GROWTH AND INVASIVE CAPACITY OF *Parthenium hysterophorus* L. UNDER DIFFERENT BIOTIC AND ABIOTIC CONDITIONS IN MALAYSIA

By

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Parthenium hysterophorus L., is an invasive weed of the family Asteraceae of global concern. It gives significant economic impacts on crop and livestock productions. Although several studies have been undertaken to determine the distribution and ecological impacts of Parthenium weed in Malaysia, they are only in limited areas such as in Kedah and Selangor. Despite numerous studies on Parthenium weed in other countries are available, a very limited initiative has been taken to investigate this weed in Malaysia despite widespread of this invasive plant in many states in the Peninsular Malaysia. Considering the urgency of the problem, a proper study needs to be taken to elucidate the Parthenium weed biology and ecology under different conditions. The Parthenium seeds used in this study originated from the population in Sg. Siput, Perak. Experiments consisted of performance and suppression ability of the weed towards okra, sweet corn, oil palm and aerobic rice were carried out by testing different Parthenium weed densities of 2, 4, 6 and 8 weeds per 0.4 m^2. Results showed that the suppression of Parthenium has not had give a big impact to the height of corn, oil palm and aerobic rice while gave significant reduction on okra. As the density of Parthenium weed increased to 8 weeds per 0.4 m^2, the dry weight of all crops decreased. Parthenium weed was able to grow under various combinations of shading percentage and period. It was able to achieve above 90% seeds germination at 30%, 50% and 70% of shading percentage during 8 weeks shading duration periods. The optimum condition for the Parthenium weed to grow was at 50% shade with shading period of 4 weeks of 100% daylight and 4 weeks of 50% shaded. In soil moisture condition, Parthenium weed was able to grow well under saturated soil followed by field capacity. However, no growth was recorded under drought and flooded soil. Concentration levels of NaCl were prepared to final concentration of 0, 8, 16, 24 dS m^{-1} in soil salinity test. Parthenium weed was able to germinate up to 69% in 8 dS m^{-1} and was significantly reduced as the salinity increased. Although the weed was still able to grow in 24 dS m^{-1} but it was greatly stunted. Parthenium also had the ability to grow under wide range of pH (4-8), although the most acidic-treated soil (pH 4.0-4.9) had significantly restricted the germination percentage and growth of Parthenium weed. Hence, this weed has the excellent ability to fully

growth under various biotic and abiotic conditions in Malaysia. However, it can be a troublesome alien weed species if it is introduced or spreads more in crop fields and can cause an increase in management cost to prevent it. The most affected crop in crop-weed competition is okra followed by aerobic rice, sweet corn and oil palm.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERTUMBUHAN DAN KEUPAYAAN INVASIF *Parthenium hysterophorus* L. TERHADAP PERBEZAAAN KEADAAN BIOTIK DAN ABIOTIK DI MALAYSIA

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Parthenium hysterophorus L., adalah rumpai invasif yang tergolong dalam keluarga Asteracae telah menjadi kerisauan seluruh dunia. Rumpai ini telah memberi impak yang besar terhadap penghasilan tanaman dan ternakan. Walaupun beberapa kajian telah dilakukan bagi mengenalpasti taburan dan impak ekologi oleh rumpai Parthenium di Malaysia, kajian tersebut hanya terhad di kawasan Kedah dan Selangor sahaja. Walaupun telah banyak kajian rumpai Parthenium di negara lain, inisiatif yang sangat terhad diambil untuk mengkaji rumpai ini di Malaysia meskipun rumpai ini telah tersebar di Semenanjung Malaysia. Berdasarkan kepentingan masalah ini, kajian yang sesuai diperlukan bagi memperjelas biologi dan ekologi rumpai Parthenium dalam keadaan persekitaran yang berbeza. Benih rumpai Parthenium yang digunakan dalam kajian ini berasal dari populasi di Sungai Siput, Perak. Eksperimen terdiri daripada prestasi dan kapasiti penekanan rumpai terhadap bendi, jagung, kelapa sawit, dan padi aerob yang telah diuji dengan pelbagai jumlah rumpai Parthenium iaitu 2, 4, 6 dan 8 rumpai per 0.4 m^2. Hasil kajian mendapati persaingan rumpai Parthenium tidak memberi kesan yang teruk kepada ketinggian jagung, kelapa sawit dan padi aerob manakala penurunan yang signifikan terhadap bendi. Berat kering untuk semua tanaman berkurang apabila jumlah rumpai Parthenium semakin meningkat kepada 8 rumpai per 0.4 m^2. Rumpai Parthenium mampu membesar dibawah pelbagai gabungan keamaatan cahaya dan tempoh teduhan. Rumpai ini mampu bercambah melebihi 90% pada peratus teduhan 30%, 50% dan 70% dalam tempoh 8 minggu teduhan yang dijalankan. Keadaan yang optimum untuk rumpai Parthenium membesar adalah pada 50% peratus teduhan dengan tempoh teduhan selama 4 minggu 100% cahaya dan 4 minggu 50% peratus teduhan. Bagi keadaan kelembapan tanah, rumpai Parthenium sesuai tumbuh pada tanah tepu (0 kPa) diikuti dengan kapasiti ladang (-30 hingga -50 kPa). Walaubagaimanapun, tiada pertumbuhan direkodkan pada tanah kering (-70 kPa) dan tanah banjir. Kadar kepekatan NaCl disediakan untuk memperolehi 0, 8, 16, dan 24 dS m^{-1} untuk kajian kemasinan tanah. Rumpai Parthenium mampu untuk bercampah melebihi 69% pada 8 dS m^{-1} dan berkurang secara signifikan apabila kemasinan meningkat. Rumpai ini mampu membesar pada 24 dS m^{-1} namun

terbantut. Parthenium mempunyai kelebihan untuk tumbuh dalam pelbagai julat pH (4 – 8), walaubagaimana pun tanah dengan rawatan bersifat asid paling tinggi (pH 4.0-4.9) telah mengurangkan peratus percambahan dan kadar pertumbuhan rumpai Parthenium dengan ketara. Oleh yang demikian, rumpai ini mempunyai keupayaan yang baik untuk tumbuh dalam kepelbagaain variasi keadaan biotik dan abiotik di Malaysia. Ia mampu menjadi spesis rumpai asing yang mengganggu apabila tersebar di ladang tanaman dan menyebabkan peningkatan kos pengurusan untuk mencegah rumpai ini. Tanaman yang paling terkesan dalam kajian tanaman-rumpai adalah bendi diikuti dengan padi, jagung manis dan akhir sekali kelapa sawit.

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LIST OF ABBREVIATIONS

DOA	Department of Agriculture
KNO_3	Potassium Nitrate
ANOVA	Analysis of Variance
SAS	Statistical analysis software
RCBD	Randomize complete block design
pH	Potential of hydrogen
PAR	Photosynthetic active radiation
g	gram
Kg	kilogram

CHAPTER 1

INTRODUCTION

1.1 Background

Parthenium hysterophorus (L.) or Parthenium weed is an invasive weed of the family Asteraceae of worldwide concern (Kaur *et al*., 2014). It has invaded many countries such as South America, India, Australia, Pakistan, Bangladesh, Sri Lanka, Thailand, and Malaysia (Shabbir, 2012). It is a dangerous invasive grass species that needs to be immediately controlled and eliminated upon sighted. A significant issue associated with Parthenium weed is that repetitive contact with the weed can lead to serious allergic reaction such as skin inflammation, eczema, asthma, hay fever, black spots, burning and blisters around eyes, severe papular erythematous eruptions, breathlessness, and choking (Adkins & Shabbir, 2014). Parthenium weed is also a pest plant of significant economic impacts on crop and livestock productions (Tamado *et al*., 2002). Parthenium weed was found to repress the germination and development of field crops (Navie *et al*., 1996; Evans, 1997). The presence of Parthenium weed in India reduced grain yield of sorghum by 30% (Channappagoudar *et al*., 1990), whereas pasture crop productivity losses due to infestation of Parthenium is 90% in Australia (Ashraf, 2014). In addition, Parthenium is also an alternative host to numerous crop pests such as scarab beetle (Navie *et al*., 1996; Singh, 1995; Ashraf, 2014) as well as parasitic weeds (Shabir, 2014).

Parthenium weed grows luxuriantly in abandoned lands, residential areas, farms, public lawns, roadsides and grazing fields. It has a short life cycle (4-6 weeks) and continues to flower until senescence (Tamado *et al*., 2002). Parthenium is a proliferant seed producer, capable to bear up to 15000 to 100000 seeds per plant (Dagar *et al*., 1976; Gnanavelet *et al*., 2013). Seeds are dispersed across long distances through livestock, grain, weed, water, birds, other animals, machineries, traffic and transported goods, and possess strong regenerative capability (Das, 2008). Parthenium can invade a wide range of crops, such as rice, wheat, maize, sugarcane, onion and sorghum which causes huge reduction yield of crops (Shabbir *et al*., 2012). In addition, Parthenium weed contains allelochemicals such as parthenin, hysterin, hymenin, and ambrosin. The exertion of these suppressing allelochemicals will cause a strong allelopathic effect on other plant species and crops (Kaur *et al*., 2014).

Despite numerous studies on Parthenium weed in other countries, very limited initiative has been taken to investigate the weed in Malaysia, even though Parthenium weed has been listed in the Plant Quarantine Act of 1976, Department of Agriculture Malaysia (DOA). Since its first discovery in 2013, almost 70 ha of land in 10 states have been reported having Parthenium weed infestation (DOA, 2015). Although invaded areas of Parthenium weed have witnessed a significant reduction to 39 ha in 2020 (Annual Meeting on Parthenium Weed Monitoring and Action Technical Committee, Malaysia, 2nd February 2021), some areas experienced an increase invasion, such as bushland near rice fields and a sugarcane farms in Baling, Kedah, and an oil palm plantation in Kulim, Kedah (The Star, 2014; UMK Research Repository, 2014; Annual Meeting on Parthenium Weed Monitoring and Action Technical Committee, Malaysia, 2nd February

2021). With its capacity to invade farms and plantation areas, and, if no immediate control measures are not undertaken to manage Parthenium, this weed could cause a serious problem to agriculture sectors affecting both the crops production and health of farm workers.

1.2 Problem Statement

Although several studies have been undertaken to determine the distribution (DOA, 2015), risk assessment and ecological impacts of Parthenium in Malaysia (UMK Research Repository, 2014), they are only in limited areas in Kedah and Selangor, and published research papers are not yet available on Parthenium infestations and impacts in Malaysia. In addition, there is no published study on the local growth responses of Parthenium weed towards different ecological and biological factors, which can become a useful tool to predict the entry pathway, spread behavior, as well as appropriate sustainable management of this invasive hazardous weed species in Malaysia. Considering the urgency of the problem, initiative was taken to elucidate the Parthenium biology, ecology, and biochemistry. Thus, this study was initiated embarking on the following objectives:

i. To quantify the competition and suppressive capacity of *Parthenium hysterophorus* on selected crops.

ii. To determine the growth responses of *Parthenium hysterophorus* under different biotic and abiotic conditions.

CHAPTER 2

LITERATURE REVIEW

2.1 Parthenium hysterophorus

Commonly known as Rumpai Miang Mexico in Malaysia, *Parthenium hysterophorus* (L.) has been identified as an alien weed species that invades and infests crop producing farm worldwide, counting in Malaysia in the account (Karim *et al*., 2017). *Parthenium hysterophorus* or Parthenium weed is a type of weed classified under the family of Asteraceae and belongs to the Heliantheae tribe and it is an annual herb (Bhateria, Renu & Snehlata, 2015). It is a species of weed that has threatened the worldwide community in terms of natural ecosystem, agroecosystem, and human and animal health condition in over 30 countries in the world (Adkins & Shabbir, 2014).

Parthenium hysterophorus originated from the Gulf of Mexico, certain parts of Northern and Southern America, as well as Northern Argentina, Sothern Bolivia and Brazilian South-west area (Adkins & Shabbir, 2014). Hitherto, this weed has invaded and infested many countries in the world, predominantly in Africa, Europe, Asia and Oceania. In Malaysia, the emergence of *Parthenium hysterophorus* was first identified in Batang Kali, Selangor in 2013, later discovered a high rate of infestation of Parthenium weed in Kedah (Maszura *et al*., 2018).

Parthenium hysterophorus is an annual weed and in under some conditions are short lived perennial weed (Adkins & Shabbir, 2014). Kaur *et al*. (2014) indicated that this weed can easily grow in areas that are very open for access by any people and are not restricted to personnel. On top of that, this weed is dominant on alkaline soil and is a short-period drought tolerance (Kaur *et al*., 2014). Singh *et al*. (2004) stated that this weed can survive in a wide range of temperature and soil moisture. However, to be able to germinate their seed, this weed requires high soil moisture.

2.2 Morphology

Figure 2.1 : Juvenile Stage of *Pathenium hysterophorus*

Parthenium hysterophorus is an erect, herbaceous, and ephemeral herb which can grow up to 2.5 metres tall when fully matured in different conditions (Haseler, 1976; Kissmann & Groth, 1992; Lorenzi, 1982; Navie *et al*., 1996). However, not all individuals are able to achieve this height (Adkins & Shabbir, 2014). This weed is a plant that has a deep taproot with complex fine rooting system beneath the ground (Bridgemohan *et al*., 2015). There are two stages can be observed in this weed growth, comprising of juvenile and the mature stages (Kaur *et al*., 2014). Juvenile stage is also called as rosette stage meanwhile mature stage is also being called as adult stage.

Juvenile stage can be recognised by the lower leaf that covering the ground, not allowing any vegetation growth surrounding it. Meanwhile, mature stage can be recognised with the occurrence of the flowering period (Lakshimi & Srivinas, 2007). During mature stage, the weed has more erected growth with increment of the lateral branches count as it approaches flowering (Bhateria, Renu & Snehlata, 2015). The Parthenium leaf are pubescent and strongly dissected into narrow lubes (Adkins & Shabbir, 2014). They are deeply-lobed, pale green covered with soft and fine hair that can take up 30 cm in length during juvenile stage (Adkins & Shabbir, 2014; Bhateria, Renu & Snehlata, 2015). As the weed begins to mature, the stem elongates hence producing a smaller, narrower and less dissected leaves (Kohli and Rani, 1994). Differences in the growth stages can also be observed by the stem. As the juvenile *Parthenium hysterophorus* stems are green, and as it gets matured the stems become woody with light brown colour (Bhateria, Renu & Snehlata, 2015). The stems became pubescent, rigid and have an octangular shape as it grows. Kohli and Rani (1994) indicates that the speciality of the weed genus is the production of the short, soft trichomes hair on the leaf and stem that are usefully as their taxonomic identification.

Figure 2.2 : *Parthenium hysterophorus* Seeds

Flower of this weed possesses both the terminal and axillary, pedunculated and slightly hairy floret (Bridgemohan *et al*., 2015). The flower is creamy white and composite. It has the disc and ray florets; which are the characters of all species in Asteraceae family. The flower is small (3-5 mm across, mostly 4 mm) with five ray florets and with 40 male disc florets that developed and grows on the tip of the stem (Adkins & Shabbir, 2014; Bridgemohan *et al*., 2015). The weed initiates flower at the terminal leaf axils, then progresses down the stems. Seeds produced are usually blacken, flatted 2 mm long covered by straw-coloured and fruit two spathulate appendages (sterile florets) at the apex (Adkins & Shabbir, 2014; Bridgemohan *et al.*, 2015). The germination rate is rapid as it can germinate, grow, mature and set seeds in four weeks compared to other weed that requires 4-8 weeks to germinate (Bhateria, Renu & Snehlata, 2015).

2.3 Dispersal of Parthenium Seeds

The spreading of Parthenium weed is totally through seeds and no existence of any vegetative part has been observed (Masum *et al*., 2013). The spread of this weed's seed is usually unintentional, as a result of natural transmission by wind or water currents, domestic and wild animals, attachment to vehicles, machinery, and animal feed. (Monaco, Weller & Ashton, 2001). Worldwide spread across different countries are mainly because of human food (grains) and stock food are contaminated with Parthenium weed seeds (Adkins & Shabbir, 2014). The seed itself can remain viable in the soil for years (Monaco, Weller & Ashton, 2001).

The spreading of the seed of *Parthenium hysterophorus* occurs rapidly and effected many countries (McFadyen, 1992). The weed was first introduced in Australia in the 1950s as a carrier via contaminated grains and pasture seeds, and it is now a major weed status in those states (Bridgemohan *et al*., 2015). The southern African countries of South Africa, Swaziland, Zimbabwe, Mozambique and most recently Botswana was infested after the extensive flooding on the East Coast in the middle of 1980s (McConnachie *et al*., 2011). Infestation and spread in India also occurred as a result of contamination on grains imported from the United States and transported into Pune in 1956 (Adkins & Shabbir, 2014).

It has been observed that Parthenium weed is capable to produce up to 20 000 seeds per plants and 340 million seeds per ha (Adkins & Shabbir, 2014). Furthermore, it is suspected that the seeds do not have a dormant period and begin to germinate estimated one week after receiving the optimal soil moisture condition (Monaco, Weller & Ashton, 2001). Parthenium weed grows well throughout the rainy season due to the abundance of rain, but it suffers from stunted growth during the dry season. The life cycle of *Parthenium hysterophorus* is complete within 180 to 240 days after germination (Aneja, 1991).

The survival of the seeds in the soil is up to 20 cm, with lesser viability as the depth increased (Singh *et al*., 2004). Compared to what has been found by Navie et al. (1996), Tamado *et al*. (2002) stated that after 26 months of burial in the soil, the viability of the seeds remained greater than 50%. Adkins and Shabbir (2014) indicated that 10 to 25˚C is the optimum temperature for seed germination. Navie *et al*. (1996) in the other hand managed to estimate the germination temperature of both Australian biotypes in between 22-25°C temperature range. But both biotypes are able to express germination in manipulated temperature of 9-360C in their experiment.

2.4 Unique Characteristics

Other than ability mentioned above, *Parthenium hysterophorus* has other unique physiological features that are very rare if compared to other species of weeds. These unique features are the possession of C3 and C4 intermediates (Navie *et al*., 2005). The manifestation of the photosynthetic ability depends on the area of infestation by the weed occur. C3 photosynthesis takes place when the temperature and the light intensity is low which C4 photosynthesis takes place at a higher temeperature ang light intensity. However, C4 is likely to occur when the soil moisture is low (Navie *et al*., 2005). It has the capacity the regenerate rapidly (Dhawan & Dhawan, 1996), growth features and allelophatic effects mediated by several chemical components inside them (Kaur *et al*., 2014).

Dhawan and Shawan (1996) stated that the ability to self-heal following injury of this weed is very rapid. In their writing, they stated that when a part of the plan is damaged due to the physical impacts or even chemical, it can be recovered in a shorter time compared to other types of weeds. New shoots will start off at a rapid rate to replace the damaged one. Some of the notable and reported allelophatic components that are detected in *Parthenium hysterophorus* are partherin, hystrin, psuedoguaianolides, phenolic acid, hymenin and ambrosin (Vivar *et al*., 1966; Kanchan & Jayachandra, 1980; Vallipan & Tower, 1988; Feunte *et al*., 2000; Kaur *et al*., 2014).

2.5 Biology and Ecology

Two different subspecies of this weed have been identified and documented. They are termed as the South American and North American races (Adkins & Shabbir, 2014). There are differences in the flower petals colour as such the Southern America possesses yellow petals while the Northern America race is white petals. In addition to that, the differences can also be observed on the allelophatic compounds possess by both subspecies. Furthermore, Towers et al. (1977) found that the sesquiterpene lactone (SLs), hymenin, found in plants from Argentina and Bolivia, differ from the lactone and parthenin found in the majority of samples collected in India, as well as North and Central America. These significant differences in morphology and biochemistry are thought to be the grand representation of *Parthenium hysterophorus* inter-subspecies or even between species of weed (Picman & Towers, 1982).

Bajwa *et al*., (2017) indicated that Northern America race has invaded Australia twice with the second invasion was highly aggressive from the first invasion in mid 19-40s. The first invasion is typed as the Toogoolawah biotype as it occurred in Toogoolawah (north of Brisbane, Queensland) meanwhile the second invasion occurred in 1958 is Claremont biotype. Navie *et al*. (2003) stated that the Toogoolawah biotype population is not invasive in Australia because of their different morphology and reproduction behaviours. The reproduction behaviour of this biotype is the self-pollination (Hanif *et al*., 2012). Clermont biotype is more aggressive compared to Toogoolawah biotype is because both of these biotypes have significant different in term of genetic make up, adaptive ability and morphological characteristics (Hanif *et al*., 2012). There are no remarkable differences within the biotype's variation in Australia and Mexico, but there are 16 sequence variations of biotype isolated from India in an experiment performed by Adkins *et al*. (1997), which suggested that the invasion in India involved introduction of multiple biotype identities and they have been crossing in between each other. The differences in between these biotypes are crucial information that can be used to develop management program to control and monitor the weed as suggested by Adkins and Shabbir (2014).

As mentioned above, *Parthenium hysterophorus* germinates in the beginning of rain seasons and starts to produce flower when rainfall begins to recede in the tropical countries. In Australia, the germination of seeds occurs mainly in spring and late-spring (Bajwa *et al.*, 2017). It dies in autumn after producing seeds (Navie *et al*., 1996). *Parthenium hysterophorus*, on the other hand, can grow all year due to its ability to germinate seeds in sufficient soil moisture (Tamado, 2001; Taye, 2002). Even though they cannot reproduce by vegetative parts, the number of seeds produced is enough for this invasive plant to be termed as prolific seed producer (Mahadevappa, 1997).

Parthenium weed seeds have the ability to survive in different soil types (Kaur *et al*., 2014), wide range of soil temperatures and moisture contents (Tamado *et al*., 2002; Singh et al., 2004), wide range of soil pH (Ahlawat *et al*., 1979), and able to tolerate drought (Stamps, 2011). Even though the seeds can survive in wide range of pH, it prefers mostly alkaline soil type for their rapid establishment (Kaur *et al*., 2014). In Malaysia, the tropical climate helps the spread and growth of the weed throughout the year as it provides a perfect temperature and moisture due to the continuous rainfall that facilitates the seed to germinate (Reddy *et al*., 2007). According to Adkins and Shabbir (2014), the spread of this weed will be aggressive in many countries in the future. It includes West Africa, South East Asia, and Eastern Europe, all of which have climates that are ideal for *Parthenium hysterophorus*.

2.6 Impact of *Parthenium hysterophorus*

2.6.1 Humans

Parthenium weed is a hazardous allergenic plant which can affect human health and has been reported from most invaded countries (Goldsworthy, 2005; Towers, 1981; Gupta, 1991). Various existing chemicals in Parthenium weed that have been naturally released by this weed pose a threat to many living organisms. The threat of this weed can give effect to human is by airborne particles, particularly from the pollen, either through direct or indirect contact such as dermatitis and rhinitis (Adkins & Shabbir, 2014).

When humans inhale the Parthenium weed pollen, it will enter the human respiratory systems and can lead to allergenic rhinitis. It can cause asthma and bronchitis while allergenic eczematous dermatitis can occur with a prolonged skin contact (Tower and Subha Rao, 1992). Approximately 10-20% human population can be easily affected and suffered from severe allergic reaction after a period of 1 to 10 years exposure to the Parthenium weed (McFadeyen, 1995). Unfortunately, there is no specific treatment for human having sensitivity to the Parthenium weed plants thru the airborne parts and no available therapies as well, although there have been several attempts to treat allergic reaction to Parthenium weed with antihistamine medication because it is not always effective (Adkins & Shabbir, 2014).

2.6.2 Crops

Parthenium weed also can cause huge significant threats to plant especially to the production of crops and increase the cost for weed management. It can give damages in a wide range of agriculture crops such as tef (*Eragrostis tef* Zucc. Trotter), maize (*Zea mays* L.), rice (*Oryza sativa* L.), sorghum (*Sorghum bicolor*) and wheat (*Triculum aestivum* L.) within invaded country of the world (Tamado *et al.*, 2002; Shabbir, 2012). In India, Parthenium infestation was estimated by Sushilkumar and Varshney (2010) to be present on 18.78 and 14.25 million hectares of barren, fallow, and wasteland land, respectively, including non-agricultural uses and croplands. Between 15 and 45 days after sowing, Das (2008) observed severe Parthenium competition, whereas Tamado *et al*. (2002) detected severe Parthenium competition in sorghum between 5- and 59-days following emergence.

This weed can turn into a secondary host to various types of crop pests and diseases and lead to indirect losses to crop production (Gananavel, 2013). Several papers have listed some important pests which are the hairy caterpillar (*Diacrisia obliqua* Walk.), tobacco streak virus and *Xantomonas camperstris* pv. Phaseoli (Sharman, Persley & Thomas, 2009; Remadevi & Sivaramakrishnan, 1996).

Pollen released by Parthenium weed can inhibit fruit set following contact with fertilization part of the crops such as tomatoes, eggplant, peppers, and beans as this weed pollen contains allelophatic chemicals (Sukhada and Jayachandra, 1980). It is believed that allelophatic effect in the pollen of the Parthenium weed possesses strong competitive ability to supress the growth and germination mechanisms of neighbouring plant species (Adkins & Sowerby, 1996). Recent study also proved that Parthenium weed aqueous extract affects the germination of seed, germination rate, growth rate of root and shoot along with seedlings dry matter production of soybean and haircot soybean (Netsere & Mendesil, 2011).

2.6.3 Animals

Parthenium weed can give harmful effects to animals similar to humans in several ways. It can be poisonous to animals and lead to death after ingested significant quantity of the weeds after 30 days (Ahmed, Rao & Mahendar, 1988). Tejinder *et al.* (2015) reported that consumption of around 10-50% Parthenium weed may kill cattle as well as buffalo and crossbred calves fed on this weed, developed toxic signs of erythematous eruptions, alopecia, skin depigmentation and edema. Composition of microbe in rumen of buffalo, dairy cattle and sheep is altered by the chemicals within the *Parthenium hysterophorus* and causing a negative effect towards the quality of the milk produced to become bitter in taste and develop undesirable flavour for cattle and sheep meats (Ayele, 2007)

2.6.4 Ecosystems

Owing to strong competitive and spreading behaviour with the addition of the allelophatic characteristics by this weed, Parthenium weed has the ability to rapidly colonize invade areas and disrupts the structure of natural ecosystems along via suppression of native plant species (Timsina *et al*, 2011; Nguyen, Navie & Adkins, 2010; Shabbir & Bajwa, 2006). Srivinas and Lakshmi (2007) reported the invasion of Parthenium weed in Australian river banks, food plains, grasslands and open woodlands causing a lot of changes in the habitat. Parthenium weed could also become a huge threat around the world by causing damage to ecosystem in many protected forest areas and national park, among affected are Kruger National Park (Strathie, McConnachie and Retief, 2011), ecosystem of Masai Mara/Serengeti in Kenya and Tanzania and Chitwan National Park in Nepal while in Australia this weed invaded Carnavon National Park (Vogler, Navie & Adkins, 2002). Sattler and Williams (1999) highlighted in their research that Parthenium weed is considered to be serious problem to the Queensland in native grasslands and the uplands in Einasleigh. Biodiversity of native flora and fauna may undergo severe reduction due to serious threat of Parthenium weed that possesses special characteristics such as absence of natural enemy, host for pests and diseases, high productive ability, fast growing rate, adaptation to various environmental conditions and allelopathic behaviour (Javaid *et al*, 2007; Nigatu *et al*., 2010).

2.7 Parthenium Invasion Status in Malaysia

In Malaysia, a researcher from Universiti Malaysia Kelantan (Karim, 2013) is the first to identify and report in 2013 on the infestations of Parthenium hysterophorus in Batang Kali, Selangor. Invasion of Parthenium weed in Malaysia is relatively new or quite recent and less papers have been published on Parthenium weed studies in Malaysia. Department of Agriculture (2014) stated that Parthenium weed has been included in the Plant Quarantine Act of 1976 as a dangerous plant that needs to be immediately controlled and removed. According to Department of Agriculture (2015) the infested area in Malaysia covers a 70.4 ha which include the highest in Kedah (23.77 ha), followed with Perak (18 ha), Negeri Sembilan (11.7 ha), Melaka (4.05 ha), Johor (3.6 ha), Pulau Pinang (2.8 ha), Perlis (2.68 ha), Selangor (2.52 ha), Pahang (1.19 ha) and lastly is Sabah with the lowest infested area (0.09 ha).

Figure 2.3 : Parthenium Infestion in Ladang Infoternak, Jabatan Perkhidmatan Veterinar Sungai Siput, Perak. Picture Was Taken in March 2018

2.8 Crop-weed Competition Experimental Studies

2.8.1 Significance of Crop-Weed Competition Studies

According to Swanton *et al*. (2015), studies on crop-weed competition will give important data to land managers and farmers on decision for weed control. The purpose of crop-weed determination is to quantify the suitable time to apply weed control practices. For example, farmers can use economic weed thresholds to help them to choose the most reduced cost of various applicable weed control methods. Growers' decision to proceed or not with weed control is decided by the guidance of knowledge of correct weed control timing in order to maintain crop yield production. (Johnson, Gibson & Conley, 2007).

The information on the many components of cropping systems is also provided in the study of experimental crop-weed competition (Swanton *et al*., 2015). The components in cropping systems include rates of seedlings, row spacing, intercropping, crop rotation, application and placement of fertilizer which will affect the competition between the crop and weed. Weed competition and cost related with weed control can be reduced with the use of competitive cropping systems that will help in enhancement of canopy cover, crop establishment and leaf appearance rate (Baskaran, Kavimani & Arunvenkatesh, 2017).

The aim to reduce the use of herbicide should be why competition study between crop and weed are important to be undertaken. This can be seen the use of intercropping, non-chemical weed control methodology, and organic farming (Weiner *et al*., 2001). As stated by Park (2003), competition on fitness act as important influence for the development of model for crop-weed competition studies to identify the loss in crop yield and invasiveness of weed in ecosystems.

2.8.2 Interspecific Competition

The aim for agronomic studies is to quantify competition between two species. The examples for interaction involve a weed species compete with crop species, between two weed species in an ecosystem, and also two different crops grown in an intercrop (Park, 2003). There are various of crop-weed experimental design and statistical analyses applied in order to understand the competition such as the replacement series, addition series, additive design, Nelder design, and neighborhood design (Gibson *et al*., 1999; Freckleton and Watkinson, 2000).

2.8.3 Crop-Weed Experimental Designs

Most of the weed competition designs are chosen based on the tested hypothesis in every research studied (Swanton *et al*., 2015). Their article focused on the experimental design that has been used to gain information of the competitive ability and interaction between weed and crop species under field conditions. Development for experimental methodology considered the importance of variables at different levels which can give influences to crop-weed competition studies. It tested in field environments such as type of soil, density of plant, environment, spatial arrangement and proportion of every species in the mixture (Maxwell & O'Donovan, 2007).

2.8.3.1 Replacement Series

In replacement series, the design involves the growth of two species with different densities while maintaining a constant overall stand density and includes the monoculture (de Wit, 1960). Replacement series is a usual method to grow crop or weed species in an arrangement of uniform spatial at different ratio of mixture to identified competitiveness between two species and information for the plant-to-plant interaction (Swanton *et al*., 2015; Radosevich, 1987). The examples ratio used in ths replacement series are 75:25, 50:50, and 25:75. Replacement series diagrams are used to present the result graphically where the relative yield for both species are plotted against its ratio in mixture (Swanton *et al*., 2015).

Wang *et al* (2006) indicate that relative crowding and aggressiveness coefficient give information on competitive interactions between species. By using replacement series, there are four possible results as stated in Swanton *et al* (2015) for the interactions between crops species and weeds. The first outcome is straight lines for the observation of yield for two species where the ability for each species to compete between each other are equivalent or location for the two species are so far apart which lead to no interactions to occur. Second, a concave and convex response curve which mean one species reported to have more competitive ability than the other. Next outcome is a mutual antagonism where convex both response curves. In this outcome, overall yield for both species in interspecific competition is lower than respective yield in a monoculture. The last possible outcome is both species shows concave responses where the total yield in interspecific competition is greater compare to monoculture stand and indicating a symbiosis.

One of the advantages in the use of replacement series is its suitability to determine the competitiveness of selected species under fixed environmental conditions. This design also can give information on mechanisms of competition between crops and weeds; interaction between two weed species or biotypes of weeds (Higgin & Mack 1987; Akey *et al*. 1991; Blackshaw & Schaalje, 1993; Wang *et al*. 2006). Replacement series can be useful to predict shifts in composition of species and calculation of ratio for every yield aid in describing pattern for the use of resources along with relative invasiveness within species (Harper, 1977). Swanton *et al* (2015) listed two disadvantages of replacement series where this design is not representative for most actual field conditions because crops grown at a constant density (fixed quantity) in field while the other disadvantages, experimental result is depending on total plant density selected or usage of fixed resource supply conditions.

2.8.3.2 Additive Design

According to Park (2003), additive design is the model where the density and ratio of species are diverse, means the density of crops will be kept constant while weeds varied over a range of densities. This is the most used crop-weed experimental competition design to study the outcome for the competition between crops and weeds. Cousens (1985) stated one formulation in additive design of the hyperbolic model used to describe damages on the crop yield caused by competition from weed.

Cousens (1985) indicated four important factors in biological of crop-weed competition. The first is absence of weeds will give a result of no yield loss in crops. Next, effects are additive at low weed densities when there is increasing weed numbers. The third is the loss of crop yield can never reach 100%. The last is at high weed densities, yield of crop to weed density response is non-linear. With the difficulties to understand the high range of species or locations, additive design also received some critic due to lack of explanation of process involving the outcome of research (Park, 2003).

Blackshaw (1993) indicated that additive design highlighted a few advantages as this design easy to handle in field conditions and the most use method to identify the result of damages by the weed towards the yield of crops. Blackshaw (1993) and O'Donovan (1985) had described additive design as the most suitable to determine the effect of relative emergence time of crops and weeds on potential outcome of competition.

Park (2003) listed two disadvantages where the changes in ratio and total density of plant give difficulties for the researcher to examine specific plant interaction and obtain information on mechanism of competition occurred. The other disadvantages is most of the result is depending on native of soil and environmental conditions which an appropriate attention needs to be considered in gathering the outcomes to wide range of geographic areas.

2.8.3.3 Addition Series

Addition series is a design involves consideration of the two species in order to study all possible combinations in a wide range where both ratio and density for each species are varied (Maxwell & O'Donovan 2007). It can be studied as a version of multiple replacement series that combine together under a number of total densities and complete or full factorial. Addition series is another version which have several densities for every species in all possible combinations.

Swanton *et al* (2015) have listed two advantages and one disadvantage in the use of addition series. The first advantage is that crop-weed competition design separates the intraspecific and interspecific competition. Next, the addition design allows researcher to analyze the competitive ability between two or more plant species. The disadvantage for this design especially under field condition, is that it can result in large experimental designs that are laborious to be undertaken and consumes large resources.

CHAPTER 3

PERFORMANCE AND SUPPRESSION OF *Parthenium hysterophorus* ON SELECTED CROPS

3.1 Introduction

Crop-weed competition studies can give information to farmers and researchers to decide on the selection of suitable weed control approaches. Crop-weed competition studies also can provide valuable understanding on the competitive and invasive capacity of selected weed on crop species, thus aiding farmers to implement weed control at critical times. According to Swanton *et al*. (2015), there are three effects that influence weed competition in crop, namely time of weed emergence compared to the crop growth, density of weed seedlings, and weed competitive ability.

Parthenium hysterophorus which is known as carrot weed is native to the North and South America (Adkins *et al*., 2018). To date, 48 countries have been invaded by Parthenium weed throughout the Asia-Pacific and African regions (Bajwa *et al*., 2016). The weeds germinate under various environment and stress tolerance (Bajwa *et al*., 2018). Previous study reported a 40% yield loss in several crops, especially in corn and sorghum (Safdar *et al*., 2015, 2016). Negative significant impacts of Parthenium weed to crops are depending on density and competition duration (Bajwa *et al*., 2019). Celebi *et al*. (2010) also mentioned that the production of alfalfa was affected by direct competition by Parthenium weed.

Oryza sativa L. (rice) is among the most important staple foods globally (Matloob *et al*., 2015). They stated that weed infestation has become serious problem in farming system of aerobic rice that were directly-seeded in which at this stage there are insufficient flooding introduce to the seedling. With the absent of standing water to suppress weed emergence, weed seed will easily germinate and grow to compete with aerobic rice (Farooq *et al*., 2011). *Cyperus* and *Echinochloa* spp. are the examples of weed that dominate under aerobic conditions (Matloob *et al*., 2015).

Okra, or *Abelmoschus esculeentus* L., is another agricultural crop whose yield production can be reduced to a maximum percentage. To avoid major losses, weed infestation must be controlled up to nine weeks following okra planting (Awodoyin & Olubode., 2011). Previous study by Adejonwo et al (1989) reported a 91% okra yield loss in Nigerian northern guinea savanna caused by uncontrolled weed growth.

Zea mays L. (sweet corn) is also a very sensitive crop towards competition against weeds at earlier growth phase (Singh *et al*., 2005). Usman *et al*. (2001) stated that 35 to 83% losses in corn occurred when exposed to crop weed competition. Severe yield reduction in weed-corn competition can be avoid by applying strong weed control.

Elaeis guineensis (oil palm) having the similar problem with weeds especially in plantation. Weed composition usually changed depending to oil palm growth stages because different stage encourages specific weed species with optimum environmental conditions for their growth (Rosli *et al*., 2010). Oil palm canopy changes the weed composition by providing shade and lead to domination of grass species (Wan Mohamed *et al*., 1987). It is difficult to quantify yield losses in oil palm-weed competition study because of oil palm long economic life but still can cause damages to growth and yield if infestation occurs continuously at the early stage (immature) of oil palm trees (Kuan *et al*., 1991).

As Parthenium weed mostly infested in direct-seeded rice, previous research by Bajwa *et al*. (2018) used additive design to study the effect cause by this invasive weed on aerobic rice as it is the most suitable design to study the crop-weed competition. Selection of an appropriate crop-weed competition design (additive design) was based on study by Swanton *et al*. (2015) which evaluate experimental procedure that provided the best method to assest the damage of weed to crops. For that purpose, additive design was chosen as the design for this study as it fit the desired information needed on crop-weed competition. Therefore, this study was performed in order to estimate the damage losses of four crops (aerobic rice, okra, corn and oil palm) caused by Parthenium weeds at different weed densities.

3.2 Methodology

3.2.1 Experimental Site and Plant Materials

Four separate experiments were conducted in a quarantine glasshouse in Ladang 15, during February to October 2018 at the Faculty of Agriculture, Universiti Putra Malaysia (2.9829° N, 101.7338° E). The soil used for this experiment was top soil. The study represents one local population in Ladang Infoternak, Jabatan Perkhidmatan Veterinar Sungai Siput, Perak. This animal eco-tourism farm has been highly infested by Parthenium weed since 2013 (unpublished data), especially in the animal paddocks where pasture crops are grown.

Seeds were collected from Parthenium weed plants in several infested animal paddocks in Ladang Infoternak (4.7421° N, 101.0601° S), Jabatan Perkhidmatan Veterinar, Sungai Siput, Perak. All the mature Parthenium seeds were harvested carefully, put in the paper bag, labelled accordingly wrapped with 2-layer plastic bag and brought back to the Weed Science Laboratory, Faculty of Agriculture, Universiti Putra Malaysia. Seeds were dried in an oven at 33°C for three days and any unnecessary or foreign materials were removed. Parthenium seeds were placed in paper bags and stored in the cabinet at room temperature (22-26 °C) until use.

3.2.2 Experimental Treatments

This study evaluated the growth effects of different Parthenium weed densities on different crops. Four different crops were selected for this experiment which were aerobic rice, 4-month-old oil palm seedlings, okra, and sweet corn. Aerobic rice, okra and sweet corn seeds were planted and grown in trays for seven days, then transplanted into 25 cm x 25 cm polybags containing a mixture of peat grow, sand, and topsoil at 3:2:1: ratio at ¾ full. The 4-month-old oil palm seedlings were purchased from Sime Darby Research Station, Pulau Carey, Banting, Selangor. Each polybag contained 1 okra seedling, 9 aerobic rice seedling (10 cm of space between each seedling), 1 sweet corn and 1 oil palm seedling, respectively.

Parthenium weed seeds were soaked in 0.2% potassium nitrate (KNO_3) for 24 hours, then soaked overnight to facilitate the germination. It was found that the KNO_3 method produced the highest germination percentage of Parthenium weed (>90%) in comparison to untreated seeds and other seed dormancy-breaking germination techniques. The pre-germinated seeds were transplanted into 35 cm x 25 cm x 5 cm trays containing soil mixture as above and allowed to grow for 7 days. Healthy and uniform Parthenium weed seedlings were transplanted at densities of 0, 2, 4, 6 and 8 plants per 0.4 m^2 (where 8 equals 20 plants per m^2 that represents the number of Parthenium weed in the infested area from the field survey that was done earlier) into the polybags containing the designated crops. The weed densities were applied 7 days after the crops had been grown in each polybag. The densities implemented here were assigned based on the area measured from the polybag size (0.4 m^2).

3.2.3 Data Collections

Plant height for all crops were measured one cm above the soil using a measuring tape. This is to achieve similar initial point for all crops during measurements. Plant height for aerobic rice were collected at day 45 while corn, oil palm, and okra were measured at day 60. Plant height was taken to determine the crop ability to grow and compete with weed.

Number of leaves were counted to determine the leaf production in each crop. Number of leaves for aerobic rice were counted at day 45 while corn, oil palm, and okra counted at day 60.

Crops were harvested only one cm above groundlevel. All dirts and foreign materials that were deposited on the crops were removed, and the fresh weight was immediately taken to prevent any drying which can lead to inaccurate data.

Harvested crops were dried at 65°C for 72 hours until constant weight was achieved, and the dried samples were weighed using analytical balance.

The design used for crop-weed competition was additive design (Park, 2003), where the density of crop was held constant while the density of the invading species (weed) varied. Each experiment was performed in a complete randomized block design (RCBD) with four replicates. All data were subjected to an Analysis of Variance (ANOVA) and means were separated using Least Significant Difference (LSD) at $P < 0.05$ by using SAS (SAS 9.1, SAS Institute, Inc. Cary NC. USA)

3.3 Results

3.3.1 Effect of Parthenium Weed Densities on Aerobic Rice

3.3.1.1 Plant Height

Aerobic rice height was not greatly affected by the presence of Parthenium weed density as $y = -0.0888x^2 - 0.4945x + 133.13$. The R^2 is less strong with the value of 0.93. There was significant reduction in height as the Parthenium weed density approached 6 and 8 weeds per 0.4 m^2 as shown in Figure 3.1. Parthenium weed densities consisted of 0, 2, and 4 weeds per 0.4 m^2 seem not significantly reduced aerobic rice height while density of 0 weed per 0.4 m^2 appeared to have the highest plant height (133.08 cm), followed by 2 weeds per 0.4 m^2 (131.43 cm) and 4 weeds per 0.4 m^2 (131.10 cm). At 8 weeds per 0.4 m^2 density, the height of aerobic rice recorded the lowest value with only 124.00 cm. The differences in plant height between 0 and 8 weeds per 0.4 m^2 was 6.82%. This indicates that any infestation of 6 and 8 Parthenium weeds per 0.4 m^2 (or 15 to 20 m^2) will affect the growth of aerobic rice plants.

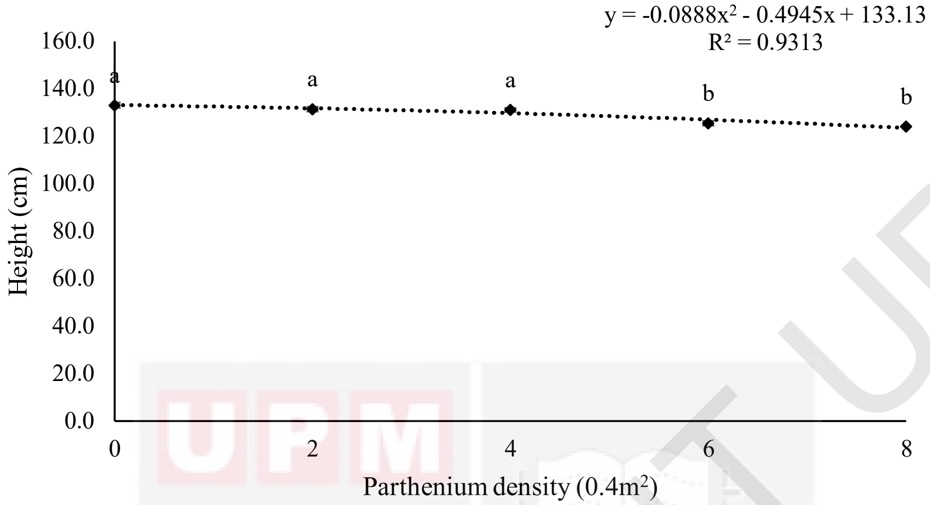

Figure 3.1 : Plant Height for Aerobic Rice at 45 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.1.2 Number of Leaves

The number of leaves was reduced significantly as the density of Parthenium weed increased, as $y = 0.0402x^2 - 0.5339xx + 8.4714$ for aerobic rice. R^2 value is very strong with 0.99. Similar to the plant height, leaves produced by aerobic rice showed the highest number at density of 0 weed per 0.4 m^2 (8.5 leaves), followed by 2 weeds per 0.4 m^2 (7.5 leaves), and 4 weeds per 0.4 m^2 (7.0 leaves), while density of 6 and 8 weeds per 0.4 m^2 recorded the lowest, with same value of 6.8 leaves produced. Aerobic rice leaves produced in 2 weeds per 0.4 m^2 density was not significantly different compared to 0 and 4 weeds per 0.4 m^2. However, between 0 and 4 Parthenium weed density treatments, there were significant differences observed as shown in Figure 3.2.

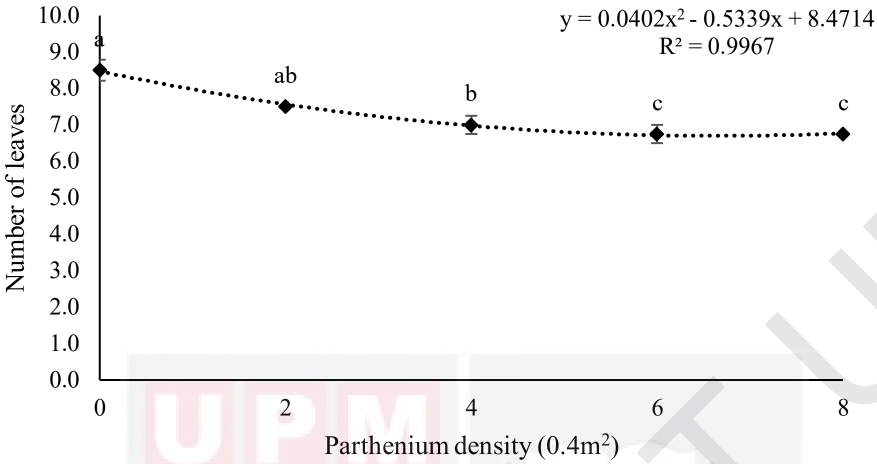

Figure 3.2 : Number of Leaves for Aerobic Rice at 45 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.1.3 Fresh Weight

The aerobic rice growth parameter for fresh weight showed a critical reduction by the application of different Parthenium weed densities ($P < 0.05$) as shown in Figure 3.3. Fresh weight was significantly reduced with the increasing of Parthenium weed density as $y = 0.5769x^2 – 12.953x + 158.48$. R^2 is strong with the value of 0.96. Treatment with zero Parthenium density (control) recorded the highest biomass with 157.46 g followed by density of 2 (139.64 g), 4 (107.73 g), 6 (107.66), and 8 weeds 0.4 m^{-2} (90.08 g). As for 4 and 6 Parthenium weeds per 0.4 m^2, the results show no significant difference for both treatments. The lowest aerobic rice fresh weight was observed at 8 Parthenium weeds with 40.79% of reduction over the control (no Parthenium weed).

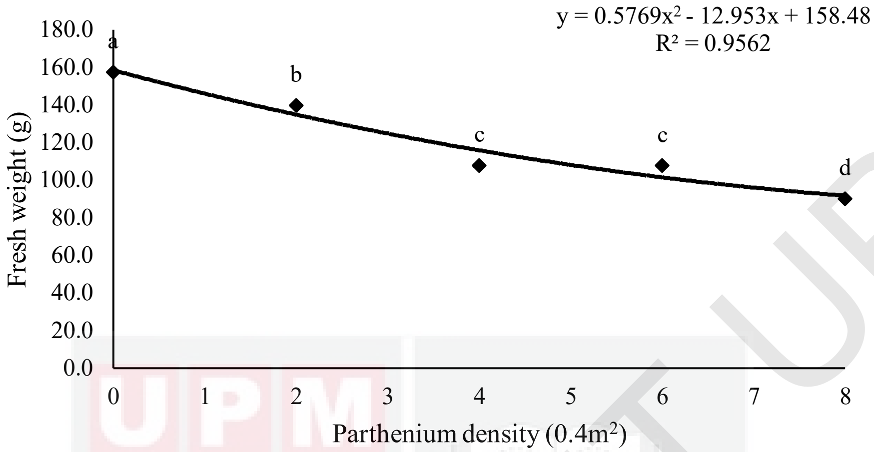

Figure 3.3 : Fresh Weight for Aerobic Rice at 45 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.1.4 Dry Weight

The reduction in aerobic rice dry weight corresponding to the increased in Parthenium weed density at $p < 0.05$ with $y = 0.0092x^2 – 1.9178x + 35.819$ is shown in Figure 3.4 with R^2 of 0.96. The greatest aerobic rice dry weight was observed in control (0 weed per 0.4 m^2), producing 35.82 g when compared to the other Parthenium weed densities. The significant reduction started at 2 weeds (32.53 g) followed by 4 (26.70 g), 6 (26.26 g) weeds, and the least aerobic rice dry weight was recorded at the highest Parthenium weed density (8 weeds per 0.4 m^2) with the value of 20.52 g only (Figure 3.4). There was no significant difference observed between treatments of 4 and 6 Parthenium weeds density. However, it was significantly reduced again as the Parthenium weed increased to 8 weeds density. The dry weight in 8 weeds density exhibiting 42.72% weight reduction as compared to the control.

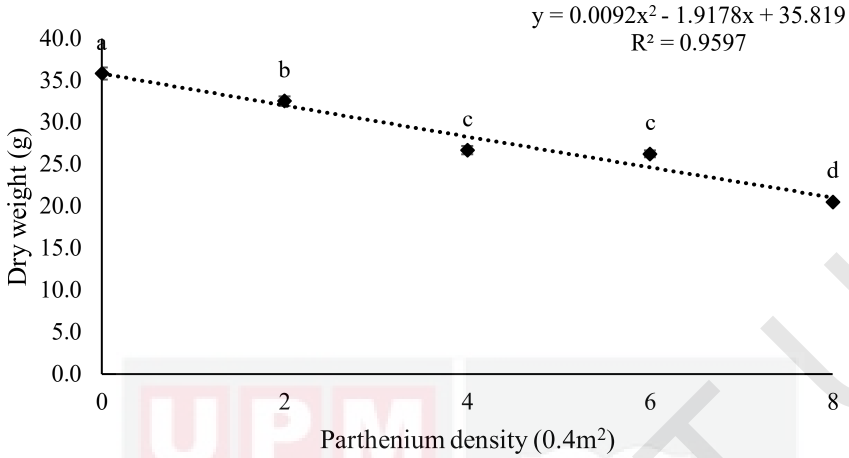

Figure 3.4 : Dry Weight for Aerobic Rice at 45 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.2 Effect of Parthenium Weed Densities on Oil Palm

3.3.2.1 Plant Height

Growth response of the 4-month oil palm seedlings to the increased density of Parthenium weed are shown in Figure 3.5. This study represents the possibility of Parthenium weed infestation in oil palm nurseries and its impact on the seedlings' growth. It is evident that the plant height for oil palm seedlings was not significantly influenced by the differences in Parthenium weed density as $y = 0.2143x^2 – 2.2043x + 70.934$ and R^2 of 0.49. The oil palm seedlings were able to achieve a height ranging from 63.98 to 70.93 cm although in the presence of maximum Parthenium weed density.

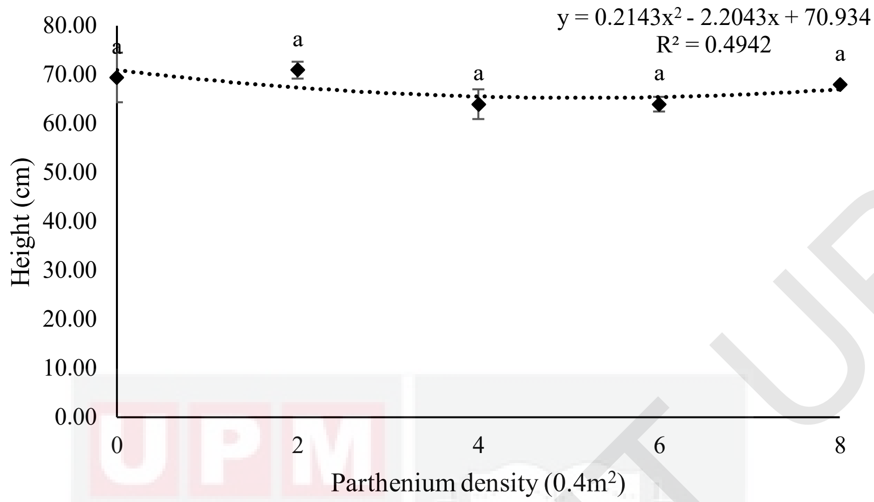

Figure 3.5 : Plant Height for Oil Palm at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.2.2 Number of Leaves

The number of leaves decreased significantly as the Parthenium weed density increased as shown in Figure 3.6 ($y = -0.0089x^2 – 0.1286x + 9.8786$) with R^2 value of 0.80. The highest number of oil palm leaves was recorded in control (no Parthenium weed) and 2 Parthenium weeds per 0.4 m^2. The number of leaves started to have significant reduction after Parthenium weed density of 6, followed by 4 and 8 Parthenium weeds per 0.4 m^2. Hence, density of 8 weeds per 0.4 m^2 caused maximum reduction in number of leaves in oil palm seedlings.

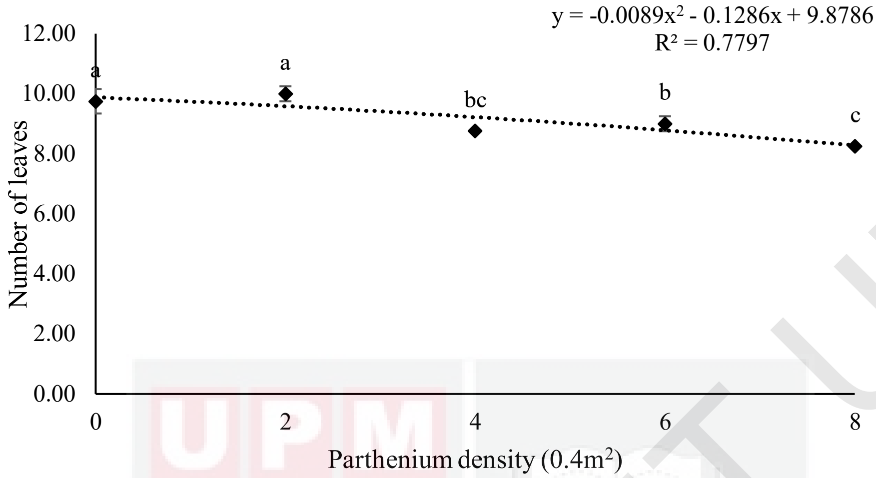

Figure 3.6 : Number of Leaves for Oil Palm at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.2.3 Fresh Weight

There was a fluctuate pattern in oil palm seedlings fresh weight when the Parthenium weed density was increased as $y = 0.1161x^2 – 4.8859x + 83.65$ and $R^2 = 0.73$ (Figure 3.7). The highest oil palm seedlings fresh weight was recorded in 2 Parthenium weeds density (82.82 g). Meanwhile, ther density treatments of control, 6, 4, and 8 weed per 0.4 m^2 reduced fresh weight by 1.9, 22.2, 33.4, and 38.6% respectively. Density of 2 weeds per 0.4 m^2 was not significantly different with densities of 0 and 6 weeds per 0.4 m^2. Between Parthenium densities of 4, 6, and 8 weeds per 0.4 m^2, there were also no significant difference observed.

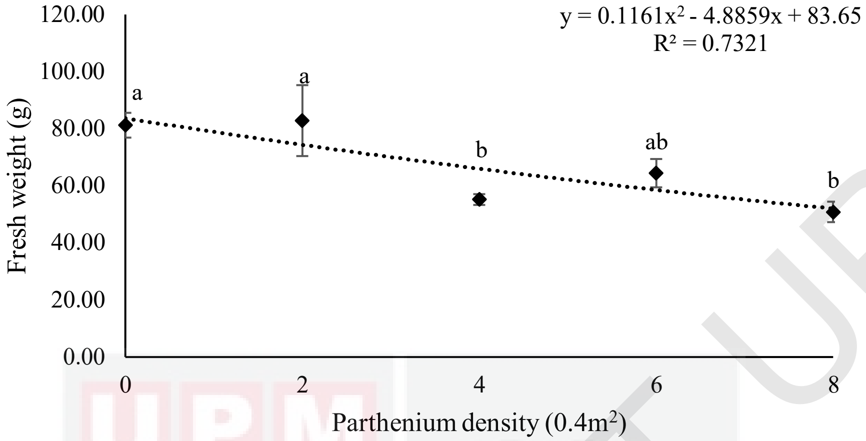

Figure 3.7 : Fresh Weight for Oil Palm at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.2.4 Dry Weight

In dry weight for oil palm seedlings as shown in Figure 3.8, an oscillating pattern was observed as the Parthenium weed density ascended with $y = -0.0298x^2 – 0.849x + 21.857$ and $R^2 = 0.72$. The highest result was recorded at density of 2 weeds per 0.4 m^2 (23.24 g). A significant reduction occurred at 4 (15.42 g), 6 (15.90 g), and 8 (13.48 g) Parthenium weeds per 0.4 m^2, although no significant difference was evident between these densities. From the results, it indicates that 8 Parthenium weed density per 0.4 m^2 reduced the oil palm seedlings dry weight for about 34.8% over the control.

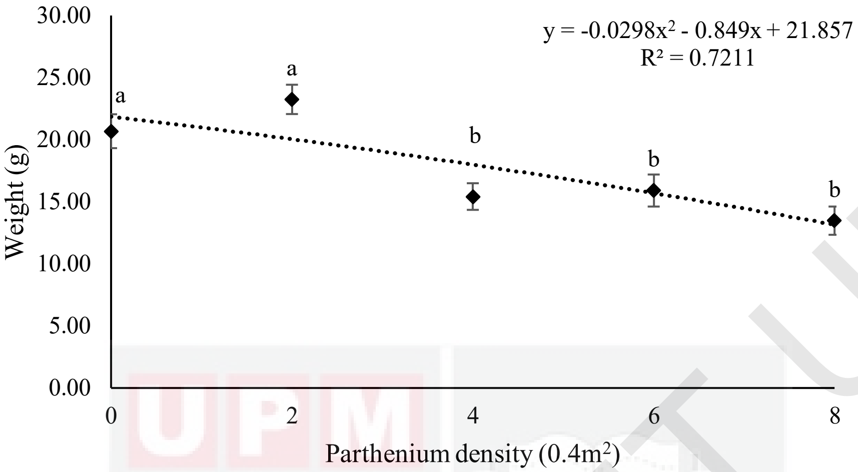

Figure 3.8 : Dry Weight for Oil Palm at 60 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.3 Effect of Parthenium Weed Densities on Okra

3.3.3.1 Plant Height

The plant height of okra crop at 60 days after growing in different Parthenium weed densities was significantly reduced as the Parthenium weed increased as $y = 1.1031x^2 - 13.484x + 97.425$ and $R^2 = 0.94$ (Figure 3.9). Okra grown in control showed the highest plant height (100.25 cm), followed with significant reduction in 2 weeds per 0.4 m^2 (68.53 cm). The lowest height was observed at 8 weeds per 0.4 m^2 (58.03 cm). However, treatment of 8 Parthenium weeds density was not significantly different when compared with 6 weeds per 0.4 m^2. This indicates that maximum Parthenium weed density of 8 weeds per 0.4 m^2 (or 20 m^2) could lead to height reduction of 42.1% in okra growth compared to control.

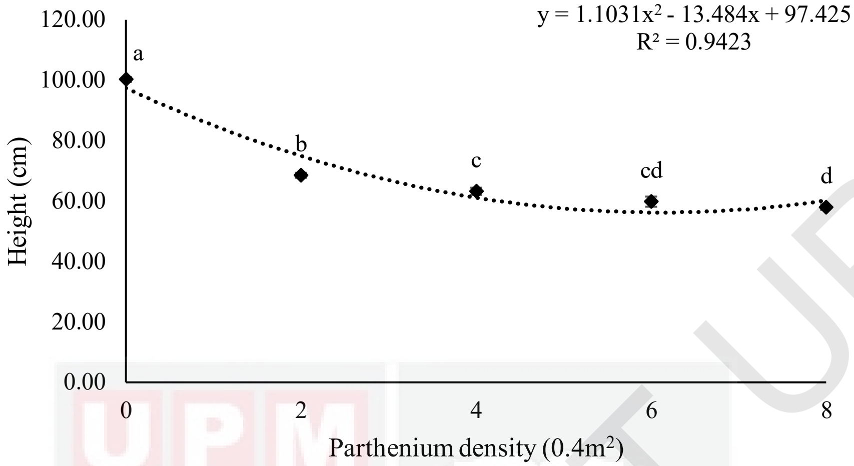

Figure 3.9 : Plant Height for Okra at 60 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.3.2 Number of Leaves

Figure 3.10 showes the effect of different Parthenium weed densities on leaves produced by the okra ($R^2 = 0.93$). Parthenium weed significantly affected ($p< 0.05$) okra leaves number starting from densities of 4 to 8 weed plants per 0.4 m^2, but no significant differences between the lower density (2 weeds per 0.4 m^2) as compared to control. Parthenium weed densities of 0 and 2 weeds per 0.4 m^2 recorded the higher number of leaves with the amount of 11.0 and 10.8 leaves, respectively, indicating that the present of at least 2 weeds per 0.4 m^2 (or 5 weeds per m^2) will not disturb the production of okra leaves.

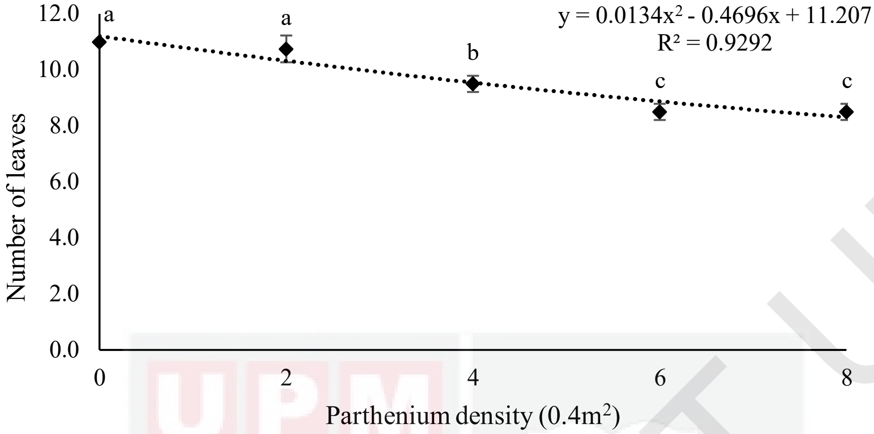

Figure 3.10 : Number of Leaves for Okra at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.3.3 Fresh Weight

Fresh weight for okra parameter showed a serious significant reduction by the application of different Parthenium weed densities ($P < 0.05$) as shown in Figure 3.11. Fresh weight parameter was significantly reduced with the increasing of Parthenium weed density as $y = 2.525x^2 - 37.744x + 199.34$ ($R^2 = 0.99$). Treatment with zero Parthenium density (control) recorded the highest fresh weight with 195.56 g followed by densities of 2 (126.36 g), 4 (84.18 g), 6 (60.80g), and 8 weeds per 0.4 m^2 (52.90 g). Compared to the highest value in control treatment, other density treatments of 2, 4, 6, and 8 weeds per 0.4 m^2 reduced fresh weight by 35.4, 57.0, 68.9, and 72.9% respectively. It defines that Parthenium weed can cause a critital effect on okra growth and will lower the yield productions.

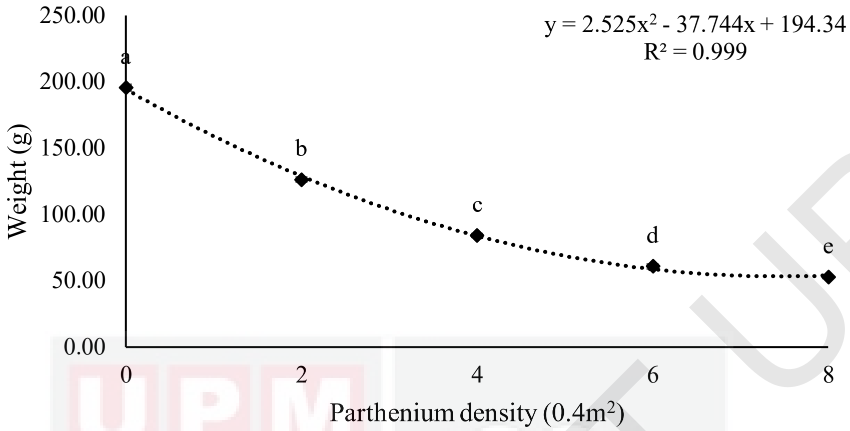

Figure 3.11 : Fresh Weight for Okra at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.3.4 Dry Weight

Figure 3.12 shows a similar result in dry weight as the Parthenium weed gave huge gap in dry weight starting at 2 weeds per 0.4 m^2 as $y = 0.4396x^2 – 5.5869x + 24.511$ (R^2 = 0.93). Compared to the highest dry weight in control with 25.78 g, the dry weight in 2 weeds per 0.4 m^2 was reduced to 11.98 g and it was 53.5% reduction. However, no significant difference on Parthenium density effect was observed between 2 and 4 weeds per 0.4 m^2. The lowest dry weight was at 6 and 8 weeds per 0.4 m^2 with no significant differences between both treatments.

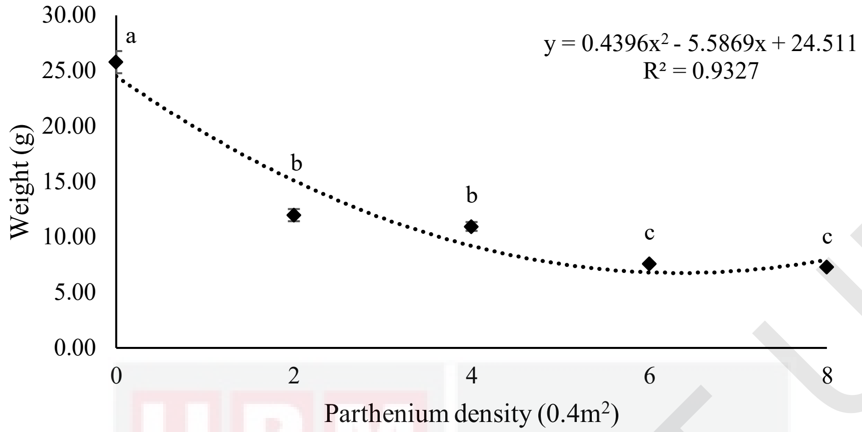

Figure 3.12 : Dry Weight for Okra at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.4 Effect of Parthenium Weed Densities on Sweet Corn

3.3.4.1 Plant Height

Difference in Parthenium densities did affect the growth for corn height in Figure 3.13 as $y = -0.2161x^2 – 2.2214x + 267.68$ ($R^2 = 0.82$). The highest corn plant height was recorded at control (0 weed per 0.4 m^2) with the value of 271.35 cm followed by 2 (255.20 cm), 4 (254.85 cm), 6 (254.40 cm), and 8 weeds per 0.4 m^2 (232.25 cm). There were no significant differences observed between treatments of 2, 4, and 6 weeds per 0.4 m^2. Althought there was significant differences showed between control and the lowest height in 8 weeds per 0.4 m^2, the sweet corn height was reduced to 14.4% only. Hence, plant height was not really affected by the maximum Parthenium density of 8 weed plants per 0.4 m^2 (or 20 weed m^2).

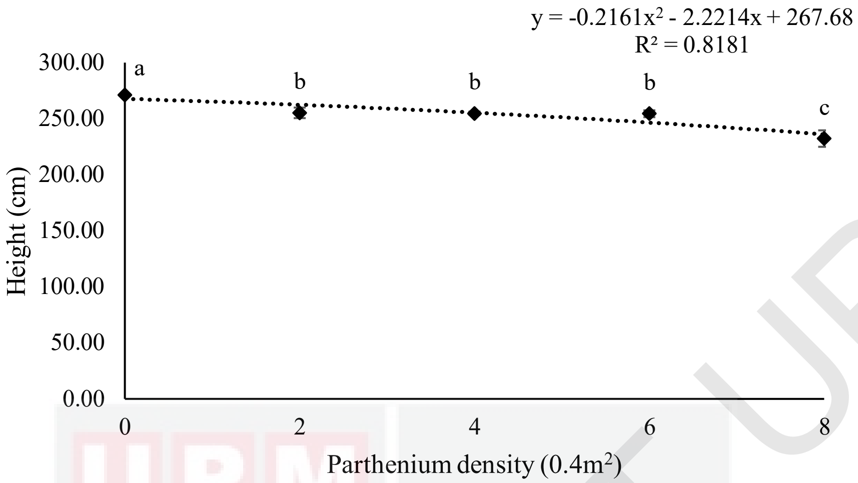

Figure 3.13 : Plant Height for Sweet Corn at 60 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.4.2 Number of Leaves

For the number of leaves parameter, Parthenium weed density did not give serious effect on the production of sweet corn leaves (Figure 3.14). As $y = -0.0804x^2 + 0.4929x + 13.507$ and $R^2 = 0.97$, the significant effect only shown at 8 weeds per 0.4 m^2 only. As for treatments of density between 0 to 6 weeds per 0.4 m^2, no significant difference was evident.

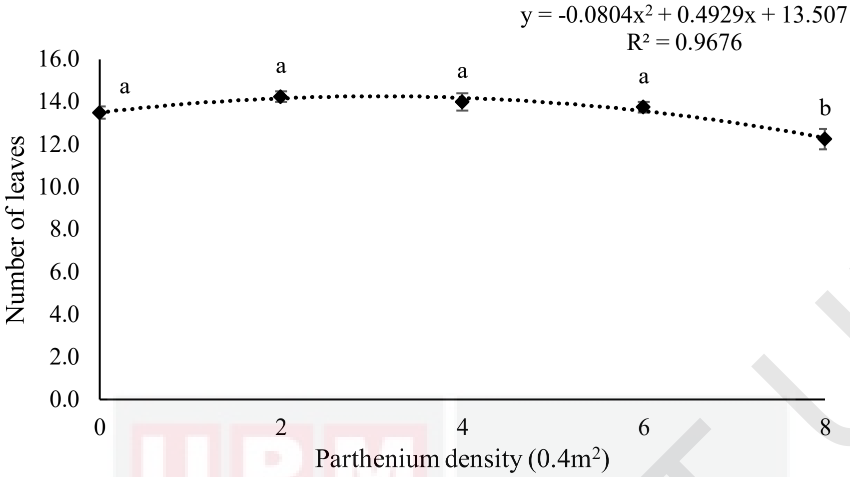

Figure 3.14 : Number of Leaves for Sweet Corn at 60 Days after Treated with Parthenium Weed Density
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.4.3 Fresh Weight

Figure 3.15 showes the observation of the fresh weight in sweet corn, with the equation $y = 0.0321x^2 - 18.749x + 481.73$ at $p< 0.05$ with $R^2 = 0.90$ showed the highest weight with treatment of 0 Parthenium weed density (control). As the Parthenium density increased to 2 weeds per 0.4 m^2, it showed significant differences compared to control with the amount of weight reduced by 15%. As for treatment between 2, 4, and 6 weeds per 0.4 m^2, no significant was recorded. However, as the density increased to 8 weeds per 0.4 m^2, fresh weight was lowered again significantly and it was 35.0% reduction compared to control.

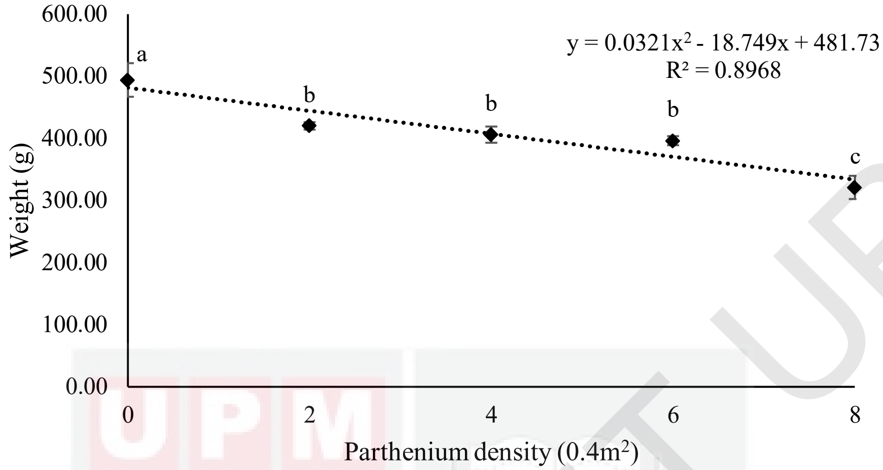

Figure 3.15 : Fresh Weight for Sweet Corn at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.3.4.4 Dry Weight

As for dry weight assessment in sweet corn (Figure 3.16) with $R^2 = 0.90$, the results also show a significant decrease in sweet corn. Control treatment recorded the maximum value of 63.79 g compared to other treaments containing Parthenium weed densities. Application of Parthenium weed densities of 2, 4, 6, and 8 weeds per 0.4 m^2 lessened sweet corn dry weights by 15.0, 19.2, 19.1, and 29.4% respectively when compared with control treatment. No significant differences were observed between Parthenium densities of 2, 4, and 6 weeds per 0.4 m^2.

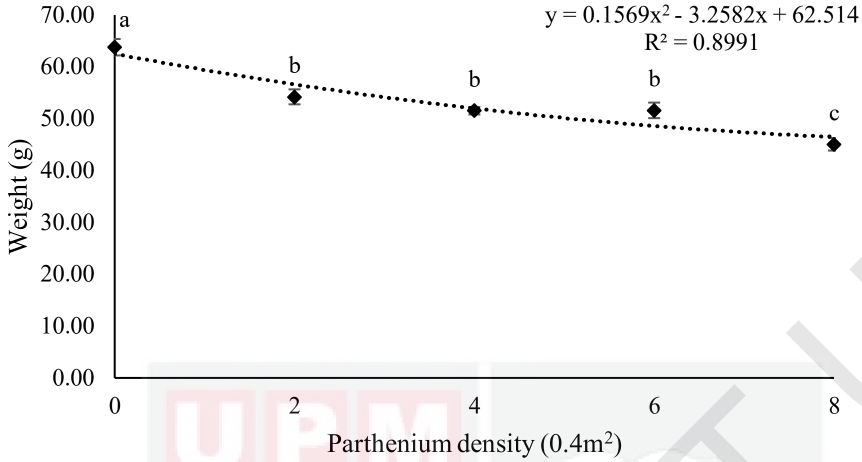

Figure 3.16 : Dry Weight for Sweet Corn at 60 Days after Treated with Parthenium Weed Density

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

3.4 Discussions

The current study evaluates the impact of Parthenium weed invasion on different selected crops, ranging from seasonal to perennial crops. However, short-cycle crops (e.g. leafy vegetables) were not included because normally these crops are usually harvested within 40 days or less, while the competitiveness impact of Parthenium weed plant are usually measured between 45-75 days (Bajwa et al., 2018; Rehman et al.,2018).

Observing the number of tillers is a fundamental technique to determine the effect of weed competitiveness towards rice crop in weed-crop competition (Abdullah Al Mamun, 2014). In this study, although there was significant difference in aerobic rice height in the presence of Parthenium weed density, it was not severely affected by the competitiveness of Parthenium weed as the decrement of plant height was only up to 6.82% (9.08 cm) at the highest density during the end of panicle initiation stage (45 days). Bajwa *et al*. (2019) reported that the height and dry biomass for rice crop were greatly reduced when exposed to longer duration (throughout the growing season) of competition with Parthenium weed. It was also observed that rice growth was beginning to be affected during 8 weeks after crop emergence (Bajwa *et al*., 2019). Although our observation on aerobic rice only lasted until 45 DAS, an observable reduction was evident when the density of Parthenium weed was increased.

According to Bajwa *et al*. (2018), rapid seed emergence of Parthenium weed during early aerobic rice growth stages becomes an important factor that will give advantage to the weed to suppress the aerobic rice growth in crop-weed competition between them. Although the height was not severely affected during initiation stage, previous study in direct-seeded rice indicated that it is critical for plant growth to fight against crop-weed development in the beginning 15-60 first days (Mukherjee *et al*., 2008).

The effect of Parthenium weed density on aerobic rice tillers were less eminent in lower Parthenium densities, but became prominent when density of the weed increased. The number of tillers kept decreasing when higher Parthenium densities were applied, as proved in this study, where as much as 20% reduction was recorded in the presence of the highest density of Parthenium. However, a more severe impact of similar high density of Parthenium weed was reported previously, in which Islam *et al*. (2003) indicated that at maximum density of 8 weeds per pot, number of tillers for rice was reduced to 72.7% compared to the weed free treatment.

For oil palm seedlings, it seems like the growth was not affected by the invasiveness of Parthenium weed, especially plant height. Although the oil palm seedlings were still at pre-nursery stage (4 months old), there was no obvious injury implicated by Parthenium weed on all growth parameters. However, slightly declining growth pattern was evident in oil palm root, indicating that there might be an implicit allelopathic interaction that exists between Parthenium weed and oil palm seedlings. Hence, if Parthenium weed is allowed to grow adjacently longer, a significant growth reduction in oil palm will be inevitable. Gunaseelan (1998) stated that parthenin in Parthenium weed is an inhibitor for the growth in monocot and dicot plants. Parthenin can give significant ecological impact from dead Parthenium leaf through leaching by rain or mist (Belz, 2007). Nevertheless, there is insufficient study of Parthenium invasiveness in oil palm plantation in Malaysia because this weed was newly introduced and would not be a bigger problem to oil palm plantations. But, other weed species such as *Asystasia gangetica* and *Mikania micrantha* have been reported to cause a yield reduction in oil palm plantation of 13% and 20%, respectively (Shariff & Rahman, 2008).

Parthenium hysterophorus is also a common weed species in okra field. According to the results obtained from this study, Parthenium weed had severely affected the growth of okra where high densities of Parthenium weed causing a harm up to 42% for okra height and 81.8% for dry weight. This result was in agreement with the previous study that reported 42% reduction in plant height and 80% reduction in okra shoot dry weight from Parthenium weed competition (Awodoyin & Olubode, 2011). Damage caused by the Parthenium weed to okra are usually due to the wide crop spacing and poor weed management control in the field (Bridgemohan *et al*., 2015). This study also found a similar observation with Bridgemohan *et al* (2015), where Parthenium weed was capable to achieve similar height with the okra. This shows that Parthenium can easily compete with okra in order to gain nutrients and space required for their growth. Parthenium weed also becomes a serious problem in India for okra, where a substantial yield reduction was reported (Kohli & Rani, 1994). In contrast, Bridgemohan *et al*. (2015) reported that vining crops such as cucumber, pumpkin and squash showed no significant reduction for the yield when allowed to compete with Parthenium weed. This is perhaps because all these crops are climbers, which could reach higher canopy and height over Parthenium weed that only grows upright, thus less affected by this invasive plant species.

Results from this study showed a 14% significant reduction for sweet corn plant height. This result was in line with Rehman *et al*. (2018) who stated that corn plant height was decreasing with an increasing in competition period and density of Parthenium weed. This occurrence may be caused by competition with Parthenium weed for the water, light and nutrient sources in soil to achieve optimum plant growth. However, a previous study concluded that weed infestation did not affect corn plant height at harvest, since as the corn plants reach maturity, they usually possess taller canopy than Parthenium weed (Alford *et al*., 2004). For sweet corn number of leaves, the leave reduction caused by Parthenium weed was below than 10%. Fresh and dry weight were reduced to 29.4% and 35% respectively by the maximum density of Parthenium. Other study reported a highest negative impact on maize growth and yield at density 15 plants per m^2 (which is equal to 6 Parthenium weed plants per 0.4 m^2 in this study) (Safdar *et al*., 2015). Our finding is almost similar to the finding by Asif *et al*. (2017) which reported a decrease in fresh fodder yield at 26.44% at the highest number of Parthenium weed at 16 plants per m^2. Hence, it is important to avoid continuous Parthenium weed competition with corn to minimize risk of yield reduction.

3.5 Conclusion

In conclusion, an increasing of Parthenium weed densities can cause significant yield loss for aerobic rice, okra, and sweet corn, while the impact of Parthenium weed on oil palm seedlings need to be continuously studied at different growth stages and invasion durations. Weed density of 8 plants per 0.4 m^2 (or 20 per m^2) and beyond have been proved to cause a critical loss in yield attributes to all seasonal crops. Therefore, Parthenium weed must be controlled early during the establishment of crop activity in the field by using suitable herbicide and proper integrated weed management.

CHAPTER 4

GERMINATION AND GROWTH PERFORMANCE OF *Parthenium hysterophorus* UNDER DIFFERENT ABIOTIC AND BIOTIC CONDITIONS

4.1 Introduction

Living organisms including weeds in the environment have been frequently facing the unfavorable conditions which can affect their growth and reproductive potential. Changes in biotic and abiotic conditions will put weeds under limitations to grow and sometimes they are not able to survive. Survival of the weeds or the adaptation under various stress environment increases the weed hardiness and make it an invasive species to the new habitat introduced. One of the most critical factors that put weeds under stress environment is light intensity and quality. Previous study by Wu *et al*. (2017) indicated that, reproductive capacity for plants that grow under low light conditions decreased in term of dry matter of leaves, stems and roots. This includes transpiration and photosynthetic rate and stomatal conductance. Plants tend to produce small leaves when there is limited light exposure.

P. hysterophorus spreading and become invasive is because it depends on the adaptation to several of climatic conditions with a short life cycle. It is also a prolific weed in nature that contributes to the occurrence of the huge seed bank (Abdulkerim –Ute and Legesse, 2016). All plant species have specific favorable conditions in the environment for the germination to initiate (Singh *et al*., 2012). The conditions were influenced by the soil pH, salt content in the soil and moisture.

Environmental conditions such as soil moisture play an important role to assess the invasiveness for some weed species on their spreading and adaptability in introduced places (Chauhan and Johnson, 2010). Based on recent study conducted by Chauhan and Johnson (2010) and Kaur *et al*. (2016), few invasive weed species tend to maintain their growth and capable of producing many seeds while facing drought conditions. This assumes that different weed species react differently to soil moisture conditions. Crop-weed competition can be induced with low water content in soil that influence the negative impact of weed towards crop as weed possess greater plasticity to maintain growth rate under stress conditions (Mahajan *et al*., 2018).

Al-karaki (2000) reported that, under salt stress in the soil, plants tend to prevent salinity stress by improving its tolerance and adjustments in their morphological and cellular level. Salt stress typically generate two common problems which are osmotic stress (excess of salts in soil) and ionic stress (overaccumulation of salt in plant cells) that will affect the soil physiological status (Ueda *et al*., 2003). Salt ions such as Na+, Ca^{2+}, Cl-, and SO^{4-} can create water deficit in the soil if the concentrations are increased. Hence, this salinity stress directly affected the plant seed germination percentage and also reduced the growth (Noureen *et al*., 2007).

Soil pH is also one of the important factors to influence the plant growth. Plant especially alien weed species tolerate differently depending on the soil pH in order to survive and maximize growth performance for adabtability in introduced places (Caplan and Yeakley, 2006). According to Loncaric *et al*. (2008), plant achieve favorable growing condition in acid soil because of high availability of micronutrients compared to neutral-alkaline soils. However, Gentili *et al*. (2018) stated that higher concentration of these micronutrients can become toxic to plant.

This experiment was conducted to determine the germination and performance of *Parthenium hysterophorus* L. under various biotic and abiotic conditions to evaluate the invasiveness of *P. hysterophorus* in the Malaysian environmental conditions. This study tested the Parthenium weed growth under different shading percentages and shading periods, soil moisture conditions, soil pH and soil salinities.

4.2 Methodology

4.2.1 Experimental Sites

There were four different experiments conducted in this study. For the first experiment, it was carried out in the open are in Rantau, Negeri Sembilan where the Parthenium weeds infested. Parameters collected for these experiments were germination percecntage, plant height, stem diameter, number of leaves, root volume, root dry weight and shoot dry weigh. Three other experiments (soil moisture, soil pH and soil salinity) were conducted in in a quarantine glasshouse in Ladang 15 at the Faculty of Agriculture, Universiti Putra Malaysia.

4.2.2 Plant Materials

The study represents local population in Ladang Infoternak, Jabatan Perkhidmatan Veterinar, Sungai Siput, Perak. Matured seeds were collected from Parthenium weed plants growing in the paddocks as mentioned in 3.2.1 (please see Chapter 3), brought to the Weed Science Laboratory and dried for three days in an oven at 33 ºC. Seeds were tested for germination percentage in petri dish before being used in the actual experiments by using pre-germinated seeds.

4.2.3 General Design and Treatments

In every four experiments, 30 pre-germinated seeds were sown in each polybag to measure the germination percentage. After 1 week, data was recorded and thinning was applied to allow only 10 Parthenium weed seedlings to grow until the end of experiments. These experiments were conducted for 8 weeks and operated independently. Randomized complete block design with four replications was applied for all experiments.

4.2.4 Experimental Design and Treatments

4.2.4.1 The Effect of Shading Percentage and Shading Period Study

Shading percentage treatments were implemented using shade-netting technique. There were four shading percentage (0%, 30%, 50% and 70%) with two shading periods (continuous 8 weeks shaded and full sunlight for 4 weeks, followed by 4 weeks shaded) and were tested on *P. hysterophorus*. Pre-germinated Parthenium weed seeds were used in this experiment and 30 seeds were sown in each polybag to test the germination percentage. After 1 week, thinning was applied as only 10 seedlings were allowed to grow in each polybag. Shading was applied at 2 different periods, namely after seed sowing until harvest (8 weeks shading period) and at 4 weeks after germination until harvest.

For every shade percentage level, it was artificially employed by using different green polypropylene shade fabrics which allowed only 70%, 50% and 30%, while light intensity under every shading percentage was recorded by using AccuPAR Ceptometer. As for control treatment (no shade), four polybags were placed under direct sunlight (100% light). The shades fabrics size for every treatment were 350 cm long x 150 cm wide x 200 cm height to cover four polybags, in four replicates. To confirm the percentage of light intensity under every netting, light intensity was measured by using AccuPAR Ceptometer model LP-80. The readings were taken three times under direct sunlight then under prepared shade to measure the average. The PAR value for each shading percentage was as follows:

Table 4.1 : Amount of Light Intensity under Different Shading Percentage

Shading percentage	PAR (uE m^{-2} s^{-1})
0% (direct sunlight)	2024
30%	1283
50%	892
70%	511

As for treatments, there were seven treatments combinations in the effect of shading percentage and shading period study on Partheniumm weed growth as shown in Table 4.2.

Table 4.2 : Treatment Combinations between Shading Percentage and Shading Period

Treatment	Combination
1	Unshaded/full sunlight (control)
2	Continuous 8 weeks 30% shaded
3	4 weeks unshaded fb 4 weeks 30% shaded
4	Continuous 8 weeks 50% shaded
5	4 weeks unshaded fb 4 weeks 50% shaded
6	Continuous 8 weeks 70% shaded
7	4 weeks unshaded fb 4 weeks 70% shaded

fb: followed by

4.2.4.2 The Effect of Soil Moisture on Parthenium Weed Study

In this soil moisture test, four different soil conditions were tested on Parthenium weed. The moisture test was prepared using clay pot filled with top soil. The soil was pressed uniformly in order to prevent any soil compaction which can affect the seedling germination. Four moisture conditions chosen for this study were:

I. Flooded (5 cm water level above the soil surface)
II. Saturated (0 kPa)
III. Field capacity (-30 to -50 kPa)
IV. Drought (-70 kPa)

Soil moisture was measured in each pot in 2-day interval using Tensiometer (Irrometer, IRROMETER Co., Inc., California, US). A total of 30 pre-germinated seeds were sown in each pot for every soil moisture condition and only 10 were allowed to grow after thinning.

4.2.4.3 The Effect of Soil Salinity on Parthenium Weed Growth Study

In soil salinity test, sodium chloride (NaCl) was used. There were four treatments of salinity concentrations which were 0, 8, 16 and 24 dS m^{-1} applied. Control treatment was irrigated by using distilled water. Salinity levels were added by 8 dS m^{-1} per day for every treatment in order to prevent salinity shock until require levels achieved. Polybags containing Parthenium weed were watered once a day with prepared treatment solutions up to 8 weeks for about 200 mL per polybag.

4.2.4.4 The Effect of Soil pH on Parthenium Weed Growth Study

Three soil pH range were chosen to test the Parthenium weed growth, namely pH 4.0 to 4.9, pH 5.0 to 5.9, pH 6.0 to 6.9 and pH 7.0 to 7.9. In order to obtain the targeted pH, $Ca(OH)_2$ (hydrated lime) and $Al_2(SO_4)_3$ (aluminum sulfate) were applied. The pH was decreased by using aluminum sulfate to acidic level and the pH was increased by using limestone to alkaline level and checked once a week to maintain the pH in every treatment. Portable pH meter was used to measure pH in every polybag.

4.2.5 Parameters Measured

4.2.5.1 Germination Percentage

Seeds germination percentage for Parthenium weed plants in all treatments was calculated by using given formula:

$$Germination\ (\%) = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seed\ in\ polybag} \times 100$$

Seed germinations were recorded when two leaves of Parthenium weed were produced.

4.2.5.2 Plant Height

The height was measured by using measuring tape from the plant base until top of plants' shoot. It was measured every 2 weeks in order to observe the effect on Parthenium weed height affected by the treatments.

4.2.5.3 Stem Diameter

The diameter for plant stem was determined by using vernier caliper. It was measured at the bottom of the stem which was above soil surface. Parthenium weed stem diameter was measured every 2 weeks in order to observe its response towards different treatments.

4.2.5.4 Number of Leaves

Number of leaves were calculated manually to determine Parthenium weed leaf production and recorded every 2 weeks.

4.2.5.5 Root Volume

Waster displacement method was used to calculate root volume. 100 mL measuring cylinder was filled with 50 mL of tap water. Then, the Parthenium roots were fully submerged in the water. The volume of the water increased after submerging roots was recorded. The added volume of water was then subtracted with the original volume. The equations are as follows:

$Root\ volume\ (cm3)$

$$= Volume\ after\ root\ added - Original\ water\ volume\ (50\ mL)$$

4.2.5.6 Root Dry Weight

Parthenium weed roots were dried at 65 ºC for 72 hours in order to remove all the moisture. Analytical balance was used to measure every root dry weight.

4.2.5.7 Shoot Dry Weight

Shoots were dried at 65 ºC for 72 hours in order to remove all the moisture. Analytical balance was used to measure the Parthenium weed shoot dry weight.

4.2.6 Data Analysis

Data obtained from these experiments were analyzed using SAS (SAS 9.4, SAS Institute, Inc. Cary NC. USA). The values obtained from this study were subjected to Analysis of Variance (ANOVA) and then proceeded with mean separation via Least Significant Difference (LSD) observed at $P<0.05$.

4.3 Results

4.3.1 Germination and Growth Performance of *Parthenium hysterophorus* under Different Shade and Shading Period

4.3.1.1 Germination Percentage

Germination percentage shows a significant difference between continuous shading and late shading periods. It showed fluctuate graph pattern (Figure 4.1). The germination percentage for Parthenium weed seeds under continuous 8 weeks shaded for all shading percentages (30%, 50% and 70%) were always higher compared to seeds grown under 4 weeks late shaded where in the first four weeks, the seeds were sown and allowed to grow under direct sunlight (100% daylight). Seeds germination for all treatments with 8 weeks shaded were all above 90%. The highest was recorded in treatment with 30% shaded (96.3% seeds germination). As 8 weeks shaded treatments, it shows no significant differences when compared to unshaded (control). Germination percentage for Parthenium weed seeds under 4 weeks shaded treatements for 30%, 50% and 70% ranged between 80.0 to 81.3% while under direct sunlight (100% light intensity), it recorded the lowest value with only 76.3% of seeds germination.

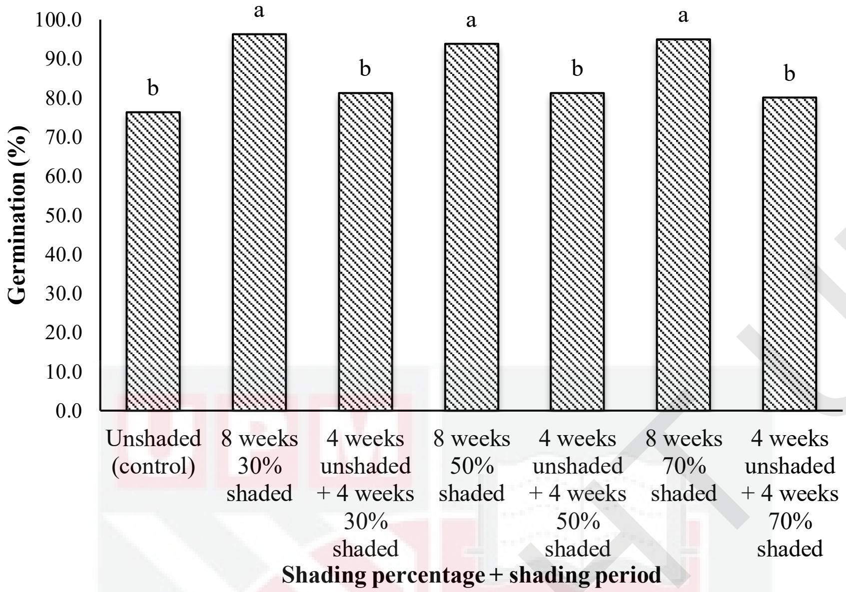

Figure 4.1 : Percentage of Seed Germination of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.2 Plant Height

Plant height for the first two weeks of observation was significantly different between 100% light intensity (unshaded) all shading treatments (Figure 4.2). As the Parthenium weed plants reached week four where it enters the maturity stage, there were four treatments which exhibited higher height with no significant difference between those treatments (4 weeks unshaded + 4 weeks 30% shaded, 8 weeks 50% shaded, 4 weeks unshaded + 4 weeks 50% shaded and 8 weeks 70% shaded) as the 50% shading was slightly higher than others. Approching week six, a clear trend in plant height corresponding to the differences in shading percentages and duration was evident. Parthenium weed height was significantly the highest in 4 weeks unshaded + 4 weeks 50% shaded, followed by continuous 8 weeks 70% shaded, while the lowest height was in 100% sunlight (control). At week eight, a similar trend was observed, where again treatment of 4 weeks unshaded + 4 weeks 50% shaded continue to record significantly higher plant height of Parthenium (17.79 cm) compared to other treatments. As for treatment with 30% and 50% shading percentage, it showed that combination of 4 weeks shading periods gave significantly higher height when compared to 8 weeks shading periods.

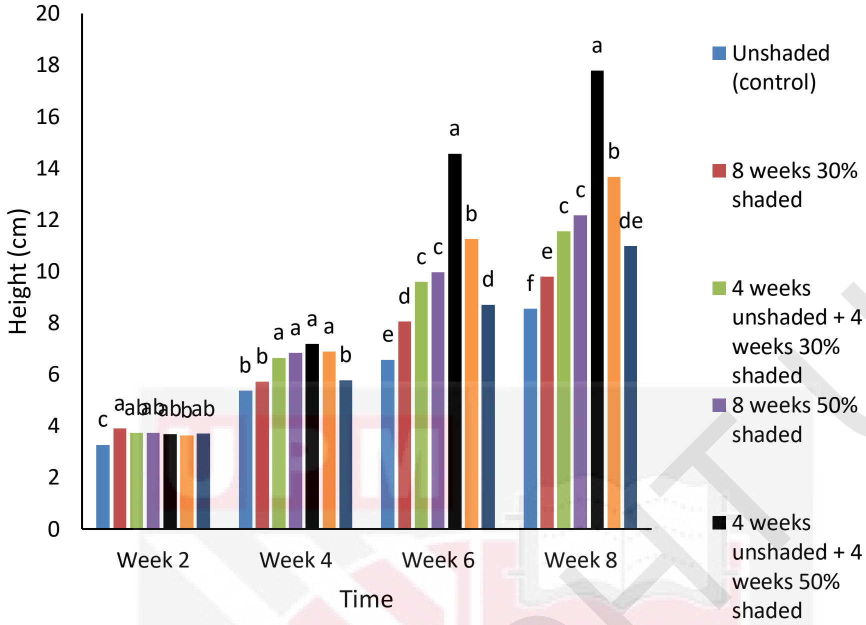

Figure 4.2 : Plant Height of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.3 Stem Diameter

For the stem diameter, different growth pattern than plant height was observed, where there were no significant differences observed during the first 2 weeks. As for week four, 4 weeks unshaded + 4 weeks 50% shading period recorded the highest value as compared to other treatment while 100% sunlight recorded the lowest diameter. During week 6, stem diameter for 100% sunlight treatment was significantly higher followed by 50% and 30% shade with combination of 4 weeks 50% shading period. At week 8, Parthenium stem diameter which grown in 100% sunlight produce the highest stem diameter (4.47 mm). Stem diameter was significantly reduced as the shading percentage were increasing to 30% to 70%. However, Parthenium weed stem diameter for plants which were grown under 4 weeks shading period produced higher diameter compared to 8 weeks shading treatment. There was no significant difference between 30%, 50% and 70% shading percentage which combined with 4 weeks shading period. The lowest stem diameter was observed in the treatment of 8 weeks 50% shading period (2.96 mm).

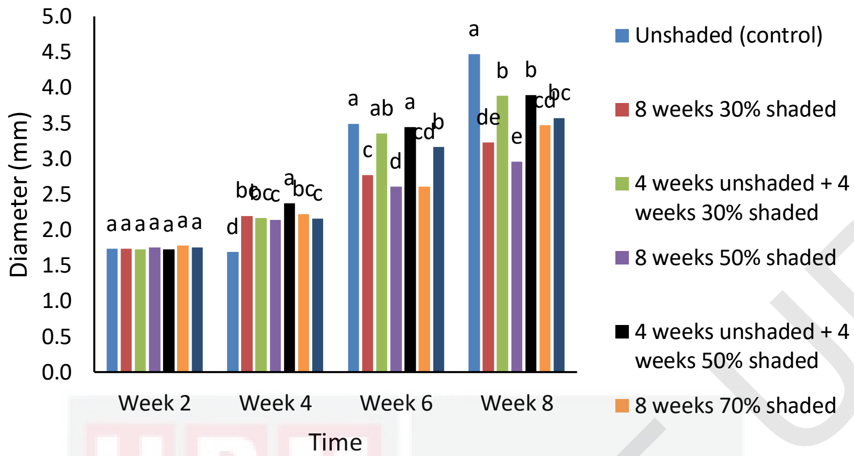

Figure 4.3 : Stem Diameter of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.4 Number of Leaves

Week 2 resulted in no significant difference between treatments of unshaded (control), 30% shaded with 8 and 4 weeks shading and 50% shade with 8 weeks shading periods on the number of leaves. Leaves production in week 2 was 5 to 6 leaves. At week 4, 30% shade with 8 weeks shading period recorded higher number of leaves compared to other treatment but no significant difference observed when compared to 50% shade with 4 weeks shading and 70% shade with both shading periods. Furthermore, the lowest leaves number were observed at 8 weeks 50% shade. At week 6, 50% shade with 4 weeks shading period gave a significantly higher number of leaves followed by unshaded (control). Treatment of 30% shade with both shading period and 8 weeks under 50% shade recorded lower value and no significant differences were shown between these treatments. Both treatments of 70% shade not difference significantly when grow up to 6 weeks. At week 8, treatment of 4 weeks unshaded followed by 4 weeks 50% shaded (14 leaves) allowed more leaves to develop as it produced higher number of leaves than same shading percentage but with 8 weeks shading duration (Figure 4.4). 8 weeks 50% shaded only produced 10 leaves and it recorded the lowest amount as compared to other treatments and control (100% light). There was no significant difference recorded between 4 weeks and 8 weeks shading period within 30% shading percentage. Similar results were observed for 70% shaded as the effect of shading period (4- and 8-weeks shading durations) not significantly affected the production of Parthenium weed leaves.

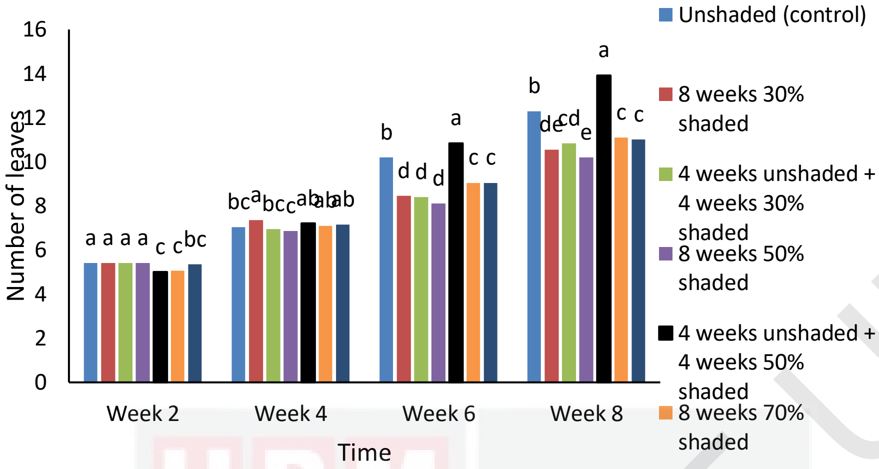

Figure 4.4 : Number of Leaves of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.5 Root Volume

As for the production of root volume for Parthenium weed (Figure 4.5), treatment with 4 weeks 100% sunlight + 4 weeks 30% shade produced higher compared to all treatments but not significantly different than 100% sunlight (control). Both of them produced 61.0 and 57.0 cm^3 of root volume, respectively. Within 8 weeks shading period treatments, the root volume was also significantly different between each other. In continuous 70% shading (8 weeks shading duration), the lowest root volume was produced (23.5 cm^3).

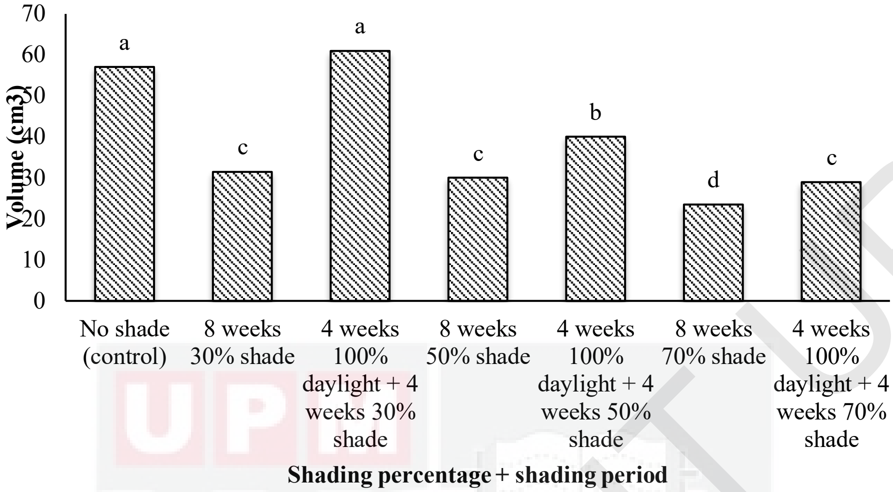

Figure 4.5 : Root Volume of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.6 Root Dry Weight

The assessment on root dry weight for Parthenium weed recorded the highest value under unshaded (control) with the weight of 8.12 g. This was followed by 8 weeks 30% shade (4.48 g) and 8 weeks 50% shade (3.98 g) (Figure 4.6). The lowest root dry weight was recorded under treatments of 4 weeks unshaded + 4 weeks 70% shaded (2.71 g) followed by 8 weeks 70% shaded (2.84 g). Both of these treatments and 8 weeks 50% shaded (3.24 g) were not significantly different between each other.

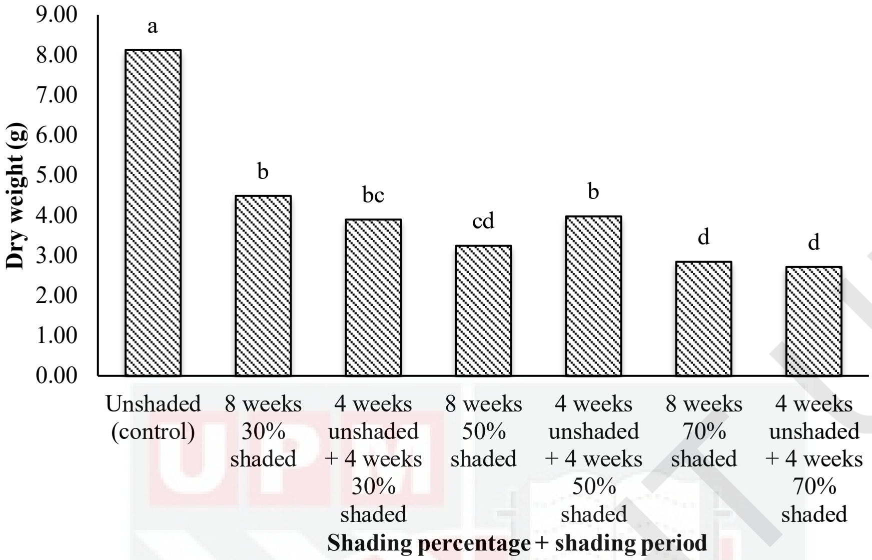

Figure 4.6 : Root Dry Weight of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.1.7 Shoot Dry Weight

Parthenium shoot dry weight was not significantly affected by different shading periods for 30% and 50% shading treatments (Figure 4.7). The highest dry weight was shared by 50% shade for 8 weeks (11.73 g) and 4 weeks (11.54 g) periods. Under 70% shade, there were significant differences between 4- and 8-weeks shading period with weight of 6.39 g and 7.11 g, respectively.

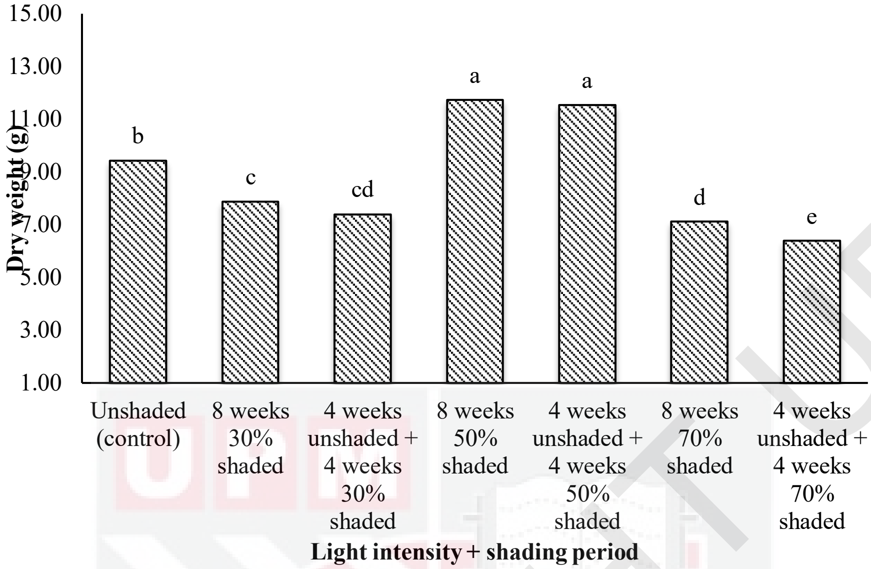

Figure 4.7 : Shoot Dry Weight of Parthenium Weed Grown under Different Shade and Shading Period 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2 Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil Moisture Conditions

4.3.2.1 Germination Percentage

Germination percentage for Parthenium weed seeds as affected by the soil moisture stress conditions is shown in Figure 4.8. Seeds grown under field capacity recorded the highest germination percentage (89.2%) followed by saturated (85.0%) while Parthenium weed seeds under drought and flooded were not able to germinate at all. There was no significant difference in germination between field capacity and saturated.

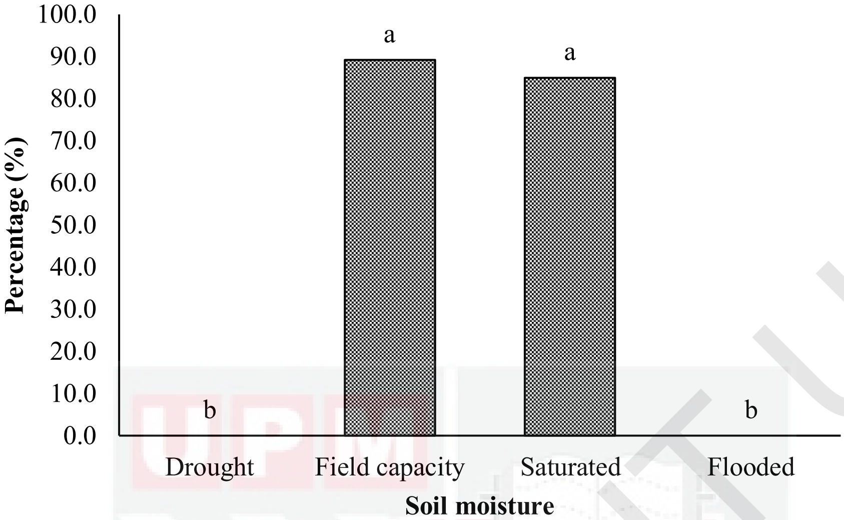

Figure 4.8 : Percentage of Seed Germination of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.2 Plant Height

No plant height was recorded in Parthenium weed grown under drought and flooded conditions, since germination was unsuccessful. No significant difference was observed between treatment of field capacity and saturated soil conditions, although result in saturated soil was insignificantly slightly higher than field capacity (Figure 4.9). It shows that Parthenium weed height was not affected when grown under either field capacity or saturated soil, at all observed dates.

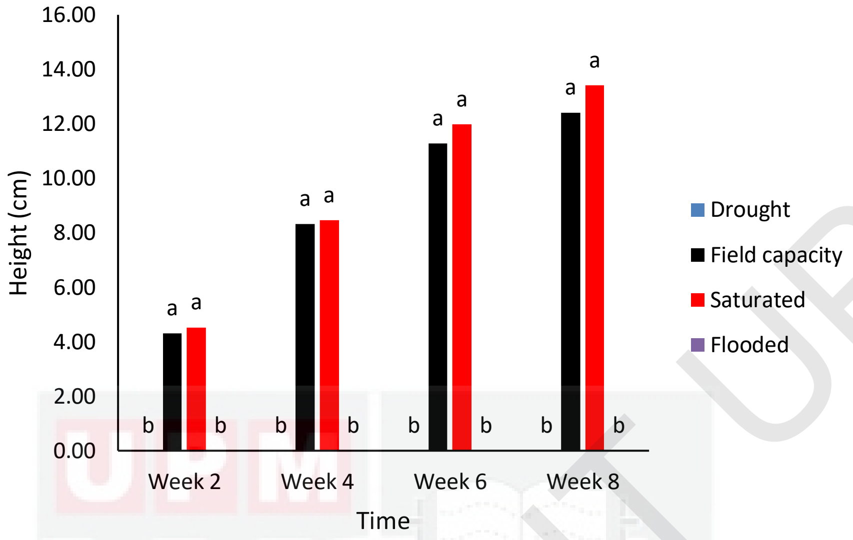

Figure 4.9 : Plant Height of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing

Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.3 Stem Diameter

Stem diameter of Parthenium weed was not significantly different when treated under field capacity and saturated soil conditions for the first 4 weeks. Increasing in stem diameter was only observed with increased in time especially at week 6 and 8. Both treatments for field capacity and saturated soil in week 2 and 4 for Parthenium were not significantly affected by the differences in soil moisture when it was under juvenile stage. As the Parthenium in matured stage, at week 6 stem diameter started to show significant difference where saturated soil resulted in higher diameter compared with field capacity. Again, at week 8, stem diameter for Parthenium weed recorded the highest diameter when grown under saturated condition (3.59 mm), followed by field capacity (2.51 mm).

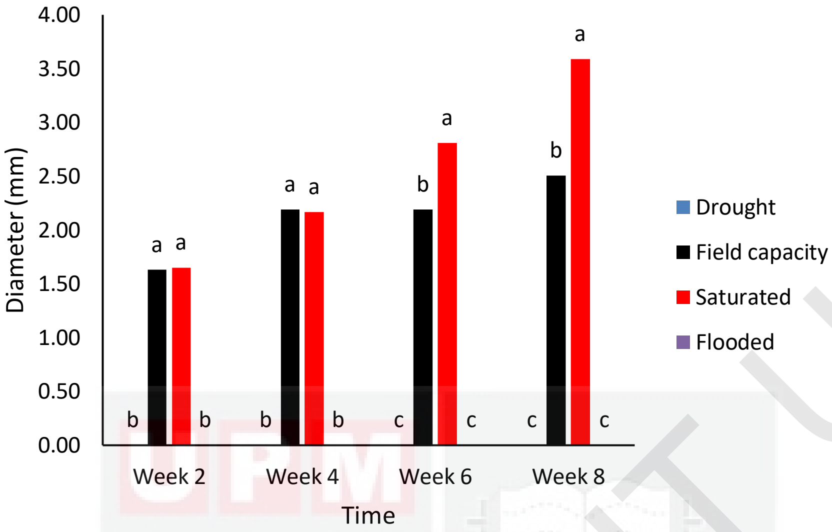

Figure 4.10 : Stem Diameter of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.4 Number of Leaves

Figure 4.11 shows the production of Parthenium weed leaves grown under drought, field capacity, saturated and flooded soil conditions. At weeks 2 to 6, no significant difference was observed between treatments. However, in week 8 it shows that the production for number of leaves for saturated conditions which was significantly higher (16 leaves) than field capacity condition (14 leaves).

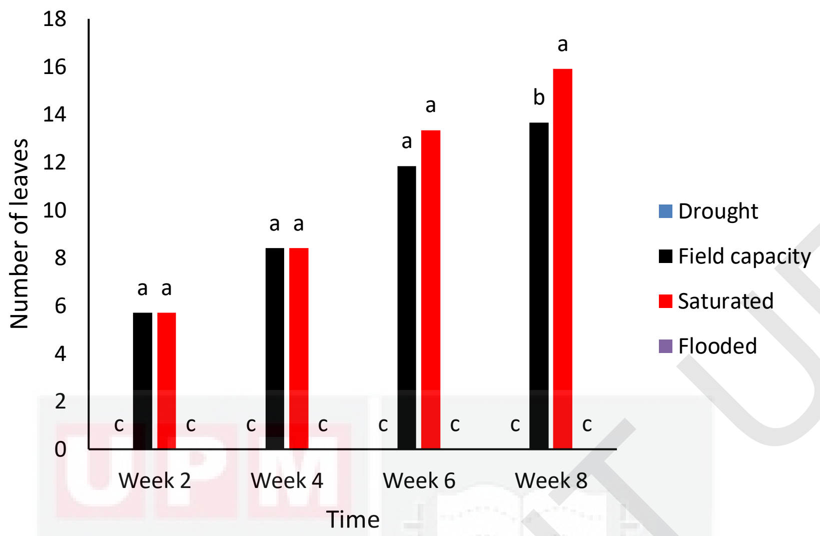

Figure 4.11 : Stem Diameter of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.5 Root Volume

The result for root volume also showed not significant different between saturated and field capacity conditions. It shows that root growth under field capacity and saturated was not affected and able to grow under these conditions.

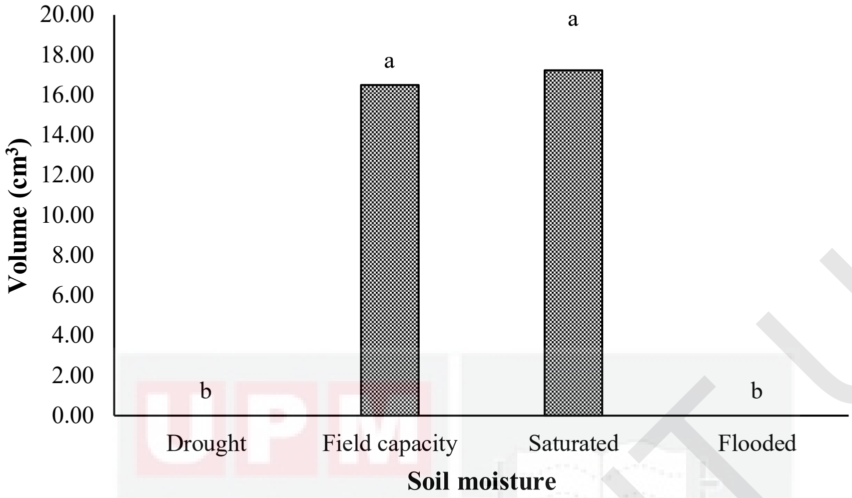

Figure 4.12 : Root Volume of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.6 Root Dry Weight

Similarly, the results for root dry weight of Parthenium weed (Figure 4.13) showed that field capacity and saturated soil conditions were not significantly different between them.

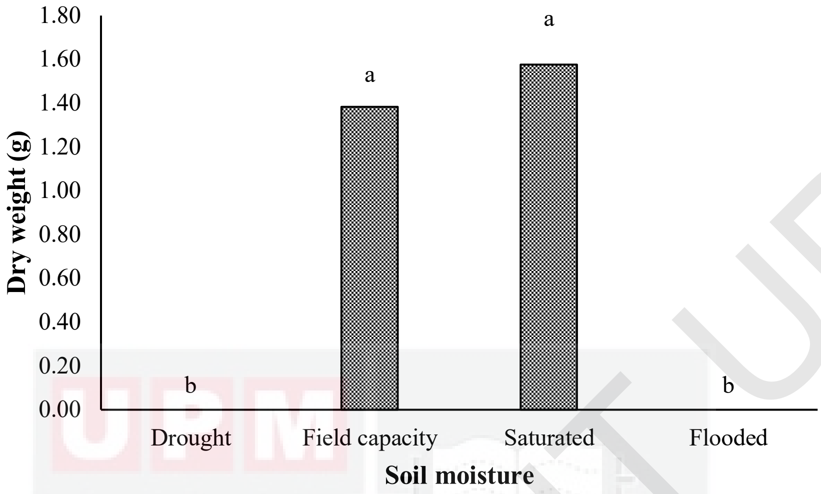

Figure 4.13 : Root Dry Weight of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.2.7 Shoot Dry Weight

From the results (Figure 4.14), there was a significant difference between field capacity and saturated soil conditions in the show dry weight of Parthenium weed plants. Saturated soil condition produced higher shoot dry weight (6.54 g) compared to field capacity (4.09 g).

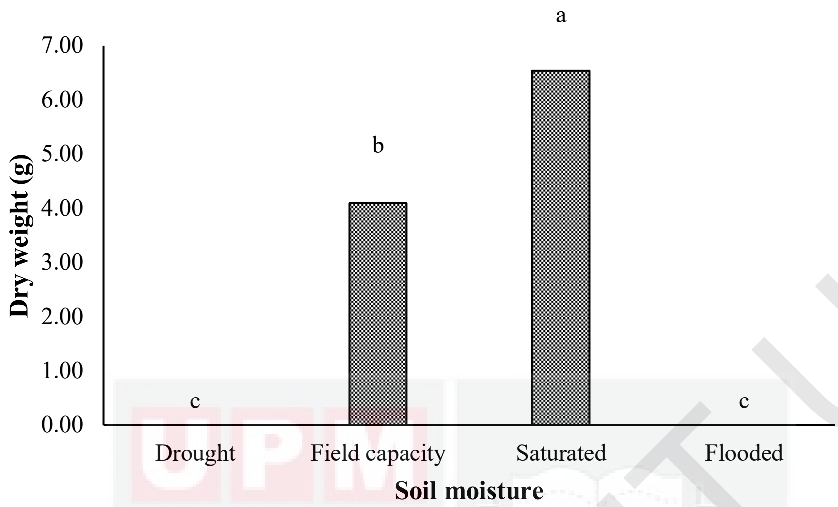

Figure 4.14 : Shoot Dry Weight of Parthenium Weed Grown under Different Soil Moisture 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3 Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil Salinities

4.3.3.1 Germination Percentage

Germination of Parthenium weed seeds in early soil salinity experiment was severely affected by the different salinity concentrations (Figure 4.15). There was no significant difference between the salinity concentrations treatments recorded. The seeds germination was reduced significantly from 91.7% (control) to 69.2% (8 dS m^{-1}), 40.0% (16 dS m^{-1}) and the lowest 20.0% (24 dS m^{-1}). The reduction of germination at maximum concentration as compared to control was 71.7%.

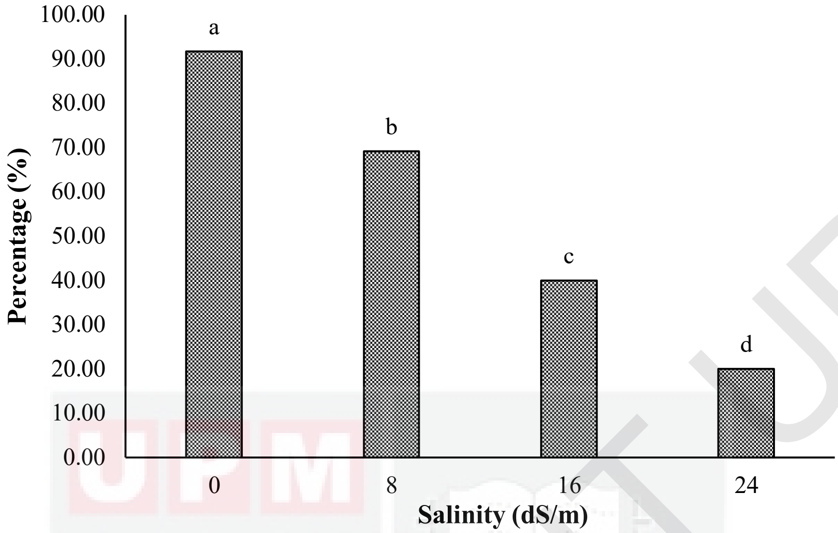

Figure 4.15 : Percentage of Seed Germination of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.2 Plant Height

Plant height for Parthenium at week 2 was not significantly influenced when treated with 0 and 8 dS m^{-1}. A significant decrease in plant height was observed at 16 dS m^{-1}, followed by 24 dS m^{-1}. Reaching week 4, salinity concentrations of 0 and 8 dS m^{-1} was again observed to be not significantly different between these treatments. At weeks 6, plant height between all treatments were significantly different between each other. The 0 dS m^{-1} recorded the highest (16.45 cm) followed by 8 dS m^{-1} (12.83 cm), 16 dS m^{-1}(5.74 cm) while 24 dS m^{-1} recorded the lowest height (3.01 cm). At week 8, the height of Parthenium weed was also affected by the increasing of salinity concentrations. The highest height was observed at control (0 dS m^{-1}) with the value of 22.7 cm while maximum NaCl concentration (24 dS m^{-1}) indicated the lowest plant height at only 3.31 cm. The result also showed significant difference between different salinity concentrations. The growth of Parthenium weed under the highest saline concentration of 24 dS m^{-1} was completely stunted at week 8.

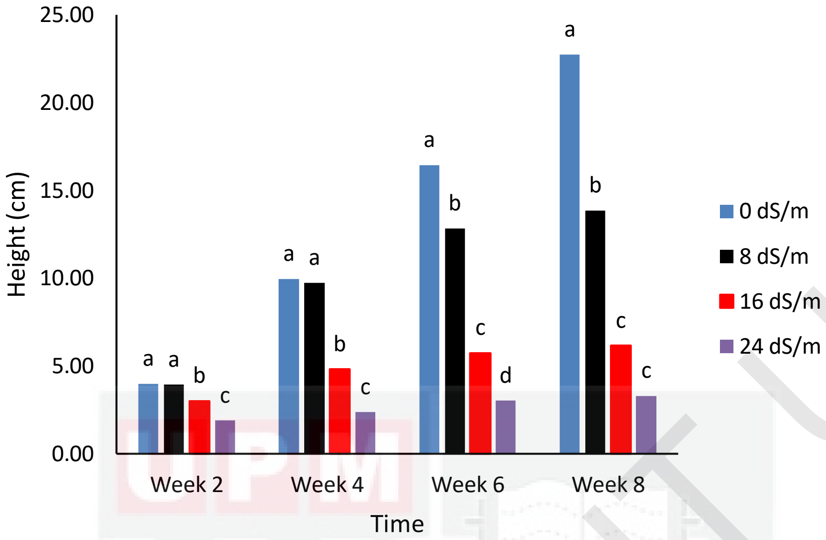

Figure 4.16 : Plant Height of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.3 Stem Diameter

Figure 4.17 shows increase in Parthenium weed stem diameter with time. Similar to plant height, the stem diameter decreased significantly in response to increased salinity concentrations of NaCl treatment. At week 2, concentrations of 0 and 8 dS m^{-1} recorded no significant difference. The lowest value was observed at 24 dS m^{-1} (0.86 mm). At week 4, concentrations of 0 and 8 dS m^{-1} were also observed not significantly different with each other. The declining in stem diameter started at 16 dS m^{-1} followed by 24 dS m^{-1} as the lowest value. Week 6 recorded 0 dS m^{-1} as the highest stem diameter with the value of 2.59 mm. Salinity of 8 and 16 dS m^{-1} showed no significant difference between each treatment. The lowest result was observed at 24 dS m^{-1} with diameter of 1.12 mm only. The trend continued at week 8. The high level of salt concentrations decreased the stem diameter of Parthenium weed. In the control concentration (0 dS m^{-1}), stem diameter was the the highest (3.09 mm), followed by 8 dS m^{-1} (2.37 mm), 16 dS m^{-1} (2.05 mm) and 24 dS m^{-1} (1.18 mm).

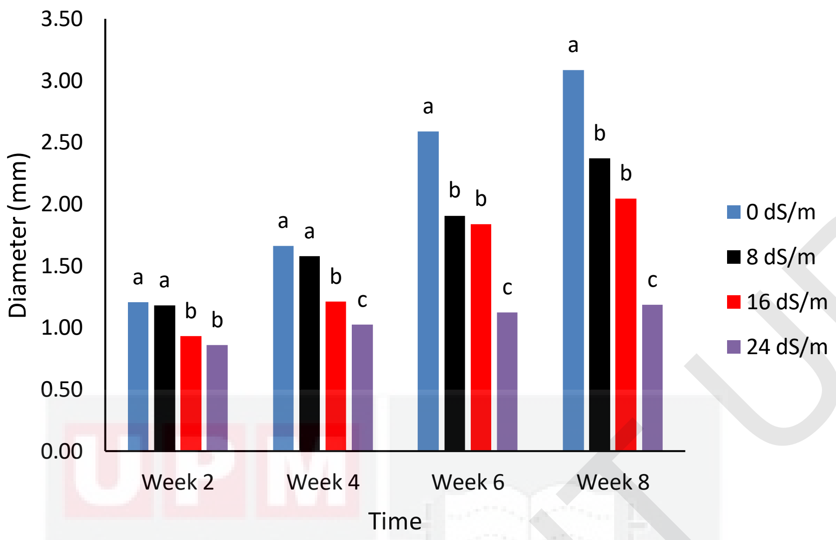

Figure 4.17 : Stem Diameter of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.4 Number of Leaves

Figure 4.18 shows the production of Parthenium weed leaves under different salinity concentrations for 8 weeks. During vegetative stage at week 2, 0 dS m^{-1} salinity recorded the highest leaves but no significant different was observed with 8 dS m^{-1} while it started to decrease significantly with concentrations of 16 and 24 dS m^{-1}. At week 4 of treatment, the leaves production under the concentrations of 0 and 8 dS m^{-1} was not significantly different as well. As the concentration increased to 16 dS m^{-1} and beyond, reduction of leaves number was evident. At week 8, number of leaves was further greatly reduced as the concentrations of salinity increased. Higher number of leaves was recorded in 0 dS m^{-1} (control), followed by 8 dS m^{-1} (13 leaves), 16 dS m^{-1} (10 leaves) and 24 dS m^{-1} (6 leaves). This indicates that the leaves production in Parthenium weed under maximum salt concentrations were stunted.

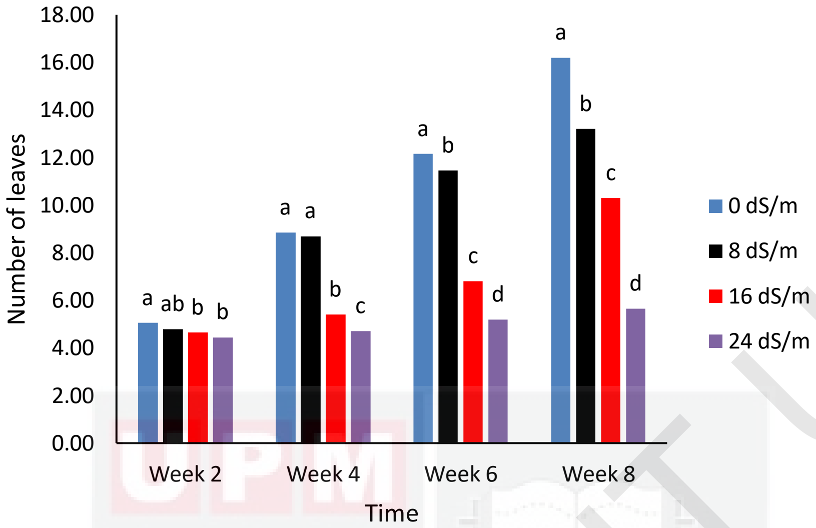

Figure 4.18 : Number of Leaves of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.5 Root Volume

Root volume of Parthenium weed growth yielded an increase with increased of salt concentrations (Figure 4.19). All treatments greatly produced different root volumes. Maximum root volume was recorded in control/no salinity (0 dS m^{-1}) with the value of 13.5 cm^3. The root volume decreased at 8 dS m^{-1} (9.25 cm^3) followed by 16 dS m^{-1} (6.0 cm^3) and 24 dS m^{-1} (3.0 cm^3).

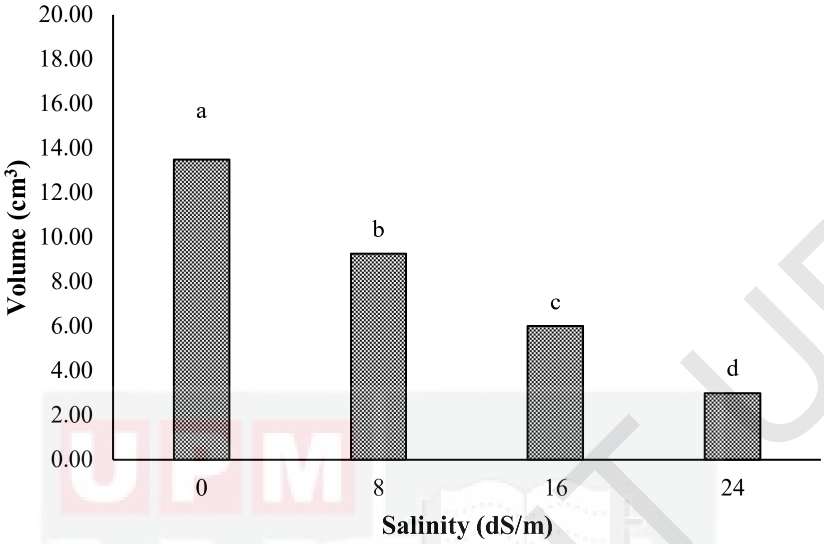

Figure 4.19 : Root Volume of Parthenium Weed Grown under Different Soil Salinity 8 Weeks After Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.6 Root Dry Weight

The dry weight of Parthenium weed roots was significantly reduced as compared to 0 dS m^{-1} which was recorded at 0.15 g (Figure 4.20). The root dry weight was reduced to 0.10 g (16 dS m^{-1}) followed by 0.06 g (8 dS m^{-1}) and 0.02 g (24 dS m^{-1}). The reduction of root dry weight from the highest value to 24 dS m^{-1} was about 86.7%.

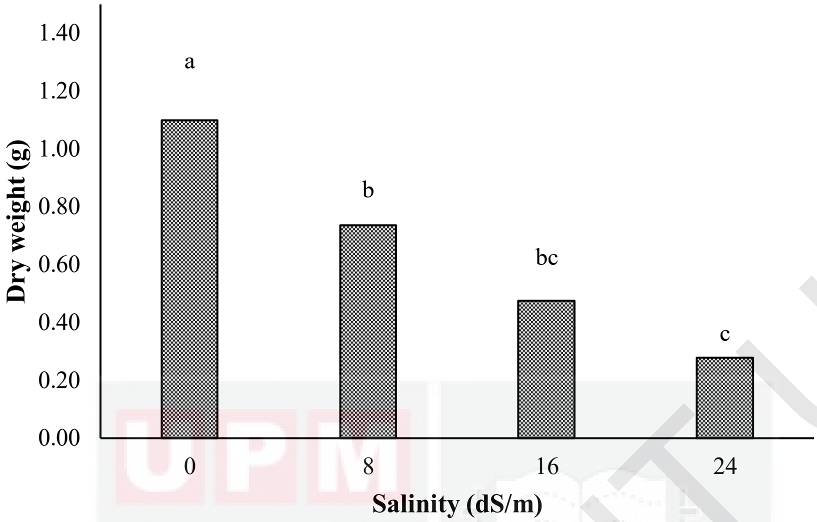

Figure 4.20 : Root Dry Weight of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.3.7 Shoot Dry Weight

As for shoot dry weight, it was recorded that 24 dS m^{-1} exhibited the lowest shoot biomass, with only 1.47 g compared to control treatment (0 dS m^{-1}) (Figure 4.21). It was reduced for about 87.7% from the highest value at control. The results pattern was same with root dry weight.

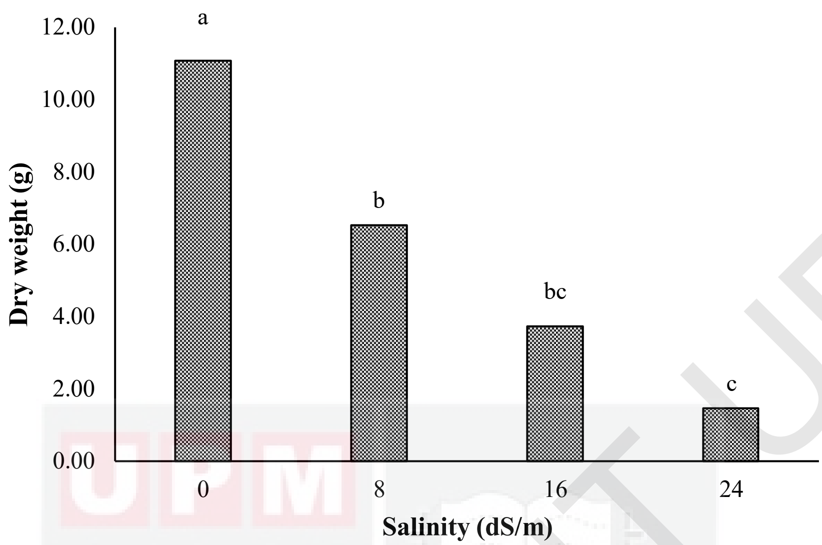

Figure 4.21 : Root Dry Weight of Parthenium Weed Grown under Different Soil Salinity 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4 Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil pH

4.3.4.1 Germination Percentage

Parthenium weed seeds managed to germinate in various soil pH, ranging from 4.0 to 7.9, but at different capacities (Figure 4.22). From the results, soil pH of 6.0 to 6.9 recorded the highest germination followed by pH 5.0 to 5.9 with 81.7 and 80.8% germination percentage, respectively. No significant difference was observed between these treatments. However, in soil having pH 7.0 to 7.9, the germination was reduced to 60.8% while at pH 4.0 to 4.9, germination percentage was only 50.8%.

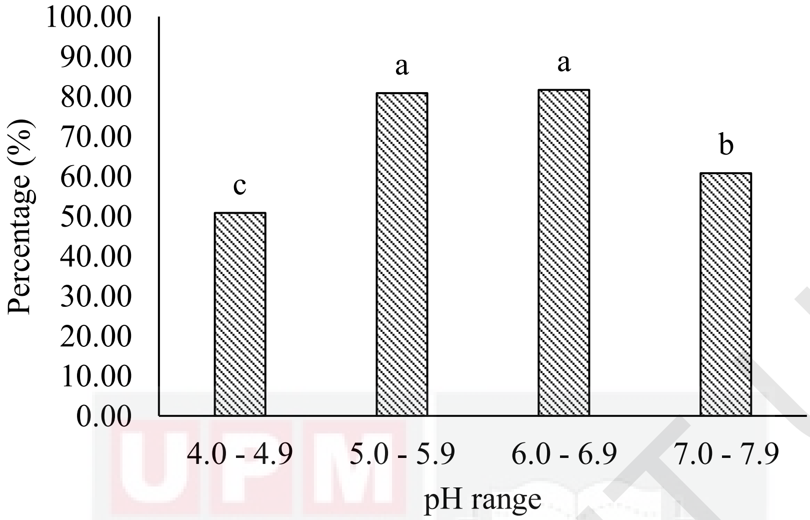

Figure 4.22 : Percentage of Seed Germination of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.2 Plant Height

The Parthenium responses pattern continued in all other growth parameters as well, where the most acidic treatment always resulted in the lowest value in comparison to other pH conditions. The plant height measured at week 2 recorded no significant difference between soil pH treatments. During the vegetative stage at week 4, the highest plant height was recorded in soil having pH of 5.0 to 5.9. This was then followed by pH 6.0 to 6.9 with no significant difference. Parthenium weed height grown in pH 4.0 to 4.9 was the shortest than those grown in other soil pH treatments. After reaching mature stage at week 6, Parthenium weed grown under soil pH of 5.0 to 5.9 and 6.0 to 6.9 did not differ significantly and still produced the highest plant height. At week 8, the highest height was recorded in pH 6.0 to 6.9 followed by pH 5.0 to 5.9. Treatments of pH 4.0 to 4.9 and 7.0 to 7.9 were not significantly different, although pH range of 4.0 to 4.9 recorded the shortest Parthenium weed height (Figure 4.23).

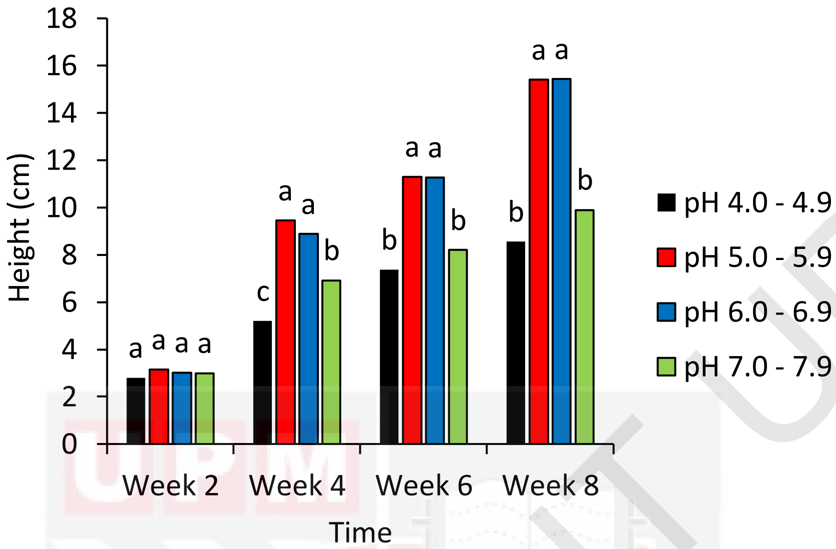

Figure 4.23 : Plant Height of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.3 Stem Diameter

Figure 4.24 shows the effect of pH towards Parthenium weed stem diameter. There were no significant differences observed at week 2. During week 4, treatments of pH 5.0 to 5.9 and 6.0 to 6.9 were significantly different compared to pH 4.0 to 4.9 and 7.0 to 7.9. Week 6 recorded that pH 6.0 to 6.9 possessed the highest stem diameter with the value of 3.30 mm followed by pH 5.0 to 5.9 with 3.21 mm. Soil pH of 4.0 to 4.9 produced the lowest stem diameter with only 1.76 mm and was significantly different compared to others. After achieving week 8, the highest stem diameter was recorded in pH 5.0 to 5.9 although it was not significantly different compared to pH 6.0 to 6.9. However, Parthenium weed grown under pH 4.0 to 4.9 produced the lowest stem diameter with the value of 2.88 mm only as compared to the highest value in pH 5.0 to 5.9 (4.51 mm).

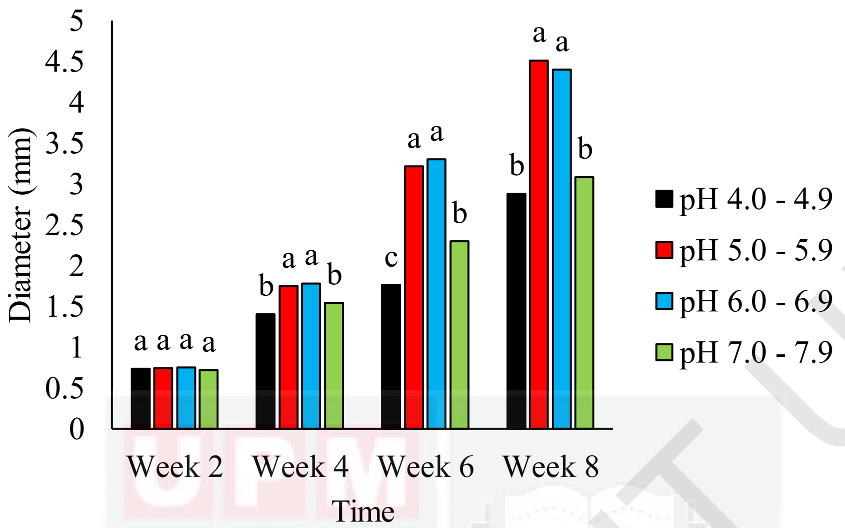

Figure 4.24 : Stem Diameter of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.4 Number of Leaves

Figure 4.25 shows the leaves production by Parthenium weed grown under different soil pH for 8 weeks. During the first 2 week, the leaves produced were not significantly difference although grown under different soil pH. As it entered week 4, the number of leaves started to differ significantly between all treatments, and pH of 6.0 to 6.9 recorded the highest leaves production (10.5 leaves). During week 6, pH 6.0 to 6.9 still maintained the highest leaves production (15.5 leaves) followed by pH 5.0 to 5.9 (14.5 leaves). However, no significant difference was observed between these treatments. Treatments of pH 4.0 to 4.9 and pH 7.0 to 7.9 both recorded no significant difference. At week 8, the trend remained the same as the highest number of leaves was in pH 6.0 to 6.9 (18.0 leaves), although no significant difference compared to pH 5.0 to 5.9 (17.3 leaves). As for pH 4.0 to 4.9 and 7.0 to 7.9, both of these treatments having the lowest leaves production with no significant difference between them.

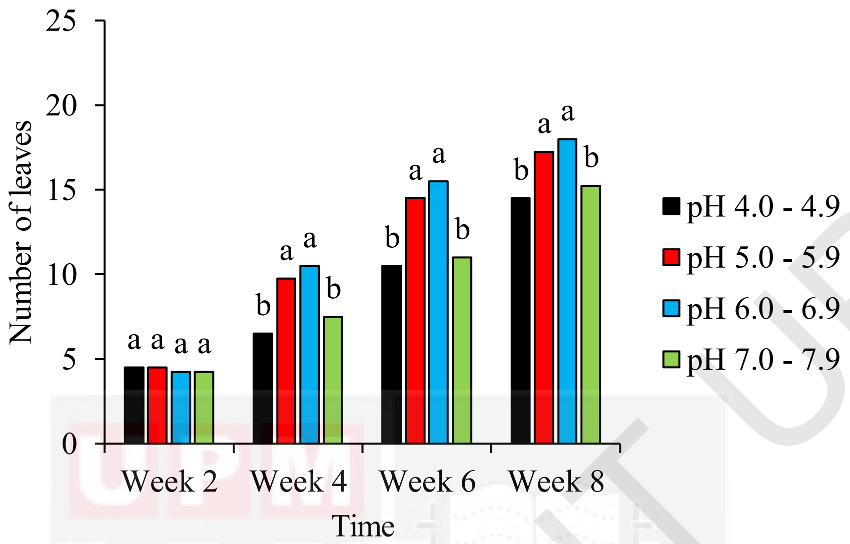

Figure 4.25 : Number of Leaves of Parthenium Weed Grown Under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.5 Root Volume

The root volume for Parthenium weed was affected significantly when allowed to grow in different soil pH (Figure 4.26). Parthenium weed grown under pH 6.0 to 6.9 showed greater root volume (29.75 cm^3) while slightly lower with no significant difference was recorded in pH 5.0 to 5.9 (27.25 cm^3). Root volume was significantly affected when treated with pH 4.0 to 4.9 as it recorded the lowest with root volume (10.00 cm^3).

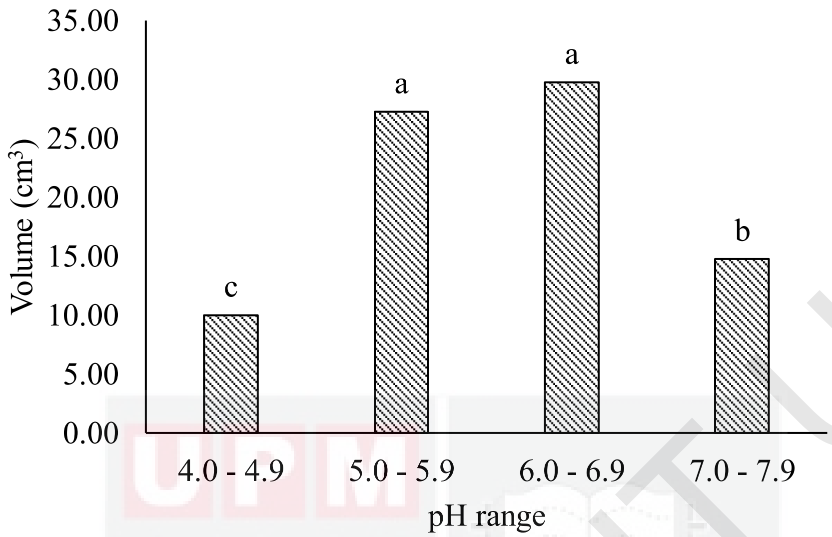

Figure 4.26 : Root Volume of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.6 Root Dry Weight

Root dry weight in Figure 4.27 recorded no significant difference between soil pH 5.0 to 5.9 and 6.0 to 6.9 with the value of 3.09 g and 3.28 g, respectively. However, both of these treatments differed significantly when compared with treatments of pH 4.0 to 4.9 (1.82 g) and 7.0 to 7.9 (1.94 g).

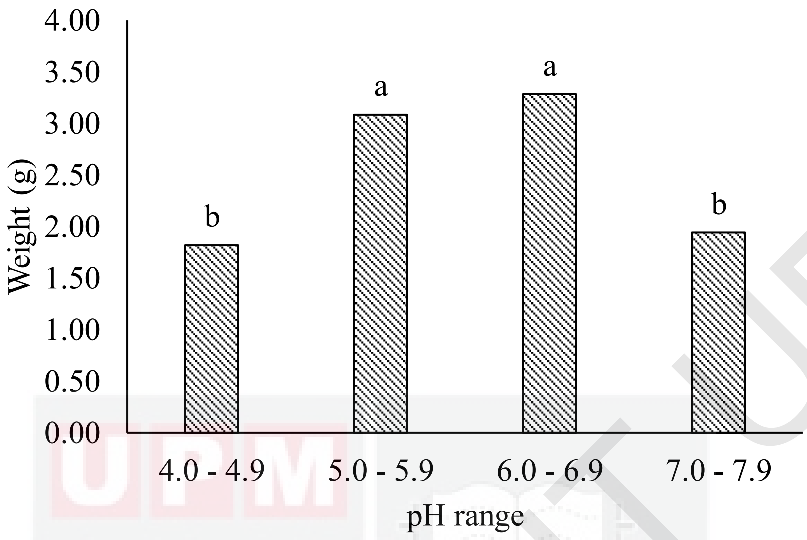

Figure 4.27 : Root Dry Weight of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.3.4.7 Shoot Dry Weight

In Figure 4.28, all soil pH treatments were significantly different between each other. Shoot dry weight recorded the highest weight under pH 6.0 to 6.9 (8.83 g) followed by pH 5.0 to 5.9 (8.02 g) and pH 7.0 to 7.9 (6.01 g), while the growth of Parthenium shoots was highly affected by the lowest pH of 4.0 to 4.9, producing biomass of 4.85 g only.

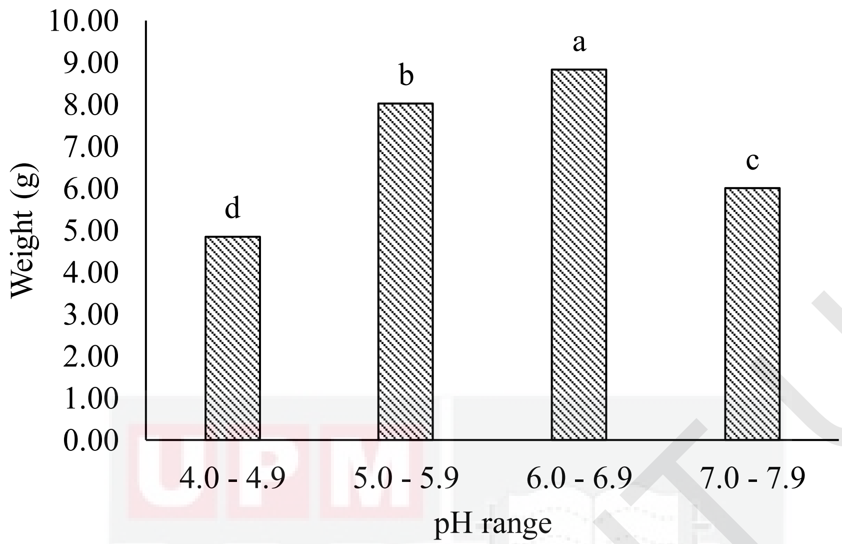

Figure 4.28 : Shoot Dry Weight of Parthenium Weed Grown under Different Soil pH Range 8 Weeks after Sowing
Note: Each letter represents the mean comparison and means following with different letter representing siginificant differences within density using LSD at $p < 0.05$.

4.4 Discussions

Seed germination recorded the highest percentage under continuous shading where Parthenium weed seeds were less exposed to sunlight. The seeds were able to germinate more than 90% either it was under 70, 50 or 30% of light exposure. However, seeds which were sown under direct sunlight (100% light intensity) were not able to fully germinate because too much sunlight caunse physical damage damage to the seeds. It shows that *P. hysterophorus* seeds require less light to germinate. As stated by Fenner and Thompson (2005), different plant species require different favorable light exposure in order for the seeds to emerge. Hence, too much light will prevent the establishment of seedlings. Although some seeds were tested to germinate under direct sunlight, *P. hysterophorus* seeds are not photosensitivity as the germination was only around 76%, lower than any other shaded periods.

Treatments of late shading period are in the same conditions of the weeds grown under big plants canopy. According Souza *et al.* (2013), competition of light between weeds and trees will result in smaller growth of the weeds as the rate of photosynthesis is decreased. In the *P. hysterophorus* case, the plant height showed maximum value at 50% light percentage which means that *P. hysterophorus* growth performance is not affected by the light source competition. It gives suitable light condition for the weed to grow.

Results from stem diameter shows that Parthenium weed which first grew under direct sunlight and late shading started at week four develop higher diameter compared to plant that was grown under continuous shading. Slow growth of stem diameter is probably caused by the low light source. This is proved by Huber *et al*. (2014) who observed that plants grow under shading have mechanical stability reduction and tend to have slender stems during stem elongation. Further research on maize by Xue *et al*. (2016a) stated that shading increase lodging probability but increasing the light intensity will strengthen the stalk and reduce lodging in maize.

Study also shows that 50% light intensity will produce maximum number of leaves but the plants need to grow under direct sunlight for the first month. The difference between Parthenium weed which was grown under continuous 50% shading and late shading were 4 leaves. However, previous study by Etemadi and Nikbakht (2018) reported that 30% shade (70% light intensity) recorded the highest number of leaves and the number decreases as the shade levelled up to 50 and 70%. In the current study, number of leaves in plants grown under full sunlight was slightly lower than 50% light intensity. This result was not similar when compared with Zervoudakis *et al*. (2012), who reported the highest leaf production of sage plant (*Salvia officinalis*) at full sunlight (100% light intensity) and decreased as the light intensity decreased.

As both results under 50% light intensity showed the highest dry weight production, this indicates that Parthenium weed reached optimum growth with 50% amount of light intensity. The results were not in line with Kumar *et al*. (2013), who witnessed that 50% and 25% light intensity reduced fresh weight and size of clary sage (*Salvia sclarea*). However, result from this study shows that 100% light was second highest after 50% light intensity treatment for dry weight. This is because some species produce maximum biomass at intermediate light condition or 50% of full sunlight (De Carvalho Goncalves *et al*., 2005).

Parthenium hysterophorus seeds have a strong capability to germinate under field capacity (-30 to -50 kPa) followed by saturated (0 kPa). It indicated that soil moisture stress under drought and flooded condition make Parthenium seeds not germinate at all although it is pre-germinated seeds. From this study, it shows that Parthenium seeds require soil moisture conditions within the rage of 0 to -50 kPa in order for the seeds to germinate up to 80%. Study by Bajwa *et al*. (2017) stated that Parthenium weed achieve optimum growth and reproductive capacity under 75% of WHC (water holding capacity). Germination of weed seeds were almost reach similar soil conditions feature for some invasive weeds but not for all species. Previous study by Kaur *et al*. (2016) reported one of the weed species that relatively close to Parthenium weed which is giant ragweed (*Ambrosia trifida* L.) also share similar results where it achieves highest vegetative growth and production of seed at 75% WHC.

Result from this study indicate that all parameters taken from Parthenium weed were achieve maximum value under saturated conditions (0 kPa). Saturation of soil condition is where the soil pore is totally filled with water. As the result shows that Parthenium were not able survive under drought and flooded conditions, biological feature of this weed which produce many seeds make it highly invasive and able to be an aggressive weed when it infests an area (Nguyen, 2011). Nguyen (2011) stated that Parthenium weed can adapt at relatively low soil WHC to sustain growth ability through morphological adaptation and physiological regulation as well as outstanding mechanisms to fully spread and reproduce.

However, result by Chauhan and Johnson (2010) reported that weed tolerance is induced if the drought conditions happened after seeds emergence and the flowering process will speed up. Hence, if drought was applied after Parthenium weed seeds germination achieved, it is possible for it to survive several days with water stress condition and shorten the cycle to reach flowering stage. Parthenium weed was reported to extend rosette stage duration and tend to produced superior shoots when it grows in high clay content soils having high WHC (Annapurna and Singh, 2003).

Seed germination in Parthenium weed decreased as the NaCl concentration increased because of low osmotic potential around the seeds which prevent uptake of water. Germination of seed is affected through osmotic effect (Welbaum *et al*., 1990). However, different plants were affected differently under salt stress conditions (Khurshid *et al*., 2012). Osmotic adjustment is the main factor for the plant to survive and grow under salinity stress (Munns and Tester, 2008).

According to Arndt *et al*. (2000) high level of salt salinity in the root zone will reduce the water uptake by the plants and soil water capacity. When the water content in soil is reduced, it will lead to the dehydration for plants at cellular level and suffer from osmotic stress (Verma *et al*., 2018). The effect of NaCl stress on growth in Parthenium weed in our study shares the same result with Beltagi *et al*. (2006) and Jamil *et al*. (2007a) on plant height where both studies reported sodium chloride severely affected plant height as the concentration increased.

In terms of number of leaves, the results were also in line with previous study by Ha *et al*. (2008), where high concentration of salinity affected the mean number of leaves for *Kyllingia peruviana*. They further reported this condition to happen because of accumulation of Na^+ in leaf tissue. Accumulation of Na^+ in leaf tissues will cause necrosis in older leaves. The symptoms will occur at the tips and margin and reduce leaf growth along with the yield (Ha *et al*., 2008). Study on tepary bean (*Phaseolus acutifolius* A. Gray), cowpea (*Vigna unguiculata* L. Walp.) and wild bean (*Phaseolus filiformis* bent) by Lopez-Aguilar *et al*. (2003) also reported the same result where the value for plant height, number of leaves and leaf area was relatively low under salinity stress. Shoot and root dry weight showed significant reduction as the NaCl concentration increased. The results were further supported by Raptan *et al*. (2001) in mungbean which observed that growth and total dry weight matter were largely reduced under saline condition.

Parthenium hysterophorus seeds was able to germinate in various soil pH ranging from 4.0 to 7.9. This result suggested that soil with strong acidic (4.0 to 4.9) and slightly alkaline (7.0 to 7.9) lower the seeds germination. Specifically, this study confirmed that Parthenium weed is able to germinate and grow with various soil pH either on highly acidic or slightly alkaline state of the soil. The optimum pH for Parthenium weed germination was between pH ranges from 5.0 to 6.9. *Ambrosia artemisiifolia* L. shows same criteria where the vegetative traits and reproductive capacity increases as the soil at pH 6 or slightly acid (Gentili *et al*. 2018).

Parthenium hysterophorus observed to grow slightly slow in pH 4.0 to 4.9. Although *Parthenium hysterophorus* was still capable to grow in pH 4.0 to 4.9 and pH 7.0 to 7.9, nonetheless the growth was stunted for all growth parameters observed. This indicates that this weed is able to adapt under strong acid and alkaline condition. Gentili *et al.* (2018) observed *A. artemisiifolia* to exhibit the lowest value of biomass at pH 7 although not significantly different from pH 5 and pH 6. In other study by Rosta and Rezaei (2014), rose plant growing in pH 6.5 had better performance in term of plant buds number, while recorded the lowest growth in pH 8.

These results were in line with research on *Lygodium microphyllum* by Soti *et al*. (2015) where soil pH 5.5 and 6.5 gave suitable growth conditions for invasive weed in Florida, to fully grow, possess good nutrient uptake and biomass production. However, they observed that the plant growth was stunted in soil pH 4.5 and 8.0. In Parthenium weed research, this weed still able to grow on pH 4.0 to 4.5 and 7.0 to 7.9, indicating that it is a highly adaptable weed under stress conditions of soil pH. Meanwhile, the root biomass was lower in strongly acidic soil (pH 4.0 to 4.9) as well as in alkaline soil (pH 7.0 to 7.9). Plants grew in these conditions was stunted as higher elements concentration inhibit the cell division at root apical meristem (Ryan *et al.,* 1993). Plants which experience damage in their roots can lead to reduction of water and nutrient intake.

Jensen (2010) stated that soil which under intermediate or sub-acid pH range is suitable for plant species because they provide optimal amount of plant nutrients that are important to support the initiation of root development. Plant tends to be exposed to mineral deficiency or metal toxicity if it is growing under strong acidic soil or strong alkaline soil as these conditions can change their ability to absorb micro- and macronutrients (Ramírez-Rodríguez *et al*., 2005). Hence, Parthenium weed reproductive performance that grows under unfavourable optimum soil pH may be affected. However, this weed is still considered as hazardous weed as it can survive under wide range of soil pH.

4.5 Conclusion

Both biotic and abiotic factors influenced the germination capacity of the *P. hysterophorus*. From the results obtained, for *P. hysterophorus* to be able to germinate, they will need a moderate sunlight rather than a strong one. In this study, *P. hysterophorus* achieved optimum growth under 50% shading. Higher intensities had stunted the growth of the seedling and only some of them sufficiently grew. Soil moisture content also plays an important role for the seedling to grow. From this research it was found that *P. hysterophorus* can grow under two type of soil moisture which were saturated and field capacity conditions. However, Parthenium weed is not drought and flood tolerance. To strengthen this statement, the seedling requires a little moisture for the meristem to grow. Thus, without water content in the soil, no seedlings will sprout further. Salinity greatly affected the survivability of Parthenium weed as the salt concentrations increased to maximum value of 24 dS m^{-1}. Although the weed capable to grow at maximum salt concentration, every parameter observed especially Parthenium height was reduced. Parthenium weed plants were able to survive under soil pH range from 4.0 to 7.9. It achieved the most favourable growth under pH 6.0 to 6.9.

CHAPTER 5

GENERAL DISCUSSIONS

Weeds are commonly recognised as undesirable in a given situation, and they are hazardous, harmful, or economically damaging, posing a severe threat to primary production and biodiversity. Parthenium weed (*Parthenium hysterophorus* L.) which from Asteraceae family is a dangerous weed globally. This invasive weed unexpectedly introduced to Malaysia and causing problems to the nature and agro-ecosystems. The first state which researcher found this weed is in Kedah where it has become the largest infested area in Malaysia.

Rapid spreading of Parthenium weed seeds in Malaysia through transport, agricultural implements, crop seed, compost make this weed infest in some of the crop fields Karim (2014). Karim (2014) also stated that it is important to analyze the critical parameters such as frequency, density and abundance of the species if we want to obtain the knowledge on weed infestation in community. In this study, Parthenium weed was allowed to grow on four types of crops which were *Oryza sativa* L. (aerobic rice), *Abelmoschus esculeentus* L. (okra), *Zea mays* L. (sweet corn) and *Elaeis guineensis* (oil palm) to learn about the crop-weed competition. Next study was to test the growth and performance of Parthenium weed under different shade percentage and duration, soil moisture, pH and salinity.

Among all of these four crops, the most sensitive and affected its growth when grown with Parthenium weed was okra, followed by aerobic rice, sweet corn and lastly pre-nursery stage oil palm. Bridgemohan *et al*. (2015) stated that Parthenium weed can achieve maximum height in okra field due to the huge gap in crop spacing. In competition between okra and Parthenium weed, the height under control treatment was able to grow up to 100.25 cm however reduced to 68.53 cm (32% reduction) with the existing of 2 weeds per 0.4 m^2 density of Parthenium weed which means there is competition between these two species to obtain nutrients from the soil. Okra normally can grow up to 160 cm in the field (Amoo *et al*. 2019).

Okra is tolerant to wide range range of rainfall and had high growth performance on sandy loam soil with optimum soil pH ranging from 6.0 to 7.0 (Kamran *et al.* 2012; Sexena *et al*. 2013). In study of Parthenium growth under different soil pH, the result shown that Parthenium weed also achieved maximum growth in all parameter between pH range of 6.0 to 6.9. Hence, if proper weed management in okra field not taken into serious matter, the yield of okra may drop if the field was infested with Parthenium weed. If the weed was allowed to growth until matured stage, okra would not fully utilize the fertilizer as it need to compete with Parthenium weed for nutrient sources.

Sweet corn is less sensitive to Parthenium weed when it tested under crop-weed competition studies. In this study, maximum density of Parthenium weed (8 weeds per 0.4 m^2) had caused 29.4% reduction for sweet corn dry weight. Safdar *et al*., 2016 stated a range of 21% to 53% reduction in corn grain yield in competition with Parthenium weed for duration of 35 days after emergence. However, some studies reported that corn yield losses between 2.5% to 20% during 14 to 36 days after emergence (Mahmoodi & Rahimi, 2009).

By referring to the Parthenium growth in different shading and duration, corn field mostly are in open field with most of the sunlight reaching the soil surface. Therefore, Parthenium weed would not be able to achieve their optimum growth as it need 50% shading percentage to achieve its best growth performance. The suitable soil condition for sweet corn is at field capacity, same optimum growing condition for Parthenium weed. Hence, it is better to undergo proper weed management properly in order to gain highest yield for the sweet corn. The requirement soil pH which are suitable for growing sweet corn between the range of 5.6 to 7.5 (Syekhfani, 2013). Hence, if the soil become acidic and reaching near 5.6, sweet corn still can survive while the growth of Parthenium weed will become stunted.

Study on pre-nursery stage oil palm with Parthenium weed resulted in less suppressive ability compared to other crops. However, if the study was tested under longer period, the effect of Parthenium may increasing. During immature stage in oil palm plantations, wide spaces between oil palms create suitable environment for the weed to grow invasively which will reduce the uptake of nutrient for oil palm (Samedani *et al.* 2013). Another invasive weed aside Parthenium weed are *Chromolaena odorata*, *Mikania cordata,* and *Mikania micrantha* which will create crop-weed competition with oil palm for nutrients, sunlight, moisture and can lead to yield reduction (Samedani *et al.* 2013). *Asystacia gangetica* is frequently found in oil palm plantations other than *Parthenium hysterophorus* and it spread quickly in most of Malaysian plantantion. Most of these weeds very adaptive in almost all type of soil such as aerated deep soil, peat soil and sandy soil (Ong *et al,* 2008). Due to high adaptation of Parthenium weed, it has great chance to survive under harsh environment in different Malaysia locations.

CHAPTER 6

CONCLUSION AND RECOMMENDATION FOR FUTURE RESEARCH

6.1 Conclusion

Parthenium hysterophorus is an invasive species that brings more harm than good. This invasive alien weed has brought critical problems in agriculture fields as local authorities and farmers need to increase the herbicide cost to prevent this weed from spreading. Information on ecological and biological growth of this weed is needed as it is one of the basic knowledges in order to fully understand the the rate of germination and optimum growth conditions of *Pathenium hysterophorus* as well as competition weed other crops and local weeds.

In this study, *Parthenium hysterophorus* competed differently with four selected crops which were aerobic rice, 4-month-old oil palm (pre-nursery stage), okra, and corn. The suppressive ability of the *Parthenium hysterophorus* depended on its density. Within these four selected crops, *Parthenium hysterophorus* seemed severely to reduce okra height with weed density of only 2 weed 0.4 m^2 (or 6 weed m^2 in actual field). However, oil palm seedlings responded differently towards Parthenium weed as the result of oil palm height was not significant. Hence, if *Parthenium hysterophorus* was allowed to grow in crop field without early prevention with herbicide or suitable weed management, it can disturb crop production by reducing crop yield.

Survivability of *Parthenium hysterophorus* was successfully shown in this study by assessing its adaptability under different shading, soil moisture, salinity, and pH. From the result on response of Parthenium weed under different shading conditions, 50% shade provided the optimum growth for Parthenium weed. As for growth under soil moisture condition, *Parthenium hysterophorus* showed excellent growth under field capacity and saturated soil conditions.

NaCl concentration with a range between 0 to 24 dS m^{-1} was tested on *Parthenium hysterophorus* to evaluate the sensitivity of this weed towards soil salinity levels. *Parthenium hysterophorus* were able to survive under these salinity conditions until it was stunted under high salinity of 24 dS m^{-1}. This proved that *Parthenium hysterophorus* is salt tolerant. *Parthenium hysterophorus* plants also were allowed to grow under different soil pH ranges, from pH 4 to pH 8 and the growth was beest between pH 5.0 to 6.9.

6.2 Recommendation for Future Research

- An extensive study on life cycle, e.g., flowering time, seed maturity, seed viability of the *Parthenium hysterophorus* under different environment conditions.
- An approach to assess the number of seeds produced by *Parthenium hysterophorus* when exposed to biotic and abiotic condition in order to predict the spreding capacity.

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APPENDICES

Appendix 1

Mean Square from Analysis of Variance (ANOVA) on Effect of Parthenium Weed Density on Aerobic Rice

Source	DF	Plant height (cm)	Number of leaves	Fresh weight (g)	Dry weight (g)
Density	4	64.14**	2.175**	2986.34**	141.83**
Replications	3	0.42^{ns}	0.33^{ns}	0.41^{ns}	1.76^{ns}
Error	12	4.45	0.2	1.33677	1.14
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 2

Mean Square from Analysis of Variance (ANOVA) on Effect of Parthenium Weed Density on Oil Palm

Source	DF	Plant height (cm)	Number of leaves	Fresh weight (g)	Dry weight (g)
Density	4	40.25^{ns}	2.08**	859.60*	65.89**
Replications	3	23.66^{ns}	0.58^{ns}	73.07^{ns}	3.47^{ns}
Error	12	40.61	0.21	195.94	6.50
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 3

Mean Square from Analysis of Variance (ANOVA) on Effect of Parthenium Weed Density on Okra

Source	DF	Plant height (cm)	Number of leaves	Fresh weight (g)	Dry weight (g)
Density	4	1210.57**	5.7**	13753.48**	230.15**
Replications	3	5.09^{ns}	0.32^{ns}	17.94^{ns}	0.66^{ns}
Error	12	5.215917	0.4	10.63063	1.3084339
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 4

Mean Square from Analysis of Variance (ANOVA) on Effect of Parthenium Weed Density on Sweet Corn

Source	DF	Plant height (cm)	Number of leaves	Fresh weight (g)	Dry weight (g)
Density	4	775.65**	2.43**	15252.88**	184.67**
Replications	3	122.64^{ns}	0.85^{ns}	1046.60^{ns}	7.20^{ns}
Error	12	57.73	0.39	1080.63	7.01
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 5

Mean Square from Analysis of Variance (ANOVA) on Germination and Growth Performance of *Parthenium hysterophorus* under Different Shade and Shading Period

Source	DF	Germination (%)	Root volume (cm3)	Root dry weight (g)	Shoot dry weight (g)
Treatment	6	281.25**	857.57**	13.72**	18.66**
Replications	3	3.27^{ns}	6.48^{ns}	0.05^{ns}	0.19^{ns}
Error	18	24.11	8.81	0.21	0.16
Total	27				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 6

Mean Square from Analysis of Variance (ANOVA) on Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil Moisture

Source	DF	Germination (%)	Root volume (cm3)	Root dry weight (g)	Shoot dry weight (g)
Moisture	4	8265.04**	380.06*	2.94**	41.67*
Replications	3	12.95^{ns}	3.06^{ns}	0.01^{ns}	0.79^{ns}
Error	12	16.06	5.62	0.05	1.73
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 7

Mean Square from Analysis of Variance (ANOVA) on Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil Salinity

Source	**DF**	**Germination (%)**	**Root volume (cm3)**	**Root dry weight (g)**	**Shoot dry weight (g)**
Salinity	4	3993.40**	81.06**	0.51**	68.40**
Replications	3	11.81^{ns}	3.06^{ns}	0.02^{ns}	12.60^{ns}
Error	12	42.68	3.62	0.04	6.45
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

Appendix 8

Mean Square from Analysis of Variance (ANOVA) on Germination and Growth Performance of *Parthenium hysterophorus* under Different Soil pH

Source	**DF**	**Germination (%)**	**Root volume (cm3)**	**Root dry weight (g)**	**Shoot dry weight (g)**
pH	4	928.44**	365.89**	2.30**	13.29**
Replications	3	30.33^{ns}	7.56^{ns}	0.08^{ns}	0.05^{ns}
Error	12	35.89	2.840	0.046	0.058
Total	19				

Note: *, ** significant difference at P < 0.05, 0.01; ns; not significant

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Zulfikar Mukhlis bin Zukiman was born on 25 January 1995 in Hospital Universiti Malaya, Kuala Lumpur. He was from Tanah Merah, Kelantan. He attended his primary and secondary school in Sekolah Kebangsaaan Gual Jedok (2002 – 2007) and proceed to Sekolah Menengah Kebangsaan Bukit Bunga (2008 – 2012) in Jeli, Kelantan. In 2013, he pursue his study in Foundation of Science in Universiti Malaysia Sarawak for a year. Then, he enrolled his degree in Plant Science and Resourse Management in Universiti Malaysia Sarawak (2014 – 2017). After finishing the degree, he continue to study in Master of Science (Pest Management) in Universiti Putra Malaysia in Faculty of Agriculture.

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