8 ± 2.50^{a}	21.0 ± 2.52^{a}	18.5 ± 5.25^{a}
T3	16.0 ± 3.11^{a}	18.0 ± 1.48^{b}	19.0 ± 1.96^{a}	25.5 ± 4.77^{a}

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

Note: Means within columns followed by the same letter are not significantly ($P < 0.05$) different according to LSD test

Table 7: Number of dead bagworms by species after subjected to different treatments at weekly intervals after four weeks after *Turnera ulmifolia* was planted

a) first round of sampling

Week observation	**Treatment**	**Species bagworm**				
		Metisa plana	***Pteroma pendula***	***Mahasena corbetti***	***Clania* sp.**	***Unknown* sp.**
5th Week	T0	0	1	2	0	2
	T1	1	0	3	0	0
	T2	0	0	1	0	0
	T3	2	0	2	0	0
6th Week	T0	8	8	1	0	6
	T1	5	9	1	0	0
	T2	21	17	1	0	1
	T3	5	13	1	0	0
7th Week	T0	34	41	0	0	1
	T1	17	5	0	0	0
	T2	26	22	0	0	1
	T3	26	32	0	0	1
8th Week	T0	17	27	2	0	0
	T1	17	1	0	0	0
	T2	13	16	0	0	0
	T3	12	9	1	0	0
9th Week	T0	62	36	0	0	3
	T1	23	12	1	0	2
	T2	48	20	0	0	2
	T3	19	20	0	0	1
	T0	62	34	0	0	3
	T1	23	3	1	0	2
	T2	48	16	0	0	2

10th Week	T3	19	5	0	0	1

b) second round of sampling

Week observation	Treatment	Species bagworm				
		Metisa plana	***Pteroma pendula***	***Mahasena corbetti***	***Clania* sp.**	***Unknown* sp.**
35th Week	T0	49	70	1	0	1
	T1	80	19	1	0	1
	T2	24	19	0	0	0
	T3	38	25	0	0	0
36th Week	T0	45	39	0	0	0
	T1	34	3	0	0	0
	T2	10	133	2	0	2
	T3	41	32	0	0	0
37th Week	T0	24	67	0	0	0
	T1	28	22	0	0	0
	T2	70	54	0	0	0
	T3	24	82	0	0	0
38th Week	T0	27	38	3	0	3
	T1	41	65	4	0	4
	T2	12	60	0	0	0
	T3	34	54	1	0	1

3.5 Effect of Present and Treated *Turnera ulmifolia* on Parasitism, and Predation on Bagworm

Individual bagworm larva was inspected for apparent signs of attack by natural enemies. The collected larvae revealed that bagworms in the study area were affected by parasitoids, and predators. The appearance of a small hole on the surface of the bagworm implied parasitisation (Figure 1a); whereas predation was characterised by the presence of a big hole that encompassed almost half of the size of the bagworm (Figure 1b).

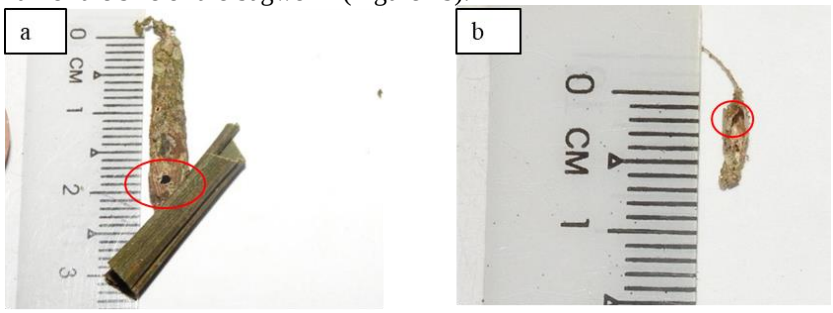

Fig. 1: The appearance of collected bagworms showing sign of a) parasitism b) predation

Tables 8a and 8b show the results of parasitism on bagworm during the two sampling periods. The number of parasitised bagworms was not significantly different between treatments during sampling on the 5th, 7th, 8th and 9th weeks, though it was higher for *T. ulmifolia* present and treated *T. ulmifolia* compared to treatment without *T. ulmifolia*. However, on the 6th week, the number of parasitism was higher due to the presence of the nectar source compared to nectar-free plant treatments. During this period, parasitism at plots that were planted with *T. ulmifolia* (T1) was higher (1.5 ± 0.86^{a}) and significantly different from plots where no *T. ulmifolia* was planted (T0) ($F = 1.70$, $P = 0.2275$). The addition of fertiliser to *T. ulmifolia* also significantly increased the number of parasitism compared to treatments without *T. ulmifolia*. On the 10th week, the T2 (0.2 g NPK) samples had the highest mean number of parasitism (2.8 ± 0.75^{a}), which was significantly different from those with no *T. ulmifolia* planted (T0) ($F = 1.57$, $P = 0.2616$).

Further evaluation was then continued thirty-three weeks after *T. ulmifolia* was established. The highest number of parasitism, 2.0 ± 0.92^{a}, 2.0 ± 5.5^{a} 1.8 ± 6.00^{ab} in T3 was recorded on the 35th, 37th and 38th weeks, and it was significantly different compared to T0 ($F = 1.70$, $P = 0.2275$) on the 38th week only.

Table 8: Number of parasitism on *Metisa plana* and *Pteroma pendula* (Mean ± SE) after subjected to different treatments at weekly intervals after four weeks after *T. ulmifolia* was planted

a) first round of sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T0	0.0 ± 0.00[a]	0.0 ± 0.00[b]	1.0 ± 0.70[a]	0.5 ± 0.29[a]	0.0 ± 0.00[a]	0.3 ± 0.25[b]
T1	0.0 ± 0.00[a]	1.5 ± 0.87[a]	0.5 ± 0.50[a]	0.5 ± 0.29[a]	0.3 ± 0.25[a]	0.8 ± 0.48[ab]
T2	0.0 ± 0.00[a]	0.3± 0.25[ab]	1.0 ± 0.58[a]	0.5 ± 0.29[a]	1.0 ± 0.41[a]	2.8 ± 0.75[a]
T3	0.0 ± 0.00[a]	0.3 ± 0.25[ab]	0.5 ± 0.29[a]	0.3 ± 0.25[a]	0.5 ± 0.50[a]	2.0 ± 1.00[ab]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round of sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T0	0.3 ± 0.25[a]	0.0 ± 0.00[b]	0.3 ± 3.2[a]	0.8 ± 0.25[b]
T1	0.5 ± 0.29[a]	1.5 ± 0.87[a]	0.5 ± 3.2[a]	0.5 ± 0.25[ab]
T2	0.5 ± 0.50[a]	0.3 ± 0.25[ab]	0.5 ± 4.1[a]	1.8 ± 1.38[a]
T3	2.0 ± 0.92[a]	0.3 ± 0.25[ab]	2.0 ± 5.5[a]	1.8 ± 6.00[ab]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).
Note: Means within columns followed by the same letter are not significantly (P < 0.05) different according to LSD test

Table 9a shows that neither untreated nor treated *T. ulmifolia* increased the number of bagworms during the first sampling period. Predation was low (average only one per treatment), and the occurrence was inconsistent weekly during the first round of sampling. During the second round of sampling (Table 9b), predation occurred weekly in T0, T2, and T3 but not in T1 (it only occurred on the 34th and 37th weeks). At both sampling periods, no insect parasitoid or predator was captured using the sweep net technique within the oil palm plantation in all the treatments.

Table 9: Number of predation on *Metisa plana* and *Pteroma pendula* (Mean ± SE) after subjected to different treatments at weekly intervals after four weeks after *Turnera ulmifolia* was planted

a) first round of sampling

	Week observation					
Treatment	**5th Week**	**6th Week**	**7th Week**	**8th Week**	**9th Week**	**10th Week**
T0	0.0 ± 0.00[a]	0.0 ± 0.00[a]	0.3 ± 0.25[a]	0.5 ± 0.50[a]	0.3 ± 0.25[a]	0.0 ± 0.00[a]
T1	0.0 ± 0.00[a]	0.0 ± 0.00[a]	0.0 ± 0.00[a]	0.0 ± 0.00[a]	0.3 ± 0.25[a]	0.3 ± 0.25[a]
T2	0.0 ± 0.00[a]	0.3 ± 0.25[a]	0.0 ± 0.00[a]	0.5 ± 0.50[a]	0.3 ± 0.25[a]	0.0 ± 0.00[a]
T3	0.0 ± 0.00[a]	0.0 ± 0.00[a]	0.5 ± 0.50[a]	0.3 ± 0.25[a]	0.0 ± 0.00[a]	0.5 ± 0.29[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).

b) second round of sampling

	Week observation			
Treatment	**34th Week**	**35th Week**	**36th Week**	**37th Week**
T0	0.8 ± 0.75[a]	0.8 ± 0.75[a]	0.8 ± 0.75[a]	0.3 ± 0.25[a]
T1	0.3 ± 0.25[a]	0.0 ± 0.00[a]	0.0 ± 0.00[a]	1.0 ± 1.00[a]
T2	0.3 ± 0.25[a]	1.5 ± 0.65[a]	1.5 ± 0.65[a]	0.3 ± 0.25[a]
T3	0.3 ± 0.25[a]	0.3 ± 0.25[a]	0.3 ± 0.25[a]	1.3 ± 0.95[a]

***T1 = *T. ulmifolia* (no fertiliser applied); T2 = *T. ulmifolia (*fertilised with 0.2 g NPK); T3 = *T. ulmifolia* (fertilised with 0.2 g NPK + 3.9 g silicon).
Note: Means within columns followed by the same letter are not significantly ($P < 0.05$) different according to LSD test

4. Discussion

4.1 Effect of Fertiliser Application on Nectar and Number Flowers of *Turnera ulmifolia* L

Results of the current study provides a foundation for ongoing research on the improvement of biological control in oil palm plantations. Previous studies have found that the presence of *T. ulmifolia* could influence biological control agents in oil palm plantations. However, the data presented herein demonstrates for the first time that by adding fertiliser to *T. ulmifolia*, bagworm occurrence could be regulated while the number of beneficial insects enhanced. Although fertiliser application had no effect on nectar during either of the sample periods, the value of nectar was higher seven months after *T. ulmifolia* was planted. In addition, enhanced flower production was apparent after seven months of *T. ulmifolia* planting. Increase in flower quantity implies increase in nectar, i.e., food for parasitoids. As a result, bagworm parasitism was higher in the treated plot, resulting in higher bagworm mortality, seven months after *T. ulmifolia* was planted. Apart from that, bagworm suppression was found, with the number of live bagworms being reduced when flowering *T. ulmifolia* treated with fertiliser was present compared to when no *T. ulmifolia* was planted.

The sugar content in nectar and the number of flowers of *T. ulmifolia* were slightly higher in treatments of T2, 0.2 g NPK (15:15:17) and plus silicon compared to untreated plants. Silicon may be beneficial to many plants metabolic processes, such as increasing photosynthetic efficiency, eventhough silicon is not considered an essential element for growth and development (Silva et al., 2012). Photosynthetic activity of leaves supplies organic compounds (primarily carbohydrates) to flower structures, including nectar. This finding is consistent with Shuel (1955) study of the effect of nutrient application on nectar secretion in non-Mediterranean plants. He observed increased nectar secretion when nitrogen levels were low, which is similar to the minimum amount of NPK used in the current study. The varying composition of nectar in the current study expected as nectar composition is dependent on plant species and environmental conditions (Herrera et al., 2006).

4.2 Effect of Present and Treated *Turnera ulmifolia* on Parasitism and Predation on Bagworm

The goal of conserving biological control agents is to improve the efficacy of arthropod biological control agents, such as parasitoids, by providing them with access to floral nectars. The suitability of a flower species to specific parasitoid, on the other hand, is determined by the morphologies of the parasitoid and the flower, as well as the quality of the nectar (Vattala et al., 2006). Findings in this study suggest that improving flowering and nectar of *T. ulmifolia* with T2, 0.2 NPK (15:15:17) and plus silicon could exert a negative effect on the occurrence of live bagworms, but a positive effect on parasitism. This was demonstrated by the enhanced parasitism and predation in the T2 treatment, which was caused by the reintroduction of appropriate flowering plants into monocultures to promote longevity, fecundity, sex ratio, and searching capacity of natural enemies such as parasitoids (Berndt & Wratten, 2005; Araj et al., 2009; Zhu et al., 2013; Pandey et al., 2018). Increasing parasitism in plots with present and treated *T. ulmifolia* could be accomplished through habitat manipulation, landscape diversification, and the provision of plants that can provide nectar and other resources to natural enemies (Juric et al., 2017). The addition of flowering plants within or around crop fields may increase the population of natural enemies by providing them with food source (nectar, pollen) and shelter (Van Rijn & Wackers, 2016; Chung, 2012; Lu et al., 2014; Delisle et al., 2015; Villa et al., 2016; Gurr et al., 2017). The nectars of flowering plant are important supplementary food for various species of parasitoids (Arnó et al., 2018). In addition to floral nectar, *T. ulmifolia* have extrafloral nectaries.

In general, extrafloral nectar is an inducible, indirect defense against herbivores and attracts predators and parasitoids to damaged plants (Heil, 2015). The lack of captured parasitoid during this study, even though the parasitism sign was recorded from the collected bagworms, could be attributed to the reliance on the use of the sweep net technique. The species of parasitoid was not determined during the dissection of dead bagworms. Predation on bagworms were also recorded in the current study. The low number of predations by predators was probably because the predator species were unattracted or deterred by *T. ulmifolia*. Indeed, Tixier et al. (2013) discovered that increasing plant diversity could improve biological control and reduce the likelihood of intraguild predation by providing natural enemies with alternative food and shelter. Although previous studies sampling by Abdullah and Rahim (2018) have similarly demonstrated the potential of *T. ulmifolia* in enhancing biological control, none have yet provided information regarding the effect of fertiliser on enhancing flowering and nectar in a plantation setting.

5. Conclusion

Based on the results of the present study, it was concluded that the 0.2 g NPK (T2) fertiliser had a positive impact on the number of flowers and nectar of *T. ulmifolia*, which was reflected by the higher flowering occurrence and sugar nectar content. Consequently, the higher flowering occurrence and nectar availability positively impacted parasitism and reduced the occurrence of bagworms. Therefore, it can be concluded that the implementation of 0.2 g NPK on *T. ulmifolia* could improve parasitism or biological control on bagworms in oil palm plantations. However, the rate of fertiliser must increase accordingly as the plants grow to meet the nutritional requirement of *T. ulmifolia*. Finally, our study did not confirm broadly supported hypotheses and highlights that interactions between flowering with parasitism and bagworm populations are complex and merit further research to obtain a better understanding of the underlying mechanisms and relevant spatial scales. Future research, including the lengthening of the study, is necessary to further understand and measure the degree of bagworm control achieved by prolonged co-cultivation of *T. ulmifolia* with oil palms and the effects on the population and diversity of natural enemies. The abiotic factor information on bagworm populations is highlighted even. Reliable data on these parameters can help predict bagworm spread in oil palm landscapes, allowing effective mitigation strategies to be developed.

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